ACCN 1 3712
TYPE 2 CAT
DB 3 ELAL
MTI 4 Radiation safety at superfund sites
TRACED 5 Environmental Response Training Program
MYDATE 6 0094
CALLNO 7 6886-9
BRANCH 8 back
LOCATION 9 elad

540R95055

FOREWORD

This manual is for reference use of participants enrolled in scheduled training courses of the U.S. Environmental Protection Agency (EPA). While it will be useful to anyone who needs information on the subjects covered, it will have its greatest value as an adjunct to classroom presentations involving discussion among the participants and the instructional staff.

Individual instructors may provide additional materials to cover special aspects of their presentations.

Because of the limited availability of the manual, it should not be cited in bibliographies or other publications.

References to products and manufacturers are for illustration only; they do not imply endorsement by EPA.

Constructive suggestions for improving content and format of the manual are welcome.

U.S. Environmental Protection Agency
Region 5, Library (PL-12J)
77 West Jackson Boulevard, 12th Floor
Chicago, IL 60604-3590

RADIATION SAFETY AT SUPERFUND SITES
(165.11)

5 Days

This is a basic course in radiation safety for individuals who, in the course of their work, become involved with Superfund sites that have radioactive material concerns.

This course is designed to provide participants with an understanding of the fundamental principles of radiation safety, with emphasis on radiation detection and contamination control.

Upon completion of this course, participants will be able to:

- Discuss fundamental concepts of atomic structure, radiation, and radioactive decay
- Identify the biological effects of radiation exposure and the existing rules and regulations that establish the protection criteria for exposure
- Discuss radiation detection, including the theory of operation, use, and selection of radiation monitoring instruments
- Conduct radiation surveys using proper methods and techniques
- Discuss contamination surveys and the setup of contaminated areas
- Review regulations regarding the transport of radioactive material
- Discuss radioactive waste disposal and remedial options for radioactive cleanup.

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Emergency and Remedial Response
Environmental Response Team

RADIATION SAFETY AT SUPERFUND SITES (165.11)

CONTENTS

Section

LECTURES

Atomic Structure and Radioactive Decay 1

Interaction of Radiation with Matter 2

Radiation Exposure and Biological Effects 3

Radiation Exposure Limits and Methods to Control Exposure 4

Basic Concepts in Radiation Detection and Measurement 5

Radiation Detection Instruments 6

Surveying for Radioactive Materials 7

Radiation Signs and Labels 8

Contamination Control 9

Anti-contamination Clothing and Respiratory Protection Devices 10

Demonstration: Radiological Control Area 11

Decontamination 12

Radioactive Material Packaging, Labeling, and Shipping 13

Radioactive Soil and Water Sampling 14

Regulations and Guidance on Radioactive Waste Disposal 15

Remedial and Disposal Options 16

REFERENCES 17

Glossary

Excerpt, Radiological Health Handbook, January 1970

10 CFR 20—Standards for Protection Against Radiation

OSHA 1910.96—Ionizing Radiation

Federal Radiation Protection Guidance for Occupational Exposure

Regulatory Guide 1.86—Termination of Operating Licenses for Nuclear Reactors

Policy and Guidance Directive FC 83-23

Regulatory Guide 8.13—Instruction Concerning Prenatal Radiation Exposure

Fundamentals of Health Physics for the Radiation Protection Officer. September 1983. Darcom P385-1. Prepared for the Department of the Army, U.S. Army Materiel Development and Readiness Command, Alexandria, Virginia. Pacific Northwest Laboratory, Richland, Washington.

A Review of the Department of Transportation Regulations for Transportation of Radioactive Materials

49 CFR 173.403—Definitions

U.S. Nuclear Regulatory Commission and Agreement State Offices, September 9, 1990

Suppliers

SECTION 1

ATOMIC STRUCTURE AND RADIOACTIVE DECAY

After completing this unit, participants will be able to:

- Describe the theoretical structure of the atom and the chemical notation system.
- Define radioactive decay and explain its cause.
- Characterize the types of radiation emissions as a result of radioactive decay.

I. Atomic Structure

A. Nucleus

-positively charged central portion of an atom that comprises nearly all of the atomic mass and that consists of protons and neutrons

1. Proton
   -positively charged
   -mass of 1 AMU (1.673×10^{-24} gram) (1 AMU = 1/12 the mass of a carbon-12 atom)
   -determines the element (**Figure 1**)

2. Neutron
   -no charge
   -mass of 1 AMU
   -determines the isotope (hydrogen-1, hydrogen-2, hydrogen-3)

B. Electrons

-negatively charged particles that orbit the nucleus and comprise nearly all of the volume of an atom. These can be thought of as a "cloud" around the nucleus.

-negatively charged
(1.602×10^{-19} coulomb)

-mass of 1/1832 AMU
(9.109534×10^{-28} gram)

-the electrons can also be thought of as filling discrete orbital shells around the nucleus. Each shell represents an energy level. This is called the Bohr model and each shell is identified by a letter (K, L, M, N....)

C. Chemical Notation

1. Element Symbol (X) - indicates what basic element the atom is (**Figure 1**)

2. Proton Number (Z) - number of protons within the nucleus

3. Neutron Number (N) - number of neutrons within the nucleus

4. Mass Number (A) - represents the total mass of the atom. It is the sum of the proton number and the neutron number (A = Z + N).

5. Convention ${}^{A}_{Z}X$

Examples: ${}^{12}_{6}C = {}^{12}C = C\text{-}12$

(see **Figure 1**)

D. Definitions

1. Isotope - atoms of one element that have the same atomic number but differ in neutron number

2. Nuclide - a species of atom characterized by the constitution of its nucleus

3. Radionuclide - a radioactive nuclide
Example: ${}^{1}_{1}H,\ {}^{2}_{1}H,\ {}^{3}_{1}H$

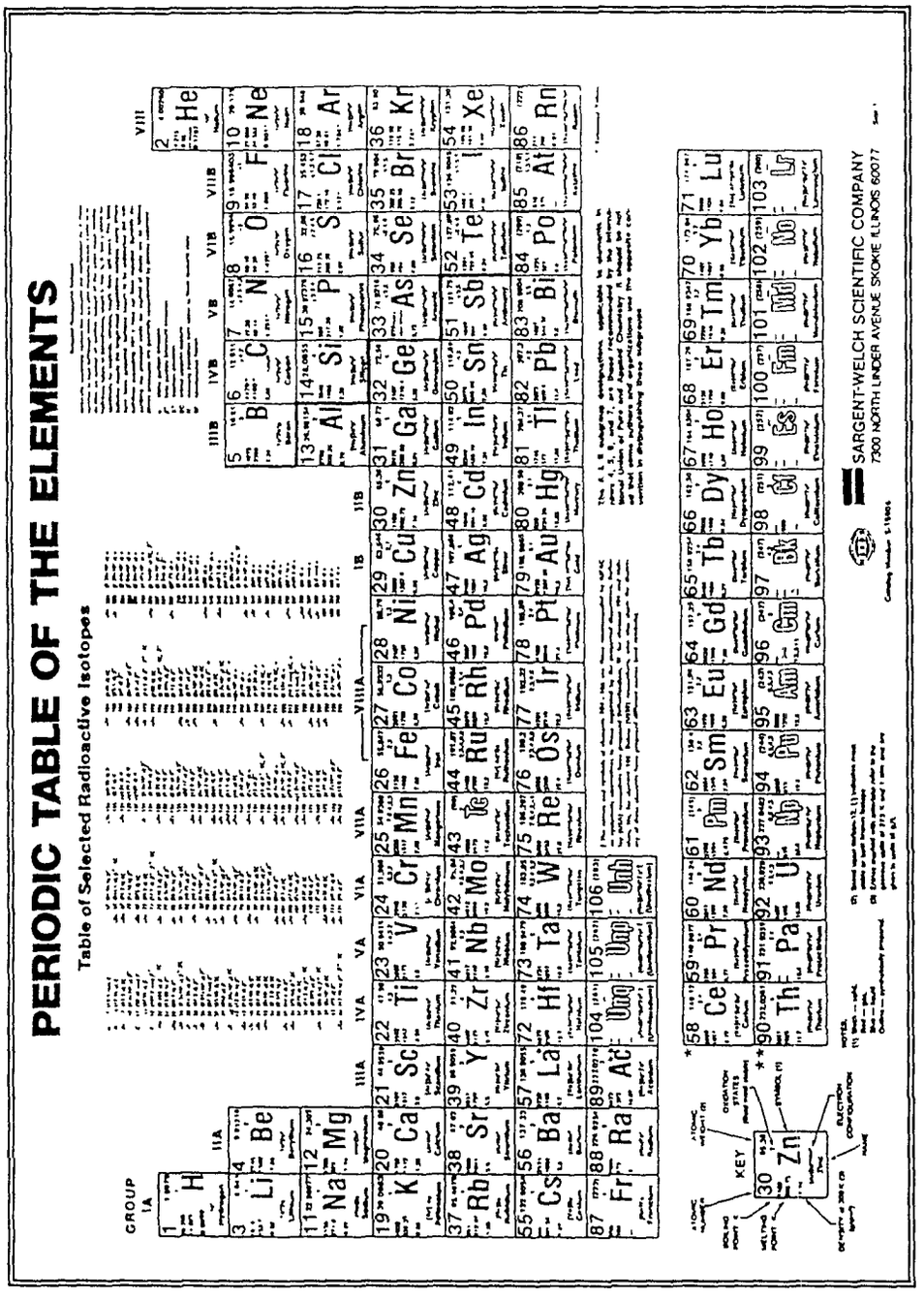


FIGURE 1
PERIODIC TABLE OF THE ELEMENTS

II. Radioactivity

A. Radioactive Decay - the disintegration of the nucleus of an unstable nuclide by spontaneous emission of particles or photons

B. Types of Unstable Nuclides

1. Excess binding energy in the nucleus

2. Unstable proton:neutron ratio

C. Mechanism of Radioactive Decay

1. Particle Emission
   a. Alpha
   b. Beta

2. Electron Capture

3. Photon Emission (Gamma)

D. Definitions

1. Radioactivity - the property of spontaneously emitting particles or photons

2. Natural Radioactivity - radioactivity exhibited by more than 50 naturally occurring radionuclides

3. Artificial Radioactivity - man-made radioactivity produced by particle bombardment or electromagnetic irradiation

4. Induced Radioactivity - radioactivity produced in a substance after bombardment with particles

III. Radiation

A. Definitions

1. Radiation - energy emitted in the form of waves or particles

2. Ionizing Radiation - radiation that has a high enough energy level to strip electrons from atoms

B. Types of Radiation

1. Particles - alpha, beta, neutron

2. Electromagnetic ray - gamma, x-ray

C. Characteristics of Each Radiation

1. Alpha

a. Make up

-2 protons and 2 neutrons
-mass = 4 AMUs
-charge = +2
-energy level = 4-7 MeV

$$kinetic\ energy = \frac{1}{2}m_o v^2$$

- expressed in units of electron volts (eV)

b. Emitted from very heavy nuclei

$Z \geq 82$ *such as* $_{86}Rn$

c. Decay scheme

$$^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He$$

2. Beta

   a. Make up

      -electron or positron
      -mass = 1/1832 AMU
      -charge = +1 or −1
      -energy level = .1 - 2.5 MeV

$$kinetic\ energy = \frac{1}{2}m_o c^2 \left[\frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}\right] - 1$$

      - expressed in units of electron volts (eV)

   b. Emission is due to an unstable proton:neutron ratio

   c. Decay schemes

      -Normal beta decay

$$^{1}_{0}N \rightarrow {}^{1}_{1}P + B^{-}\ ejected$$

      -Positron decay

$$^{1}_{1}P \rightarrow {}^{1}_{0}N + B^{+}\ ejected$$

      - Electron capture

$$^{1}_{1}P + e^{-}\ orbital \rightarrow {}^{1}_{0}N$$

3. Gamma Ray

   a. Make up

      -electromagnetic ray (pure energy)
      -no mass
      -no charge
      -energy level measured in units of electron volts (eV)

b. Emission is from a nucleus that has been left in an excited state following a particle emission or capture

c. The gamma is usually emitted immediately after particle ejection but may be several hours later

IV. Decay Pathways

A. Definitions

1. Radioactive Decay - the disintegration of the nucleus of an unstable nuclide by spontaneous emission of particles or photons

2. Decay Pathway - consists of particle emission or capture, possibly followed by one or more gamma rays

B. Notes of Interest

1. Some radionuclides can decay via more than one decay pathway

2. The pathways differ with the energy of decay and subsequent gamma rays

3. The number and energy of the emissions are characteristic of a given radionuclide

4. A single nucleus can decay by only one of the various pathways

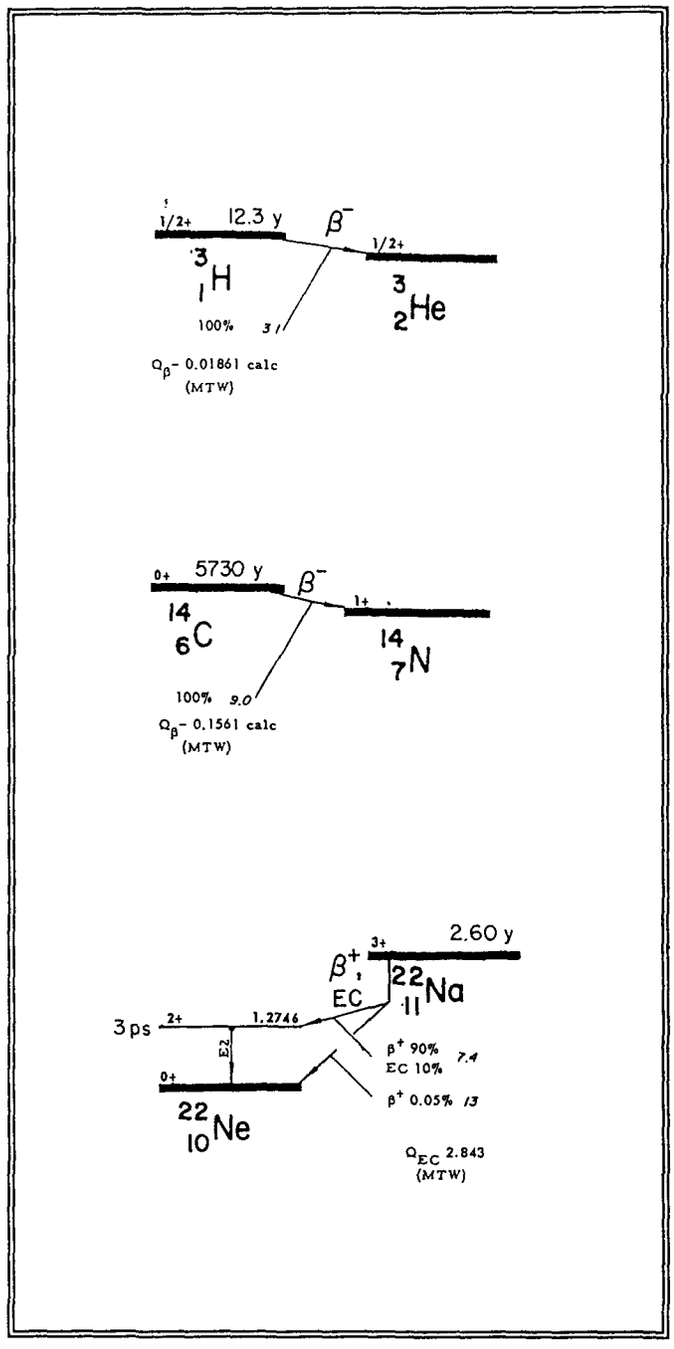
C. Rate of Decay

1. Half-Life (T 1/2) - that amount of time required for one-half of a radionuclide population to decay away

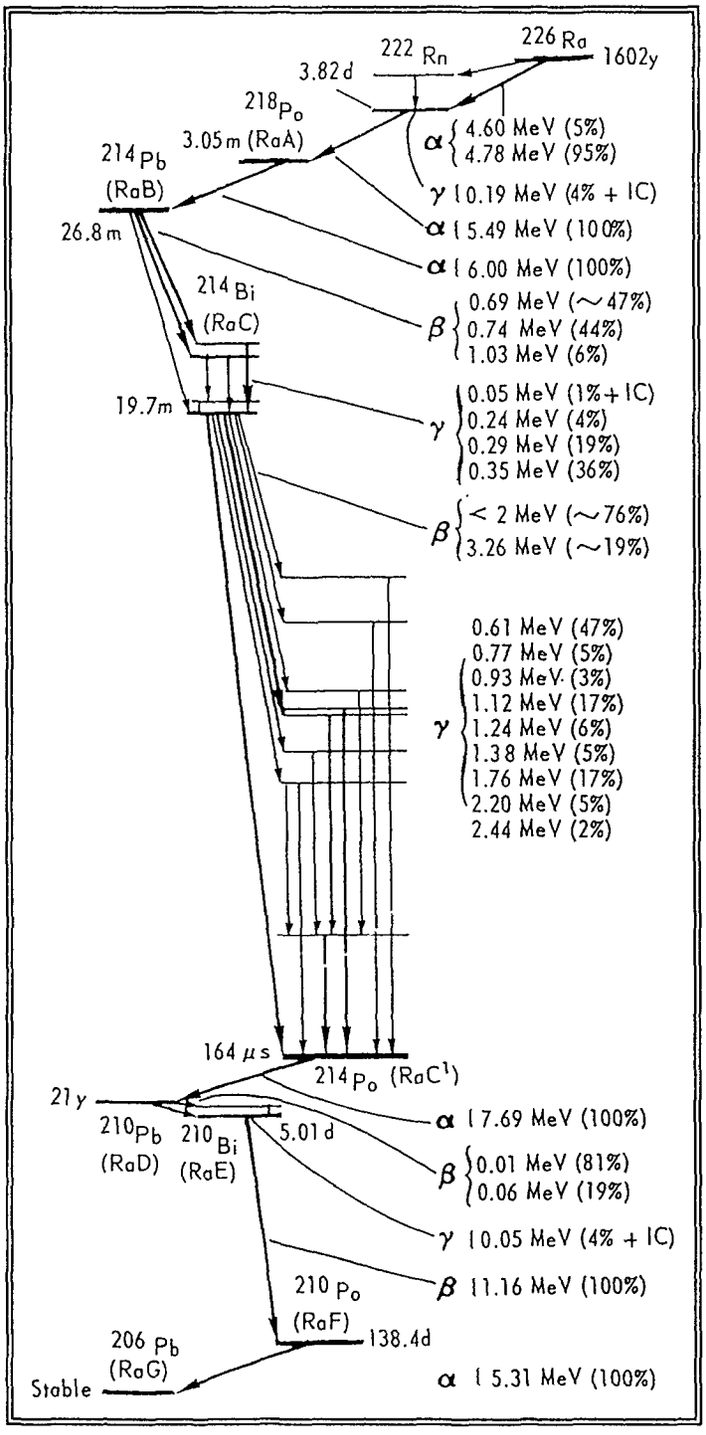
2. Decay Constant (λ)

$$\lambda = \frac{ln2}{T_{\frac{1}{2}}}$$

See Figures 2 and 3



TRITIUM, CARBON, AND SODIUM DECAY SCHEME
FIGURE 2



RADIUM DECAY SCHEME
FIGURE 3

V. Measuring Radioactive Material

Radioactive material is measured by counting the number of disintegrations that occur over some period of time. This is call its "Activity."

Activity (A) = disintegrations/time
(i.e., dps or dpm)

A. Traditional Units

1 curie (Ci) = 3.7×10^{10} dps
= 2.2×10^{12} dpm

B. Subunits

1 microcurie (μCi) = 1×10^{-6} Ci
1 picocurie (pCi) = 1×10^{-12} Ci

C. International System (SI)

1 Becquerel (Bq) = 1 dps

D. Activity Determination

$$A = A_o e^{-\lambda t}$$

where:
A = activity after time t
A_o = original activity
e = base of natural logarithm (2.718)
λ = decay constant (ln2/half life)
t = elapsed time

E. Radioactive Contamination

1. Definition

Radioactive contamination is a fine form of radioactive material in a place that it is not wanted.

2. Radioactive Contamination Measurement - Applied Units

   a. Surface area - dpm/100 cm^2

   b. Air - μc/mL

   c. Water - μc/mL

   d. Solids (specific activity) - Ci/g

SECTION 2

INTERACTION OF RADIATION WITH MATTER

After completing this unit, participants will be able to:

- Describe the mechanisms by which alpha, beta, gamma, and neutron radiations interact with matter.

I. Basic Interaction Results

A. Excitation - the forced movement of an electron from an inner shell to some outer shell of an atom (Note: when the electron jumps back to its original shell, a photon is emitted)

B. Ionization - the stripping of an orbital electron from an atom

C. Secondary Ionization - the ionization caused by a particle which is itself a result of ionization (sometimes termed "delta rays")

D. Linear Energy Transfer - the amount of energy deposited by a specific radiation over a specific distance

$$LET = \frac{dE_l}{dl}$$

(Note: Ultimately, the energy transferred either to tissue or to any other material is dissipated as heat)

II. Specific Radiation Interactions

A. Alpha - because of its high charge (+2) and large mass, it actually pulls electrons off as it goes past atoms or molecules
- it has a very high LET (tens of thousands of ions per centimeter in air)

B. Beta

1. Electron

a. Ionization/Excitation - the single negative charge and small mass interacts by a repelling "collision," where the two electrons do not actually touch

The beta pushes the orbital electron out of its shell
- it has a medium LET (hundreds of ions per centimeter in air)

b. Bremsstrahlung (Braking Radiation)
- x-rays are given off during the course of electron deceleration around the nucleus of an atom

2. Positron

a. Ionization/Excitation - single positive charge and small mass ionizes by attraction

b. When the positron has slowed down, it combines with an electron, they annihilate one another, generating two gamma rays with energies equivalent to the mass of the original particles (0.51 MeV each)

C. Gamma Rays

1. Photoelectric Effect

a. The photon interacts with a tightly bound electron and ejects it from its orbit
   i. the photon disappears
   ii. all of the photon's energy goes into breaking the electron's bond and the resulting kinetic energy of the electron. The electron then becomes the primary ionizer.

2. Compton Scattering

a. Elastic collision between a "free" electron (one whose binding energy

is far lower than the photon's energy), where the electron gets some kinetic energy and the photon still exists but at a lower energy (longer wavelength)

3. Pair Production - this is the primary interaction for photons greater than 1.02 MeV

   a. the photon passes near a nucleus and disappears

   b. an electron and a positron appear and are attenuated in their normal manner

4. Absorption (photodisintegration)

   a. the photon is captured in the nucleus, which then emits a neutron

   b. usually a very high energy is required for this (except Beryllium-9). Only a 1.666 MeV gamma is required to give a $^{9}Be(\gamma,n)^{8}Be$ reaction.

III. Neutron Radiation

A. Neutron Characteristics

1. Neutrons are not part of normal atom decay schemes; an interaction must occur for a neutron to be ejected

2. mass = 1 AMU

3. charge = 0

4. energy level is expressed in units of electron volts

B. Neutron-Generating Mechanisms

1. Nuclear Reaction - when either a uranium or a plutonium atom is split, there are an average of 2.54 neutrons generated

2. Cyclotron Bombardment - *deuterons* are accelerated and bombarded into a beryllium target

$$^{9}_{4}Be + ^{2}_{1}D \rightarrow (^{11}_{5}B)^{*} \rightarrow ^{10}_{5}B + ^{1}_{0}N$$

3. Alpha Bombardment - mix the fine powders of beryllium and an alpha emitter (radium, polonium, or plutonium) together and seal it in a capsule

$$^{9}_{4}Be + ^{4}_{2}He \rightarrow (^{13}_{6}C)^{*} \rightarrow ^{12}_{6}C + ^{1}_{0}N$$

4. Photodisintegration - a photon is absorbed by the nucleus and a neutron is ejected

$$^{9}_{4}Be\ (\gamma, ^{1}_{0}N)\ ^{8}_{4}Be$$

C. Classification of Neutrons

1. Fast Neutron - a high kinetic energy neutron with a KE > 0.1 MeV - all neutrons are fast upon generation

2. Thermal Neutrons - these have the same average kinetic energy as the gas molecules in their environment (which is set by temperature)

3. Middle Range - this covers all of the area between fast and thermal neutrons. Depending on the author, they could be called Intermediate, Resonance, or Slow Neutrons; these terms are used very loosely.

D. Neutron Interaction with Matter

1. Scattering

a. Inelastic scattering - this is actually two steps:

i. Neutron is captured by a nucleus

ii. Neutron is re-emitted, at a lower energy, by that nucleus with a gamma photon

b. Elastic scattering

i. occurs between fast neutrons and low atomic number absorbers (such as hydrogen-rich material like water or a poly material)

ii. This is a billiard ball type collision

2. Absorption

a. A thermal neutron can be <u>captured</u> by a nucleus

$$^{1}H(n,\gamma)^{2}H$$

$$^{14}N(n,p)^{14}C$$

$$^{10}B(n,a)^{7}Li$$

$$^{113}Cd(n,\gamma)^{114}Cd$$

b. Activation is when the capture of a thermal neutron results in the atom becoming radioactive

$$^{50}Cr + {}^{1}_{0}N \rightarrow {}^{51}Cr + \gamma$$

$$^{59}Co + {}^{1}_{0}N \rightarrow {}^{60}Co + \gamma$$

SECTION 3

RADIATION EXPOSURE AND BIOLOGICAL EFFECTS

After completing this unit, participants will be able to:

- Define radiation dose and exposure.
- Define the units of measurement for radiation dose and exposure.
- Describe the toxicological or biological impacts due to radiation exposure.

I. Radiation Exposure

A. Measurement Concepts

1. Exposure

The measurement of radiation passing through air that an individual would be subjected to if they were to stand in that spot. This is normally measured in units of Roentgen (R).

2. Dose

The deposition of energy into soft tissue (human body) by a specific form and energy level of radiation. This is normally measured in units of Rad (an acronym for Radiation Absorbed Dose).

3. Dose Equivalent

The estimation of the biological risk associated with radiation exposure regardless of the type of radiation or its energy level. This is normally measured in units of Rem.

B. Units of Measurement

1. Roentgen (R)

The quantity of x-ray or gamma radiation producing one electrostatic unit of charge in one cubic centimeter (cc) of dry air at standard temperature and pressure.

Notes:
- absorption of 1R in 1cc of air results in formation of 2.08×10^9 ion pairs.
- in terms of energy per unit mass of dry air, this converts to 87.8 ergs/gram

- when applied to muscle tissue (instead of dry air), it leads to the absorption of 95 ergs/gram of muscle tissue.

2. Rad

A measure of the dose of any ionizing radiation to body tissue in terms of the energy absorbed per unit mass of tissue (1 Rad = .00 erg/gram of body tissue).

3. Rem (Roentgen Equivalent Man)

The amount of radiation that causes damage equivalent to the damage done by the absorption of 100 ergs X (or γ) radiation per gram of soft body tissue.

4. Quality Factor (QF)

QF accounts for the differences in the biological effect of different types of radiation as compared to that of X-radiation.

Radiation	QF
γ	1
X	1
B^- > .03 MeV	1
B^- < .03 MeV	1.7
N_{th}	3
N_f	10
P	10
α	20
Heavy Ions	20

C. Subunits

1. Milli (m) - one thousandth of the indicated unit.
ex: 1 millirem = 10^{-3} rem

2. Micro (μ) - one millionth of the indicated unit.
   ex: 1 microrem = 10^{-6} rem

3. Kilo (k) - one thousand of the indicated unit
   ex: 1 keV = 10^{3} eV

4. Mega (M) - one million of the indicated unit
   ex: 1 MeV = 10^{6} eV

II. Biological Effects

A. Chemical Toxicity

1. Chemical toxicity is the harm that can be caused by an element due to its chemical nature.

2. Most chemicals have a level at which they become toxic (poisonous).

3. Radioactive chemicals interact by the same chemical interaction as their nonradioactive counterparts.

B. Radiotoxicity

1. Radioactivity indicates the relative radiological hazard associated with internally deposited radionuclides.

2. Alpha particles or high-energy beta particles present the greatest hazard when they are emitted internally.

C. Interaction of Radiation with Tissue

1. Effects of damage to cells whether through direct or indirect action of radiation are:

a. cell dies
b. cell lives normally
c. cell produces daughter cells that die
d. cell produces mutated daughter cells

2. Direct Action

a. ~1 atom in 10 million is affected by a dose of 450 rads

Proof:

$$\frac{(4Gy)(6.25x10^{18}\frac{ev}{g\ Gy})}{34\frac{ev}{ion}} = 7.35 \times 10^{17}\ \frac{ions}{g\ of\ tissue}$$

i. estimate 9 atoms excited for each 1 ionized

ii. 7.35×10^{18} atoms/kg of tissue are directly affected. There are $\sim 9.5 \times 10^{25}$ atoms/kg in soft tissue.

$$\frac{10^{18}}{10^{25}} = \frac{1}{10^{7}}$$

Note: The reason that this is of interest is LD_{50} = 450 rads

b. If the affected atom is on the DNA molecule, genetic information may not be transferred.

c. Germinal cells - mutation is passed on to next individual

Somatic cells - mutation is passed on to daughter cell

3. Indirect Action

a. Most of the body is water; therefore, most of radiation's direct action is on water.

$$H_2O \xrightarrow{\gamma} H_2O^+ + e^-$$

$$H_2O + e^- \rightarrow H_2O^-$$

$$H_2O^+ \rightarrow H^+ + OH$$

$$H_2O^- \rightarrow H + OH^-$$

High LET radiation:

$$OH + OH \rightarrow H_2O_2$$

$$H + H \rightarrow H_2$$

If dissolved O_2 is present:

$$H + O_2 \rightarrow HO_2$$

$$H + HO_2 \rightarrow H_2O_2$$

D. Radiosensitivity

1. Law of Bergonie and Tribondeau

"The radiosensitivity of a tissue is directly proportional to its reproductive capacity and inversely proportional to its degree of differentiation."

(i.e., cells most active in reproducing themselves and cells not fully mature will be most harmed by radiation)

2. Specific Classifications of Mammalian Cell Sensitivity

Group 1 (Extremely Radiosensitive)
Mature lymphocytes - a major class of circulating white blood cell
Erythroblast - red blood cell precursor
Spermatogonia - most primitive cell in the spermatogenic series

Group 2 (Slightly less radiosensitive than group 1)
Granulosa cells - cells surrounding ovum which develop and mature in the ovarian follicles
Myelocytes - (in bone marrow) precursor to a leukocyte (colorless ameboid/white blood cell)
Intestinal crypt cells - part of the intestine lining
Germinal cells of the epidermal layer of skin - primitive development level of the cell

Group 3 (Radiosensitive)
Gastric gland cells - stomach gland cells
Endothelial cells - lining of small blood vessels

Group 4 (Moderately Radiosensitive)
Osteoblasts - bone-forming cells
Osteoclasts - bone-absorbing cells
Chondroblasts - precursors to cartilage cells
Spermatocytes
Spermatids

Group 5 (Slightly Radioresistant)
Granulocytes - white blood cells
Osteocytes - bone cells
Sperm
Superficial cells of the Gastrointestinal tract

Group 6 (Moderately Radioresistant)
Parenchymal and duct cells of glands
Fibroblasts - form intercellular fibrous matrix
Endothelial cells of large blood vessels
Erythrocytes - red blood cells

Group 7 (Radioresistant)
Fibrocytes - connective tissue cells
Reticular cells - fixed hemato-poietic stem cells
Chondrocytes - cartilage cells
Phagocytes - scavengers

Group 8 (Very Radioresistant)
Muscle cells and nerve cells - fully differentiated, incapable of division

E. Exposure Rate

1. Acute Exposure - a radiation exposure received in a short period of time, usually considered to be less than 1 day

2. Chronic Exposure - a radiation exposure spread over a long period of time, usually considered to be over a period of years

F. Overall (Gross) Biological Effect

1. Acute Radiation Syndrome (immediate effects)

25 Rem - blood changes

200 Rem - Hemopoietic Syndrome
symptoms that develop within several hours following exposure:
nausea, vomiting, malaise, fatigue, fever, blood changes

symptoms that develop 2 to 3 weeks after exposure:
epilation (hair loss)

symptoms that develop 1 to 2 months after exposure: death

400 - 600 Rem - Bone marrow destruction (reversible)

700 Rem - Irreversible destruction of bone marrow

1000 Rem - Gastrointestinal Syndrome
immediately after exposure:
severe nausea, vomiting and diarrhea 1 to 2 weeks after exposure:
death

2000 Rem - Central Nervous System Syndrome
minutes after exposure:
unconsciousness hours after exposure: death

2. Latent Effects

a. May be due to either a single large overexposure or continuing low-level overexposure

b. Exposure may be due to external radiation fields or internally deposited radioisotopes

c. Genetic mutations - mutations of germ cells
- direct evidence of radiation-induced mutation in man is lacking
- largest group available for study are descendants of Hiroshima and Nagasaki
- no detectable effect on frequency of prenatal or neonatal deaths or malformations
- not enough time has passed to reveal recessive damage
- doubling dose for spontaneous mutation rate is probably:

15-30 rads: acute
100 rads: chronic

d. somatic mutations - mutations that are produced in cells which are not germ cells

i. Cataract Formation - <u>critical dose</u> estimated between 20 and 40 rads

<u>Fractionation</u> of dose delays time of on set and decreases the incidence of severity

ii. Life Shortening
- slightly less than 1% per 100 rads chronic
- between 1 and 1.5% per 100 rads acute

iii. Cancer
- **Leukemia** Japanese survivors had an increase in incidence of leukemia @ 100 to 900 rads.

Average rate of increase was linear, giving between 1 and 2 cases/10^6/yr/rad. Latent period is shorter at higher dose.

- **Skin Cancer** common in early radiologists and dermatology patients

- **Bone Tumors** radium has increased incidence of bone tumors in individuals w/skeletal burdens such as the dial painters. Latent period of 20 to 30 years.

- **Lung Cancer** in mine workers exposed to radon gas and its daughter products (high percentage develop bronchogenic carcinoma within 15 years after beginning work in mines).

3. Teratogenic Effects

   a. Implantation occurs at about 11 days after fertilization, with major organogenesis extending to about day 38

      i. irradiation during the first 2 weeks of pregnancy results

in spontaneous abortions and gross abnormalities

ii. irradiation between the 3rd and 6th weeks may produce gross abnormalities

iii. beyond day 40 the embryo is more radioresistant

b. Study at Nagasaki

i. 30 women exposed within 2,000 meters of hypocenter estimated at >20 rads total dose each

ii. 16 children survived, 4 with mental retardation

iii. therapeutic abortions have been suggested following exposures to 10R

SECTION 4

RADIATION EXPOSURE LIMITS AND METHODS TO CONTROL EXPOSURE

After completing this unit, participants will be able to:

- Describe the base criteria for occupational radiation exposure limits.
- Define the OSHA exposure limits for external radiation.
- Explain the basis of the new recommended limits (*Federal Register*, 1/27/87).
- Describe how time, distance, and shielding can be used to minimize radiation exposure.

RADIATION EXPOSURE LIMITS AND METHODS TO CONTROL EXPOSURE

NOTES

I. Base Criteria

A. There should not be any occupational exposure to workers from ionizing radiation without the expectation of an overall benefit from the activity causing the exposure.

B. A sustained effort should be made to ensure that collective dose, as well as individual annual, committed, and cumulative lifetime doses, are maintained as low as reasonably achievable (ALARA).

C. Radiation dose received as a result of occupational exposure should not exceed the limiting values for assessed dose to individual workers.

II. OSHA Exposure Limits to External Radiation

A. 29 CFR 1910.96 (b)

1. Standard Limits

a. 1.25 Rem/calendar quarter

whole body; head and trunk, active blood-forming organs, lens of eyes, or gonads

b. 18.75 Rem/calendar quarter

hands and forearm, feet and ankles

c. 7.5 Rem/calendar quarter

skin of whole body

NOTES

2. Extension of Limit

The whole-body limit can be exceeded if:

a. the dose to the whole body does not exceed 3 Rem during any calendar quarter

b. the cumulative dose to the whole body shall not exceed 5(N-18) Rem where N is the individual age, in years, at his or her last birthday

c. the employer maintains adequate past and current exposure records to prove 5(N-18) Rem is not exceeded.

3. Individuals under 18 years of age are not allowed to receive a dose in excess of 10 percent of the standard's limits.

B. Regulatory Guide 8.13—Instruction Concerning Prenatal Radiation Exposure

1. Sites in National Commission on Radiation Protection's (NCRP) recommendation that a fetus should not be exposed to more than 500 mrem during the gestation period.

III. New Recommended Limits - Federal Register dated 1/27/87

A. Basis of Limits

1. Cancer and genetic effect risks are limited by the effective dose equivalent (H_E).

2. Other health effects are limited by dose equivalent (H_T) to individual organs.

NOTES

B. Limits

1. Adult Worker - External Exposure

a. Annual effective dose equivalent, H_E, should not exceed 5 rems where H_E is defined as:

$$H_E = \sum_T W_T H_T$$

W_T is the weighing factor and H_T is the annual dose equivalent averaged over organ tissue T.

Values of W_T and their corresponding tissues are:

gonads	0.25
breasts	0.15
red bone marrow	0.12
lungs	0.12
thyroid	0.03
bone surfaces	0.03
remainder	0.30

"Remainder" means the five other organs with the highest doses. The weighing factor for each such organ is 0.06.

b. The dose equivalent, H_T, received in any year should not exceed 15 rems to the lens of the eye, and 50 rems to any other organ tissue, or extremity of the body.

2. Adult Worker - Internal Exposure

a. Committed dose equivalent $H_{T,50}$ is the sum of all dose equivalents to organ or tissue that may accumulate over an individual anticipated

NOTES

remaining lifetime (taken as 50 years) from radionuclides that are retained in the body. $H_{T,50}$ is defined as:

$$H_{E,50} = \sum_T W_T H_{T,50}$$

b. The committed effective dose equivalent from any radionuclide's intake plus any annual effective dose equivalent from external exposure will not exceed 5 rems.

c. The dose equivalent to any organ or tissue from any radionuclide intake plus any annual dose equivalent from external exposure will not exceed 50 rems.

3. Occupational dose equivalent to individuals under the age of 18 should be limited to one-tenth of the values for adults.

4. Exposure of an unborn child should not exceed 500 mR during the entire gestation period.

C. Notes clarifying application of the recommendations

1. Occupational exposure does not include background or medical radiation exposures.

2. The numerical values provided by these recommendations do not apply to workers responsible for the management of response emergencies.

3. Emergency exposures are controlled by the individual federal agencies having jurisdiction.

IV. Methods to Control Radiation Exposures

A. Time

1. Radiation exposure is a function of time. The longer an individual stays in a radiation area, the more exposure they will receive.

2. Performance of work in an efficient manner reduces time. This does not mean "do it fast"; it means to do it right the first time in the least time that is necessary.

a. pre-job planning

b. mock ups

c. tool inventories

d. walk-throughs

B. Distance

1. Radiation levels decrease with distance from the source.

a. reach rods

b. move the work

c. simply work at arms length if possible

C. Shielding

1. Shielding is simply a method of putting something between you and the source.

NOTES

2. Tenth Value - that amount of shielding required to reduce the radiation levels to one-tenth its original value.

a.	gamma	2" lead, 4" steel, 24" H_2O
b.	neutron	10" H_2O, 10" poly material
c.	alpha	1 sheet of paper
d.	beta	1 sheet of aluminum foil

3. Considerations when shielding

   a. The very act of installing and removing shielding can result in radiation exposure. It may take more exposure to put it up and take it down than is saved by having it there for the job.

   b. Weight of the shielding materials, such as lead, is very heavy. Two inches of lead for any size container is a significant weight problem. Structural consideration of the floor should be made for any shielding project.

D. Awareness

   1. You cannot see, smell, taste, or feel radiation. When people start to work, they tend to forget about the radiation exposure that is occurring. You can reduce your exposure just by paying attention to what is going on and use time, distance, and shielding to your advantage.

SECTION 5

BASIC CONCEPTS IN RADIATION DETECTION AND MEASUREMENT

After completing this unit, participants will be able to:

- Describe the basic components of radiation detection instruments.
- Define energy resolution, dead time, absolute efficiency, and intrinsic efficiency.
- Describe how source characteristics affect the measurement of radiation.

I. Components of Instruments

A. Sensing element (detector): responds to the radiation and provides a measurable signal to the indicating element

B. Indicating element

1. meter
2. recorder
3. scaler
4. speaker

II. Characteristics of Instruments

A. Radiation Interaction with the Detector

1. Ionization

2. Excitation

3. Both ionization and excitation (directly or indirectly) result in the formation of electrical charges

4. If an electrical field is applied across the detector, the electrical charges generated in the detector can be collected

B. Operating Mode of the Indicating Element

1. Pulse mode: records an output pulse for each individual interaction between the detector and the radioactive particle or photon

2. Current mode: records the amount of ion pairs produced by the radiation in the detector.

C. Recording Modes of Meters

1. Rate meters: record the pulse or current rate; units include cpm, mR/hr, or mrem/hr

2. Integrating instruments: tally the pulses or total current for the duration of the measurement

D. Advantages of Pulse Meters

1. Greater sensitivity; lower limit of detection

2. Can measure pulse height (amplitude)

   a. amplitude *is proportional to energy* of the radiation

   b. knowledge of the radiation energy and detector design can identify the type of emission

   c. specific radionuclide may be identified

3. Discriminator: allows only pulses of a specific amplitude to pass to the indicating element

   a. used to differentiate pulse heights

   b. sometimes can identify radionuclide

E. Other Characteristics of Instruments

1. Dead Time: the minimum amount of time required, after radiation interaction with the detector, in order for the next interaction to register as a separate pulse.

a. an ionizing event occurring during the dead time will not produce a pulse

b. counts recorded can be corrected for dead-time losses

2. Energy Resolution: ability of a detection system to distinguish between two pulses of slightly different sizes

3. Counting Efficiency

a. some radiation will pass through the detector without interacting with it

b. all radiation emitted from the source does not pass through the probe

4. Absolute Efficiency (ae): indicates how well the radiation detector counts all of the radiation emitted from the source.

$$ae = \frac{number\ of\ pulses\ recorded}{number\ of\ source\ emissions}$$

5. Intrinsic Efficiency (ie): accounts for the fact that all of the radiation emitted by the source may not reach the detector. It also indicates how well the radiation detector counts all of the radiation that passes through the detector.

$$ie = \frac{number\ of\ pulses\ recorded}{number\ of\ incident\ radiations}$$

Note: incident radiations are those that reach the detector

III. Source Characteristics

A. Isotropism: radiation is emitted by the source in all directions with equal frequency

B. Source Geometry: the physical shape of the source

1. Point source: a source that is very small compared to the distance from the source to the detector

2. Line source: finite line sources extending along a single axis, such as small pipes

C. Geometry Factor: the fraction of the source sphere that actually intercepts the detector

1. 4 π Geometry: completely enclosing the source within the sensitive volume of the detector

2. 2 π Geometry: enclosing one-half of the source sphere within the sensitive volume of the detector (the situation for nearly all instruments)

D. Self-absorption: the absorption of radiation within the source itself

1. encapsulated alpha and beta sources

2. samples of large mass

E. Attenuation: unless the sample is placed under a vacuum, the air space between the source and the detector will absorb a portion of the radioactive emissions

SECTION 6

RADIATION DETECTION INSTRUMENTS

After completing this unit, participants will be able to:

- Explain the ionization curve.
- Describe the operation of a direct reading dosimeter.
- List the requirements that are considered in the selection of radiation instruments.

I. Gas Ionization Detectors

A. Principle of operation

1. Detector: usually consists of a power supply and a closed, electrically conductive cylinder filled with a gas **(Figure 1)**

a. metal chamber walls: penetrated by photons and high-energy beta particles

b. chamber wall "window": a portion of the chamber wall may be made of mylar or mica, which is easily penetrated by alpha and low-energy beta particles

c. the chamber may be made "directional" by adding a window and/or shielding

d. anode: a thin wire in the center of the chamber, positively charged

e. cathode: the chamber wall, negatively charged

f. incident radiation causes ionization of the gas, producing an ion pair (a free electron and a positively charged gas molecule

g. number of ion pairs produced depends on type of gas as well as the type and energy of the radiation

h. on average, one ion pair is produced for every 30 to 35 eV of energy transferred to the gas

i. when voltage is applied across the chamber, the ion pairs produced move to their respective electrodes

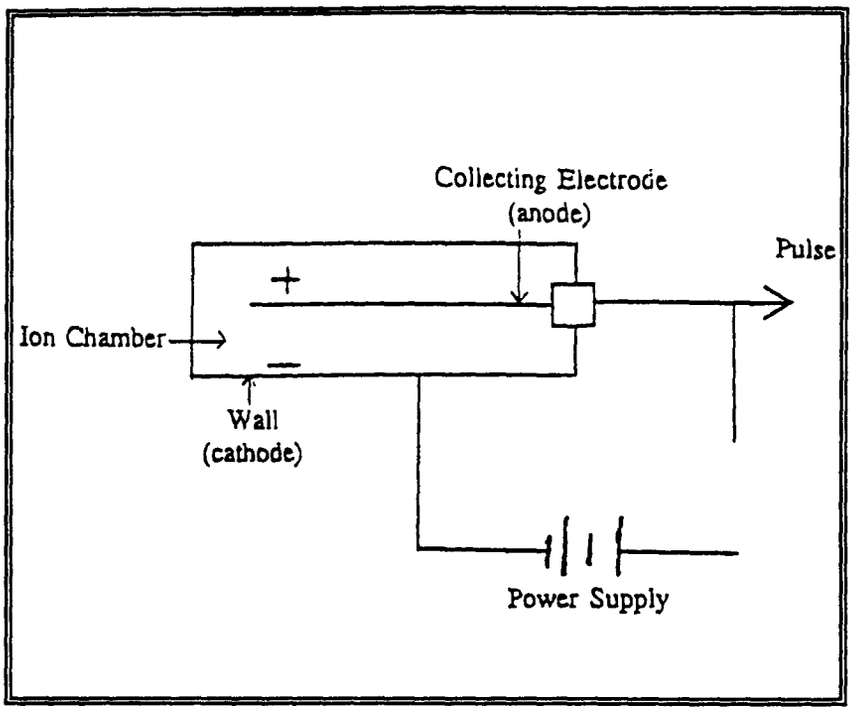


FIGURE 1
BASIC DETECTOR SCHEMATIC

B. Relationship between applied voltage and the number of electrons collected at the anode **(Figure 2)**

1. Recombination Region

a. voltage across the electrodes is low

b. attraction between ion pairs may be greater than that between ion pairs and electrodes

c. no radiation detectors operate in this region

2. Ionization Chamber Region (saturation region)

   a. voltage across electrodes sufficient to cause the collection of all electrons

   b. moderate increases in voltage do not increase the electron current

   c. different types of radiation can be distinguished from each other because of the different pulse heights produced

3. Proportional Region

   a. voltage increased such that the ion pairs collected are greater than the number of primary ion pairs formed (accelerated electrons cause secondary ionizations in gas)

   b. gas amplification factor, or multiplication factor: a measure of secondary ions produced

   c. multiplication factor is constant over small voltage ranges

   d. proportional detectors can distinguish among alpha, beta, and gamma radiation

4. Limited Proportional Region: no useful purpose for radiation measurement

5. Geiger Region: voltage high enough to cause avalanche along entire length of anode

a. all pulses are the same size, regardless of the type of radiation (detector cannot distinguish among different types of radiation)

b. cation removes electron from detector wall producing x-rays

c. quenching gas, which supplies electrons, is added to the chamber to prevent continuous discharge

d. typical quenching gases include bromine, chlorine, ethanol, and methane

6. Continuous Discharge Region: voltage increased until arcing occurs across the electrodes *(operation in this region can permanently damage detectors)* **(Figure 2)**

C. Ionization Chambers: instruments designed to operate in the ionization chamber region

1. Passive ion chambers: voltage is applied by charging a capacitor. Ions formed by incident radiation neutralize the charge

a. drop in voltage proportional to dose

b. loss of charge due to leakage results in false reading

c. pocket ionization chamber:

i. integrating instrument

ii. quartz fiber attached to a rigid metal electrode

iii. positive charge is applied to the electrode, causing the repulsion of the quartz fiber

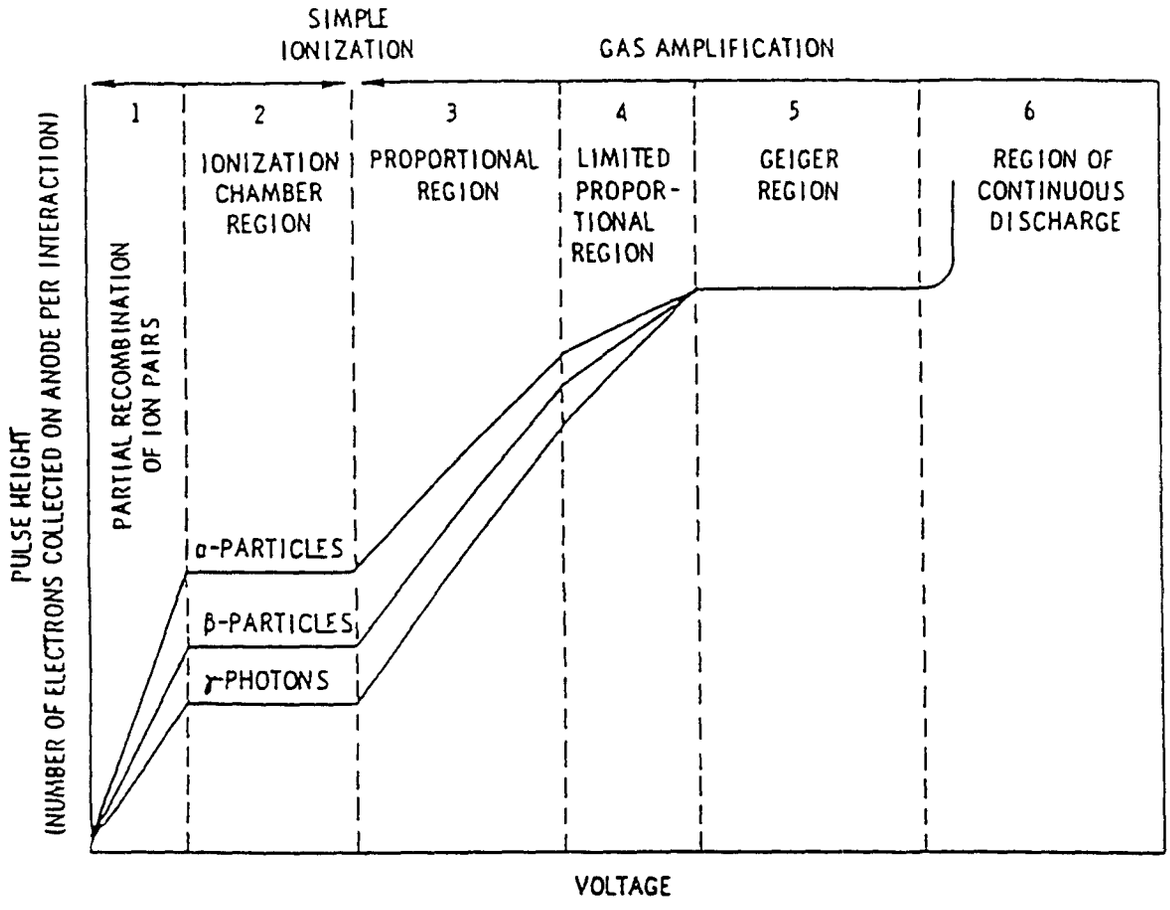


FIGURE 2
RELATIONSHIP BETWEEN APPLIED VOLTAGE AND THE NUMBER OF ELECTRONS COLLECTED AT THE ANODE

iv. electrons produced by incident radiation neutralize the charge on the electrode and the quartz fiber moves toward the electrode

v. available in direct reading and non-self-reading models **(Figure 3)**

2. Active Ionization Chamber: internal high voltage supply

a. integrating meter measures total current

b. nonintegrating functions as a rate meter

c. "cutie pie" is prototype

i. thin window with beta shield

ii. yields gross beta-gamma and gross gamma

iii. beta-gamma minus gamma equals beta

iv. relative response as a function of energy flat from 10 to 1000 keV (RR = 1 for gamma and x-rays)

v. seldom used for alpha radiation

D. Proportional Counters: a gas ionization detector that operates in the proportional region of the pulse-height voltage curve

1. Ionization gases provide stable operating characteristics and high amplification. Examples include P-10 (10% methane and

90% argon) or 4% isobutylene and 96% helium.

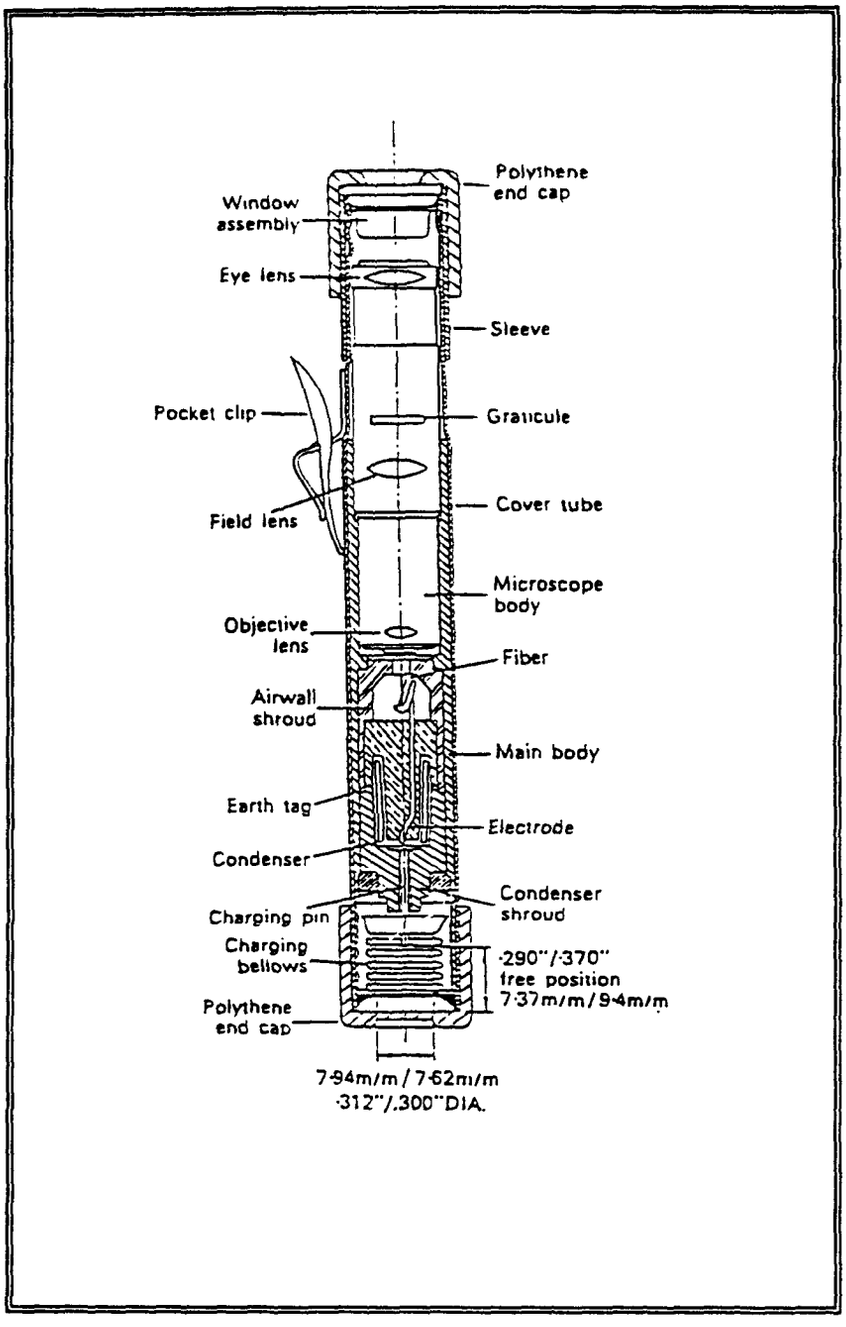


FIGURE 3
CROSS-SECTION OF A DIRECT-READING POCKET DOSIMETER

2. Easily differentiate alpha from beta radiation (**Figure 4**)

   a. alpha particles have a higher specific ionization than beta particles and require lower voltage to collect ions formed by incident radiation

   b. plotting the count rate as a function of operating voltage yields a graph with two plateaus

      i. only alpha particles are collected at low voltage (alpha plateau)

      ii. increasing voltage allows the collection of beta particles and the development of the beta plateau (the beta plateau is not as flat as the alpha plateau because of the wide variations in beta energies)

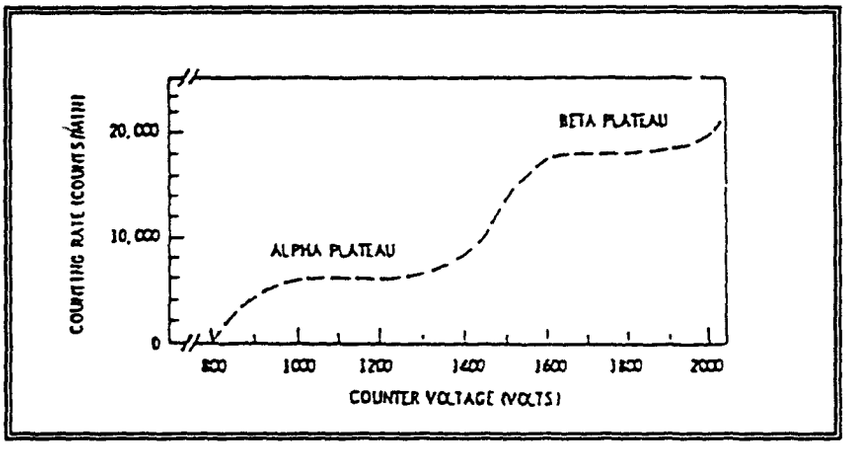


FIGURE 4
PLATEAUS FOR TYPICAL PROPORTIONAL COUNTER

3. Sealed proportional counters: have limited life due to degradation of ionizing gas

4. Gas-flow proportional detectors: longer life due to replacement of ionizing gas

5. Neutron measurement using proportional counters

   a. neutrons do not interact directly with the ionization gas

   b. chamber is filled with boron trifluoride gas

   c. thermal (low-energy) neutrons interact with the boron trifluoride and produce alpha particles, which interact with the ionization gas

   d. Fast (high-energy) neutrons are measured by wrapping the boron trifluoride tube with polyethylene, paraffin, or some other hydrogen-rich material. The wrapping moderates (decreases the energy) the fast neutrons.

   e. BF-3 tubes measure only neutron radiation **(Figure 5)**

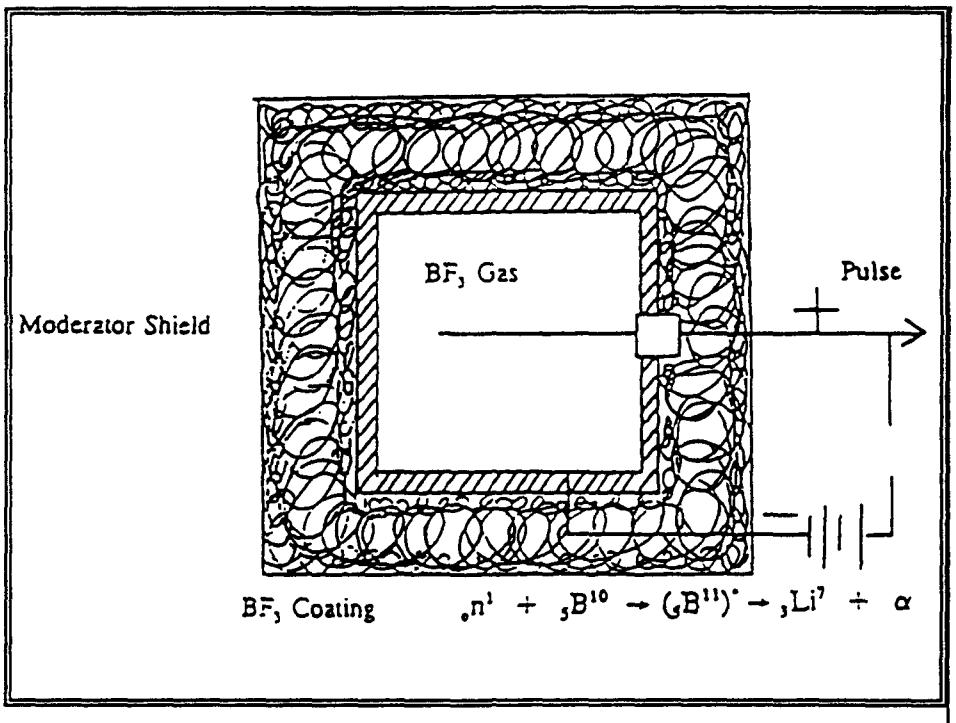


FIGURE 5
BF-3 TUBE

E. Geiger-Mueller Counters: ionization detectors operate in the Geiger region of the pulse height-voltage curve

1. Characteristics

a. used to count alpha, beta and gamma radiation

b. cannot distinguish among different types of radiation (all pulses same size in Geiger region)

c. wall and window thicknesses

i. 30 mg/cm^2 for gamma and high energy beta

ii. 0.4 to 1.4 mg/cm^2 for alpha and low-energy beta

d. most versatile radiation detectors; inexpensive, easy to operate, sensitive, and reliable

e. subject to continuous discharge in high radiation fields

2. Operating modes

a. pulse counter

b. portable survey meters

i. activity (CPM)

ii. dose rate (mR/hr)

3. Common detector configurations

a. stainless steel tube with 30 mg/cm^2 wall housed in ABS plastic as optional beta shield (HP-270)

b. "Pancake" GM tube, 5 cm diameter 1.4 to 2.0 mg/cm^2 mica window. Sensitive to alpha > 3 MeV.

II. Scintillation Detectors: radiation interacting with the detector creates visible light photons **(Figure 6)**

A. Principles of operation

1. Incident radiation transfers energy to the phosphor by ionization or excitation

2. Excited electrons move into defects or gaps in the lattice called "traps"

3. "Trapped" electrons return to lower energy levels and emit visible light

4. Signal is amplified with a photomultiplier tube and an electron amplifier

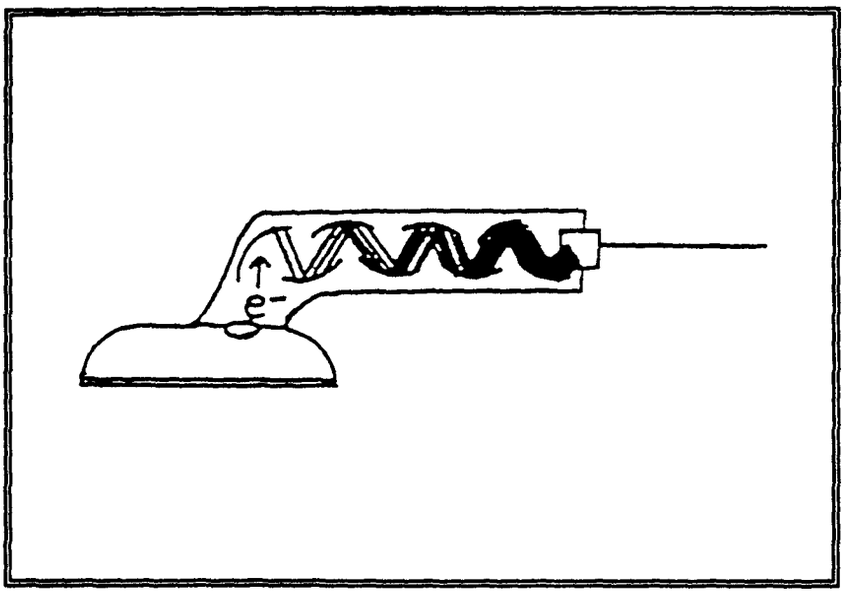


FIGURE 6
DIAGRAM OF DETECTOR

B. Peripheral Circuitry

1. Survey meters

   a. pulse shaper

   b. rate meter

2. Pulse Height Analyzers (**Figure 7**)

   a. Spectrometry: gamma and alpha radiation is emitted at discrete energy levels. Identification of the radionuclide is possible by analysis of the energy spectrum.

b. Pulse height analyzer: pulse height is proportional to the energy of the incident radiation. The pulse height analyzer sorts the detector signals by height (energy).

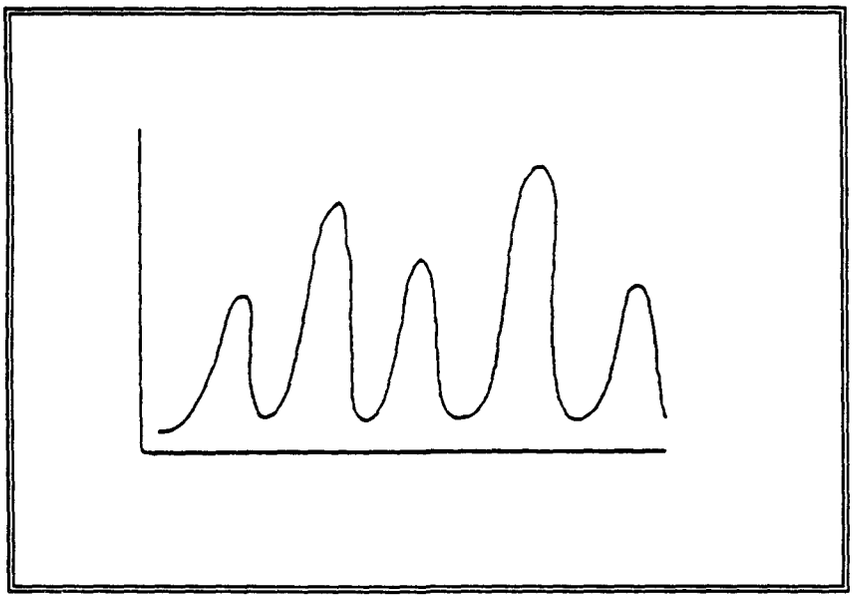


FIGURE 7
PULSE HEIGHT HISTOGRAM

c. Single channel analyzer: manually operated, analyzes only one channel

d. Multichannel analyzer: several hundred to thousand single channel analyzers. Accumulated data displayed as a spectrum with channel number (photon energy) on the x-axis versus counts per channel on the y-axis.

C. Inorganic Scintillators

1. Crystals of alkali halides (NaI) with thallium inclusions

a. used for gamma and x-ray detection

b. poor energy resolution

2. Zinc sulfide (ZnS) with silver inclusions

a. used for heavy charged particles such as alpha

b. often applied to the back of thin window or painted on the face of photomultiplier tube for alpha survey meters

Note: The following detection principles will not be applied in this course but you will hear reference to them when dealing with lab results.

D. Liquid Organic Scintillators

1. Produced by dissolving an organic scintillator material in an organic solvent

2. Counting efficiencies approach 100%

3. Particularly advantageous for counting low-energy beta emitters such as C-14 and H-3

4. Can be used for alpha emitters

5. Cocktail (scintillator plus sample) is placed in glass or plastic vial

6. Sample counted with photomultiplier tube in light-tight enclosure

E. Semiconductor Detectors

1. Principle of operation

a. detector made of a solid crystalline material

b. "impurities" are added to the crystalline material

c. similar to gas ionization detector; ionizations in the sensitive volume of the detector cause a voltage pulse which is amplified and counted on a scaler (secondary ions are not produced)

d. primary use is gamma spectroscopy because of high degree of resolution of energy peaks

e. semiconductor detectors have lower counting efficiencies than sodium iodide crystals, but better energy resolution

f. semiconductor detectors are expensive and fragile

g. there are two predominant types in use: germanium-lithium (GeLi) and selenium-lithium (SeLi)

i. GeLi detectors require cooling with liquid nitrogen for proper operation

ii. SeLi detectors can be operated at room temperature, but have lower counting efficiencies than GeLi detectors

III. Instrument Selection Criteria

A. Purpose of Monitoring

1. Exposure rate

2. Count rate

NOTES

B. Degree of Accuracy and Precision

1. Detection vs. measurement

2. Sensitivity and lower limit of detection

C. Types of Radiation

1. The principle factor in instrument selection

D. Source Form

1. Physical state and matrix

E. Radiation Field Characteristics

1. Intensity of radiation field

2. Uniformity of radiation field

SECTION 7

SURVEYING FOR RADIOACTIVE MATERIALS

After completing this unit, participants will be able to:

- Explain the purpose of surveying for radioactive materials.
- Define different types of sampling protocols and how sampling data are reported.
- Define and compare different sampling methods.

I. Surface Contamination.

A. Loose Surface Survey.

1. Dry smear.

2. Wet smear.

3. Solvent smear.

4. Large area wipes.

B. Fixed Surface Survey.

1. Direct frisk.

II. Soil.

A. Considerations.

1. Accurate determination of mass.

2. Self attenuation must be taken into account.

3. Usually loaded into small planchets.

III. Water.

A. Bulk.

1. Liter bottles.

2. Small samples taken and boiled off, counting the residue.

IV. Air.

A. Particulate Contaminants.

1. High-volume "grab" samples.

a. 5-10 minutes sample time.

b. Used for:

- Quick check of an area for entry.
- Monitoring airborne causing evolutions.
- Routine air monitoring.

2. Low-volume Samples.

a. 1-12 hours sample time.

b. Used as "proof" that nothing happened or to assess damage if something did.

c. Placed in work areas based on expected airborne contamination levels.

d. Routine air monitoring.

B. Gaseous Contaminants.

1. Noble gases - Maranelli sampler or liter bottle (nonreactive, needs to be volume collected).

2. Iodine - Charcoal filter cartridges (reactive, charcoal used for most).

C. CAM (Constant Air Monitor). Primarily used for particulates, but can also detect gaseous contaminants.

1. Continuous air monitoring.

2. Alarm capability.

3. Some have isotopic identification capability.

4. Placed in areas where airborne contamination may occur, early warning is desired, or continuous documentation of air quality is required.

V. Dose Rate Survey (1 mR/hr EPA action limit).

A. General Area.

1. Waist level
(Center of the "whole body").

2. >12 inches away from any surface (18 inches for commercial power plants).

B. Contact Dose Rates.

1. On contact with an object or surface.

C. Hot spot (contact reading).

1. 5 times the general area. Used as a thumbrule.

2. >150 mR/hr. Used as a thumbrule.

NOTE: The thumbrules are general guidance. Hot spots are normally small areas where radiation levels are significantly higher than normal area radiation levels. This is of primary interest when controlling personnel exposures.

VI. Documentation.

A. Survey sheet.

1. Surveyor name(s).

2. Date and time of samples (isolation time is critical).

3. Locations of samples.

4. Conditions of samples.

5. Instruments used (with serial numbers). Ensure instrument is in calibration at time of use.

6. Area or item description.

7. Type of survey performed.

Note:

Any additional information that may be useful in supplementing a survey should also be documented (e.g., survey after decontamination, initial survey, subsequent survey, and incident survey)

SECTION 8

RADIATION SIGNS AND LABELS

After completing this unit, participants will be able to:

- Identify the OSHA regulation that provides posting requirements for ionizing radiation.
- Define, according to OSHA, the following: radiation area, high radiation area, airborne radioactivity, and radioactive material.
- Describe one example of a posting practice found in industry.

I. 29 CFR 1910.96 Posting Requirements

A. Conventions

1. The radiation caution color scheme is magenta on a yellow background.

2. The radiation symbol is a three blade design called a trefoil (see **Figure 1**).

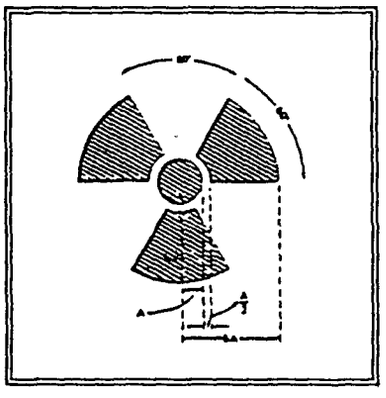


Figure 1
CONVENTIONAL RADIATION CAUTION SYMBOL

B. Definitions and Posting Requirements

1. Radiation Area

a. "Radiation Area" means any area, accessible to personnel, in which there exists radiation at such levels that a major portion of the body could receive in any 1 hour a dose in excess of 5 millirem, or in any 5 consecutive days a dose in excess of 100 millirem.

2. Each radiation area shall be conspicuously posted with a sign or signs bearing the radiation caution symbol and the words:

Caution
Radiation Area

3. High Radiation Area

   a. "High Radiation Area" means any area, accessible to personnel, in which there exists radiation at such levels that a major portion of the body could receive in any 1 hour a dose in excess of 100 millirem.

   b. High radiation areas must be locked or guarded.

   c. High radiation areas shall be conspicuously posted with a sign or signs bearing the radiation caution symbol and the words:

Caution
High Radiation Area

4. Airborne Radioactivity Area

   a. "Airborne Radioactivity Area" means any room, enclosure, or operating area in which airborne radioactive material exists in concentrations:

      i. in excess of the amounts specified in 10 CFR 20 Appendix B, Table I, Column I, or;

ii. which averaged over the number of hours in any week during which individuals are in the area, exceed 25% of the amounts specified in 10 CFR 20 Appendix B, Table I, Column I (see **Figure 2**).

APPENDIX B—CONCENTRATIONS IN AIR AND WATER ABOVE NATURAL BACKGROUND—Continued

(See footnotes at end of Appendix B)

Element (atomic number)	Isotope [1]		Table I		Table II	
			Col. 1—Air (μCi/ml)	Col. 2—Water (μCi/ml)	Col. 1—Air (μCi/ml)	Col. 2—Water (μCi/ml)
		I	$2 \cdot 10^{-7}$	$1 \cdot 10^{-3}$	$6 \cdot 10^{-9}$	$3 \cdot 10^{-5}$
Californium (98)	Cf 249	S	$2 \cdot 10^{-12}$	$1 \cdot 10^{-7}$	$5 \cdot 10^{-14}$	$4 \cdot 10^{-9}$
		I	$1 \cdot 10^{-10}$	$7 \cdot 10^{-7}$	$3 \cdot 10^{-12}$	$2 \cdot 10^{-8}$
	Cf 250	S	$5 \cdot 10^{-12}$	$4 \cdot 10^{-7}$	$2 \cdot 10^{-13}$	$1 \cdot 10^{-8}$
		I	$1 \cdot 10^{-10}$	$7 \cdot 10^{-7}$	$3 \cdot 10^{-12}$	$3 \cdot 10^{-8}$
	Cf 251	S	$2 \cdot 10^{-12}$	$1 \cdot 10^{-7}$	$6 \cdot 10^{-14}$	$4 \cdot 10^{-9}$
		I	$1 \cdot 10^{-10}$	$8 \cdot 10^{-7}$	$3 \cdot 10^{-12}$	$3 \cdot 10^{-8}$
	Cf 252	S	$6 \cdot 10^{-12}$	$2 \cdot 10^{-7}$	$2 \cdot 10^{-13}$	$7 \cdot 10^{-9}$
		I	$3 \cdot 10^{-11}$	$2 \cdot 10^{-7}$	$1 \cdot 10^{-12}$	$7 \cdot 10^{-9}$
	Cf 253	S	$8 \cdot 10^{-10}$	$4 \cdot 10^{-6}$	$3 \cdot 10^{-11}$	$1 \cdot 10^{-7}$
		I	$8 \cdot 10^{-10}$	$4 \cdot 10^{-6}$	$3 \cdot 10^{-11}$	$1 \cdot 10^{-7}$
	Cf 254	S	$5 \cdot 10^{-12}$	$4 \cdot 10^{-8}$	$2 \cdot 10^{-13}$	$1 \cdot 10^{-9}$
		I	$5 \cdot 10^{-12}$	$4 \cdot 10^{-8}$	$2 \cdot 10^{-13}$	$1 \cdot 10^{-9}$
Carbon (6)	C 14	S	$4 \cdot 10^{-8}$	$2 \cdot 10^{-3}$	$1 \cdot 10^{-9}$	$8 \cdot 10^{-5}$
	(CO_2)	Sub	$5 \cdot 10^{-7}$		$1 \cdot 10^{-8}$	
Cerium (58)	Ce 141	S	$4 \cdot 10^{-7}$	$3 \cdot 10^{-3}$	$2 \cdot 10^{-8}$	$9 \cdot 10^{-5}$
		I	$2 \cdot 10^{-7}$	$3 \cdot 10^{-3}$	$5 \cdot 10^{-9}$	$9 \cdot 10^{-5}$
	Ce 143	S	$3 \cdot 10^{-7}$	$1 \cdot 10^{-3}$	$9 \cdot 10^{-9}$	$4 \cdot 10^{-5}$
		I	$2 \cdot 10^{-7}$	$1 \cdot 10^{-3}$	$7 \cdot 10^{-9}$	$4 \cdot 10^{-5}$
	Ce 144	S	$1 \cdot 10^{-8}$	$3 \cdot 10^{-5}$	$3 \cdot 10^{-10}$	$1 \cdot 10^{-6}$
		I	$6 \cdot 10^{-9}$	$3 \cdot 10^{-5}$	$2 \cdot 10^{-10}$	$1 \cdot 10^{-6}$
Cesium (55)	Cs 131	S	$1 \cdot 10^{-6}$	$7 \cdot 10^{-3}$	$4 \cdot 10^{-8}$	$2 \cdot 10^{-4}$
		I	$3 \cdot 10^{-6}$	$3 \cdot 10^{-3}$	$1 \cdot 10^{-7}$	$9 \cdot 10^{-5}$
	Cs 134m	S	$4 \cdot 10^{-6}$	$2 \cdot 10^{-3}$	$1 \cdot 10^{-7}$	$6 \cdot 10^{-5}$
		I	$6 \cdot 10^{-9}$	$3 \cdot 10^{-5}$	$2 \cdot 10^{-10}$	$1 \cdot 10^{-6}$
	Cs 134	S	$4 \cdot 10^{-10}$	$3 \cdot 10^{-6}$	$1 \cdot 10^{-11}$	$9 \cdot 10^{-8}$
		I	$1 \cdot 10^{-9}$	$1 \cdot 10^{-5}$	$4 \cdot 10^{-11}$	$4 \cdot 10^{-7}$
	Cs 135	S	$5 \cdot 10^{-7}$	$3 \cdot 10^{-3}$	$2 \cdot 10^{-8}$	$1 \cdot 10^{-4}$
		I	$9 \cdot 10^{-7}$	$7 \cdot 10^{-3}$	$3 \cdot 10^{-8}$	$2 \cdot 10^{-4}$
	Cs 136	S	$4 \cdot 10^{-7}$	$2 \cdot 10^{-3}$	$1 \cdot 10^{-8}$	$9 \cdot 10^{-5}$
		I	$2 \cdot 10^{-7}$	$2 \cdot 10^{-3}$	$6 \cdot 10^{-9}$	$6 \cdot 10^{-5}$
	Cs 137	S	$6 \cdot 10^{-8}$	$4 \cdot 10^{-4}$	$2 \cdot 10^{-9}$	$2 \cdot 10^{-5}$
		I	$1 \cdot 10^{-7}$	$1 \cdot 10^{-3}$	$5 \cdot 10^{-10}$	$4 \cdot 10^{-6}$
Chlorine (17)	Cl 36	S	$4 \cdot 10^{-7}$	$2 \cdot 10^{-3}$	$1 \cdot 10^{-8}$	$8 \cdot 10^{-5}$
		I	$2 \cdot 10^{-7}$	$2 \cdot 10^{-3}$	$8 \cdot 10^{-10}$	$6 \cdot 10^{-6}$
	Cl 38	S	$3 \cdot 10^{-6}$	$1 \cdot 10^{-2}$	$9 \cdot 10^{-8}$	$4 \cdot 10^{-4}$
		I	$2 \cdot 10^{-6}$	$1 \cdot 10^{-2}$	$7 \cdot 10^{-8}$	$4 \cdot 10^{-4}$
Chromium (24)	Cr 51	S	$1 \cdot 10^{-5}$	$5 \cdot 10^{-2}$	$4 \cdot 10^{-7}$	$2 \cdot 10^{-3}$
		I	$2 \cdot 10^{-6}$	$5 \cdot 10^{-2}$	$8 \cdot 10^{-8}$	$2 \cdot 10^{-3}$
Cobalt (27)	Co 57	S	$3 \cdot 10^{-6}$	$2 \cdot 10^{-2}$	$1 \cdot 10^{-7}$	$5 \cdot 10^{-4}$
		I	$2 \cdot 10^{-7}$	$1 \cdot 10^{-3}$	$6 \cdot 10^{-9}$	$4 \cdot 10^{-5}$
	Co 58m	S	$2 \cdot 10^{-5}$	$8 \cdot 10^{-2}$	$6 \cdot 10^{-7}$	$3 \cdot 10^{-3}$
		I	$9 \cdot 10^{-6}$	$6 \cdot 10^{-2}$	$3 \cdot 10^{-7}$	$2 \cdot 10^{-3}$
	Co 58	S	$8 \cdot 10^{-7}$	$4 \cdot 10^{-3}$	$3 \cdot 10^{-8}$	$1 \cdot 10^{-4}$
		I	$5 \cdot 10^{-6}$	$3 \cdot 10^{-2}$	$2 \cdot 10^{-7}$	$9 \cdot 10^{-5}$
	Co 60	S	$3 \cdot 10^{-7}$	$1 \cdot 10^{-3}$	$1 \cdot 10^{-8}$	$5 \cdot 10^{-5}$
		I	$9 \cdot 10^{-9}$	$1 \cdot 10^{-5}$	$3 \cdot 10^{-10}$	$3 \cdot 10^{-7}$
Copper (29)	Cu 64	S	$2 \cdot 10^{-6}$	$1 \cdot 10^{-2}$	$7 \cdot 10^{-8}$	$3 \cdot 10^{-4}$
		I	$1 \cdot 10^{-6}$	$6 \cdot 10^{-3}$	$4 \cdot 10^{-8}$	$2 \cdot 10^{-4}$
Curium (96)	Cm 242	S	$1 \cdot 10^{-10}$	$7 \cdot 10^{-7}$	$4 \cdot 10^{-12}$	$2 \cdot 10^{-8}$
		I	$2 \cdot 10^{-10}$	$7 \cdot 10^{-7}$	$6 \cdot 10^{-12}$	$2 \cdot 10^{-8}$
	Cm 243	S	$6 \cdot 10^{-12}$	$1 \cdot 10^{-7}$	$2 \cdot 10^{-13}$	$5 \cdot 10^{-9}$
		I	$1 \cdot 10^{-10}$	$7 \cdot 10^{-7}$	$3 \cdot 10^{-12}$	$2 \cdot 10^{-8}$
	Cm 244	S	$9 \cdot 10^{-12}$	$2 \cdot 10^{-7}$	$3 \cdot 10^{-13}$	$7 \cdot 10^{-9}$
		I	$1 \cdot 10^{-10}$	$8 \cdot 10^{-7}$	$3 \cdot 10^{-12}$	$3 \cdot 10^{-8}$
	Cm 245	S	$5 \cdot 10^{-12}$	$1 \cdot 10^{-7}$	$2 \cdot 10^{-13}$	$4 \cdot 10^{-9}$
		I	$1 \cdot 10^{-10}$	$8 \cdot 10^{-7}$	$4 \cdot 10^{-12}$	$3 \cdot 10^{-8}$
	Cm 246	S	$5 \cdot 10^{-12}$	$1 \cdot 10^{-7}$	$2 \cdot 10^{-13}$	$4 \cdot 10^{-9}$
		I	$1 \cdot 10^{-10}$	$8 \cdot 10^{-7}$	$4 \cdot 10^{-12}$	$3 \cdot 10^{-8}$
	Cm 247	S	$5 \cdot 10^{-12}$	$1 \cdot 10^{-7}$	$2 \cdot 10^{-13}$	$4 \cdot 10^{-9}$
		I	$1 \cdot 10^{-10}$	$6 \cdot 10^{-7}$	$4 \cdot 10^{-12}$	$2 \cdot 10^{-8}$
	Cm 248	S	$6 \cdot 10^{-13}$	$1 \cdot 10^{-8}$	$2 \cdot 10^{-14}$	$4 \cdot 10^{-10}$
		I	$1 \cdot 10^{-11}$	$4 \cdot 10^{-8}$	$4 \cdot 10^{-13}$	$1 \cdot 10^{-9}$
	Cm 249	S	$1 \cdot 10^{-6}$	$6 \cdot 10^{-3}$	$4 \cdot 10^{-8}$	$2 \cdot 10^{-4}$
		I	$1 \cdot 10^{-6}$	$6 \cdot 10^{-3}$	$4 \cdot 10^{-8}$	$2 \cdot 10^{-4}$

FIGURE 2
EXCERPT: 10 CFR 20, APPENDIX B

b. Each airborne radioactivity area shall be conspicuously posted with a sign or signs bearing the radiation caution symbol and the words:

Caution
Airborne Radioactivity Area

4. Radioactive Materials Area

a. Each area or room in which radioactive material is used or stored and which contains any radioactive material (other than natural uranium or thorium) in any amount exceeding 10 times the quantity of such material specified in Appendix C to 10 CFR Part 20 (see **Figure 3**) shall be conspicuously posted with a sign or signs bearing the radiation caution symbol and the words:

Caution
Radioactive Materials

b. Each area or room in which natural uranium or thorium is used or stored in any amount exceeding 100 times the quantity of such material specified in Appendix C to 10 CFR 20 shall be conspicuously posted with a sign or signs bearing the radiation caution symbol and the words:

Caution
Radioactive Materials

APPENDIX C—Continued

Material	Microcuries
Manganese-56	10
Mercury-197m	100
Mercury-197	100
Mercury-203	10
Molybdenum-99	100
Neodymium-147	100
Neodymium-149	100
Nickel-59	100
Nickel-63	10
Nickel-65	100
Niobium-93m	10
Niobium-95	10
Niobium-97	10
Osmium-185	10
Osmium-191m	100
Osmium-191	100
Osmium-193	100
Palladium-103	100
Palladium-109	100
Phosphorus-32	10
Platinum-191	100
Platinum-193m	100
Platinum-193	100
Platinum-197m	100
Platinum-197	100
Plutonium-239	.01
Polonium-210	0.1
Potassium-42	10
Praseodymium-142	100
Praseodymium-143	100
Promethium-147	10
Promethium-149	10
Radium-226	.01
Rhenium-186	100
Rhenium-188	100
Rhodium-103m	100
Rhodium-105	100
Rubidium-86	10
Rubidium-87	10
Ruthenium-97	100
Ruthenium-103	10
Ruthenium-105	10
Ruthenium-106	1
Samarium-151	10
Samarium-153	100
Scandium-46	10
Scandium-47	100
Scandium-48	10
Selenium-75	10
Silicon-31	100
Silver-105	10
Silver-110m	1
Silver-111	100
Sodium-24	10
Strontium-85	10
Strontium-89	1
Strontium-90	0.1
Strontium-91	10
Strontium-92	10
Sulphur-35	100
Tantalum-182	10
Technetium-96	10
Technetium-97m	100
Technetium-97	100
Technetium-99m	100
Technetium-99	10
Tellurium-125m	10

APPENDIX C—Continued

Material	Microcuries
Tellurium-127m	10
Tellurium-127	100
Tellurium-129m	10
Tellurium-129	100
Tellurium-131m	10
Tellurium-132	10
Terbium-160	10
Thallium-200	100
Thallium-201	100
Thallium-202	100
Thallium-204	10
Thorium (natural)[1]	100
Thulium-170	10
Thulium-171	10
Tin-113	10
Tin-125	10
Tungsten-181	10
Tungsten-185	10
Tungsten-187	100
Uranium (natural)[2]	100
Uranium-233	.01
Uranium-234—Uranium-235	.01
Vanadium-48	10
Xenon-131m	1,000
Xenon-133	100
Xenon-135	100
Ytterbium-175	100
Yttrium-90	10
Yttrium-91	10
Yttrium-92	100
Yttrium-93	100
Zinc-65	10
Zinc-69m	100
Zinc-69	1,000
Zirconium-93	10
Zirconium-95	10
Zirconium-97	10
Any alpha emitting radionuclide not listed above or mixtures of alpha emitters of unknown composition	.01
Any radionuclide other than alpha emitting radionuclides, not listed above or mixtures of beta emitters of unknown composition	.1

[1]Based on alpha disintegration rate of Th-232, Th-230 and their daughter products

[2]Based on alpha disintegration rate of U-238, U-234, and U-235.

NOTE: For purposes of § 20.303, where there is involved a combination of isotopes in known amounts, the limit for the combination should be derived as follows: Determine, for each isotope in the combination, the ratio between the quantity present in the combination and the limit otherwise established for the specific isotope when not in combination. The sum of such ratios for all the isotopes in the combination may not exceed "1" (i.e., "unity").

[35 FR 6425, Apr. 22, 1970, as amended at 36 FR 16898, Aug. 26, 1971; 38 FR 29314, Oct. 24, 1973; 39 FR 23991, June 28, 1974; 45 FR 71763, Oct. 30, 1980]

FIGURE 3
EXCERPT: 10 CFR 20, APPENDIX C

5. Containers

a. Each container in which is transported, stored, or used a quantity of any radioactive material (other than natural uranium or thorium) greater than the quantity of such material specified in Appendix C to 10 CFR Part 20 shall bear a durable, clearly visible label bearing the radiation caution symbol and the words:

Caution
Radioactive Materials

b. Each container in which natural uranium or thorium is transported, stored, or used in a quantity greater than 10 times the quantity specified in Appendix C to 10 CFR Part 20 shall bear a durable, clearly visible label bearing the radiation caution symbol and the words:

Caution
Radioactive Materials

c. A label shall not be required:

i. If the concentration of the material in the container does not exceed that specified in Column 2 of Table I of Appendix B to 10 CFR Part 20, or

ii. For laboratory containers, such as beakers, flasks, and test tubes, used transiently in laboratory procedures, when the user is present.

d. Where containers are used for storage, the labels required in this subparagraph shall state also the quantities and kinds of radioactive materials in the containers and the date of measurement of the quantities.

C. Exceptions from Posting Requirements

1. A room or area is not required to be posted with a caution sign because of the presence of a sealed source, provided the radiation level 12 inches from the surface of the source container or housing does not exceed 5 millirem per hour.

2. Rooms or other areas in onsite medical facilities are not required to be posted with caution signs because of the presence of patients containing radioactive material, provided that there are personnel in attendance who shall take the precautions necessary to prevent the exposure of any individual to radiation or radioactive material in excess of the limits established in 29 CFR 1910.96 Section (b).

3. Caution signs are not required to be posted in areas or rooms containing radioactive materials for periods of less than 8 hours, provided that:

   a. The materials are constantly attended during such periods by an individual who shall take the precautions necessary to prevent the exposure of any individual to radiation or radioactive materials in excess of the limits established in 29 CFR 1910.96 Section (b).

b. Such area or room is subject to the employer's control.

II. Industry Accepted Conventions

NOTE: THE FOLLOWING POSTING PRACTICES ARE SITE SPECIFIC

A. "Very High Radiation Area"

1. Posted when an area in the room has a general area dose rate >1 R/hr

2. Normally a sign is conspicuously posted that bears the radiation caution symbol and the words:

Caution
Very High Radiation Area

B. "Surface Contaminated Area"

1. Posted when radioactive loose surface contamination exceeds the limits for an uncontrolled area.

2. Normally a sign is conspicuously posted that bears the radiation caution symbol and the words:

Caution
Surface Contaminated Area

3. Step-off pads are posted areas that designate the point of entry and exit for a contaminated area.

4. Yellow and magenta boundary tape is used to establish the perimeter of a contaminated area.

NOTES

C. MultiPocket Signs

1. Used to identify areas that:
   a. are temporary
   b. have changing requirements
   c. that fall into more than one classification (i.e. "High Radiation Area" which is also a "Contaminated Area")

D. Radiation Area Ribbon/Rope

1. Yellow and magenta ribbon or rope, set waist high, used to separate a radiological control area from an noncontrolled area. Applicable signs are hung on the rope.

SECTION 9

CONTAMINATION CONTROL

After completing this unit, participants will be able to:

- Define contamination and give one example of a contamination problem.
- Describe contamination surveying techniques.
- Describe radwaste reduction techniques.

I. Definitions and Units of Measure

A. Radioactive contamination is a fine form of radioactive material in a place that it is not wanted.

1. Loose surface contamination is contamination that comes off of a surface when it is wiped by a dry filter paper; this is called a dry smear.

2. Fixed surface contamination will not come off on a dry smear.

B. Units of Measurement

Contamination is radioactive material, so it has to be measured in the same units as any other radioactive material,(i.e., dpm or curies). However, contamination is a very fine form of radioactive material, consequently, subunits tend to be used, (i.e., microcuries).

The main concern with contamination is keeping it from entering our bodies. The routes of entry are the same as for any hazardous material: open cut or wound, puncture, inhalation, or ingestion. Consequently, the important question when measuring contamination is the location of contamination, that is, is it on a solid surface, in the air, in water, or mixed in soil. Depending on the medium containing the contamination, the following units are used:

Surface	-	(dpm/100 cm^2)= dpm per 100 square centimeters
Air	-	(μCi/mL)= microcuries per milliliter of air
Water	-	(μCi/mL)= microcuries per milliliter of water

Soil	(μCi or pCi/g)= microcuries or picocuries per gram of soil

II. Surface Contamination

A. Regulatory Guide 1.86 - Termination of Operating License for Nuclear Reactors

1. This document presents the guidance that is normally referenced when contamination limits are needed (**Table 1**).

2. The limits apply to contamination on personnel, personal items, tools, equipment, and large surfaces areas (i.e., floors).

B. Contamination Identification - Original Problem

1. Identification starts with the recognition of a possible problem.

   a. spills

   b. leaks

   c. maintenance activities that require the opening of a contaminated system

   d. sampling exercises

2. Identification continues with surveying the area:

   a. smear survey - for loose surface contamination

ACCEPTABLE SURFACE CONTAMINATION LEVELS

NUCLIDE[a]	AVERAGE[b c]	MAXIMUM[b d]	REMOVABLE[b e]
U-nat, U-235, U-238, and associated decay products	5,000 dpm α/100 cm^2	15,000 dpm α/100 cm^2	1,000 dpm α/100 cm^2
Transuranics, Ra-226, Ra-228, Th-230, Th-228, Pa-231, Ac-227, I-125, I-129	100 dpm/100 cm^2	300 dpm/100 cm^2	20 dpm/100 cm^2
Th-nat, Th-232, Sr-90, Ra-223, Ra-224, U-232, I-126, I-131, I-133	1000 dpm/100 cm^2	3000 dpm/100 cm^2	200 dpm/100 cm^2
Beta-gamma emitters (nuclides with decay modes other than alpha emission or spontaneous fission) except Sr-90 and others noted above.	5000 dpm β-γ/100 cm^2	15,000 dpm β-γ/100 cm^2	1000 dpm β-γ/100 cm^2

[a]Where surface contamination by both alpha- and beta-gamma-emitting nuclides exists, the limits established for alpha- and beta-gamma-emitting nuclides should apply independently.

[b]As used in this table, dpm (disintegrations per minute) means the rate of emission by radioactive material as determined by correcting the counts per minute observed by an appropriate detector for background, efficiency, and geometric factors associated with the instrumentation.

[c]Measurements of average contaminant should not be averaged over more than 1 square meter. For objects of less surface area, the average should be derived for each such object.

[d]*The maximum contamination level applies to an area of not more than 100 cm^2.*

[e]The amount of removable radioactive material per 100 cm^2 of surface area should be determined by wiping that area with dry filter or soft absorbent paper, applying moderate pressure, and assessing the amount of radioactive material on the wipe with an appropriate instrument of known efficiency. When removable contamination on objects of less surface area is determined, the pertinent levels should be reduced proportionally and the entire surface should be wiped.

TABLE 1
EXCERPT: REGULATORY GUIDE 1.86

b. direct survey with an instrument for both loose and fixed contamination; this is called "frisking"

3. Once contamination is identified or suspected, the area is "posted"

a. ropes

b. signs

c. step-off pads

C. Contamination Identification - Problem Control

1. Direct survey (frisking) - whole body, hands and feet, or equipment:

a. use a count rate meter instrument (beta-gamma or alpha)

b. hold the probe close to the surface between one quarter to one half an inch away

c. move the probe slowly, about 1 to 2 inches per second

d. observe the meter for any increase in count rate

2. Automatic Contamination Monitors

a. timed counter "gates"

b. walk-through monitors

c. computer counters

3. Removal of Material from a Contaminated Area

   a. all material leaving a contaminated area must be treated as contaminated until proven otherwise

   b. bag the item and move it to the place where it will be dealt with, (e.g., storage or decon)

   c. to release the item for unrestricted use, it must be surveyed for both loose and fixed surface contamination

4. Documentation

   a. All surveys should be properly recorded

   b. All contamination events should be recorded including an investigation to determine root cause. This is the only way that recurrence can be prevented.

D. Radioactive Waste

1. Most radioactive waste is actually material that is contaminated with radioactive deposits.

   Example: A pipe wrench might be used in a contaminated area. The teeth of the wrench could get contamination embedded in them. If that happens, the entire wrench is not radioactive. The only thing that is radioactive is the radioactive material deposited on the teeth. But, the entire wrench must be handled as radioactive until these deposits are removed, (i.e., decontaminated).

Consequently, if the wrench cannot be decontaminated, and it is to be disposed of, the entire wrench is considered "radioactive waste."

2. Radwaste Reduction Techniques

   a. limit the entry of tools, equipment, and packing material into potentially contaminated areas

   b. keep contaminated and non-contaminated materials separate

   c. reuse tools and equipment with fixed contamination (make up a contaminated tool crib)

   d. establish a sorting and segregation practice that reduces the volume of the radioactive waste (**Figure 1**)

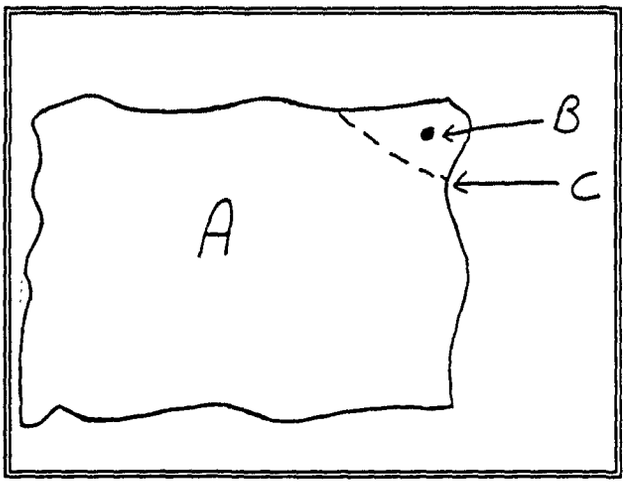


FIGURE 1
CONTAMINATED RAG

Steps for sorting and segregating the cloth

1. Survey the article (A)
2. Locate the contamination (Part B)
3. Remove the contaminated section (cut on line C)
4. Dispose of noncontaminated section as regular waste (Part A)
5. Dispose of contaminated section as radioactive waste (Part B)

3. Liquids and wet material should be kept segregated from dry contaminated waste.

   a. all radioactive waste has to be totally dry for disposal

   b. liquids and wet materials have to be either solidified or dried

III. Airborne Contamination

A. Definitions

1. Airborne contamination - radioactive material in the air that exceeds the limits established in 10 CFR 20, Appendix B

   a. particulate

   b. gaseous

2. Internal Exposure - exposure to radiation from radioactive material which is deposited inside of the body

B. Types of Airborne Contamination

1. Particulate - radioactive material that exists in a solid state at standard temperature and pressure (STP). Ex: ^{60}Co or ^{90}Sr

   a. usually bound up in some form of a metal complex or salt (cobalt oxide or radium bromide)

   b. ability to go airborne is directly related to the physical medium it is in

      i. dry and dusty

      ii. water

      iii. oil

   c. can be removed from the air by high-efficiency filtration

2. Gaseous - any radioactive material that exists in a gas state at STP Ex: ^{131}I, ^{133}I

   a. Reactive gas (iodine)

      i. can be removed from the air by filtering through an activated charcoal medium

   b. Noble gas (radon, krypton)

      i. cannot be removed from the air in this form

C. Regulations

1. 29 CFR 1910.96 (c) **(Figure 2)**

(1) No employer shall possess, use, or transport radioactive material in such a manner as to cause any employee, within a restricted area, to be exposed to airborne radioactive material in an average concentration in excess of the limits specified in Table 1 of Appendix B to 10 CFR Part 20. The limits given in Table 1 are for exposure to the concentrations specified for 40 hours in any workweek of 7 consecutive days. In any such period where the number of hours of exposure is less than 40, the limits specified in the table may be increased proportionately. In any such period where the number of hours of exposure is greater than 40, the limits specified in the table shall be decreased proportionately.

(2) No employer shall possess, use, or transfer radioactive material in such a manner as to cause any individual within a restricted area, who is under 18 years of age, to be exposed to airborne radioactive material in an average concentration in excess of the limits specified in Table II of Appendix B to 10 CFR Part 20. For purposes of this subparagraph, concentrations may be averaged over periods not greater than 1 week.

(3) "Exposed" as used in this paragraph means that the individual is present in an airborne concentration. No allowance shall be made for the use of protective clothing or equipment, or particle size.

FIGURE 2
EXCERPT: 29 CFR 1910.96 (c)

2. 10 CFR 20, Appendix B
(Table 2)

Part 20, App. B **10 CFR Ch. I (1-1-91 Edition)**

APPENDIX B—CONCENTRATIONS IN AIR AND WATER ABOVE NATURAL BACKGROUND—Continued

(See footnotes at end of Appendix B)

Element (atomic number)	Isotope [1]		Table I		Table II	
			Col. 1—Air (μCi/ml)	Col. 2—Water (μCi/ml)	Col. 1—Air (μCi/ml)	Col. 2—Water (μCi/ml)
Californium (98)	Cf 249	I	$2 \cdot 10^{-1}$	1×10^{-3}	$6 \cdot 10^{-5}$	3×10^{-7}
		S	$2 \cdot 10^{-12}$	$1 \cdot 10^{-4}$	5×10^{-14}	4×10^{-6}
	Cf 250	I	$1 \cdot 10^{-10}$	$7 \cdot 10^{-4}$	$3 \cdot 10^{-12}$	$2 \cdot 10^{-5}$
		S	$5 \cdot 10^{-12}$	$4 \cdot 10^{-4}$	$2 \cdot 10^{-13}$	1×10^{-5}
	Cf 251	I	$1 \cdot 10^{-10}$	$7 \cdot 10^{-4}$	$3 \cdot 10^{-12}$	3×10^{-5}
		S	$2 \cdot 10^{-12}$	$1 \cdot 10^{-4}$	6×10^{-14}	4×10^{-6}
	Cf 252	I	$1 \cdot 10^{-10}$	8×10^{-4}	3×10^{-12}	3×10^{-5}
		S	$6 \cdot 10^{-12}$	2×10^{-4}	2×10^{-13}	7×10^{-6}
	Cf 253	I	$3 \cdot 10^{-11}$	$2 \cdot 10^{-4}$	1×10^{-13}	7×10^{-6}
		S	$8 \cdot 10^{-10}$	$4 \cdot 10^{-3}$	3×10^{-11}	1×10^{-4}
	Cf 254	I	$8 \cdot 10^{-10}$	4×10^{-3}	3×10^{-11}	1×10^{-4}
		S	$5 \cdot 10^{-12}$	4×10^{-4}	2×10^{-13}	1×10^{-5}
		I	$5 \cdot 10^{-12}$	4×10^{-6}	2×10^{-13}	1×10^{-7}
Carbon (6)	C 14	S	$4 \cdot 10^{-6}$	$2 \cdot 10^{-7}$	$1 \cdot 10^{-7}$	8×10^{-9}
	(CO_2)	Sub	$5 \cdot 10^{-6}$		$1 \cdot 10^{-6}$	
Cerium (58)	Ce 141	S	$4 \cdot 10^{-7}$	$3 \cdot 10^{-9}$	$2 \cdot 10^{-8}$	$9 \cdot 10^{-11}$
		I	$2 \cdot 10^{-7}$	$3 \cdot 10^{-9}$	$5 \cdot 10^{-9}$	$9 \cdot 10^{-11}$
	Ce 143	S	$3 \cdot 10^{-7}$	$1 \cdot 10^{-8}$	$9 \cdot 10^{-9}$	$4 \cdot 10^{-10}$
		I	$2 \cdot 10^{-7}$	$1 \cdot 10^{-8}$	$7 \cdot 10^{-9}$	$4 \cdot 10^{-10}$
	Ce 144	S	$1 \cdot 10^{-8}$	$3 \cdot 10^{-10}$	$3 \cdot 10^{-10}$	$1 \cdot 10^{-11}$
		I	$6 \cdot 10^{-9}$	$3 \cdot 10^{-10}$	$2 \cdot 10^{-10}$	$1 \cdot 10^{-11}$
Cesium (55)	Cs 131	S	$1 \cdot 10^{-6}$	$7 \cdot 10^{-9}$	$4 \cdot 10^{-8}$	$2 \cdot 10^{-10}$
		I	$3 \cdot 10^{-6}$	$3 \cdot 10^{-8}$	$1 \cdot 10^{-7}$	$9 \cdot 10^{-10}$
	Cs 134m	S	$4 \cdot 10^{-6}$	$2 \cdot 10^{-8}$	$1 \cdot 10^{-7}$	6×10^{-9}
		I	$6 \cdot 10^{-6}$	$3 \cdot 10^{-8}$	$2 \cdot 10^{-7}$	1×10^{-9}
	Cs 134	S	$4 \cdot 10^{-8}$	$3 \cdot 10^{-10}$	$1 \cdot 10^{-9}$	9×10^{-12}
		I	$1 \cdot 10^{-7}$	$1 \cdot 10^{-9}$	$4 \cdot 10^{-9}$	4×10^{-11}
	Cs 135	S	$5 \cdot 10^{-7}$	$3 \cdot 10^{-9}$	$2 \cdot 10^{-8}$	$1 \cdot 10^{-10}$
		I	$9 \cdot 10^{-7}$	$7 \cdot 10^{-9}$	$3 \cdot 10^{-8}$	$2 \cdot 10^{-10}$
	Cs 136	S	$4 \cdot 10^{-7}$	$2 \cdot 10^{-9}$	$1 \cdot 10^{-8}$	$9 \cdot 10^{-11}$
		I	$2 \cdot 10^{-7}$	$2 \cdot 10^{-9}$	$6 \cdot 10^{-9}$	$6 \cdot 10^{-11}$
	Cs 137	S	$6 \cdot 10^{-8}$	$4 \cdot 10^{-10}$	$2 \cdot 10^{-9}$	$2 \cdot 10^{-11}$
		I	$1 \cdot 10^{-7}$	$1 \cdot 10^{-9}$	$5 \cdot 10^{-10}$	$4 \cdot 10^{-12}$
Chlorine (17)	Cl 36	S	$4 \cdot 10^{-7}$	$2 \cdot 10^{-9}$	$1 \cdot 10^{-8}$	$8 \cdot 10^{-11}$
		I	$2 \cdot 10^{-6}$	$2 \cdot 10^{-8}$	$8 \cdot 10^{-10}$	$6 \cdot 10^{-12}$
	Cl 38	S	$3 \cdot 10^{-6}$	$1 \cdot 10^{-7}$	$9 \cdot 10^{-9}$	$4 \cdot 10^{-10}$
		I	$2 \cdot 10^{-6}$	$1 \cdot 10^{-7}$	$7 \cdot 10^{-9}$	$4 \cdot 10^{-10}$
Chromium (24)	Cr 51	S	$1 \cdot 10^{-6}$	$5 \cdot 10^{-7}$	$4 \cdot 10^{-8}$	$2 \cdot 10^{-9}$
		I	$2 \cdot 10^{-6}$	$5 \cdot 10^{-8}$	$8 \cdot 10^{-8}$	$2 \cdot 10^{-9}$
Cobalt (27)	Co 57	S	$3 \cdot 10^{-6}$	$2 \cdot 10^{-8}$	$1 \cdot 10^{-7}$	5×10^{-10}
		I	$2 \cdot 10^{-6}$	$1 \cdot 10^{-7}$	$6 \cdot 10^{-9}$	4×10^{-10}
	Co 58m	S	$2 \cdot 10^{-6}$	$8 \cdot 10^{-8}$	$6 \cdot 10^{-8}$	3×10^{-9}
		I	$9 \cdot 10^{-6}$	$6 \cdot 10^{-8}$	$3 \cdot 10^{-7}$	2×10^{-9}
	Co 58	S	$8 \cdot 10^{-7}$	$4 \cdot 10^{-8}$	$3 \cdot 10^{-8}$	1×10^{-9}
		I	$5 \cdot 10^{-6}$	$3 \cdot 10^{-8}$	$2 \cdot 10^{-8}$	9×10^{-10}
	Co 60	S	$3 \cdot 10^{-7}$	$1 \cdot 10^{-8}$	$1 \cdot 10^{-8}$	$5 \cdot 10^{-10}$
		I	$9 \cdot 10^{-7}$	$1 \cdot 10^{-8}$	3×10^{-8}	3×10^{-10}
Copper (29)	Cu 64	S	$2 \cdot 10^{-6}$	$1 \cdot 10^{-7}$	$7 \cdot 10^{-8}$	3×10^{-9}
		I	$1 \cdot 10^{-6}$	$6 \cdot 10^{-8}$	$4 \cdot 10^{-8}$	2×10^{-9}
Curium (96)	Cm 242	S	$1 \cdot 10^{-10}$	$7 \cdot 10^{-7}$	$4 \cdot 10^{-12}$	$2 \cdot 10^{-8}$
		I	$2 \cdot 10^{-10}$	$7 \cdot 10^{-7}$	$6 \cdot 10^{-12}$	$2 \cdot 10^{-8}$
	Cm 243	S	$6 \cdot 10^{-12}$	$1 \cdot 10^{-7}$	$2 \cdot 10^{-13}$	5×10^{-9}
		I	$1 \cdot 10^{-10}$	$7 \cdot 10^{-7}$	$3 \cdot 10^{-12}$	$2 \cdot 10^{-8}$
	Cm 244	S	$9 \cdot 10^{-12}$	$2 \cdot 10^{-7}$	$3 \cdot 10^{-13}$	$7 \cdot 10^{-9}$
		I	$1 \cdot 10^{-10}$	$8 \cdot 10^{-7}$	$3 \cdot 10^{-12}$	$3 \cdot 10^{-8}$
	Cm 245	S	$5 \cdot 10^{-12}$	$1 \cdot 10^{-7}$	$2 \cdot 10^{-13}$	$4 \cdot 10^{-9}$
		I	$1 \cdot 10^{-10}$	$8 \cdot 10^{-7}$	$4 \cdot 10^{-12}$	3×10^{-8}
	Cm 246	S	$5 \cdot 10^{-12}$	$1 \cdot 10^{-7}$	$2 \cdot 10^{-13}$	4×10^{-9}
		I	$1 \cdot 10^{-10}$	$8 \cdot 10^{-7}$	$4 \cdot 10^{-12}$	3×10^{-8}
	Cm 247	S	$5 \cdot 10^{-12}$	$1 \cdot 10^{-7}$	$2 \cdot 10^{-13}$	$4 \cdot 10^{-9}$
		I	$1 \cdot 10^{-10}$	$6 \cdot 10^{-7}$	$4 \cdot 10^{-12}$	2×10^{-8}
	Cm 248	S	$6 \cdot 10^{-13}$	$1 \cdot 10^{-8}$	$2 \cdot 10^{-13}$	$4 \cdot 10^{-10}$
		I	$1 \cdot 10^{-11}$	$4 \cdot 10^{-8}$	$4 \cdot 10^{-12}$	$1 \cdot 10^{-9}$
	Cm 249	S	$1 \cdot 10^{-6}$	$6 \cdot 10^{-8}$	$4 \cdot 10^{-8}$	$2 \cdot 10^{-9}$
		I	$1 \cdot 10^{-6}$	$6 \cdot 10^{-8}$	$4 \cdot 10^{-8}$	$2 \cdot 10^{-9}$

TABLE 2
EXCERPT: 10 CFR 20, APPENDIX B

D. Indicators of an unposted airborne radioactive materials area

a. leaks

b. dusty conditions

IV. Soil Contamination

A. NRC Policy and Guidance Directive FC 83-23: Termination of By-product, Source and Special Nuclear Material Licenses

1. This document provides guidance on acceptable soil contamination level (**Table 3**).

Acceptable Soil Contamination Levels

Kind of Material	Soil Concentration Level for unrestricted area
i) Natural Uranium (U-238 + U-234) with daughters present and in equilibrium	10 (pCi/gm of soil)
ii) Depleted Uranium or Natural Uranium that has been separated from its daughters Soluble or Insoluble	35 (pCi/gm of soil)
iii) Natural Thorium (Th-232 + Th-228) with daughters present and in equilibrium	10 (pCi/gm of soil)
iv) Enriched Uranium Soluble or Insoluble	30 (pCi/gm of soil)
v) Plutonium (Y) or (W) compounds	25 (pCi/gm of soil)
vi) Am-241 (W) compounds	30 (pCi/gm of soil)
vii) All Byproduct Material	Soil concentrations shall be determined on a case by case basis
viii) External Radiation	10 microroentgens/hr above background measured at one meter from the ground surface

TABLE 3
EXCERPT: NRC POLICY AND GUIDANCE DIRECTIVE FC 83-23

NOTES

V. Water Contamination Levels

A. Surface and groundwater contamination levels should be below EPA's National Primary Drinking Water Regulations (40 CFR 141).

SECTION 10

ANTICONTAMINATION CLOTHING AND RESPIRATORY PROTECTION DEVICE EQUIPMENT

After completing this unit, participants will be able to:

- Explain the limitation of anticontamination protective clothing.
- Describe one example of a radiologically engineered contamination control device.
- List two respiratory protection devices and under what circumstances they would be worn.

NOTES

I. Introduction

The purpose of wearing anticontamination clothing is to prevent an individual from getting contamination on them.

A. Types of Clothing

1. General - The general practice is to not wear personal items with anti-contamination clothing

2. Modesty Garments

3. Gloves

- cotton liners
- surgical gloves
- rubber gloves
- work gloves

4. Shoe Covers

- toe/heel covers
- booties (plastic/cloth)
- rubber shoe covers
- boot (low tops or waders)

5. Coveralls (one or two piece, hooded or nonhooded)

- cotton (zipper/velcro/drawstring
- paper
- plastic (zipper/button/drawstring)

6. Laboratory Coats

7. Head Covers

- hoods
- skull caps

NOTES

B. Selection Process

Note: When you dress out for this type of work, you may be dressed out for very long periods of time. The affects of heat stress and comfort of the worker must be considered.

1. Factors to consider

a. Levels of contamination

- low
- medium
- high

b. Location of contamination

- localized or widely dispersed
- floors
- walls
- overheads
- equipment

c. Body position relative to the contamination location

- walking
- kneeling
- crawling
- under contaminated objects

d. Work to be performed

- light and easy
- physically demanding

e. Is wet or will it become wet

- feet
- body
- hands

C. Donning and Doffing of Anti-C's

1. Donning Steps

a. plastic shoe covers

b. cotton liners

c. coveralls

d. plastic shoe covers

e. rubber shoe covers

f. rubber gloves

g. tape

h. hood

2. Doffing Steps

a. tape

b. rubber shoe covers

c. rubber gloves

d. hood

e. plastic shoe covers

f. coveralls

g. plastic shoe covers

h. cotton liners

D. General Practices Performed in Anti-C's

1. Dosimetry should be kept on the breast pocket of the anti-C's

NOTES

Note: If entering an area with significant radiation levels, a second pocket dosimeter should be worn on the outside for convenient monitoring.

2. If at any time protective clothing is torn or an individual is injured by any type of penetration (such as a minor puncture wound), the individual must exit the area immediately and have the area of the penetration checked.

II. Respiratory Protection Devices

A. Regulations, Guidelines and Standards

1. OSHA 29 CFR 1910.134

2. ANSI Z88.2-1969 and ANSI Z88.2-1980

3. NIOSH

4. NRC 10 CFR 20 listed Assign Protection Factors (APF)

a.	APR	-	50
b.	Airline	-	1,000
c.	Bubble hood	-	1,000
d.	SCBA	-	10,000

$$APF = \frac{Concentration\ outside\ mask}{Concentration\ inside\ mask}$$

2. Concentrations Limiting Respirator Use

   a. Maximum use concentration (MUC)- The highest concentration, not exceeding IDLH concentrations, of a specific contaminant in which a given style respirator can be worn.

   b. Maximum permissible concentration (MPC)- The maximum concentration of radioactive contaminant in air that an individual can be exposed to for a 13 week period without exceeding their quarterly dose limit.

   MUC = APF x MPC

B. Display and Discuss Respirators

   1. APR

      a. High-efficiency particulate air filter (99.97% efficient for 0.03-micron particles)

   2. Airline

      a. 300 feet maximum hose length

      b. tangles very easily

      c. more comfortable than APR

   3. Bubble Hood

      a. same hose problems as the airline

      b. the most comfortable with the best vision

4. SCBA

   a. most reliable

   b. heavy

   c. limited air supply

III. Engineering Controls

A. Containment Devices

1. Catch containers

2. Glove bags

   a. simple

   b. complex

3. Dog houses

   a. small work

   b. sorting tables

4. Tents

   a. temporary

   b. permanent enclosures

B. Ventilation Systems

1. HEPA - 99.97% efficiency

2. Charcoal absorber - normally used for the removal of iodine gas

SECTION 11

DEMONSTRATION OF RADIOLOGICAL CONTROL AREA

After completing this unit, participants will be able to:

- Explain the purpose of a radiological control area.
- List the equipment that is used in a radiological control area.
- Describe the entry procedure for a radiological control area.

I. Preparation for Entry

A. Control Point Setup

1. ropes
2. signs
3. step-off pads
4. frisking station
5. waste containers
6. decon area with supplies
7. bags

B. Counting Area Setup

1. Equipment Setup

a. selection of:
alpha frisker
beta-gamma frisker
alpha bench counter
beta-gamma bench counter

b. instrument checks:
battery check
calibration sticker check
efficiency determination

2. Area Layout

a. smear/air sample handling area

b. clean area for maps and notes

c. clean waste bags

d. contaminated waste bags

C. Survey Preparation

1. Map

   a. already drawn, or

   b. materials ready to draw map

2. Contamination Survey Instruments

   a. smears numbered

   b. envelopes prepared

3. Radiation Survey Instrument

   a. instrument selected

      i. battery check

      ii. calibration

      iii. response check

4. Air Sampler

   a. loaded for sample

   b. envelope prepared

   c. bag ready for removal of air sampler from the contaminated area

D. Anti-C's

1. Selection

2. Donning Steps

   a. plastic shoe covers

   b. cotton gloves

c. coveralls

d. plastic shoe covers

e. heavy shoe covers

f. rubber gloves

g. tape

h. hood

II. Entry

A. Air Sample

1. Set up air sampler on clean cloth/plastic away from the floor

2. Start air sampler and record the time

3. Secure air sampler after 5 minutes and record the time

4. Remove the air sample and place it in an envelope

B. Radiation Survey

1. Dose rates are taken first as a worker moves around the room

2. Record dose rates on survey map

a. general area dose rates are taken 12 inches from any surface and at waist level

b. contact dose rates are marked with an asterisk (*)

3. Place the instrument in the lay-down area identified as "to be surveyed" if contamination is not expected

C. Contamination Survey

1. Take ~ 100 cm^2 smears

2. Mark location on the map with sequentially numbered circles (i.e., ①, ②, ③)

3. Place all smears in an envelope

D. Tool Decon

1. Simple decon

III. Exiting From a Contaminated Area

A. Air Sampler Removal

1. Wipe down the air sampler if contamination is expected

2. Either set the sampler in the area "to be surveyed" or put it in a bag

B. Survey Equipment Removal

1. Place smear envelope into a bag

2. Place survey map into a bag

C. Remove Anti-C's

1. tape

2. rubber shoe covers

3. rubber gloves

4. hood

5. coveralls

6. plastic shoe covers

7. cotton liners

D. Frisk

IV. Count Area Demo

A. Frisk Smears

1. Alpha

2. Beta

B. Count Air Sample

1. Cut sample

2. Count for both alpha and beta

3. Calculate curie content

C. Survey the equipment that is to be removed from the contaminated area

SECTION 12

DECONTAMINATION

After completing this unit, participants will be able to:

- Explain the need for radiological decontamination.
- Define the types of radiological contamination.
- Compare different decontamination methods and techniques.

NOTES

I. Definition:

Radioactive decontamination can be defined as the systematic removal of radioactive contamination.

II. Define the purpose of radioactive decontamination as a process of contamination control.

A. Decontamination has three purposes:

1. To prevent any uptake of radioactive material into the human body.

2. To limit external radiation exposure.

3. To prevent the further spread of contamination.

III. Categories of radioactive contamination:

A. Personnel

B. Equipment and Material

C. Air

D. Water

E. Soil

IV. Normal decontamination efforts usually apply to personnel, equipment, and material contamination. There are two types of contamination that are of concern for decontamination:

A. Fixed contamination.

1. Contamination not detected by smear survey.

2. Contamination that cannot be removed by normal washing.

3. Removal normally requires chemical solvents or mechanical applications.

B. Loose surface contamination.

1. Most decontamination efforts will be in this category.

2. Can be detected by smear survey.

3. Can usually be removed by normal washing.

4. Does not require mechanical applications.

V. General steps for decontamination.

A. Evaluate project and needs.

1. Determine what is to be decontaminated.

a. Decontamination may be required for tools, equipment, materials, work areas, clothing, and personnel.

2. Determine why decontamination is necessary.

a. Will result in a cleaner area.

b. Reduction in the use of protective clothing and respiratory equipment.

c. Reduced inventory of contaminated tools and materials.

d. Reduction in accumulated personnel exposures.

e. Removal of personnel contamination.

f. Release to unrestricted areas.

3. The very nature of decontamination generates radioactive waste.

   a. Minimize the use of water and materials.

   b. Cleaning solutions, cloths, or other materials actually used in the decontamination process must be disposed of as radioactive waste.

   c. Consider waste generation and disposal prior to undertaking decontamination operations.

4. Establish decontamination boundaries and control access to the area.

   a. Boundaries should allow for adequate work space and prevent other personnel from entering decontamination work area.

   b. Access to and from the work area can be controlled by setting up an entry/exit control point.

5. Investigate how contamination occurred and review survey data.

   a. May aid in knowing what kind of radioactive materials you are dealing with.

   b. Help determine needed instrumentation.

   c. Help determine protective clothing and equipment requirements.

d. Help to set decontamination priorities.

e. Help determine corrective actions to prevent future recurrence.

6. Evaluate specific items or areas to be decontaminated.

a. This will aid in selection of de ontamination equipment and materials.

7. Assess radiation and contamination protection requirements for personnel involved in decontamination efforts.

a. The main concern is to protect personnel from becoming contaminated and to keep radiation exposures as low as reasonably achievable (ALARA).

b. Personnel performing decontamination should take all necessary precautions to protect themselves.

B. Obtain equipment and materials.

1. Use the information gathered in project evaluation to aid in equipment and material needs.

2. Select appropriate radiation and contamination detection instruments.

a. Selection shall be based on the type of contaminants involved.

i. alpha probe for alpha contamination.

NOTES

ii. beta-gamma probe for beta-gamma contamination.

b. If needed, use a dose rate instrument to monitor external radiation exposure.

i. personnel dosimeters may also be desired.

3. Select appropriate protective clothing and equipment to perform decontamination efforts. Selection should be based on:

a. Type of contaminants.

b. Physical condition of the contaminated material (i.e., is it wet or dry).

c. Extent of contamination.

d. Decontamination methods used.

e. Any other considerations needed to help prevent personnel contamination.

4. Select appropriate decontamination method(s) and obtain needed equipment.

a. Based on what is to be decontaminated.

b. Methods may be used individually or in combination.

c. Guidance for selection of methods can be found in Chapter 7 of DARCOM P385-1, Table 7.4, located in the reference section of this manual.

C. Start mild.

1. Select the least harsh or abrasive method suitable for what needs to be decontaminated before employing the more drastic methods.

   a. Adhesive tape or mild soap and water are good starting points for most loose surface decontamination efforts.

2. When more than one method is employed, start with the least harsh or abrasive method first.

D. Work from outside to inside.

1. Decontamination normally begins at the perimeter of a contaminated area and progresses toward the center.

   a. Stroking motions toward the center, rather than side to side scrubbing motions, tend to help prevent spreading the contamination.

2. Care should be exercised to ensure excess water is not used.

   a. Water has a tendency to run, possibly spreading the contamination to other areas of the surface.

3. Perimeters should be surveyed and reestablished as the size of the contaminated area is reduced. Document results.

4. When decontamination involves vertical surfaces (i.e., walls), decontamination should start at the top and progress toward the bottom.

E. Clean highest contamination first.

1. The idea is to attack the greater hazard first, reducing it to fairly consistent levels with the rest of the area to be decontaminated.

    a. If there is an area with a significant (gross) amount of contamination, that area should be cleaned up first.

        i. use the same technique of starting at the perimeter and working toward the center.

2. Will help lessen the degree of hazard in the event of cross contamination.

3. In some cases will help control exposure.

4. Depending on the evaluation of the high contamination area, you may elect to use a different decontamination method or combination of methods.

F. Minimize contaminated waste.

1. All waste materials used in decontamination are treated as contaminated waste; therefore, use only what is needed to perform the tasks and do not use materials excessively.

    a. Although some areas may need to be cleaned several times before decontamination is complete, using one applicator (i.e., rag) at a time instead of several will help in reducing contaminated waste.

        i. be careful not to use the same applicator surface more than once.

2. Again, be careful not to use too much water or liquids in decontamination.

a. Liquids tend to run (spreading contamination).

b. Liquids will ultimately generate more contaminated waste.

c. There should be no free-standing liquids in contaminated waste.

3. There are many concerns regarding storage and disposition of radioactive or contaminated wastes industry-wide. The general practice is to take all measures practical to reduce the generation of these wastes.

a. Do not create unnecessary waste.

G. Minimize airborne contamination.

1. Decontamination methods may generate or stir up loose contamination that could become airborne. Caution should be taken to prevent this from occurring whenever possible, because it will only tend to create another hazard which would have to be taken into consideration.

2. Be conscientious of your decontamination techniques.

a. Be careful how you move around. Move slowly and try not to stir up loose contamination.

b. Lay plastic sheeting down whenever practical to help prevent airborne contamination.

c. Be careful during cleaning not to stir up loose contamination. Wipe carefully!!

3. In cases where it may be impractical to avoid the possible creation of airborne (i.e., grinding), other means of controlling airborne contamination can be used.

   a. Portable HEPA filtered exhausters.

      i. help filter contaminants being generated.

   b. Containment tents and glove boxes.

      i. help contain contaminants being generated.

4. Be conscientious of area ventilation and air movements. Some air movements may be strong enough to create airborne contamination. In some cases, decreasing the air flow will help prevent airborne contamination.

H. Survey between major steps and document results.

1. Surveys and documentation between major steps is vital to assessing how well the decontamination efforts are working. The data can be used:

   a. To verify cleanliness.

   b. For reclassification or rezoning of areas.

   c. For isolation.

   d. To support release to unrestricted status.

2. Surveys between steps can also be used to measure the effectiveness of decontamination methods. A helpful tool in measuring the effectiveness is the DECONTAMINATION

FACTOR (DF), which can be calculated as follows:

$$DF = \frac{\text{Surface contamination before decon}}{\text{Residual contamination after decon}}$$

or

$$DF = \frac{\text{dpm before decon}}{\text{dpm after decon}}$$

The higher the decontamination factor (DF), the more effective the method.

3. Where extensive decontamination work is to be performed, several methods or combinations of methods can be tested on different areas of the same surface and the results can be compared using the decontamination factor.

I. Document completion.

1. Document the completion of decontamination.

   a. Include standard information such as name, date, time of completion, and survey results.

   b. The information provided on the survey data sheet will serve as verification of cleanliness.

   c. Survey results will be used in classifying the area after decontamination.

      i. If decontamination efforts are proved to be effective, the area will most probably be downgraded to a lesser hazard status or released as unrestricted.

ii. Accordingly, protective clothing and equipment requirements may be down-graded.

2. For personnel decontamination, results would show 1) that the exposure hazard to the person no longer exists or 2) the extent of exposure (if it takes considerable time for the contamination to be completely removed).

VI. Personnel decontamination.

A. Observe physical effects.

1. Evaluate the physical condition of the person(s) needing decontamination for any health-related problems.

a. Check for burns, bleeding, shock, irregular breathing, and life-threatening circumstances. Get medical assistance immediately if needed.

B. Assess injuries.

1. Assess the extent of any injuries.

a. Medical treatment of injuries takes priority over decontamination.

b. Consult immediately with medical personnel if injury warrants medical attention.

c. If it is determined that the injury is minor, decontamination may continue with medical consent. Remain cautious of the injury in question.

2. Immediately flush with water any skin contamination involving caustic, corrosive, or organic solvent solutions.

   a. Skin contact with these solutions will require medical attention. In addition, the solutions will cause skin breakage, possibly spreading the contamination deeper into human tissue.

C. Survey person, document results.

1. Determine the extent and magnitude of contamination using personnel survey techniques, and document results.

   a. During the survey, particular attention should be paid to locating any hot spots of contamination.

   b. Will provide information needed to set a baseline prior to decontamination.

   c. Will provide information regarding where the contamination is located on the body.

   d. Will help set priorities for performing decontamination.

2. The results and assessment of the survey should be recorded on a Personnel Contamination Record form. An example of this form can be found in Chapter 7 of DARCOM P385-1, Figure 7.1, located in the reference section of this manual.

D. Remove contaminated clothing.

1. Remove any contaminated clothing, place in a plastic bag, and hold for further disposition.

   a. Clothing must be removed carefully to help control the spread of contamination.

   b. The clothing can later be used to help determine how the personnel contamination occurred.

   c. Help determine whether the clothing requirements for the particular tasks need to be reassessed.

   d. Help prevent possible cross contamination from the clothing during decontamination efforts.

   e. Help prevent any exposure that may be caused by the contaminated clothing.

2. The contaminated clothing will eventually end up as contaminated waste.

E. Perform decontamination.

1. Various procedures for personnel decontamination of skin, hair and scalp, general body, face, eyes, ears, mouth, and nose can be found in Chapter 7 of DARCOM P385-1, Appendix 1, located in the reference section of this manual. These procedures have been found to be acceptable practices in decontamination.

   Note: Medical personnel should be consulted for decontamination of eyes, ears, nose, or mouth; or, if chemicals other

than soap and water will be used.

2. Personnel should be decontaminated as quickly as possible using the least drastic means necessary.

   a. Begin with mild methods such as adhesive tape or mild soap and warm water.

3. Soaps and detergents emulsify and dissolve contamination and are frequently all that is needed.

   a. Continue as long as they are effective, and progress to harsher methods only if necessary.

   Note: Caution shall be exercised to prevent excessive skin irritation. Stop decontamination efforts if evidence of skin damage appears or if person complains of soreness; contact medical personnel for assistance.

   Water temperature should be maintained lukewarm to avoid causing pores to open or close. The opening and closing of pores can cause contamination to become embedded in the skin.

4. Frisking shall be conducted after each attempt to reduce contamination until contamination levels are acceptable.

   a. The progress of decontamination should be closely monitored by

surveying between successive washings or techniques.

b. A log of methods used and survey results should be maintained.

i. An example of a typical log sheet for personnel decontamination can be found in Chapter 7 of DARCOM P385-1, Figure 7.2, located in the reference section of this manual.

F. Investigate how contamination occurred.

1. A thorough investigation of the contamination incident should be performed as soon as possible.

a. The results of the investigation should show a valid cause of the contamination, along with corrective actions to prevent the reoccurrence of the incident.

i. There are a number of reasons why contamination events occur, but the main issue becomes assessment of corrective controls for future prevention.

b. Document results of the investigation.

VII. Equipment and material decontamination.

A. Equipment and materials may need to be decontaminated for a number of reasons. Some are:

1. Release for unrestricted use.

2. Salvage of valuable equipment.

3. Reduce radiation exposure to personnel.

4. Reduce the volume of contaminated waste.

B. Evaluate the need for decontamination versus disposal or limited use. Three examples are given below:

1. A highly contaminated area may warrant decontamination because its use would require frequent occupancy.

   a. Decontamination in this case would minimize the collective exposures of personnel expected to work in these areas.

2. Some equipment and materials are of significant value but cannot easily be decontaminated or are not cost-effective to decontaminate.

   a. Should be considered for limited use in normally contaminated areas until its use is no longer desired and final disposition is determined.

   b. Expensive specialized tools may fall in this category. They can be stored in a contaminated tool locker.

3. Some equipment and materials are not of significant value (low replacement cost materials) and are not easy or cost- effective to decontaminate.

   a. May require more time and effort to decontaminate than they are worth.

   b. These materials should be considered for disposal as contaminated waste or

assigned for use in normally contaminated areas.

c. Materials such as wood, clothing, scrap metal, cords, hoses, and damaged equipment may fall in this category.

C. Many methods and techniques have been developed for decontaminating equipment and materials.

1. Most are physical or chemical processes.

2. In Chapter 7 of DARCOM P385-1, Appendix B (located in the reference section of this manual) are some suggested contamination removal methods (Table 7.2) and decontamination methods for various surfaces (Table 7.4).

3. Document contamination levels before and after each application, and post decontamination results.

SECTION 13

RADIOACTIVE MATERIAL PACKAGING, LABELING, AND SHIPPING

After completing this unit, participants will be able to:

- Identify the federal regulations and/or organizations that govern the transport of radioactive materials.
- Given reference materials, determine package limits for individual radionuclides, mixtures of radionuclides, and material with unknown quantities of radionuclides.
- Given the package radiation readings, indicate the category of radioactive label required.

I. Federal regulators and/or organizations that govern the transport of radioactive materials.

A. Interstate Commerce Commission (ICC)

1. Established first regulations governing the shipment of radioactive materials

2. Still exercise jurisdiction over the economic aspects of radioactive materials transport through the issuance of operating authorities to carriers

B. Nuclear Regulatory Commission (NRC) - 10 CFR 71

1. Responsibility for safety in the possession, use, and transfer (including transport) of by-product, source, and special nuclear materials (Atomic Energy Act of 1954)

2. Promulgated 10 CFR Part 71; requirements for licensees to deliver licensed materials to a carrier for transport if fissile materials or quantities exceeding Type A are involved

3. The NRC assists and advises DOT, has adopted portions of DOT regulations by reference, and inspects its licensees for compliance with DOT regulations

4. Agreement States have entered into formal agreements with the NRC for regulatory authority over by-product, source, and less than critical quantities of special nuclear material

C. Department of Transportation (DOT) - 49 CFR 100-177

1. Regulatory responsibility for safety in the transportation of all hazardous materials,

including radioactive materials (Department of Transportation Act of 1966)

2. Promulgated 49 CFR Parts 100-199; jurisdiction includes all modes of transport in interstate or foreign commerce, except for postal shipments

D. Postal Service - U.S. Postal Service Regulations, Part 124

1. Jurisdiction over all postal shipments of radioactive materials

2. Domestic Mail Manual, U.S. Postal Service Regulations, Part 124

3. Mailable quantity limits are generally one-tenth of the values listed in DOT regulations

E. International Air Transport Association (IATA)

1. A body of air carriers that publishes the regulations for air transport of radioactive materials through the Dangerous Goods Regulations

II. Radioactive materials are defined in 49 CFR 173.403 as:

A. Those materials which spontaneously emit ionizing radiation and have a specific activity in excess of 0.002 uCi/g

NOTE: Materials not defined as radioactive by the DOT may be subject to NRC or EPA regulations

III. Classification of Radioactive Materials

A. Identification Requirements

1. Identity of the radionuclides being shipped (if known) and proper shipping name for radioactive material as specified by the Hazardous Materials Table (49 CFR 172.101; see **Appendix I**), in addition to the following information:

   a. identifies the class of material

   b. specifies or references packaging requirements

   c. lists identification numbers

   d. specifies labeling and other requirements

      Note: A grid of the six proper shipping names and their corresponding quantity Type is also shown in **Appendix I**

2. Form (degree of prepackaging) of the radioactive material

   a. Special Form (49 CFR 173.403 (z))

      - Encapsulations can only be opened by destroying the capsule

      - At least one external physical dimension must exceed 5 mm

      - Quantity restrictions for "special form" materials are generally larger than quantity restrictions for "normal form" materials (see **Figure 1**)

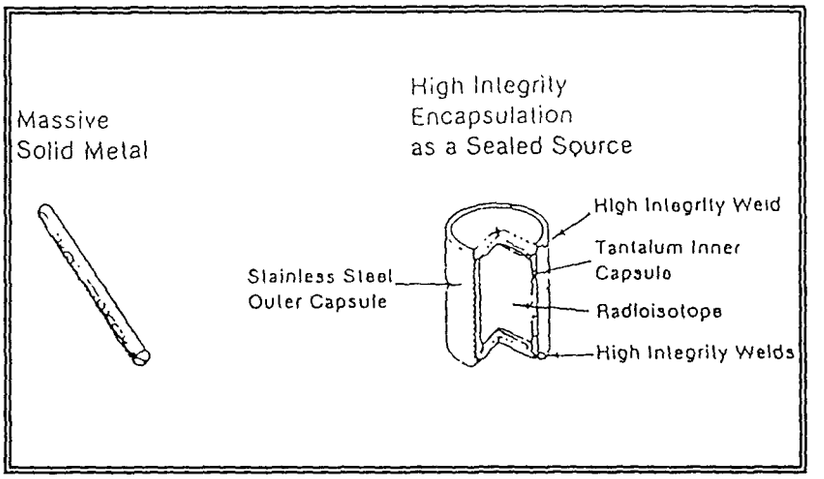


FIGURE 1
SPECIAL FORM ENCAPSULATION EXAMPLES

b. Normal Form (49 CFR 173.403 (s))

- Any radioactive materials that do not qualify as "special form" (see **Figure 2**)

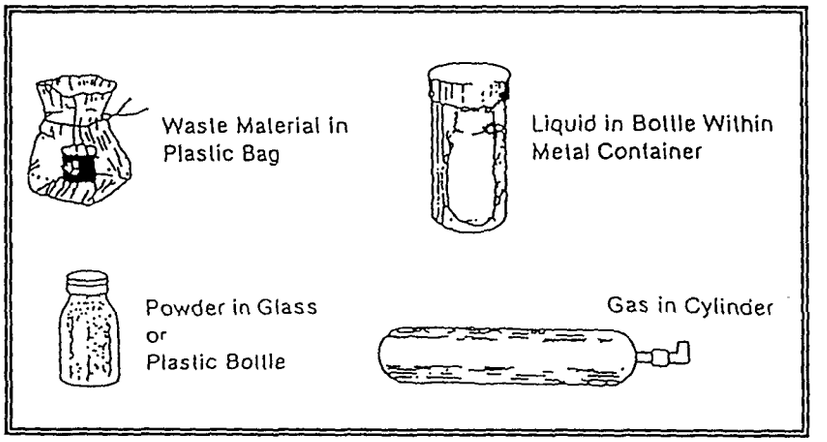


FIGURE 2
NORMAL FORM EXAMPLES

B. Quantity Determination for Radioactive Materials

1. A_1 and A_2 System (49 CFR 173.433) is used to determine package limits based on the radionuclide activity/quantity of radioactive

material (see **Appendix II** for A_1 and A_2 chart)

a. A_1 and A_2 System

- Points of reference for activity limitation per package based on the radionuclides present
- Maximum activity in curies for radionuclides that can be transported in a Type A package
- Based on the radionuclide's radiotoxicity
- A_1 values apply to special forms of radioactive material
- A_2 values apply to normal forms of radioactive material
- The "ratio rule" is used to calculate the A_1 and A_2 values for mixtures of radionuclides

$$\frac{R_1}{X_1} + \frac{R_2}{X_2} + \frac{R_N}{X_N} \leq 1$$

where:

R = radionuclide (amount in Ci)

X = A_1 or A_2 value for that radionuclide

b. Limited Quantity, Instruments, and Articles (49 CFR 173.421)

- Very small quantities of activity
- Examples:

  medical test kits, diagnostic aids, some low-level waste shipments, button sources
- Excepted from most packaging and labeling requirements
- Activity limits per package, instrument or article are shown in **Figures 3 and 4**

LIMITED QUANTITIES
(package limits in curies)

	SOLID	LIQUID	GAS
Special Form	$10^{-3}A_1$		$10^{-3}A_1$
Normal Form	$10^{-3}A_2$	$10^{-4}A_2$	$10^{-3}A_2$
Tritium	In paint or adsorbed on carrier		20

FIGURE 3
PACKAGE LIMITS FOR "LIMITED QUANTITIES"

INSTRUMENTS AND ARTICLES
(limits in curies)

	SOLID		LIQUID		GAS	
	Item	Package	Item	Package	Item	Package
Special Form	$10^{-2}A_1$	A_1			$10^{-3}A_1$	$10^{-2}A_1$
Normal Form	$10^{-2}A_2$	A_2	$10^{-3}A_2$	$10^{-1}A_2$	$10^{-3}A_2$	$10^{-2}A_2$
Tritiated Water	Based on Ci/liter					
Tritium Gas	In paint or adsorbed on a solid carrier				20	200

FIGURE 4
LIMITS FOR INSTRUMENTS AND ARTICLES

- Calculation:

  Determine the limited quantity (LQ) maximum amount per package for normal form material containing ^{129}I

  Solution:

  $A_2 = 2$ Ci
  LQ Package Limit = 10^{-3}

  2 Ci x 10^{-3} = 0.02 Ci

2. Low Specific Activity (LSA) (49 CFR 173.403 (n))

   a. Present a relatively low hazard as a result of limited concentration of radioactive material

      - Examples:

        Uranium or thorium ores and physical or chemical concentrations of those ores

Unirradiated natural or depleted uranium or unirradiated natural thorium

Tritium oxide in aqueous solution, provided the concentration does not exceed 5.0 mCi/mL

Nonradioactive materials that are externally contaminated with nondispersible radioactive material, and whose surface contamination when averaged over 1 square meter does not exceed 0.0001 mCi/cm^2

b. Mixtures are subject to the "ratio rule"

c. Quantity limits are shown in **Figure 5**

A_2 Value	Estimated Average Concentration does not exceed
.05 Ci or less	0.0001 mCi/gram
More than .05 Ci up to 1.0 Ci	0.005 mCi/gram
more than 1 Ci	0.3 mCi/gram

Nonradioactive material externally contaminated

A_2 Value	Allowable Concentration
Less than .05 Ci	0.0001 mCi/cm^2 of surface
.05 Ci or greater	0.001 mCi/cm^2 of surface

FIGURE 5
LOW SPECIFIC ACTIVITY QUANTITY LIMITS

3. Type A quantity (49 CFR 173.435)

   a. Relatively small quantities of activity that are less than or equal to the appropriate A1 or A2 values

      - Examples:

        radiopharmaceuticals

        research isotopes

        industrial sources

      - Calculation:

        Determine the maximum activity for a Type A quantity per package of normal form material containing ^{129}I

      - Solution:

        A_2 = 2 Ci, therefore the maximum activity would be 2 Ci

4. Type B quantity (10 CFR 71)

   a. Large quantity of activity that exceeds the A_1 or A_2 where appropriate and is less than the Highway Route-Control Quantity designation

      - Examples:

        radiography sources

        spent fuel shipments

        high-level waste shipments

- Calculation:

  Determine the activity limits for a Type B quantity per package of normal form material containing ^{129}I

- Solution:

  A_2 = 2 Ci
  Highway Route-Control Quantity = 2 Ci × 3,000 = 6,000 Ci. Therefore, the activity would be greater than 2 Ci but less than 6,000 Ci

5. Highway Route-Control Quantity - (49 CFR 173.403(1))

   a. Large quantity of activity that is either 3,000 times the A_1 or A_2 value, or 30,000 curies, whichever is the least

   - Calculation:

     Determine the activity for a highway route-control quantity per package of normal form material containing ^{129}I

   - Solution:

     A_2 = 2 Ci
     Highway Route-Control Quantity (HRCQ)
     = 2 Ci × 3,000 = 6,000 Ci
     HRCQ= 6,000 Ci, which is less than 30,000 Ci

6. Quantity determination for mixtures

a. The "ratio rule" is used to calculate the A_1 and A_2 values for mixtures of radionuclides

$$\frac{R_1}{X_1} + \frac{R_2}{X_2} + \frac{R_N}{X_N} \leq 1$$

where:

R = radionuclide (amount in Ci)

X = A_1 or A_2 value for that radionuclide

- Calculation:

  Determine the Type A quantity amount for normal form material containing a mixture of 0.5 Ci of ^{137}Cs, 0.5 Ci of ^{60}Co, and 0.2 Ci of ^{90}Sr

- Solution:

	A_2
^{137}Cs	10 Ci
^{60}Co	7 Ci
^{90}Sr	0.4 Ci

$$\frac{0.5}{10} + \frac{0.5}{7} + \frac{0.2}{0.4} = 0.62Ci$$

0.62 Ci is less than 1; therefore, the mixture is a Type A quantity

7. Reportable Quantity (49 CFR 172.101)

a. Material listed as a hazardous substance under Section 101(14) of CERCLA

- Example:

  1 pound of radionuclides

8. Fissile Material (49 CFR 173.403 and 173.455)

   a. Material that contains one or more fissile radionuclides (^{233}U, ^{235}U, ^{238}Pu, ^{239}Pu, or ^{241}Pu)

9. Determination of A_1 and A_2 Values for Unknowns (49 CFR 173.433)

   a. Radioactive material containing one single unknown radionuclide

      - the value of A_1 is 2 Ci and the value of A_2 is 0.002 Ci

      - if the atomic number of the radionuclide is less than 82, the value of A_1 is 10 curies and the value of A_2 is 0.4 curies

   b. Radioactive materials with known radionuclide identities but unknown individual radionuclide activities

      - same as "a" above

      - all radionuclides whose individual activities are not known (but whose total activity is known) must be classified in a single group, and the most restrictive A_1 or A_2 applicable to any one of

them shall be used as the value of A_1 or A_2 in the denominator of the fraction

c. Radioactive materials with known radionuclides but individual activities unknown

- the most restrictive value of A_1 or A_2 applicable to any one of the radionuclides present is the applicable value

d. Radioactive materials containing unknown radionuclides

- the value of A_1 is 2 curies and the value of A_2 is 0.002 curies
- if alpha emitters are known to be absent, the value of A_2 is 0.4 curies

e. Packages containing samples for which a reasonable doubt exists as to its class and labeling requirements and for which a sample must be transported for laboratory analysis may be labeled according to the shipper's tentative class assignment based upon (49 CFR 172.402):

- defining criteria in 49 CFR Parts 100 to 177
- the hazard precedence prescribed in 49 CFR 173.2
- the shipper's knowledge of the material

IV. Radioactive Material Packaging Requirements

NOTES

A. Limited Quantities Packaging Requirements (49 CFR 173.421)

1. Strong, tight packages that will not leak any of the radioactive materials during conditions normally incident to transportation

2. Radiation level at any point on the external surface of the package cannot exceed 0.5 mR/hr

3. The external surface of the package must be free of significant removable contamination (limits contained in 49 CFR 173.443)

4. For instruments and articles, the radiation level at 4 inches from any point on the surface (unpacked) may not exceed 10 mR/hr

5. A description of the contents is in, on, or forwarded with the package

B. Low Specific Activity Quantities Packaging Requirements (49 CFR 403 (n))

1. Nonexclusive use shipments - "essentially Type A packages"

2. Exclusive use - "strong, tight packages"

C. Type A Packaging Requirements

1. Designated for the containment of Type A quantities

2. Shipper must make an assessment and certification of the particular package design against performance requirements

NOTES

3. General packaging requirements contained in 49 CFR Sections 173.24, 173.411, and 173.412

4. Typically performance-based DOT Specified 7A packaging (49 CFR 178.350)

5. Package must withstand normal conditions of transport without loss or dispersal of radioactive contents (49 CFR 173.465)

6. Shipper of each DOT Specified 7A package must maintain on file for at least 1 year after the latest shipment a complete certification and supporting safety analysis that:

   i) construction methods, packing design, and materials of construction are in compliance with 49 CFR 173.461

   ii) all the requirements of Sections 173.24, 173.463, and 173.465 are met

D. Type B Packaging Requirements

1. Designated for the containment of Type B and High Route-Control Quantities

2. Must meet all of the performance standards for Type A packages

3. Must withstand certain serious accident damage test conditions (10 CFR 71.73), including:

   a. 30-foot free drop onto an unyielding surface

NOTES

b. a puncture test, which is a free drop (over 40 inches) onto a 6-inch diameter steel pin

c. thermal exposure at 1,475 degrees Fahrenheit for 30 minutes

d. water immersion for 8 hours

E. Highway Route-Control Quantity Packaging Requirements

1. Must meet all the performance standards for Type B packages

F. General Packaging Requirements (49 CFR 173.411)

1. The smallest outside dimension of any radioactive materials package (other than excepted quantities)

2. Package must have a tamper seal

3. Packages must be designed to maintain shielding efficiency and leak tightness under conditions normally incident to transportation. Internal bracing or cushioning must be adequate.

4. External package surface must be easily decontaminated

5. Characteristics of a package used for radioactive materials in a liquid form (173.412 (n)):

a. Leak-resistant inner container

b. Package must be adequate to prevent loss or dispersal of the contents

c. Enough absorbent to absorb at least twice the volume of radioactive liquid present

V. Radiological Limits and Control for Radioactive Material Packages

A. Radiation limits for radioactive material packages (49 CFR 173.441)

1. Radiation level cannot exceed 200 mrem/hr at any point on the external surface of the package, and the transport index must not exceed 10 mrem/hr (dose rate at 1 meter from surface of package)

2. Packages exceeding the limit must comply with additional requirements

3. Contamination Control (49 CFR 173.443)

a. The level of nonfixed (removable) radioactive contamination on the external surfaces of the package cannot exceed the limits as shown in **Figure 6**

TABLE 10—REMOVABLE EXTERNAL RADIOACTIVE CONTAMINATION—WIPE LIMITS

Contaminant	Maximum permissible limits	
	uCi/cm²	dpm/cm²
Beta-gamma emitting radionuclides; all radionuclides with half-lives less than ten days; natural uranium; natural thorium; uranium-235; uranium-238; thorium-232; thorium-228 and thorium-230 when contained in ores or physical concentrates	10^{-3}	22
All other alpha emitting radionuclides	10^{-4}	2.2

FIGURE 6
EXCERPT: 49 CFR 173.443

b. Radiological survey procedure

- Take a swipe of a 300 cm^2 area on the exterior surfaces of the package
- Measure activity on swipe sample and record in disintegrations per minute per square centimeter
- Perform radiation dose rate at package surface and at 1 meter from the surface of the package

B. Radiation Limits for Highway Transport Vehicles of Radioactive Materials (see **Appendix III**)

VI. Hazard Communications and Shipping Papers Requirements for Radioactive Material Packages

A. Marking and labeling requirements for radioactive material packages

1. Three types of radioactive labels (49 CFR 172.403 (c)) are selected based on the external dose rate of the package and/or transport index (TI)

a. Radioactive - White I

b. Radioactive - Yellow II

c. Radioactive - Yellow III

2. Required Label Information

a. Identity of radionuclide(s)

b. Activity in Ci

NOTES

c. Dose rate and/or TI

3. TI (49 CFR 173.403 (bb))

   a. A number marked on the radioactive label that represents the maximum radiation level in mrem per hour at 1 meter (3.3 feet) from the external surface of the package

   b. A number marked on the radioactive label of a package containing fissile materials that designates the degree of control exercised by the carrier to reduce the risk of a criticality

   c. The number of packages at any one location must be limited so that the total TI number (cumulative) does not exceed 50

4. A chart of labeling requirements relative to TI and fissile class is shown in **Figure 7**

LABEL CATEGORY	MAXIMUM PKG. SURFACE (MREM/HR)	TRANSPORT INDEX (MREM/HR)	FISSILE DATA
WHITE I	0 5	N.A.	CLASS I ONLY
YELLOW II	50	1	FISSILE I OR II, TI OF 1 OR LESS NO FISSILE III
YELLOW III	200	10	FISSILE II, TI OVER 1 ALL FISSILE III

White I Yellow II Yellow III

FIGURE 7
LABELING REQUIREMENTS

B. Shipping Paper Information (See **Appendix IV** for example of a typical shipping paper form)

1. Package marking requirements (49 CFR 172.300 - 172.310)

   a. Proper shipping name

   b. Identification number (Section 172.101)

   c. The appropriate specification number (Section 173.24(c)(I)(i))

   d. The gross weight of any packages in excess of 50 kilograms

   e. "Type A" or "Type B" in letters 1/2 inch high as appropriate

2. Required shipping paper information (49 CFR 172.202(a)(I))

   a. Proper shipping name from 172.101

   b. Hazard class from Section 172.202(a)(2))

   c. Identification number from Section 172.202(a)(3)

   d. Net quantity of material by weight or volume from Section 172.202(a)(4)

   e. Radionuclide(s) contained in the package which comprise 1% or more of the total activity

   f. The physical form of the material or a statement that the material is "special form"

   g. The activity in curies

   h. Category of "RADIOACTIVE" labels applied to package

   i. "Transport Index" if labeled RADIOACTIVE-Yellow II or RADIOACTIVE-Yellow III

   j. Identification markings shown on the package

   k. Other information as required by the mode of transportation or subsidiary hazard of the material

   Note: See **Appendix 4** for an example of a typical shipping paper

C. Conditions for which the placarding of a transport vehicle with radioactive materials is required (49 CFR 172.504) (see **Figure 8**)

1. Highway Route-Control

2. LSA, exclusive use

3. Radioactive Yellow III

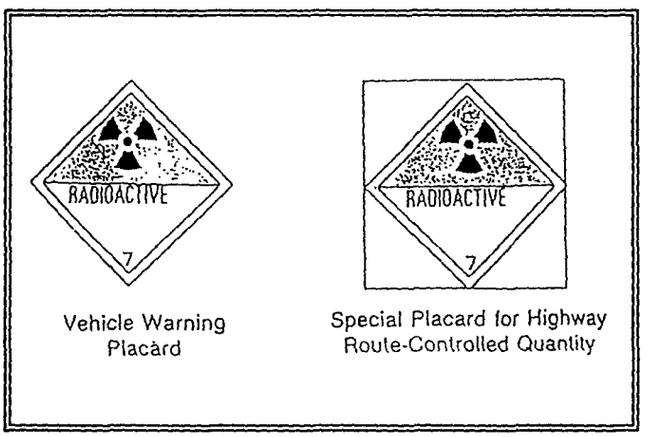


FIGURE 8
VEHICLE PLACARDS

4. Placards are to be affixed on each side and each end of a transport vehicle

D. Shipper's Certification (49 CFR 172.402 (a))

1. Required for all shipments, other than air

"This is to certify that the above-named materials are properly classified, described, packaged, marked, and labeled, and are in proper condition for transportation according to the applicable regulations of the Department of Transportation."

2. For air transportation

NOTES

"I hereby certify that the contents of this consignment are fully and accurately described above by the proper shipping name and are classified, packed, marked, labeled, and in proper condition for carriage by air according to the applicable national governmental regulations."

APPENDIX I

§ 172.101 HAZARDOUS MATERIALS TABLE - Continued

Symbols	Hazardous materials descriptions and proper shipping names	Hazard class or Division	Identification Numbers	Packing group	Label(s) required (if not excepted)	Special provisions	(8) Packaging authorizations (§ 173.***) Exceptions	(8) Non bulk packaging	(8) Bulk packaging	(9) Quantity limitations Passenger aircraft or railcar	(9) Quantity limitations Cargo aircraft only	(10) Vessel stowage requirements Vessel stowage	(10) Vessel stowage requirements Other stowage provisions
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8A)	(8B)	(8C)	(9A)	(9B)	(10A)	(10B)
	Pyrophoric liquids, n.o.s.	4.2	UN2845	I	SPONTANEOUSLY COMBUSTIBLE	B11, T42	None	181	244	Forbidden	Forbidden	D	18
	Pyrophoric metals, n.o.s., *or* Pyrophoric alloys, n.o.s.	4.2	UN1383	I	SPONTANEOUSLY COMBUSTIBLE	B11	None	187	242	Forbidden	Forbidden	D	
	Pyrophoric solids, n.o.s.	4.2	UN2846	I	SPONTANEOUSLY COMBUSTIBLE		None	187	242	Forbidden	Forbidden	D	
	Pyrosulfuryl chloride	8	UN1817	II	CORROSIVE	B2, T9, T27	154	202	242	1 L	30 L	C	8, 40
	Pyroxylin solution or solvent, see Nitrocellulose												
	Pyrrolidine	3	UN1922	II	FLAMMABLE LIQUID	T1	150	202	242	5 L	60 L	B	40
	Quebrachitol pentanitrate	Forbidden											
	Quicklime, see Calcium oxide												
	Quinoline	6.1	UN2656	III	KEEP AWAY FROM FOOD	T8	153	203	241	60 L	220 L	A	12, 48
	R 114, see Dichlorotetrafluoroethane												
	R 115, see Chloropentafluoroethane												
	R 116, see Hexafluoroethane												
	R 124, see Chlorotetrafluoroethane												
	R 133a, see Chlorotrifluoroethane												
	R 152a, see Difluoroethane												
	R 500, see Dichlorodifluoromethane and difluoroethane, *etc.*												
	R 502, see Chlorodifluoromethane and chloropentafluoroethane mixture, *etc.*												
	R 503, see Chlorotrifluoromethane and trifluoromethane, *etc.*												
	R 12, see Dichlorodifluoromethane												
	R 1281, see Chlorodifluorobromomethane												
	R 13, see Chlorotrifluoromethane												
	R 1381, see Bromotrifluoromethane												
	R 14, see Tetrafluoromethane												
	R 21, see Dichlorofluoromethane												
	R 22, see Chlorodifluoromethane												
	Radioactive material, excepted package-articles manufactured from natural *or* depleted uranium *or* natural thorium.	7	UN2910		None		421-1, 424	421-1, 424	421-1, 424			A	
	Radioactive material, excepted package-empty packaging.	7	UN2910		EMPTY		427	427	427			A	
	Radioactive material, excepted package-instruments *or* articles.	7	UN2910		None		421-1, 422	421-1, 422	421-1, 422			A	
	Radioactive material, excepted package-limited quantity of material.	7	UN2910		None		421, 421-1	421, 421-1	421, 421-1			A	
	Radioactive material, fissile, n.o.s.	7	UN2918		RADIOACTIVE.		453	417	417			A	40, 95
	Radioactive material, low specific activity (LSA), n.o.s.	7	UN2912		RADIOACTIVE.		421, 422, 424	425	425			A	
	Radioactive material, n.o.s.	7	UN2982		RADIOACTIVE.		421, 422, 424	415, 416	415, 416			A	40, 95
	Radioactive material, special form, n.o.s.	7	UN2974		RADIOACTIVE.		421, 422	415, 416	415, 416			A	
	Railway torpedo, see Signals, railway track, explosive												
	Rare gases and nitrogen mixtures	2.2	UN1981		NONFLAMMABLE GAS.		306	302	None	75 kg	150 kg	A	
	Rare gases and oxygen mixtures	2.2	UN1980		NONFLAMMABLE GAS.		306	302	None	75 kg	150 kg	A	
	Rare gases, mixtures	2.2	UN1979		NONFLAMMABLE GAS.		306	302	None	75 kg	150 kg	A	
	RC 318, see Octafluorocyclobutane												
	RDX and cyclotetramethylenetetranitramine, wetted *or* desensitized *see* RDX and HMX mixtures, wetted or desensitized.												
	RDX and HMX mixtures, wetted *with not less than 15 percent water by mass or* RDX and HMX mixtures, desensitized *with not less than 10 percent phlegmatizer by mass.*	1.1D	UN0391	II	EXPLOSIVE 1.1D.		None	62	None	Forbidden	Forbidden	B	1E, 5E
	RDX and Octogen mixtures, wetted *or* desensitized *see* RDX and HMX mixtures, wetted or desensitized *etc.*												
	RDX and Octogen mixtures, wetted *or* desensitized *see* RDX and HMX mixtures, wetted or desensitized *etc.*												

APPENDIX I (cont.)

Proper Shipping Name	Limited Quantity	Low Specific Activity	Type A	Type B	HRCQ
1. Radioactive Material, Limited Quantity, N.O.S. (UN 2910)	*				
2. Radioactive Material, Instruments and Articles (UN 2911)	*				
3. Radioactive Material, Low Specific Activity, N.O.S. (UN 2912)		*			
4. Radioactive Material, Fissile, N.O.S. (UN 2918)			*	*	*
5. Radioactive Material, Special Form, N.O.S. (UN 2974)	*		*	*	*
6. Radioactive Material, N.O.S. (UN 2982)			*	*	*

of A_1 or A_2 as appropriate. All the radionuclides whose individual activities are not known (but whose total activity is known) must be classed in a single group and the most restrictive value of A_1 or A_2 applicable to any one of them shall be used as the value of A_1 and A_2 in the denominator of the fraction.

(5) When the identity of each radionuclide is known but the individual activity of the radionuclides is not known, the most restrictive value of A_1 or A_2 applicable to any one of the radionuclides present is the applicable value.

(6) When the identity of the radionuclides is not known, the value of A_1 is 2 curies and the value of A_2 is 0.002 curies. However, if alpha emitters are known to be absent, the value of A_2 is 0.4 curies.

[Amdt. 173-162, 48 FR 10226, Mar. 10, 1983; 48 FR 13432, Mar. 31, 1983, as amended at 48 FR 31218, July 7, 1983; Amdt. 173-165, 50 FR 11055, Mar. 19, 1985]

§ 173.434 Activity-mass relationships for uranium and natural thorium.[1]

Radioactive material	Curies per gram	Grams per curie
Uranium—(Wt% ^{235}U present):		
0.45	5.0×10^{-7}	2.0×10^{6}
0.72 (natural)	7.06×10^{-7}	1.42×10^{6}
1.0	7.6×10^{-7}	1.3×10^{6}
1.5	1.0×10^{-6}	1.0×10^{6}
5.0	2.7×10^{-6}	3.7×10^{5}
10.0	4.8×10^{-6}	2.1×10^{5}
20.0	1.0×10^{-5}	1.0×10^{5}
35.0	2.0×10^{-5}	5.0×10^{4}
50.0	2.5×10^{-5}	4.0×10^{4}
90.0	5.8×10^{-5}	1.7×10^{4}
93.0	7.0×10^{-5}	1.4×10^{4}
95.0	9.1×10^{-5}	1.1×10^{4}
Natural thorium	2.2×10^{-7}	4.6×10^{6}

[1] The figures for uranium include representative values for the activity of uranium-234 which is concentrated during the enrichment process. The activity for thorium includes the equilibrium concentration of thorium-228.

§ 173.435 Table of A_1 and A_2 values for radionuclides.

Symbol of radionuclide	Element and atomic number	A_1(Ci) special form	A_2(Ci) normal form
^{227}Ac	Actinium (89).	1000	0.003
^{228}Ac		10	4
^{105}Ag	Silver (47)	40	40
^{110m}Ag		7	7
^{111}Ag		100	20
^{241}Am	Americium (95)[1]	8	0.008
^{243}Am		8	0.008
^{37}Ar (compressed or uncompressed).	Argon (18)	1000	1000
^{41}Ar (uncompressed).		20	20
^{41}Ar (compressed).		1	1
^{73}As	Arsenic (33)	1000	400
^{74}As		20	20
^{76}As		10	10
^{77}As		300	20
^{211}At	Astatine (85).	200	7
^{193}Au	Gold (79)	200	200
^{196}Au		30	30
^{198}Au		40	20
^{199}Au		200	25
^{131}Ba	Barium (56)	40	40
^{133}Ba		40	10
^{140}Ba		20	20
^{7}Be	Beryllium (4).	300	300
^{206}Bi	Bismuth (83).	5	5
^{207}Bi		10	10
^{210}Bi (daughter)		100	4
^{212}Bi		6	6
^{249}Bk	Berkelium (97).	1000	1
^{77}Br	Bromine (35).	70	25
^{82}Br		6	6
^{11}C	Carbon (6)	20	20
^{14}C		1000	60
^{45}Ca	Calcium (20).	1000	25
^{47}Ca		20	20
^{109}Cd	Cadmium (48).	1000	70
^{115m}Cd		30	30
^{115}Cd		80	20
^{139}Ce	Cerium (58)	100	100
^{141}Ce		300	25
^{143}Ce		80	20
^{144}Ce		10	7
^{249}Cf	Californium (98).	2	0.002
^{250}Cf		7	0.007
^{252}Cf		2	0.009
^{36}Cl	Chlorine (17).	300	10

Symbol of radionuclide	Element and atomic number	A_1(Ci) special form	A_2(Ci) normal form
^{38}Cl		10	10
^{242}Cm	Curium (96)	200	0.2
^{243}Cm		9	0.009
^{244}Cm		10	0.01
^{245}Cm		6	0.006
^{248}Cm		6	0.006
^{56}Co	Cobalt (27)	5	5
^{57}Co		90	90
^{58m}Co		1000	1000
^{58}Co		20	20
^{60}Co		7	7
^{51}Cr	Chromium (24).	600	600
^{129}Cs	Cesium (55)	40	40
^{131}Cs		1000	1000
^{134m}Cs		1000	10
^{134}Cs		10	10
^{135}Cs		1000	25
^{136}Cs		7	7
^{137}Cs		30	10
^{64}Cu	Copper (29)	80	25
^{67}Cu		200	25
^{165}Dy	Dysprosium (66)	100	20
^{166}Dy		1000	200
^{169}Er	Erbium (68)	1000	25
^{171}Er		50	20
^{152m}Eu	Europium (63).	30	30
^{152}Eu		20	10
^{154}Eu		10	5
^{155}Eu		400	60
^{18}F	Flourine (9)	20	20
^{52}Fe	Iron (26)	5	5
^{55}Fe		1000	1000
^{59}Fe		10	10
^{67}Ga	Gallium (31)	100	100
^{68}Ga		20	20
^{72}Ga		7	7
^{153}Gd	Gadolinium (64).	200	100
^{159}Gd		300	20
^{68}Ge	Germanium (32).	20	10
^{71}Ge		1000	1000
^{3}H	Hydrogen (1) See T-Tritum.		
^{181}Hf	Hafnium (72).	30	25
^{197m}Hg	Mercury (80).	200	200
^{197}Hg		200	200
^{203}Hg		80	25
^{166}Ho	Holmium (67).	30	30
^{123}I	Iodine (53)	50	50
^{125}I		1000	70
^{126}I		40	10
^{129}I		1000	2
^{131}I		40	10
^{132}I		7	7
^{133}I		30	10
^{134}I		8	8
^{135}I		10	10
^{111}In	Indium (49)	30	25
^{113m}In		60	60
^{114m}In		30	20
^{115m}In		100	20
^{190}Ir	Iridium (77)	10	10
^{192}Ir		20	10
^{194}Ir		10	10
^{42}K	Potassium (19)	10	10
^{43}K		20	10
^{85m}Kr (uncompressed)	Krypton (36)	100	100
^{85m}Kr (compressed)		3	3
^{85}Kr (uncompressed)		1000	1000
^{85}Kr (compressed)		5	5
^{87}Kr (uncompressed).		20	20
^{87}Kr (compressed).		0.6	0.6
^{140}La	Lanthanum (57)	30	30
LSA	Low specific activity material—see § 173.403		
^{177}Lu	Lutetium (71)	300	25
MFP	Mixed fission products	10	0.4
^{28}Mg	Magnesium (12)	6	6
^{52}Mn	Manganese (25)	5	5
^{54}Mn		20	20
^{56}Mn		5	5
^{99}Mo	Molybdenum (42)	100	20
^{13}N	Nitrogen (7)	20	10
^{22}Na	Sodium (11)	8	8
^{24}Na		5	5
^{93m}Nb	Niobium (41)	1000	200
^{95}Nb		20	20
^{97}Nb		20	20
^{147}Nd	Neodymium (60)	100	20
^{149}Nd		30	20
^{59}Ni	Nickel (28)	1000	900
^{63}Ni		1000	100
^{65}Ni		10	10
^{237}Np	Neptunium (93)	5	0.005
^{239}Np		200	25
^{185}Os	Osmium (76)	20	20
^{191}Os		600	200
^{191m}Os		200	200
^{193}Os		100	20
^{32}P	Phosphorus (15)	30	30
^{230}Pa	Protactinium (91)	20	0.8
^{231}Pa		2	0.002
^{233}Pa		100	100
^{201}Pb	Lead (82)	20	20
^{210}Pb		100	0.2

APPENDIX II

Symbol of radionuclide	Element and atomic number	A_1(Ci) special form	A_2(Ci) normal form
^{212}Pb		6	5
^{103}Pd	Palladium (46).	1000	700
^{109}Pd		100	20
^{147}Pm	Promethium (61).	1000	25
^{148}Pm		100	20
^{210}Po	Polonium (84).	200	0.2
^{142}Pr	Praseodymium (59).	10	10
^{143}Pr		300	20
^{191}Pt	Platinum (78).	100	100
^{193m}Pt		200	200
^{197m}Pt		300	20
^{197}Pt		300	20
^{238}Pu	Plutonium (94)[1].	3	0.003
^{239}Pu		2	0.002
^{240}Pu		2	0.002
^{241}Pu		1000	0.1
^{242}Pu		3	0.003
^{223}Ra	Radium (88)	50	0.2
^{224}Ra		6	0.5
^{226}Ra		10	0.05
^{228}Ra		10	0.05
^{81}Rb	Rubidium (37).	30	25
^{86}Rb		30	30
^{87}Rb		Unlimited	Unlimited
Rb (natural)		Unlimited	Unlimited
^{186}Re	Rhenium (75).	100	20
^{187}Re		Unlimited	Unlimited
^{188}Re		10	10
Re (natural)		Unlimited	Unlimited
^{103m}Rh	Rhodium (45).	1000	1000
^{105}Rh		200	25
^{222}Rn	Radon (86)	10	2
^{97}Ru	Ruthenium (44).	80	80
^{103}Ru		30	25
^{105}Ru		20	20
^{106}Ru		10	7
^{35}S	Sulphur (16)	1000	60
^{122}Sb	Antimony (51).	30	30
^{124}Sb		5	5
^{125}Sb		40	25
^{46}Sc	Scandium (21).	8	8
^{47}Sc		200	20
^{48}Sc		5	5
^{75}Se	Selenium (34).	40	40
^{31}Si	Silicon (14)	100	20
^{147}Sm	Samarium (62).	Unlimited	Unlimited
^{151}Sm		1000	90
^{153}Sm		300	20
^{113}Sn	Tin (50)	60	60
^{119m}Sn		100	100
^{125}Sn		10	10
^{85m}Sr	Strontium (38).	80	60
^{85}Sr		30	30
^{87m}Sr		50	50
^{89}Sr		100	10
^{90}Sr		[illegible]	0.4

Symbol of radionuclide	Element and atomic number	A_1(Ci) special form	A_2(Ci) normal form
^{91}Sr		10	10
^{92}Sr		10	10
T (uncompressed).	Tritium (1)	1000	1000
T (compressed).		1000	1000
T (activated luminous paint).		1000	1000
T (adsorbed on solid carrier).		1000	1000
T (tritiated water).		1000	1000
T (other forms).		20	20
^{182}Ta	Tantalum (73).	20	20
^{160}Tb	Terbium (65).	20	10
^{98m}Tc	Technetium (43).	1000	1000
^{96}Tc		6	6
^{97m}Te		1000	200
^{97}Te		1000	400
^{99m}Te		100	100
^{99}Te		1000	25
^{125m}Te	Tellurium (52).	1000	100
^{127m}Te		300	20
^{127}Te		300	20
^{129m}Te		30	10
^{129}Te		100	20
^{131m}Te		10	10
^{132}Te		7	7
^{227}Th	Thorium (90).	200	0.2
^{228}Th		6	0.008
^{230}Th		3	0.003
^{231}Th		1000	25
^{232}Th		Unlimited	Unlimited
^{234}Th		10	10
Th (natural).		Unlimited	Unlimited
Th (irradiated)[2].			
^{200}Tl	Thallium (81).	20	20
^{201}Tl		200	200
^{202}Tl		40	40
^{204}Tl		300	10
^{170}Tm	Thulium (69).	300	10
^{171}Tm		1000	100
^{230}U	Uranium (92).	100	0.1
^{232}U		30	0.03
^{233}U		100	0.1
^{234}U		100	0.1
^{235}U		100	0.2
^{236}U		200	0.2
^{238}U		Unlimited	Unlimited
U (natural).		Unlimited	Unlimited
U (enriched).			

Symbol of radionuclide	Element and atomic number	A_1(Ci) special form	A_2(Ci) normal form
<20%		Unlimited	Unlimited
20% or greater.		100	0.1
U (depleted).		Unlimited	Unlimited
U (irradiated)[2].			
^{48}V	Vanadium (23).	6	6
^{181}W	Tungsten (74).	200	100
^{185}W		1000	25
^{187}W		40	20
^{127}Xe (uncompressed).	Xenon (54)	70	70
^{127}Xe (compressed).		5	5
^{131m}Xe (compressed).		10	10
^{131m}Xe (uncompressed).		100	100
^{133}Xe (uncompressed).		1000	1000
^{133}Xe (compressed).		5	5
^{135}Xe (uncompressed).		70	70
^{135}Xe (compressed).		2	2
^{87}Y	Yttrium (39)	20	20
^{90}Y		10	10
^{91m}Y		30	30
^{91}Y		30	30
^{92}Y		10	10
^{93}Y		10	10
^{169}Yb	Ytterbium (70).	80	80
^{175}Yb		400	25
^{65}Zn	Zinc (30)	30	30
^{69m}Zn		40	20
^{69}Zn		300	20
^{93}Zr	Zirconium (40).	1000	200
^{95}Zr		20	20
^{97}Zr		20	20

[1] For shipments solely within the United States the A_1 value is 20 curies for americium and plutonium contained in Am-Be or Pu-Be neutron sources or in nuclear-powered pacemakers.

[2] The values of A_1 and A_2 must be calculated in accordance with the procedure specified in § 173.433 of this subchapter, taking into account the activity of the fission products and of the uranium-233 in addition to that of the thorium.

[3] The values of A_1 and A_2 must be calculated in accordance with the procedure specified in § 173.433 of this subchapter, taking into account the activity of the fission products and plutonium isotopes in addition to that of the uranium.

[Amdt. 173-162, 48 FR 10226, Mar. 10, 1983; 48 FR 13432, Mar. 31, 1983, as amended at 48 FR 31219, July 7, 1983; Amdt. 173-207, 53 FR 38274, Sept. 29, 1988]

§ 173.441 Radiation level limitations.

(a) Except as provided in paragraph (b) of this section, each package of radioactive materials offered for transportation shall be designed and prepared for shipment so that under conditions normally incident to transportation the radiation level does not exceed 200 millirem per hour at any point on the external surface of the package, and the transport index does not exceed 10.

(b) A package which exceeds the radiation level limits specified in paragraph (a) of this section shall be transported by exclusive use shipment only and the radiation levels for such shipment must not exceed the following during transportation:

(1) 200 millirem per hour (2 millisievert per hour) on the external surface of the package unless the following conditions are met, in which case the limit is 1000 millirem per hour (10 millisievert per hour).

(i) The shipment is made in a closed transport vehicle;

(ii) The package is secured within the vehicle so that its position remains fixed during transportation; and

(iii) There are no loading or unloading operations between the beginning and end of the transportation;

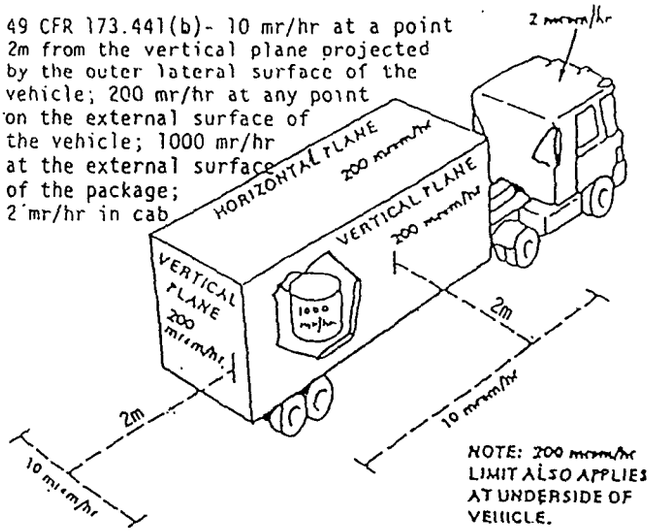
(2) 200 millirem per hour (2 millisievert per hour) at any point on the outer surfaces of the vehicle, including the top and underside of the vehicle; or in the case of a flat-bed style vehicle, at any point on the vertical planes projected from the outer edges of the vehicle, on the upper surface of the load (or enclosure is used), and on the lower external surface of the vehicle;

(3) 10 millirem per hour (0.1 millisievert per hour) at any point 2 meters (6.6 feet) from the outer lateral surfaces of the vehicle (excluding the top and underside of the vehicle); or in the case of a flat-bed style vehicle, at any point 2 meters (6.6 feet) from the vertical planes projected by the outer edges of the vehicle (excluding the top and underside of the vehicle); and

(4) 2 millirem per hour (0.02 millisievert per hour) in any normally occupied space, except that this provision

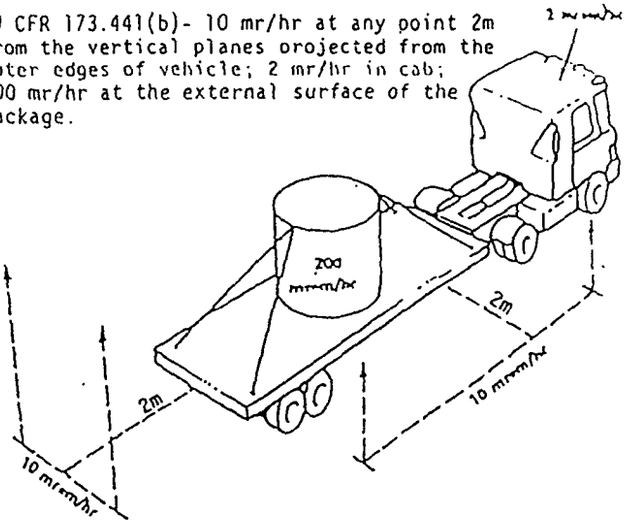
APPENDIX III

49 CFR 173.441(b)- 10 mr/hr at a point 2m from the vertical plane projected by the outer lateral surface of the vehicle; 200 mr/hr at any point on the external surface of the vehicle; 1000 mr/hr at the external surface of the package; 2 mr/hr in cab



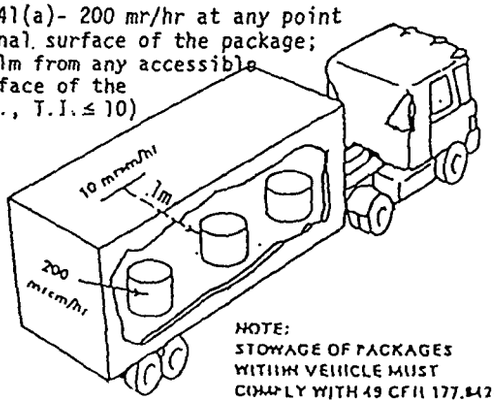
EXCLUSIVE-USE CLOSED TRANSPORT

49 CFR 173.441(b)- 10 mr/hr at any point 2m from the vertical planes projected from the outer edges of vehicle; 2 mr/hr in cab; 200 mr/hr at the external surface of the package.



EXCLUSIVE-USE OPEN TRANSPORT

49 CFR 173.441(a)- 200 mr/hr at any point on the external surface of the package; 10 mr/hr at 1m from any accessible external surface of the package (i.e., T.I. ≤ 10)



NOTE: TOTAL TI IS NOT TO EXCEED 50 PER 49 CFR 177.842(a).

NOTE: STOWAGE OF PACKAGES WITHIN VEHICLE MUST COMPLY WITH 49 CFR 177.842(b).

NON-EXCLUSIVE-USE OPEN OR CLOSED TRANSPORT

RADIATION LIMITS

49 CFR 173.441
(6/87)

RADIOACTIVE MATERIAL PACKAGING, LABELING, AND SHIPPING

APPENDIX IV

STRAIGHT BILL OF LADING — SHORT FORM — ORIGINAL — NOT NEGOTIABLE.

RECEIVED, subject to the classifications and tariffs in effect on the date of the issue of this Bill of Lading.

The property described below, in apparent good order, except as noted (contents and condition of contents of packages unknown), Marked, consigned, and destined as indicated below, which said carrier (the word carrier being understood throughout this contract as meaning any person or corporation in possession of the property under the contract) agrees to carry to its usual place of delivery at said destination, if on its route, otherwise to deliver to another carrier on the route to said destination. It is mutually agreed, as to each carrier of all or any of said property over all or any portion of said route to destination, And as to each party at any time interested in all or any of said property, that every service to be performed hereunder shall be subject to all the terms and conditions of the uniform domestic straight bill of lading set forth (1) in official, Southern, Western and Illinois Freight Classifications in effect on the date hereof, if this is a rail or a rail water shipment. Or (2) in the applicable motor carrier classification or tariff if this is a motor carrier shipment.

Shipper hereby certifies that he is familiar with all the terms and conditions of the said bill of lading, including those on the back thereof, set forth in the classification or tariff which governs the transportation of this shipment, and the said terms and conditions are hereby agreed to by the shipper and accepted for himself and his assigns.

(MAIL OR STREET ADDRESS OF CONSIGNEE — FOR PURPOSES OF NOTIFICATION ONLY.)

Control Number

Tractor No _____

Trailer No _____

LENGTH

HEIGHT

WIDTH

FROM _____ Date _____

AT _____

CONSIGNED TO _____

DESTINATION _____ STATE _____ COUNTY _____

NO. PKGS.	HM	KIND OF PACKAGE, DESCRIPTION OF ARTICLES, LINER NUMBERS, SPECIAL MARKS & EXCEPTIONS	*WEIGHT (Subject to Correction)

IMPORTANT: This is to certify that the above named materials are properly classified, described, packaged, marked and labeled and are in proper condition for transportation according to the applicable regulations of the Department of Transportation.

Signature _____

Company _____ Date _____

Received the property described above in good condition, except as otherwise noted.

Carrier _____

Driver _____

Date and Time _____

	DATE	TIME		DATE	TIME	
SCHEDULED TO ARRIVE		A.M. P.M.	COMPLETED LOADING		A.M. P.M.	SHIPPER'S SIGNATURE
ARRIVED AT SHIPPER		A.M. P.M.	LEFT SHIPPER		A.M. P.M.	SHIPPER'S SIGNATURE

IMPORTANT NOTE: Your signature certifies that the above dates and times are correct for record keeping and billing purposes.

SECTION 14

RADIOACTIVE SOIL AND WATER SAMPLING

After completing this unit, participants will be able to:

- Explain the purpose of radioactive soil and water sampling.
- Given a site with radioactive soil and/or water contamination, list the minimum protective clothing requirements.
- List the three reference documents regarding unrestricted release.
- List the three primary radiation monitoring instruments used during soil sampling.
- Explain proper area setup for soil and water sampling.
- Explain proper protocol for radioactive soil and water sampling.
- Given a soil and/or water sample, determine whether the sample is radioactively contaminated.
- Describe the procedure for handling a contaminated sample.

I. Purpose

A. To determine whether the soil or water is radioactively contaminated

B. To characterize the radioactive components by laboratory isotopic analysis

C. To effectively control the radiological hazard

II. Sampling Preparation

A. Reference documents for unrestricted release

1. 10 CFR 20, Appendix B, Table II for water

2. Regulatory Guide 1.86, Table I for surface contamination

3. Policy and Guidance Directive FC 83-23 for soil

B. Protective clothing

1. Minimum protective clothing requirements shall include waterproof shoe covers (preferably boots) and waterproof gloves (preferably mid-forearm length)

2. Waterproof apron

C. Monitoring and survey equipment

1. Portable alpha probe instrument

2. Portable beta-gamma probe instrument

3. Portable dose rate instrument

4. Smear paper (swipes, wipes)

5. Small plastic bags

6. Pen and data sheet for documentation

D. Sampling equipment and supplies

1. Sampling apparatus. Optional depending on type and depth of desired sample (i.e., auger, bailer)

2. Sample container(s) (i.e., 1 liter polyethylene bottle with cap)

3. Metal tray

4. Medium mesh screen (sieve - about 1 ft. by 1 ft.)

5. Trowel or spoon

6. Plastic bags (medium and large)

7. Plastic sheeting

8. Absorbent materials (i.e., cotton rags or diapers)

9. Adhesive tape

10. Mild soap or detergent

11. Bucket of water

12. Barrier rope or tape, and stanchions

13. Appropriate work site posting (i.e., EPA work area, do not enter without approval)

14. Scissors

15. Yellow and magenta radiation rope

16. Radiological Control Area signs (e.g., Radiologically Contaminated Water, Controlled Surface Contamination Area)

III. Simple Soil and Water Sampling Procedure

A. Don protective clothing

1. Put on minimum shoe covers, gloves, and apron

B. Set up work area

1. Take area and surface readings to ensure no surface contamination or exposure dose rates are significant (Ref: U.S. EPA SOSGs).

2. Establish perimeter work area.

3. Install barriers and posting (EPA work area).

4. Spread plastic sheeting near sampling location.

5. Set up small cleaning area on plastic sheeting (about 2 ft. by 2 ft.). Surround with absorbent material.

6. Place bucket of mild soapy water, large plastic bag, and some absorbent cleaning material near cleaning area, but not inside cleaning area.

7. Set up staging area near sampling location and place remainder of equipment.

C. Prepare to obtain sample

1. Ensure monitoring instruments are near sampling location and operating

2. Have open sample bottle and cap handy

3. Have dry and dampened absorbent material handy

D. Obtain sample

1. Draw sample and monitor with portable contamination instruments while sample is being obtained (Primarily beta-gamma, spot check with alpha)

2. If background levels increase, it is a good indication the sample is radioactive. Use dose rate instrument to periodically monitor and continue to draw sample

3. Soil sample - use dampened absorbent to wipe container while still positioned over sample area. Water sample - use dry absorbent to wipe container while still positioned over sample area. Dispose of absorbents as waste.

4. Cap container

Note 1: If soil sample is too chunky, break up with trowel or use medium mesh screen to sift sample onto metal tray. Spread into thin layer, field monitor, and transfer to sample container.

Note 2: If exposure rate increases to 3-5 times above background, work can continue, but a health physicist should be consulted.

Note 3: If exposure rate reaches 1 mR/hr or above, stop work and consult with a health physicist. If not, continue as normal.

E. Survey sample(s) for surface contamination

1. Survey outer surfaces of sample container

2. If no contamination is detected by dry smears, you can assume container is free of loose surface contamination. Continue as normal.

3. If any contamination at all is detected on outer surfaces of container, dispose of smears and used adsorbents in large plastic bag as contaminated waste. A direct reading increase with beta-gamma probe may indicate sample itself is contaminated. Document results.

F. Treatment of contaminated sample

1. If sample container is found to have loose contamination on the outer surfaces, it must be decontaminated. Transfer sample to cleaning area, change gloves, and prepare to decontaminate.

2. Use bucket of mild soapy water and dip some absorbent cleaning material in it. Hand wring over bucket, then wipe outer surfaces of container inside decontamination area. Dry and resurvey for contamination. Dispose of smears and adsorbents as contaminated. Repeat as necessary.

3. After outer surfaces are found to be contamination free using dry smears, decontamination is complete. Change gloves. Place sample in medium plastic

bag and seal bag using adhesive tape. Document results.

Note: 4 If outer surfaces remain contaminated after decontamination, place sample in medium plastic bag and seal. Repeat using second medium plastic bag and seal. Document results on data sheets and containment labels.

4. Ensure outer surfaces of plastic bag containment is contamination free and prepare sample for shipment to analytical laboratory using prescribed radioactive materials labeling and shipping methods.

IV. Termination of Sampling Work

A. Monitor unused materials to verify they are contamination free, and remove from work area. Document results.

B. Monitor remaining materials, and decontaminate as necessary. Those that can be verified as contamination free shall be removed from work area. Those that remain contaminated shall be disposed of in large plastic waste bag, or sealed in large plastic bag for subsequent use. Document results.

C. Blot any wet areas on plastic sheeting using dry absorbent material. Carefully roll or fold up plastic sheeting and dispose of in large plastic waste bag.

D. Perform surface contamination survey of entire work area to ensure no residual contamination is left on the ground. Document results.

E. If any freestanding water is noticeable in contaminated waste bag, place some additional dry absorbent material in bag to absorb water.

V. Securing the Work Area/Setting up Radiological Area

A. Remove the work site perimeter barriers and postings. Monitor to ensure they are contamination free.

B. Replace perimeter barriers with yellow and magenta radiation rope.

C. Classify area based on survey results by posting appropriate radiological control area signs. Postings should be about waist high, and seen from all accessible approaches.

D. Secure contaminated waste inside posted area or properly transport for disposal as contaminated waste.

VI. Final Monitoring

A. Monitor protective clothing; remove and properly dispose

B. Perform whole-body personnel monitoring prior to leaving work site

VII. Considerations

A. Be conscientious of cross contamination at all times

B. Change gloves regularly, especially when performing different tasks. Consider wearing two pair of gloves.

C. Work carefully to prevent the spread of contamination and be conscious of where potentially contaminated areas may be.

D. Monitor yourself whenever you suspect you may have become contaminated, and between steps

NOTES

E. Bring extra protective clothing

F. Dispose of all used smear paper as contaminated waste or place in small plastic bags to go to laboratory for further analysis

G. Ensure no freestanding water is noticeable in contaminated waste bag(s)

H. Remember double containment

SECTION 15

REGULATIONS AND GUIDANCE ON RADIOACTIVE WASTE DISPOSAL

After completing this unit, participants will be able to:

- Explain the technical basis for radioactive waste regulation development.
- Identify a source and category of radioactive waste.
- Identify the principle agencies governing radioactive waste disposal activities.

REGULATIONS AND GUIDANCE ON RADIOACTIVE WASTE DISPOSAL

NOTES

I. Exposure pathways associated with radioactive waste

A. inhalation of radionuclides

B. gamma radiation

C. ingestion of radionuclides

II. Technical basis for radioactive waste regulation development

A. ALARA

As low as reasonably achievable, taking into account the state of technology the economics of improvements in relation to 1) the benefits to the public health and safety and other societal and socioeconomic considerations and 2) the use of atomic energy in the public interest

B. Biological Risk

The probability of adverse health effects to the public due to radiation exposure

C. Comparable Risk

The probability of risks of adverse health effects associated with different and/or alternative disposal methods

III. Regulated waste management activities relating to radioactive waste disposal

A. Accumulating

B. Processing

C. Handling

D. Packaging

E. Transporting

F. Storing

G. Disposing

IV. Radioactive waste sources and types

A. Radioactive waste definition

1. Equipment or materials that are radioactive or have radioactive contamination and are required pursuant to any governing laws, regulations, or licenses to be disposed of as radioactive waste.

2. Waste that has a specific activity (the activity of radionuclides per unit mass) greater than 0.002 μCi per gram.

3. Waste that meets the criteria in 10 CFR 61.55

B. Sources of radioactive waste

1. Fuel cycle facilities

2. Institutions

3. Commercial business

4. Government agencies

C. Categories of radioactive waste

1. Mill tailings - rock and soil that are naturally radioactive and are by-products of uranium mining and milling operations

2. Low level - waste that contains small amounts of radioactive material dispersed in

large volumes and poses little potential hazard

3. Transuranic - waste that contains more than 100 nanocuries of alpha-emitting isotopes, with half-lives greater than 20 years per gram of waste

4. High level - waste that is highly radioactive and decays very rapidly

5. Mixed - waste that contains hazardous properties, as defined by 40 CFR 261, and radioactive properties

6. NARM - naturally occurring and accelerator radioactive waste

V. Federal Regulations and Guidance Documents

A. Regulators/Responsible Parties

1. U.S. Environmental Protection Agency (EPA)

a. Office of Radiation Programs (ORP)

2. Nuclear Regulatory Commission (NRC)

3. U.S. Department of Energy (DOE)

4. U.S. Department of Transportation (DOT)

5. Agreement States

6. International Atomic Energy Agency (IAEA)

B. Radioactive waste regulation chronology

1. Atomic Energy Act of 1946

a. Established the Atomic Energy Commission (AEC)

- Chartered to conduct research and development on peaceful application of nuclear materials

- Regulatory authority

2. Atomic Energy Act of 1954

a. Emphasized domestic and international uses of atomic applications

b. Provided for the control of source, by-product, and special nuclear materials

3. National Environmental Policy Act of 1969

a. Established the Council On Environmental Quality

b. Established the EPA in the executive branch

c. Requires the assessment of every federal action that may have a significant impact on the environment

4. Energy Reorganization Act of 1974

a. AEC divided into NRC and Energy Research and Development Administration (ERDA)

b. ERDA role was research, development, and production

- National defense uses of radioactive materials

c. NRC role was regulatory

- Nondefense-related uses of radioactive materials

5. Energy Organization Act of 1977

a. Replaces ERDA with DOE

b. DOE National Security and Military Applications of Nuclear Energy Authorization Act, Public Law 96-164 (1979)

c. Authorized the DOE to site and construct the Waste Isolation Pilot Project

6. Nuclear Waste Policy Act of 1982 - Public Law 97-425

a. Title 1, Subtitle A - Repositories for Disposal of High Level and Special Nuclear Fuel

- Mandates the following:

EPA must promulgate generally applicable standards for the protection of the general environment from radioactive material in repositories

NRC must promulgate technical requirements and criteria that it will apply in approving or disapproving repository construction authorizations, operating

licenses, and closure and decommissioning authorizations

DOE must issue general guidelines for the recommendation of sites for repositories

b. Title 2, Research and Demonstration Regarding Disposal of High Level and Special Nuclear Fuel

- Authorizes DOE to provide for overall management for construction, operation, and maintenance of a deep geological test and evaluation facility

c. Title 3, Other Provisions Relating to Radioactive Waste

7. Low-Level Radioactive Waste Policy Amendments Act of 1985

a. Endorses the below regulatory concern (BRC) concept

b. NRC role is to establish procedures for acting on petitions to exempt specific radioactive wastestreams

c. EPA role is to define radiation exposure allowable in such BRC deregulation

d. States are responsible for low-level waste generated within their boundaries, with the exception of DOE wastes and U.S. Navy wastes

- States may form compacts that shall not take effect until Congress has consented by law to the compact

- Compacts may restrict the use of the regional disposal facilities to the disposal of waste generated within its compact region after January 1, 1986

- Extension of deadline from 1986 to 1992 for states to take responsibility for internally generated waste with the following interim milestones:

  July 1986 - ratify compact of state intent to site a disposal facility

  January 1988 - select host state, or site and developer, or certify that storage will be provided

  January 1992 - license application

- Established disposal facility volume caps and increasing surcharges during transition period

  1986 to 1987-$10.00 per cubic foot

  1988 to 1989-$20.00 per cubic foot

1990 to 1992-$40.00 per cubic foot

8. Nuclear Waste Policy Amendments Act of 1987

   a. Placed a moratorium on all site-specific activity at all candidate sites except Yucca Mountain in the state of Nevada

   b. Suspended any site-specific activities regarding a second repository

   c. Authorized the construction of a Monitored Retrievable Storage (MRS) facility

   d. Authorized payments to Nevada of $10 million per year during siting and construction of the Yucca Mountain repository, and $20 million per year during operation, and half of those amounts to the state of Indian tribe where an MRS is located

C. Regulatory requirements applicable to radioactive waste disposal

   1. Title 40 - Protection of Environment, Parts 190-192: EPA's Radiation Protection Programs

      a. 40 CFR 191 - Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High Level and Transuranic Radioactive Wastes

      b. 40 CFR 192 - Health and Environmental Protection

Standards for Uranium Mill Tailings

2. Title 10 - Energy, Parts 0-199: NRC

   a. 10 CFR 20 - Standards for Protection Against Radiation

      - Establishes standards for protection against radiation hazards arising out of activities (possession, use, and transfer of radioactive materials) under licenses by the NRC, pursuant to the Atomic Energy Act of 1954, as amended, and the Energy Reorganization Act of 1974

   b. 10 CFR 51 - Environmental Protection Regulations for Domestic Licensing and Related Regulatory Functions

      - Establishes the NRC policy and procedure for the preparation and processing of environmental impact statements and related documents for actions significantly affecting the quality of the human environment

   c. 10 CFR 60 - Disposal of High-Level Radioactive Wastes in Geological Repositories

- Prescribes rules governing the licensing of DOE to receive and possess source, special nuclear, and by-product material at a geologic repository operations area sited, constructed, or operated in accordance with the Nuclear Waste Policy Act of 1982.

d. 10 CFR 61 - Licensing Requirements for Land Disposal of Radioactive Waste

- Establishes, for land disposal of radioactive waste, the procedures, criteria, terms, and conditions upon which the NRC issues licenses for the disposal of radioactive wastes containing by-product, source, and special nuclear material

e. 10 CFR 71 - Packaging and Transportation of Radioactive Material

- Sets requirements for packaging, preparation for shipment, and transportation of licensed radioactive

materials, and procedures and standards for NRC approval of packaging and shipping procedures for fissile material and for a quantity of other licensed material in excess of a Type A quantity

f. 10 CFR 73 - Physical Protection of Plants and Materials

- Prescribes requirements for the establishment and maintenance of a physical protection system for the protection of special nuclear material at fixed sites and in transit, and of plants in which special nuclear material is used

3. Title 49 - Transportation, Parts 171-179

a. 49 CFR 173 - Shippers-General Requirements for Shipments and Packaging

- Sets forth requirements for the transportation of radioactive materials by carriers and shippers

NOTES

4. IAEA Transport Regulations

   a. Sets forth minimum safety requirements based on performance standards that would be universally applicable and could serve as a basis for national and international regulations applicable to the transportation radioactive materials

SECTION 16

REMEDIAL AND DISPOSAL OPTIONS

After completing this unit, participants will be able to:

- Identify two characteristics of CERCLA remediation activities.
- List the two kinds of disposal options and give an example of an associated disposal technique for each.
- Discuss one remedial treatment technology.

I. *Technological Approaches to the Cleanup of Radiologically Contaminated Superfund Sites*, EPA/540/2-88/002, August 1988

A. Comprehensive Environmental Response, Compensation and Liability Act mandates:

1. Protective actions

2. Permanent solutions

3. Use of alternative treatment technologies or resource recovery options to the maximum extent practicable

4. Cost efficiency

5. Consideration of any applicable or relevant and appropriate requirements (ARARs)

B. Radiation Risk Assessment Procedures

1. Developed by the ICRP in 1979, adopted by EPA in Federal Guidance Report 11, 1988

2. Guidance on potential ARARs is available in the *CERCLA Compliance with Other Laws* manual (US EPA 1988c)

C. Technological Approaches to the Cleanup of Radiologically Contaminated Superfund Sites

1. Focus - treatment and disposal of radiation contaminated soils and radon control

2. Principle contaminants

a. by-products of uranium, thorium, and radium processing

b. contaminated buildings and equipment

c. stream sediments

D. DOE Remediation Sites

NOTES

1. Formerly Utilized Sites Remedial Action Project (FUSRAP) -
   29 sites (3 on NPL)

2. Uranium Mill Tailings Remedial Action Project (UMTRAP) - 24 sites

3. Grand Junction Remedial Action Project (GJRAP) - 1 site

4. Surplus Facilities Management Program (SFMP) - 17 sites

   Notes:

   - thousands of DOE vicinity properties

   - single largest problem is the disposal of waste

E. Remedial and Disposal Options

   1. Categories of Disposal

      a. Onsite - waste is disposed of at the site of generation

      b. Offsite - waste is disposed of at a site other than the site of generation

   2. Onsite Disposal Methods

      a. Capping - covering the radioactive material with a barrier sufficiently thick and impermeable to minimize diffusion of radon gas and attenuate penetrating radiation, as well as prevent or minimize water infiltration without enhancing erosion.

         i. Advantages

            - ease of application

            - high reliability if properly maintained

- soil characteristics not as critical as other treatment technologies

ii. Disadvantages

- no reduction in radioactivity
- long-term maintenance
- site security

b. Vertical Barriers - installation of a wall of low-permeability material around the outside of contaminated area to limit lateral migration

i. Grout materials: Portland cement, alkali silicate, and organic polymers

ii. Advantages

- simple to install
- act as a treatment vessel

iii. Disadvantages

- difficult to obtain low permeability
- chemical waste incompatibility
- requires detailed physical and chemical data on soil characteristics

3. Offsite Disposal Methods

a. Land Encapsulation - the physical isolation of waste in a structure that is entombed in the ground

i. Advantages

- mature technology

- complete removal of contamination from site
- simple prerequisite informational needs

ii. Disadvantages

- site selection
- acceptance of waste by existing facility
- handling and transportation
- concentration of wastes may result in unacceptably high radioactivity

b. Land Spreading - excavating the contaminated material, transporting it to a suitable site, and spreading it on unused land, assuming that the radioactivity levels will be the same as natural background

i. Advantage

- suitable for dry, granular tailings and soils

ii. Disadvantage

- not appropriate for mixed waste

c. Underground Mine Disposal - the placement of waste in subterranean mines

i. Advantages

- suitable for highly concentrated waste
- suitable for untreated wastes

ii. Disadvantages

- high cost

- additional research is needed on costs and risks associated with transportation of material

- groundwater contamination must be considered and prevented

d. Ocean Disposal - the disposal of low-level waste in the sea

i. Advantage

- extreme isolation of low-level waste

ii. Disadvantage

- high degree of risk due to transportation safety issues

4. Remedial Treatment Technologies

a. General

i. Radioactive contaminants are not altered or destroyed by treatment technologies. The volume of contaminated material may be reduced, with a corresponding elevation in concentration, but containment and/or burial is the only remedy.

ii. Chemical extraction and physical separation technologies have been used in a site remediation situation. The same holds true for stabilization and solidification. Only excavation and land encapsulation have been used at radiologically contaminated Superfund sites.

b. Onsite Treatment

i. Stabilization or solidification - immobilization or restraint of radionuclides by trapping them in an impervious matrix

(i.e., Portland cement, silica grout, or chemical grout)

(a) Advantages

- can be accomplished *in situ* or by excavation, mixing, and replacement
- can be combined with capping

(b) Disadvantage

- interference by hazardous chemicals

ii. Vitrification - immobilization of radioactive waste by melting waste material between two or more electrodes, resulting in a glassy mass after cooling

(a) Advantage

- effective immobilization

(b) Disadvantages

- energy intensive
- volatilization of waste substances

iii. Chemical extraction - concentrate radioactive contaminants by chemical extraction, thereby reducing the volume of waste for final disposal

(a) Water - contaminated soils or tailings are mixed with large quantities of water. The water, with soluble radionuclides fraction is removed by physical separation

(i) Advantages

- inexpensive, simple technology

(ii) Disadvantages

- consumes large quantities of water
- low efficiency of extraction

(b) Inorganic Salts - theory of operation similar to water extraction

(i) Considerations

- nature of the tailings; geochemistry particle size, and chemical composition; concentration of salt solution
- pH
- solid-to-liquid ratio
- process time
- temperature
- method of extraction

(c) Mineral Acids - soils are ground and mixed with water to form a slurry. Contaminants are leached from the slurry using inorganic acids. Radionuclides are removed from leachate by ion exchange, solvent extraction, or precipitation

(i) Application

extraction of radium, thorium, and uranium as well as other metals

(ii) Advantages

- high extraction efficiency
- other metals are removed
- relatively small liquid-to-solid ratio compared to extraction with water or inorganic salts
- costs can be reduced by recycling acids

(iii) Disadvantages

- increased operating costs due to expensive reagents, higher operating temperatures, and stainless steel reaction vessels necessary for strong corrosives
- multistage process
- chemically leached material containing nitrates or chlorides that may be more harmful than the original contaminated soils

(d) Complexing Agents - complexing agents in the slurry

(i) Application

- removal of radium from contaminated soils

(ii) Liquid Treatment

- precipitation and coprecipitation

- solvent extraction
- ion exchange

(iii) Advantages

- high extraction efficiency for radium
- low volume of reagent needed

(iv) Disadvantages

- reagents are very expensive
- only effective for radium

5. Superfund Innovative Technology Evaluation (SITE) Program

a. General

i. Administered by EPA's Office of Research and Development

ii. Encourages the development of innovative treatment technologies

iii. Evaluates new treatment technologies

iv. Disseminates technical information on treatment technologies

b. SITE Program Description

i. Emerging technology

ii. Demonstration program

iii. Monitoring and measurement technologies program

iv. Technical transfer program

c. SITE Information Resources

i. Alternative Treatment Technology Information Center (ATTIC), System Operator: 1-301-670-6294

ii. Vendor Information System for Innovative Treatment Technologies (VISITT)

Hotline: 1-800-245-4505

iii. SITE Clearinghouse Hotline:

1-800-424-9346 or 1-202-382-3000

iv. Center for Environmental Research Information (CERI): 1-513-569-7562

v. ORD Publications, 26 Martin Luther King Dr. (G72), Cincinnati, OH 45268

GLOSSARY

ABSORPTION: The process by which radiation imparts some or all of its energy to any material through which it passes.

ACCELERATOR, PARTICLE: A device for imparting large quantities of kinetic energy to electrically charged particles such as electrons, protons, and helium ions.

ACTIVATION: The process of inducing radioactivity by irradiation.

ACTIVITY: The number of nuclear transformations occurring in a given quantity of material per unit time. The unit of measure is the curie (Ci).

ACUTE EXPOSURE: Exposure occurring over a short, up to a few days, period of time.

AGREEMENT STATE: Any state in the United States with which the NRC has made an effective agreement under Subsection 274(b) of the Atomic Energy Act of 1954, as amended, relative to the licensing and control of radioactive material used or produced within that state.

AIRBORNE CONTAMINATION: The term applied to radioactive contamination loose in air, filtered from the air, or deposited from the air, as contrasted with contamination spread by splashing, dripping, etc...

AIR-WALL IONIZATION CHAMBER: An ionization chamber in which the materials of the wall and electrodes are so selected as to produce ionization essentially equivalent to that in a free-air ionization chamber. This is possible only over limited photon energy ranges. Such a chamber is normally called an "air-equivalent ionization chamber".

ALARA: An acronym for "As Low As Reasonably Achievable"; refers to the operating philosophy in which occupational exposures are maintained as far below the specified limits as is reasonable to achieve.

ALPHA PARTICLE: A charged particle that is emitted from the nucleus of an atom, and that has a mass and charge equal in magnitude to those of the helium nucleus, i.e., two protons and two neutrons.

AMPLIFICATION: As related to radiation detection instruments, the process (gas, electronic or both) by which ionization effects are magnified to a degree suitable for their measurement.

ANALYZER, PULSE HEIGHT: An electronic circuit that sorts and records pulses according to their height.

ANGULAR DEPENDENCE: The varying ability of an instrument to detect radiation, depending on its orientation with respect to the radiation field.

ANODE: A positive electrode; the electrode to which negative ions are attracted.

ARTIFICIAL RADIOACTIVITY: Manmade radioactivity produced by bombardment or electromagnetic irradiation.

ATOMIC NUMBER The number of protons in the nucleus of an atom.

ATTENUATION: The process by which a beam of radiation is reduced in intensity or energy when passing through some material.

AUTHORIZED MATERIAL: Radioactive material not requiring a specific NRC license. The receipt, possession, use, or transfer of radioactive material requires authorization by a specific agency or organization.

AVALANCHE: The multiplicative process by which a single charged particle accelerated by a strong electric field produces additional charged particles through collision with neutral gas molecules. This cumulative increase in ions is also known as "Townsend Avalanche" or "Townsend Ionization".

BACKGROUND RADIATION: Radiation arising from radioactive material other than the one directly under consideration. Background radiation due to cosmic rays and natural radiation is always present. There may also be background radiation due to the presence of radioactive substances in other parts of a building.

BEAM: A unidirectional or approximately unidirectional flow of electromagnetic radiation or of particles.

BECQUEREL: The SI unit of activity equal to a nuclear disintegration rate of 1 disintegration per second.

BETA PARTICLE: A charged particle emitted from the nucleus of an atom, with a mass and charge equal in magnitude to that of an electron.

BIOASSAY: An evaluation of the amount of radioactivity taken into the body.

BREMSSTRAHLUNG: Secondary photon radiation produced by the deceleration of charged particles passing through matter.

BYPRODUCT MATERIAL: Any material (except special nuclear material) made radioactive by either exposure to radiation, or the process of producing or using special nuclear material.

CALIBRATION: The determination of a measuring instrument's variation from the standard, to ascertain necessary correction factors.

CATHODE: A negative electrode. The electrode to which the positive charged ions are attracted.

CELL, BIOLOGICAL: The fundamental unit of structure and function in organisms.

CHARACTERISTIC RADIATION: Radiation originating from an atom resulting from removal of an electron or excitation of the nucleus. The wavelength of the emitted radiation is specific, depending only on the nuclide and the particular energy levels involved.

CHRONIC EXPOSURE: Radiation exposure occurring over a long but not necessarily continuous period of time.

COLLECTIVE DOSE EQUIVALENT: The sum of dose equivalents received by a given population or group of workers, expressed in units of person-rem.

COLLISION: An encounter between two subatomic particles that changes the initial momentum and energy conditions. The products of the collision need not be the same as the initial system.

COMPTON EFFECT: An attenuation process observed for X or gamma radiation in which the incident photon interacts with an orbital electron of an atom to produce a recoil electron and the scattered photon with an energy less than that of the incident photon.

CONDENSER R-METER: An instrument consisting of an air-wall ionization chamber together with the auxiliary equipment for charging and measuring voltage. It is used as an integrating instrument for measuring the exposure of X or gamma radiation in Roentgens (R).

CONTAMINATION, RADIOACTIVE: The deposition of radioactive material in any place where it is not desired, and particularly in any place where its presence may be harmful.

CONDENSER R-METER: An instrument consisting of an air-wall ionization chamber together with auxiliary equipment for charging and measuring its voltage. It is used as an integrating instrument for measuring the exposure of x or gamma radiation in roentgens (R).

CONTAMINATION, RADIOACTIVE: The deposition of radioactive material in any place where it is not desired, and particularly in any place where its presence might be harmful.

CRITICAL ORGAN: The organ of the body receiving a specified radioisotope that results in the greatest physiological damage to the body. For exposure to ionizing radiation from external sources, the critical organs are the skin, blood-forming organs, gonads, and eyes.

CROSS-CONTAMINATION: Contamination not from an original source, but acquired from another contaminated object.

CUMULATIVE DOSE: The total dose resulting from repeated exposure over some period of time.

CURIE: The unit of activity (abbreviated Ci). One curie equals exactly 3.7 X 10 (10) nuclear disintegrations per second.

DAUGHTER: Synonym for radioactive decay product.

DECAY CONSTANT: The fraction of the number of atoms of a radioactive nuclide that decay per unit time.

DECAY, RADIOACTIVE: The disintegration of the nucleus of an unstable nuclide by the spontaneous emission of charged particles or electromagnetic waves.

DECONTAMINATION: The reduction or the removal of radioactive contamination from any given surface.

DETECTOR, INTEGRATING: A detector that measures the total accumulated radiation quantity (such as exposure or dose) rather than the rate of the accumulation of the radiation. Devices that accumulate and hold charges (e.g. electrometers) and that indicate measures proportional to the total dose are this type. Examples of integrating detectors are electrometers, film badges, pocket dosimeters, and neutron activation detectors.

DETECTOR, RADIATION: Any device for converting radiant energy to a form more suitable for observation. An instrument used to determine the presence, and sometimes the amount, of radiation.

DETECTOR, SCINTILLATION: A radiation detector whose response is a light signal generated by the incident radiation and a scintillating medium. The light signal is transformed into an electronic signal through an adjacent, optically coupled, photo-sensitive device.

DETECTOR, SOLID STATE: A detector that uses a semiconductor such as selenium or germanium that responds to radiation with an electronically measurable pulse.

DETECTOR, TRACK ETCH: A device that records the paths of heavy charged particles in a transparent solid. The tracks may be directly visible, or may be enhanced by etching with an appropriate reagent (such as potassium hydroxide for etching cellulose acetate).

DISINTEGRATION, NUCLEAR: A spontaneous nuclear transformation (radioactivity) characterized by the emission of energy and/or mass from the nucleus.

DOSE: A term denoting the quantity of radiation energy absorbed. The term must be qualified. If unqualified, it refers to absorbed dose.

DOSE, ABSORBED: The amount of energy deposited in matter per unit mass of material by ionizing radiation. The common unit of absorbed dose is the rad, which is equal to 100 ergs of absorbed energy per gram of material (or 0.01 J/Kg). The SI unit of absorbed dose is the gray, which is equal to 1 J/Kg of material.

DOSE, WHOLE-BODY: The average uniform absorbed dose or dose equivalent received by a person whose whole body is exposed to ionizing radiation from a source.

DOSE, EQUIVALENT: The product of the absorbed dose, quality factor, and other modifying factors necessary to evaluate the effects of irradiation received by exposed persons. this unit of measure takes into account the particular characteristics of the exposure. The common unit of dose equivalent is the rem. The SI unit is the sievert. Absorbed doses of different types of radiation are not additive, but dose equivalents are, because they express on a common scale the amount of damage incurred.

DOSIMETER: An instrument to detect and measure accumulated radiation exposure. In common usage, a pencil sized ionization chamber with a self-reading electrometer, used for personnel monitoring.

DOSIMETER, FILM: An integrating detector that uses photographic film and density measuring instruments to determine the absorbed dose.

DOSIMETER, PERSONNEL: A dosimeter of small size carried by a person to determine the exposure, absorbed dose, and/or dose equivalent received during the wearing period.

DOSIMETER, POCKET: An ion chamber type dosimeter the shape and size of a pencil with a clip, to be worn in the pocket like a fountain pen.

DOSIMETER, THERMOLUMINESCENT: An integrating detector that utilizes a phosphor sensitive to ionizing radiation. The phosphor stores the energy of the ionizing radiation within itself and releases it as low-energy photons (light) when heated. The total amount of light emitted is proportional to the total absorbed dose.

EFFICIENCY, COUNTING: A measure of the probability that a count will be recorded when radiation is incident on the detector. Uses of this term vary considerably, so it is well to ascertain which factors (window transmission, sensitive volume, energy dependence, etc.) are included in a given case.

ELASTIC COLLISION: A collision in which there is no change either in the internal energy of each participating system or in the sum of their kinetic energies.

ELECTRON: A stable elementary particle that has an electric charge equal to (+/-) 1.60210 X 10-19 coulomb and a rest mass equal to 9.81091 X 10-30 Kg.

ELECTRON VOLT: A unit of energy equivalent to the energy gained by an electron in passing through a potential difference of 1 volt.Larger multiple units of the electron volt are frequently used: KeV, MeV. 1 eV = 1.6 X 10-12 ergs.

EMULSION, NUCLEAR: A photographic emulsion specially designed to permit observation of the individual tracks of ionizing radiation.

ENERGY DEPENDENCE: The characteristic response of a radiation detector to a given range of radiation energies or wavelengths, compared with the response of a standard free-air chamber.

ENRICHED MATERIAL: (1) Material in which the relative amount of one or more isotopes of a constituent has been increased.

(2) Uranium in which the abundance of the U-235 isotope is increased above natural levels.

EXCITED STATE: An unstable condition of the nucleus of a atom after the entrance of a nuclear particle or gamma ray photon.

EXPOSURE: (1) The incidence of radiation upon inanimate or living matter by intent or accident.

(2) For X or gamma radiation, the sum of the electrical charges of all ions of one sign produced in air when all electrons liberated by photons in a suitable small volume of air are completely stopped in air, divided by the mass of air in the volume.

The unit of exposure is the roentgen (R).

EXPOSURE RATE: (1) The exposure divided by the time over which it was accumulated.

(2) The increment of exposure during a suitably small interval of time, divided by that interval of time.

The typical unit for exposure rate is roentgens per hour (R/hr).

EXTERNAL RADIATION: Radiation from a source outside of the body.

FINGER DOSIMETER: A dosimeter in the form of a ring to be worn by personnel to determine radiation doses to the hands.

FISSILE: A nuclide capable of undergoing fission by interaction with thermal neutrons.

FISSILE MATERIAL: Plutonium-238, 239, 241, uranium-233, 235, or any material containing any of the foregoing [49 CFR 173.389(a) and 173.398(a)].

FISSION, NUCLEAR: A nuclear transformation characterized by splitting of a nucleus into at least two other nuclei and the release of a relatively large amount of energy.

FISSIONABLE: Pertaining to a nuclide that is capable of undergoing fission by any process.

FISSION PRODUCTS: Elements or compounds resulting from fission.

FLUORESCENCE: The emission of radiation of particular wavelengths by a substance as a result of the absorption of radiation of shorter wavelengths. This emission occurs essentially only during irradiation.

GAS AMPLIFICATION: As applied to gas-ionization instruments for detecting radiation, the ration of the charge collected to the charge produced by the initial ionizing event.

GEIGER-MUELLER COUNTER: A highly sensitive, gas-filled radiation measuring device. It operates at voltages high enough to produce avalanche ionization.

GEOMETRY, GOOD: In nuclear physics measurements, an arrangement of source and detecting instrument that introduces little error when a finite source size and finite detector aperture are used.

GEOMETRY, POOR: In a nuclear experiment, an arrangement in which the angular aperture between the source and the detector is large, introducing a comparatively large uncertainty for which a correction would be necessary.

GEOMETRY, RADIATION: A nuclear physics term referring to the physical relationship and symmetry of the parts of a radiation detection instrument. Counting efficiency is closely related to geometry.

GLOW CURVE: In thermoluminescent dosimetry, a graph of the released luminescence photon fluence as a function of temperature or time of heating.

GLOW PEAK: In thermoluminescent dosimetry, the time or temperature during the heating of a thermoluminescent phosphor at which the release rate of the luminescent photons is at its maximum.

GRAY: The SI unit for absorbed dose, equal to the absorbed energy from ionizing radiation of 1 joule/kg, and equal to 100 rads.

GROUND STATE: The state of a nucleus, atom, or molecule at its lowest energy. All other states are "excited"

HALF-LIFE, BIOLOGICAL: The time required for the body to eliminate one half of an administered dosage of any substance by process of elimination.

HALF-LIFE, EFFECTIVE: The time required for a radioactive element in the body to be diminished by one half as a result of the combined biological elimination and radioactive decay.

HALF-LIFE, RADIOACTIVE: The time required for a radioactive substance to lose one half of its activity due to radioactive decay. Each radionuclide has a specific half-life.

HALF-VALUE LAYER (HVL): The thickness of a specified substance that, when introduced into the path of a given beam of radiation, reduces the exposure rate by one half.

HEALTH PHYSICS: A science and profession devoted to protecting man and environment against unnecessary radiation exposure.

INDUCED RADIOACTIVITY: Radioactivity produced in a substance after bombardment with neutrons or other particles.

INELASTIC COLLISION: A collision in which there are changes both in the internal energy of one or more of the colliding systems and in the sums of the kinetic energies of translation before and after the collision.

INTENSITY: The amount of energy per unit time passing through a unit area perpendicular to the line of propagation at the point in question.

INTENSITY, SOURCE: A general term for the magnitude of the source emission rate. Source intensity is usually expressed in units of curies or bequerels.

INTERNAL RADIATION: Radiation from a source within the body as a result of deposition of radionuclides in body tissue.

IN-VIVO COUNTING: Measurements of internal radiation made at the surface of the body and based on the fact that radioisotopes emit radiation that can traverse the tissues and be measured outside the subject. In-vivo counting is synonymous with whole-body counting.

ION: An atomic particle or atom bearing an electric charge, either positive or negative.

IONIZATION: The process by which a neutral atom or molecule acquires a positive or negative charge.

IONIZATION CHAMBER: An instrument designed to measure a quantity of ionizing radiation in terms of the charge of electricity associated with ions produced within a defined volume.

ION PAIR: Two particles of opposite charge, usually referring to the electron and the positive atomic or molecular residue resulting from interaction with ionizing radiation.

ISOMERS: Nuclides with the same number of neutrons and protons but capable of existing, for a measurable period of time, in different quantum states with different energies and radioactive properties.

ISOTOPES: Nuclides that have the same number of protons, hence the same atomic number, but differ in neutron number and therefore differ in atomic mass.

JOULE: The unit for work and energy, equal to 10-7 ergs.

LATENT PERIOD: The interval of seeming inactivity between the time of irradiation and the appearance of an effect.

LICENSE, SPECIFIC: A document issued by NRC under 10 CFR that gives the bearer the right to procure, receive, store, transfer, use, export, and import specified radioactive items under specific terms.

LICENSE-EXEMPT MATERIAL: Radioactive material not subject to NRC or exempt from NRC licensing under 10 CFR.

LICENSED MATERIAL: Source, special nuclear, or byproduct material received, stored, possessed, used, or transferred under a general or specific license issued by the NRC or an Agreement State.

LINEAR ENERGY TRANSFER: The linear rate of loss of energy per unit distance transited by an ionizing particle moving through a medium.

MAN-REM: A unit of collective dose equivalent. Man-rem is the product of the population times their average dose equivalent.

MAXIMUM CREDIBLE ACCIDENT: The worst accident in a reactor or nuclear energy installation that, by agreement, need be taken into account in devising protective measures.

MONITORING: Periodic or continuous determination of the amount of ionizing radiation or radioactive contamination present in an occupied region.

MONTE CARLO METHOD: A method of permitting the computer solution of physics problems, such as those of neutron transport, by determining the history of a large number of elementary events by the application of the mathematical theory of random variables.

NEUTRINO: A neutral particle of very small rest mass originally postulated to account for the continuous distribution of energy among particles in the beta-decay process.

NEUTRON: An elementary particle with neutral charge and a mass of 1.008 mass units, and is found in the nucleus of the atom.

NUCLEON: The common name for a constituent particle of the nucleus, usually applied to protons and neutrons.

NUCLEUS: That part of the atom in which the total positive charge and most of the mass are concentrated.

NUCLIDE: A species of atom characterized by the constitution of its nucleus. To be a nuclide, the atom must exist for a measurable period of time. Thus nuclear isomers are considered separate nuclides.

PAIR PRODUCTION: An absorption process for x or gamma radiation in which the photon is annihilated in the vicinity of a nucleus of an atom with the production of an electron and positron. Minimum energy for this reaction to occur is 1.022 MeV.

PARENT: A radionuclide which upon disintegration, yields a specified nuclide, either directly or as a later member of a radioactive decay series.

PERSONNEL MONITOR: An instrument that measures a radiation quantity proportional to dose equivalent, for use by an individual working in a radiation area.

PHANTOM: A volume of material approximating as closely as possible the density and effective atomic number of body tissue. Ideally, a phantom should absorb radiation in the same way tissue does. Radiation dose measurements made with a phantom provide a means of determining the radiation dose within the body or tissue under similar exposure conditions.

PHOSPHORESCENCE: The emission of radiation by a substance as a result of the previous absorption of radiation of shorter wavelength. In contrast to fluorescent emissions, phosphorescent emissions may continue for a considerable time after cessation of the existing irradiation.

PHOTOELECTRIC EFFECT: The process by which a photon ejects an electron from an atom. All energy of the photon is absorbed in ejecting the electron and imparting kinetic energy to it.

PHOTON: A quantity of electromagnetic energy (E) whose value in joules is the product of its frequency (v) in hertz and Planck's constant (h). The equation is $E=hv$.

PIG: A container, usually made of lead, used to ship or store radioactive materials.

PRIMARY IONIZATION: (1) In collision theory: the ionization produced by primary particles, as contrasted with total ionization, which includes secondary ionization.

(2) In counter theory: the total ionization produced by incident radiation without gas amplification.

PROPORTIONAL COUNTER: A gas filled detector that operates in that range of applied voltage in which gas amplification occurs, such that the total charge collected is proportional to the charge liberated by the original ionizing event.

PROTECTIVE CLOTHING: The clothing worn by radiation workers to prevent radioactive contamination of the body or personal clothing.

PROTECTIVE EQUIPMENT: Safety devices such as goggles or clothing used to do a job safely.

PROTON: An elementary nuclear particle with a positive electric charge equal numerically to the charge of the electron and a mass of 1.007277 mass units.

QUALITY FACTOR (Q): The factor dependent on linear energy transfer by which absorbed doses are multiplied to obtain a quantity that expresses the effect of the absorbed dose on a common scale for all ionizing radiation.

QUENCHING: The process of inhibiting continuous or multiple discharge in a counter tube that uses gas amplification.

RAD: The unit of absorbed dose equal to 0.01 J/kg in any medium.

RADIATION: Energy travelling through space in the form of electromagnetic waves or energetic particles.

RADIATION AREA: Any accessible area where a major portion of the body can receive an exposure of 5 mrem in any one hour, or 100 mrem in any five consecutive days.

RADIATION, PRIMARY: Radiation emitted by the primary nuclear reaction / transformation (as opposed to the subsequent atomic or nuclear interactions as a result of the primary radiation)

RADIATION, SCATTERED: Radiation reaching a given location after having undergone at least one scattering.

RADIATION, SECONDARY: Radiation emitted by some nuclear or atomic process as a result of previous nuclear or atomic interactions by the primary radiation source.

RADIOACTIVE MATERIAL: Any material which spontaneously emits ionizing radiation, or any item contaminated with material which emits ionizing radiation.

RADIOACTIVE WASTE: Waste materials that include the following:

a. property contaminated to the extent that economical decontamination is not feasible.
b. surplus radioactive material whose sale, transfer, or donation is prohibited.
c. surplus radioactive material that it is determined to be unwanted after being advertised as surplus.
d. waste that is radioactive due to production, possession, or use of radioactive material.

RADIOACTIVITY: A natural and spontaneous process by which the unstable atoms of an element emit or radiate excess energy from their nuclei as particles or photons and thus change (decay) to atoms of a different element or to a lower state of the same element.

RADIOBIOLOGY: The branch of biology that deals with the effects of ionizing radiation on biological systems.

RADIOCHEMISTRY: The aspects of chemistry connected with radionuclides and their properties, with the behavior of minute quantities of radioactive materials, and with the use of radionuclides in the study of chemical processes.

RADIOSENSITIVITY: The relative susceptibility of cells, tissues, organs, organisms, or any living substance to the injurious effects of radiation.

REM: A special unit of dose equivalent. The dose equivalent in rems is numerically equal to the absorbed dose in rads times the quality factor and any other necessary modifying factors.

ROENTGEN: A unit of exposure equal to the charge liberated by x or gamma radiation of 2.58 X 10-4 coulombs per kilogram of dry air. It is equal to the absorbed energy in air of 87.7 ergs/g or in tissue of 96.5 ergs/g.

SATURATION, ION CHAMBER: The condition in an ionization chamber in which the applied voltage is sufficient to collect all of the primary ion pairs, but insufficient to cause secondary ionizations.

SCATTERING: Change of direction of subatomic particles or photons as a result of interaction or collision.

SEALED SOURCE: Any radioactive material that is permanently bonded or fixed in a capsule or matrix designed to prevent the release or dispersal of the material under the most severe conditions encountered in normal use or handling.

SECONDARY IONIZATION: (1) In collision theory: Any ionizing particle that results from the interaction of primary radiation as it passes through a medium.

(2) In detector theory: Any ionizing radiation that is a result of the gas amplification of the ionizations caused by the incident ionizing radiation.

SELF-ABSORPTION: The absorption of radiation (emitted by radioactive atoms) by the material in which the atoms are located; in particular, the absorption of radiation within a sample being assayed.

SERIES, RADIOACTIVE: A succession of nuclides, each of which transforms by radioactive disintegration into the next until a stable nuclide results. The first member is called the "parent," the intermediate members are called "daughters," and the final stable member is called the "end product".

SHIELD: A body of material used to reduce the intensity of ionizing radiation at a given point by placing the material between the source of radiation and the respective point.

SIEVERT: The SI unit for dose equivalent equal to the absorbed dose in grays multiplied by the quality factor and other necessary modifying factors.

SOURCE GEOMETRY: The shape, size, and configuration of a radiation source, taken as a whole.

SOURCE MATERIAL: Uranium or thorium or a combination of both, in any physical form, or ores that contain one-twentieth or more by weight of uranium or thorium or any combination. Source material does not include special nuclear material.

SPECIAL NUCLEAR MATERIAL: Plutonium or uranium enriched in the isotope 233 or 235, and any other material the NRC determines to be special nuclear material.

SPECIFIC ACTIVITY: The total activity of a given nuclide per gram of a compound, element, or radioactive nuclide.

SPECIFIC IONIZATION: The number of ion pairs produced per unit path length of ionizing radiation in a medium.

SPECTROMETER: A device or instrument, usually electronic, capable of measuring the energy distribution of nuclear transformations.

STABLE ISOTOPE: A nonradioactive isotope of an element.

THIMBLE IONIZATION CHAMBER: A small cylindrical or spherical ionization chamber, usually with walls of tissue equivalent material.

THRESHOLD DOSE: The minimum absorbed dose that produces a detectable effect.

TISSUE DOSE: The absorbed dose received by tissue in a region of interest, expressed in rads.

TISSUE EQUIV. ION CHAMBER: An ionization chamber in which the materials of the walls, electrodes, and gas are so selected as to produce a response to radiation similar to the response of tissue.

TISSUE EQUIV. MATERIAL: A liquid or solid whose absorbing and scattering properties for a given radiation simulate as closely as possible those of a given biological material, such as fat, bone, or muscle.

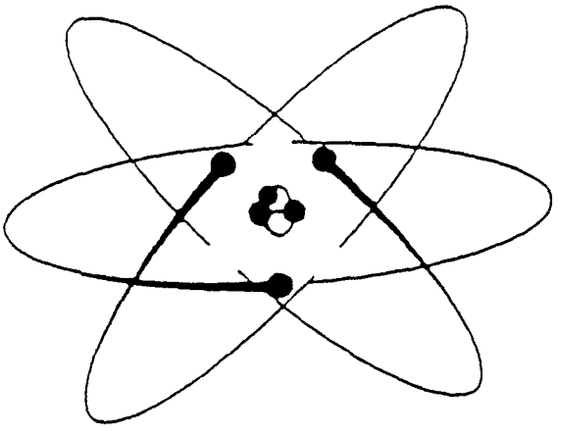
TRACK: The visual manifestation of the path of an ionizing particle in a chamber or photographic emulsion.

VOLUME, SENSITIVE: The portion of a detector that responds to a specific radiation.

X-RAYS: Penetrating electromagnetic radiation whose wavelengths are shorter than those of visible light and originate external to the nucleus. These rays are sometimes called roentgen rays after their discoverer, W.K. Roentgen.

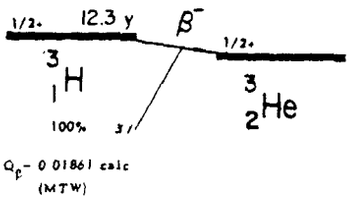
RADIOLOGICAL HEALTH

HANDBOOK

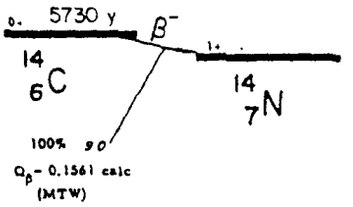


REVISED EDITION
JANUARY 1970

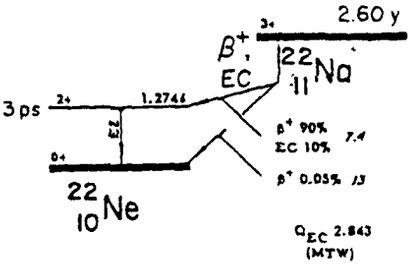
U.S. DEPARTMENT OF
HEALTH, EDUCATION, AND WELFARE
Public Health Service



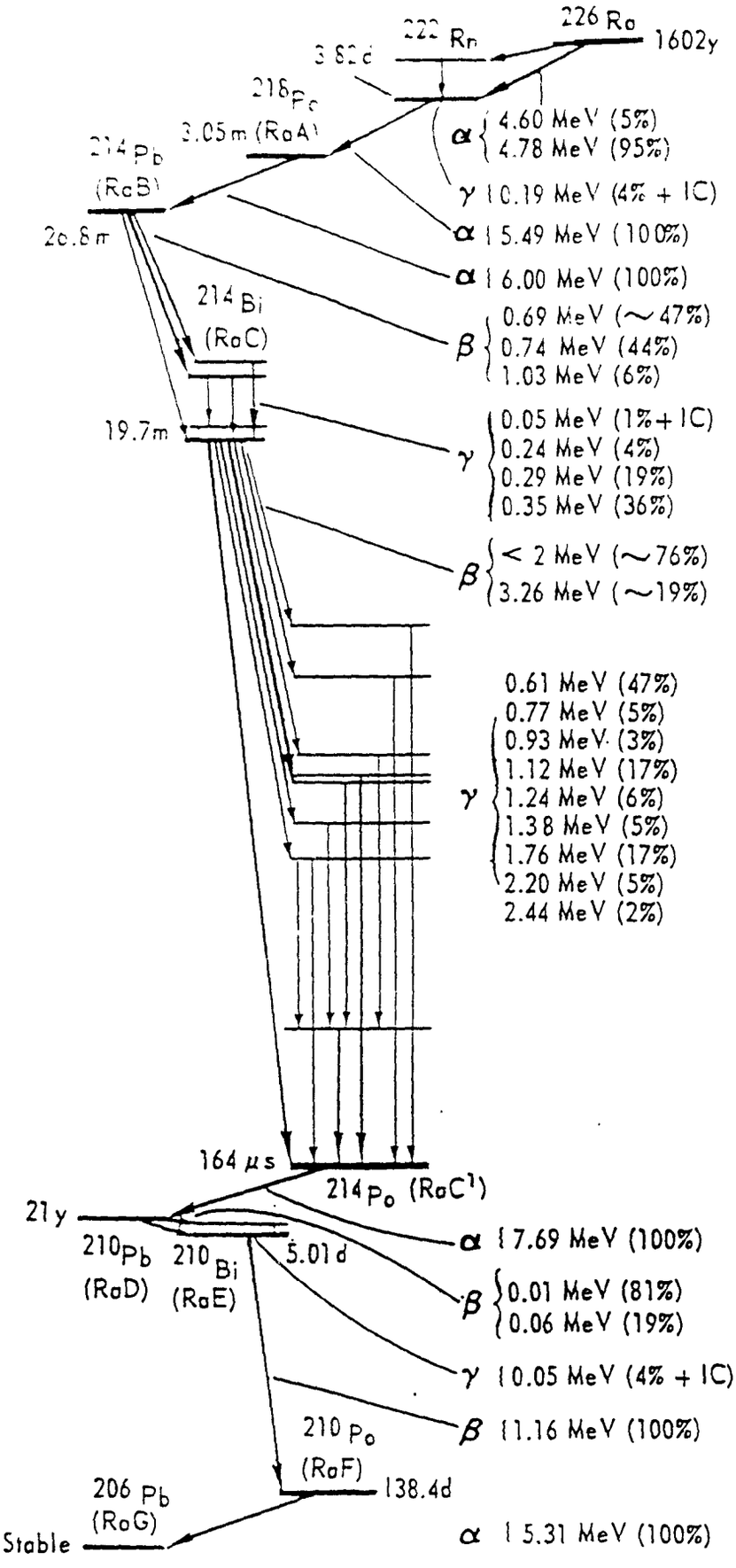
^{3}H (12.3 y):
I: 1/2 atomic spect, μ: +2.97885 NMR (Lindgl64)
β^-: 0.0186 mag spect (PortP59)
others (LangeL52, CurrS49, HamiD53a, HannG49)

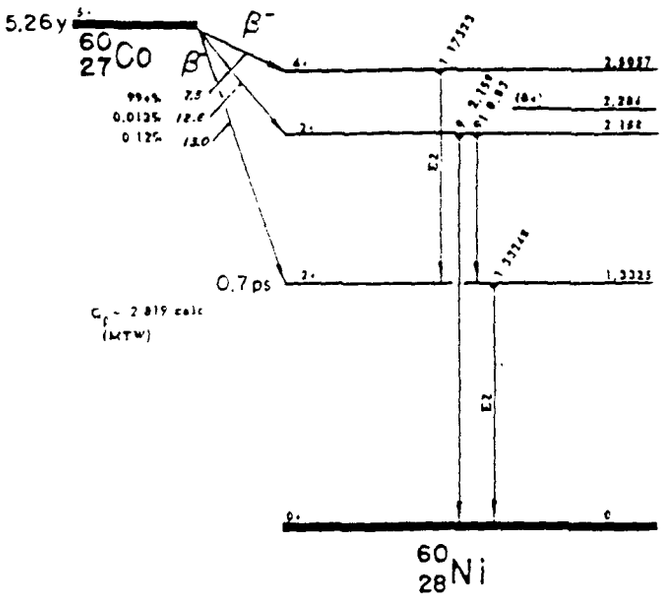


^{14}C (5730 y):
I: 0 atomic spect, microwave (Lindgl64)
β^-: 0.155 mag spect (FelL49a, WarsS50, ForH54); ion ch (AngJ49) 0.156 (CookCS48d); 0.154 (LevyP47); 0.159 (PohA55); mag spect others (MolA54)
γ: no conv, mag spect conv (LevyP47); no γ (RubeS41)



^{22}Na (2.60 y):
I: 3, μ: +1.746 atomic beam (Lindgl64)
β^+: β_2 0.545 (DaniH58a); 0.543 (HamiJ58a); 0.542 (MackP50a); 0.540 (WonC54); mag spect
β_1 1.83 (I 0.06), β_2 0.540 (I 100) mag spect (WriB53)
others (GooW46, MorgK49, LeuH61, BranW64a, CharP65)
γ: γ_1 1.2746 semicond spect (RobiR65)
γ_1 (e/γ 6.7 x 10^{-6}) (NakY63, LeamR54)
others (MarlK65, SinP59, AlbuD49, AjzF55, GooW46)
βγ(θ): (GrabZ65, DaniH60a, SubB61b, StevD51, MullH65)
βγpolariz(θ): (SteiR59, BloS42, AppH59, BhaS65, SchoH57)


226 Ra
1602y
222 Rn
3.82d
218 Po
3.05m (RaA)
214 Pb
(RaB)
26.8m
214 Bi
(RaC)
19.7m
164 μs
214 Po (RaC')
21y
210 Pb
(RaD)
210 Bi
(RaE)
5.01d
210 Po
(RaF)
138.4d
206 Pb
(RaG)
Stable
α 4.60 MeV (5%)
4.78 MeV (95%)
γ 0.19 MeV (4% + IC)
α 5.49 MeV (100%)
α 6.00 MeV (100%)
β 0.69 MeV (~47%)
0.74 MeV (44%)
1.03 MeV (6%)
γ 0.05 MeV (1% + IC)
0.24 MeV (4%)
0.29 MeV (19%)
0.35 MeV (36%)
β < 2 MeV (~76%)
3.26 MeV (~19%)
γ 0.61 MeV (47%)
0.77 MeV (5%)
0.93 MeV (3%)
1.12 MeV (17%)
1.24 MeV (6%)
1.38 MeV (5%)
1.76 MeV (17%)
2.20 MeV (5%)
2.44 MeV (2%)
α 7.69 MeV (100%)
β 0.01 MeV (81%)
0.06 MeV (19%)
γ 0.05 MeV (4% + IC)
β 1.16 MeV (100%)
α 5.31 MeV (100%)



Q_β - 2.819 calc (MTW)

^{60}Co (5.26 y):

I: δ, μ: ±3.75 ESR (Lindg164)

β⁻: β_2 0.319 (KamaK58); 0.309 (BolG54); 0.318 (WagM50); 0.306 (FanC52), 0.314 (KelG54); mag spect
β_1 1.48 (0.12%) (CamD61); 1.48 (0.010%) (WolfsJ56); 1.48 (0.15%) (KelG54); mag spect
others (DeuM45, BonhF59, YosY53, MillA47)

γ: γ_1 1.17323, γ_2 1.33248 mag spect, mag spect conv (MurG65)
γ_1 (ε_K/γ 0.000165) mag spect, mag spect conv (FreyW62)
γ_1 (ε_K/γ 0.000173), γ_2 (ε_K/γ 0.000129) mag spect conv (WagM50, WagM50a)
γ_1 (ε_K/γ 0.000150, K/LaMa+... 9.1), γ_2 (ε_K/γ 0.000116, K/LaMa+... 9.1) mag spect conv (KamaK58)
γ_1 (ε_K/γ 0.000173), γ_2 (ε_K/γ 0.000124) mag spect conv (FanC52)
γ_1 + γ_2 (ε^2/γ 0.004) $\gamma^a\gamma^a$ coinc (LanghH61a)
γ_2 2.158 (γ 0.0012%) mag spect (WolfsJ56)
2.5 (=0.00004%) D-γ-n (MoriH59)
others (AveM58, LindsG53, HornW49, KlemE53, AepH52a, ChatS53, LawJS53, LamH54, WieT54, ColeS55, DzhB51, SiegK50a)

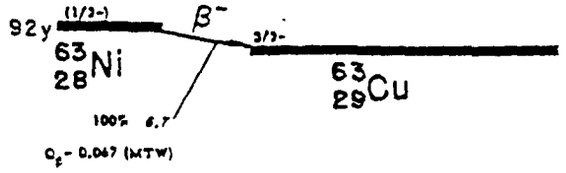
γγ(θ): (GargJ60, BradE50, KloR52, ChatS53, KlemE53, LawJS53, WieT54)

γγpolariz(θ): (MetF50, WilliAH50, KloR52)

βγ(θ): (DanlH60a, LobV62a, GarwR49, AlleR50, BeysJ50a, NoveT50, SinW51)

βγpolariz(θ): (JagP60, Blo562, AppH59, LobV59, SteiR59, PagL58, BhaS65, DebP57, LunA57, SchoH57)

nucl align: (SamB61, LeviM60, DanlJ61, GracM59, KogA58, BloC52, DanlJ52)

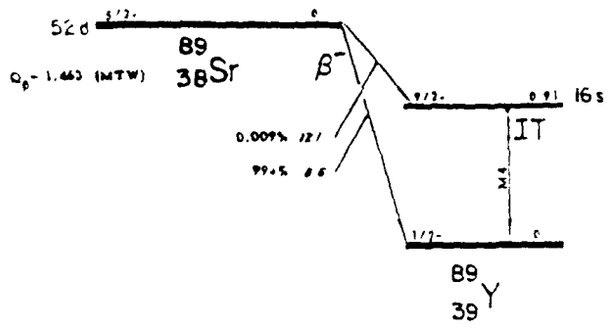


Q_β - 0.067 (MTW)

^{63}Ni (92 y):

β⁻: 0.067 ion ch (PreiI57, BrosA51), scint spect (HorrD62)
0.062 electrostatic analyzer (KohY53a)
0.073 abs, ion ch (MEwaJ59)
0.063 ion ch (WilsH49)

γ: no γ (WilsH49, BrosA51)



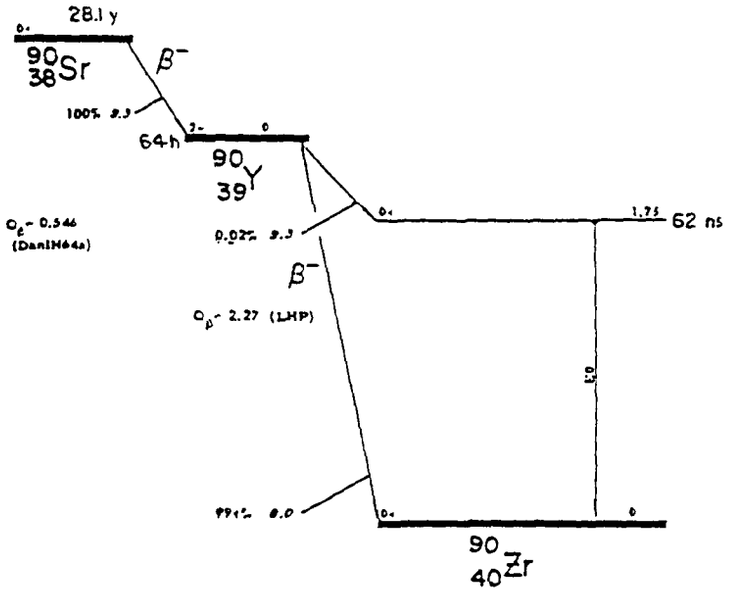
^{89}Sr (52 d).

β^-: 1.443 (LangeL49), 1.462 (BisA55d), mag spect
others (SlaL49a, RalW47)

γ: no γ (NoveT51, StewD37, StewD39)
0.913 (with ^{89m}Y) (HerrmG56, LyoW55b, SatA62)

^{89m}Y (16 s).

γ: γ_1 0.908 scint spect (VPatD64); 0.913 scint spect (SatA62); mag spect conv (ShoF51); 0.915 scint spect (MonaS61, HamIJ60)
γ_1 (e/γ 0.01) mag spect conv, scint spect (ShuK51, GoldhM51)
γ_1 (K/L+M+... 7) mag spect conv (BandW52)
others (HydE51)



^{90}Sr (28.1 y):

β^-: 0.546 mag spect (DanIH64a)
others (BerlE56, NaiT56, LagL50, MeyW48a, BradC49)

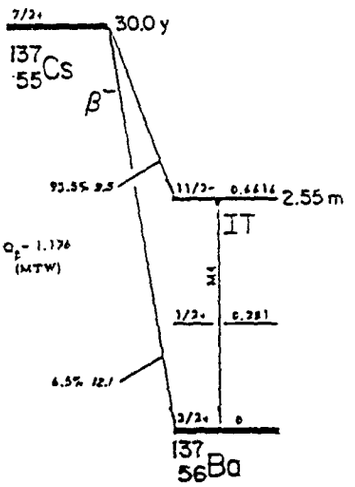
γ: no γ abs (GleL51c)

^{90}Y (64 h):

μ: 2, μ: −0.163 atomic beam (Lindg164)

β^-: 2.268 (AndrS64, JohnO58), 2.271 (NicR61), 2.284 (DanIH64a), 2.273 (LangeL64a) mag spect
others (YuaT57b, BerlE56, LangeL49, MajJ52, JohnO55, BradC49, LasL50, NaiT56)

γ: γ_1 1.734 (ϵ^- 0.016%, $\epsilon^-/\gamma > 30$, ϵ^K/ϵ^- 3) mag spect conv, scint spect (YuaT56a, YuaT57a)
γ_1 1.75 (ϵ^- 0.5%, ϵ/γ very large) mag spect conv (JohnO55)
γ_1 ($I_{\gamma\gamma}/I_{\epsilon^-}$ <0.0006) mag spect conv (RydH63b)
others (GoroS61a, GoroS61f, LanghH61, AlbuD58, RydH61, DeuM57, GreeJ56)



137 Cs (30.0 y):

I: 7/2, μ +2.8382 atomic beam; g: +0.050 opt double res (Lun6g164)

β^-: β_1 1.176 (6.5%), β_2 0.514 (93.5%) mag spect (DanH62b)

β_1 1.176 (7.6%), β_2 0.514 (92.4%) mag spect (YosY58)

others (KatoT57, AgnH58, OlsJ54, LangeL51, AzuT54, WapA54a, BroyC59, PeaC49, OsoJ49, RiccR57, DrabC55, MacqP54, BesH63a, CharP65)

137m Ba (2.55 m):

γ: γ_1 0.6616 (K/L_I/L_{II}/L_{III} 1000/151/22/19) mag spect conv (GsiJ62)

γ_1 (ϵ_K/γ 0.093, K/L+M+... 4.5) mag spect conv (DanH62b)

γ_1 (ϵ_K/γ 0.095) mag spect, mag spect conv (HulS61)

γ_1 (K/L/M 56/10/2.2) mag spect conv (ChuY64a)

γ_1 (K/L/M 566/100/26.0) mag spect conv (YosY58)

γ_1 (γ 86%, ε/γ 0.1100) semicond spect (MerJ65)

γ_1 ($I_{\gamma\gamma}/I_\gamma$ 6 × 10^{-6}) (BeuW60)

others (MullD52, LindsG53a, GravG52, LangeL50b, DVriC60b, HulS59, SubB61c, KurcT63, WapA54a, WagM51, MGowF57a, KatoT57, MaeR53, AzuT54, BendW52, KruP52, MilA49, OsoJ49, TownJ48, RiccR57, VerhJ54, AntoL56a, AntoL56, DolV53, BhaS54, DrabG55, BesH63a, RaoMR65)

Isotope Z A	Half-life	Type of decay (%, % abundance, Mass excess (Δ=M−A), MeV (C^{12}=0); Thermal neutron cross section (σ), barns	Class, identification Genetic relationships	Major radiations approximate energies (MeV) and intensities	Principal means of production
$_{26}Fe^{61}$	6.0 m (StraJ66, RiccE57) others (RiccE55)	%: β^- (RiccE55, RiccE57) Δ: −59 (MTW)	A: chem, genet (RiccE55, RiccE57, StraJ66) parent Co^{61} (RiccE55, RiccE57, StraJ66)	β^-: 2.8 max γ: 0.13 (I 11), 0.30 (I 48), 1.03 (I 98), 1.20 (I 100) daughter radiations from Co^{61}	Ni^{64}(n, α) (RiccE57) Ni^{64}(d, αp) (RiccE57)
$_{27}Co^{54}$	0.194 s (FreeJ65) others (MartiW52, LeiO56, TyrH54)	%: β^+ (MartiW52) Δ: −47.99 (MTW)	C: excit (MartiW52, FreeJ65)	β^+: (7.23 max) γ: [0.511 (200%, γ^a)]	Fe^{54}(p, n) (FreeJ65, MartiW52)
Co^{54}	1.5 m (SutD59)	%: β^+ (SutD59)	E: excit (SutD59, FreeJ65)	β^+: 4.3 max γ: 0.41 (100%), 0.511 (200%, γ^a) 1.14 (100%), 1.41 (100%)	Fe^{54}(p, n) (FreeJ65)
Co^{55}	18.2 h (DarB37) 17.9 h (RudG52) 18.0 h (LivJ41)	%: β^+ 81%, EC 19% (MukA58) β^+ =60%, EC =40% (calc from DeuM49) Δ: −54.01 (MTW)	A: chem (DarB37) chem, cross bomb, genet (LivJ41) parent Fe^{55} (LivJ41)	β^+: 1.50 max γ: Fe X-rays, 0.480 (12%), (511 (160%, γ^a), 0.930 (80%), 1.41 (13%)	Fe^{54}(d, n) (DarB37, LivJ41, DeuM49) Fe^{54}(p, γ) (LivJ41) Fe^{56}(p, 2n) (MukA58)
Co^{56}	77.3 d (WrlH57) 77 d (BurgW56) others (CookCS42, LivJ41)	%: EC 80%, β^+ 20% (CookCS56) Δ: −56.03 (MTW)	A: chem, excit, cross bomb (LivJ41) daughter Ni^{56} (ShelR52, WorW52)	β^+: 1.49 max γ: Fe X-rays, 0.511 (40%, γ^a), 0.847 (100%), 1.04 (15%), 1.24 (66%), 1.76 (15%), 2.02 (11%), 2.60 (17%), 3.26 (13%)	Fe^{56}(p, n) (KieP59, GrabZ60a, SakM54) Mn^{55}(α, 3n) (ChenL52a) daughter Ni^{56} (ShelR52, WorW52) Fe^{56}(d, 2n) (LivJ41, JensA41, PieE42, EllsL43a) Ni^{58}(d, α) (LivJ41, CookCS42, EllsL43a)
Co^{57}	270 d (LivJ41) 267 d (CorkJ55)	%: EC, no β^+, lim 0.002% (CraaB55) Δ: −59.339 (MTW)	A: chem, excit, cross bomb (LivJ41) daughter Ni^{57} (FrieG52)	γ: Fe X-rays, 0.014 (9%), 0.122 (87%), 0.136 (11%), 0.692 (0.14%) e^-: 0.007, 0.013, 0.115, 0.129	Ni^{58}(γ, p); Fe^{56}(d, n) (LivJ38a, PerrC38, BarrG39, LivJ41) Fe^{56}(p, γ) (LivJ41) Mn^{55}(α, 2n) (ChenL52a)
Co^{58}	71.3 d (SchumR56) 71.0 d (CorkJ55) 72 d (LivJ41, HoffD52, PrelI60)	%: EC 85%, β^+ 15% (GooW46, CookCS56) Δ: −59.84 (MTW) σ_c: 2500 (GoldmDT64)	A: chem, excit, cross bomb (LivJ41)	β^+: 0.474 max γ: Fe X-rays, 0.511 (30%, γ^a), 0.810 (99%), 0.865 (1.4%), 1.67 (0.6%)	Mn^{55}(α, n) (LivJ38a, LivJ41)
Co^{58m}	9.2 h (ChrisD50) 9.0 h (PrelI60) 8.8 h (StraK50)	%: IT, no β^+ (StraK50) Δ: −59.81 (LHP, MTW) σ_c: 1.4×10^5 (GoldmDT64)	A: chem, excit (StraK50)	γ: Co X-rays e^-: 0.017, 0.024	Mn^{55}(α, n) (StraK50)
Co^{59}		%: 100 (MilJ41) Δ: −62.233 (MTW) σ_c: 19 (to Co^{60}) 38 (to Co^{60m}) (GoldmDT64)			
Co^{60}	5.263 y (CorkS63) 5.24 y (GelKW57) 5.20 y (LocE56) 5.21 y (KaaJ53a) 5.27 y (TobJ55, TobJ51) others (LocE55, LivJ41, BrewG50, SinW51)	%: β^- (RisJ37) Δ: −61.651 (MTW) σ_c: 6 (GoldmDT64)	A: n-capt (SamM36) chem, excit, cross bomb (LivJ41)	β^-: 1.48 max (0.12%), 0.314 max (99+%) γ: 1.173 (100%), 1.332 (100%)	Co^{59}(n, γ) (RisJ37, LivJ38a, LivJ41, SerL47b, YafL51)
Co^{60m}	10.47 m (BarthR53b) 10.3 m (SchmW63) 10.5 m (PrelI60) 10.7 m (LivJ41)	%: IT 99+%, β^- 0.25% (SchmW63) IT 99+%, β^- 0.28% (DeuM51) Δ: −61.593 (LHP, MTW) σ_c: 100 (GoldmDT64)	A: n-capt (HeyF37a) chem, excit, cross bomb (LivJ41) daughter Fe^{60} (RoyJ57)	β^-: 1.55 max e^-: 0.051, 0.058 γ: Co X-rays, 0.059 (2.1%), 1.33 (0.25%)	Co^{59}(n, γ) (HeyF37a, LivJ38a, LivJ41, SerL47b)

Isotope Z A	Half-life	Type of decay (λ), % abundance, Mass excess (Δ=M−A), MeV (C^{12}=0), Thermal neutron cross section (σ), barns	Class, Identification, Genetic relationships	Major radiations approximate energies (MeV) and intensities	Principal means of production
$_{38}Sr^{86}$		% 9.86 (NierA38b) 9.87 (AldL53) Δ −84.499 (MTW) σ_c 1.3 (to Sr^{87m}) (GolamDT64)			
$_{38}Sr^{87}$		% 7.02 (NierA38b, AldL53) Δ −84.865 (MTW)	daughter Rb^{87} (mass spect) (HahO37, MattaJ37)		
Sr^{87m}	2.83 h (BormM65) 2.80 h (MannL51, HydE51) 2.88 h (GravG52) others (HerrmG56, DubL40)	λ IT 99+%, EC(K) 0.6% (SunA60) Δ −84.477 (LHP, MTW)	A chem, excit (StewD37) chem, excit, cross bomb, genet (DubL40) daughter Y^{87} (DubL39, DubL40, MannL50, MannL51, LundnM50a, HydE51)	γ Sr X-rays, 0.388 (80%) e^- 0.372, 0.386	daughter Y^{87} (DubL39, MannL50, MannL51) Sr^{86}(n, γ) (StewD37, DubL39, RedH40, RedH40a) Rb^{87}(p, n) (DubL39)
$_{38}Sr^{88}$		% 82.56 (NierA38b, AldL53) Δ −87.89 (MTW) σ_c 0.006 (GolamDT64)			
Sr^{89}	52.7 d (FlyK65a) 50.4 d (OsmR59) 53.6 d (SatA62) 50.5 d (HerrmG54, HerrmG55) others (KjeA56, NoveT51, LieC39, StewD39, GoeR49, GrumW46)	λ β^- (StewD37) Δ −86.22 (MTW) σ_c 0.4 (GolamDT64)	A chem, excit (StewD37) chem, mass spect (HaydR48) daughter Rb^{89} (GlasG40, HahO40, HahO40b, HahO43, GrumW46) parent Y^{89m} 0.009% (SatA62); 0.02% (LyoW55b); 0.01% (HerrmG56); <0.0005% (BisA55d)	β^- 1.463 max γ 0.91 (0.009%, with Y^{89m})	Sr^{88}(d, p) (StewD37, StewD39) Sr^{88}(n, γ) (SerL47b, StewD37, StewD39)
Sr^{89m}	10 d (HerrmG54, HerrmG55)		C activity not observed (HerrmG56, SatA62, FleJ62)		
Sr^{90}	27.7 y sp act, mass spect (WileDM55) 28.0 y (FlyK65) 28.4 y (ReeG55) others (AniM58, PowR50)	λ β^- (NotR51) Δ −83.95 (MTW, LHP) σ_c 1 (GolamDT64)	A chem, genet (HahO42) chem, mass spect (HaydR48) daughter Rb^{90} (DilC51, DilC51a, KofO51b) parent Y^{90} (HahO42, HahO43, GrumW46, NotR51) descendant Kr^{90} (DilC51, DilC51a)	β^- 0.546 max γ no γ daughter radiations from Y^{90}	fission (DilC51, DilC51a, KofO51b, GrumW46, GrumW48)
Sr^{91}	9.67 h (AmeD53) 9.7 h (HerrmG54, HerrmG55, FinB51, Vasil58, BakH65) others (HahO43)	λ β^- (GotH41) Δ −83.68 (MTW)	A chem, genet (GotH41) chem, excit (SeeW43b) parent Y^{91m}, parent Y^{91} (GotH41, HahO43, FinB51) daughter 1.2 m Rb^{91}, daughter 14 m Rb^{91} (KofO51b) no 14 m Rb parent of Sr^{91} (WahA62)	β^- 2.67 max γ 0.645 (15%), 0.748 (27%), 0.93 (3%), 1.025 (30%), 1.413 (5%) daughter radiations from Y^{91m}, Y^{91}	fission (GotH41, HahO43, FinB51, KatcS48, FinB51c) Zr^{94}(n, α) (SeeW43b)
Sr^{92}	2.71 h (FritK60) 2.60 h (HerrmG56) 2.7 h (GotH41)	λ β^- (GotH41) Δ −82.9 (MTW)	A chem, genet (GotH41) parent Y^{92} (GotH41, HeaE51b) daughter Rb^{92} (FritK60)	β^- 1.5 max (10%), 0.55 max γ 0.23 (3%), 0.44 (4%), 1.37 (90%) daughter radiations from Y^{92}	fission (HahO40, HahO43, HahO43b, KatcS51a, BradE51, KatcS48)
Sr^{93}	8.3 m (ValliD61) 7.5 m (FritK60) 8.5 m (BakH65) 6 m (KniJD59) 7 m (LieC39)	λ β^- (LieC39) Δ −79.4 (MTW, SteinE65)	A chem (LieC39, HahO43) chem, sep isotopes (BakH65) parent Y^{93} (HahO43, HahO43b, KniJD59) daughter Rb^{93} (FritK60)	β^- 4.8 max ? (weak), 2.9 max γ 0.60, 0.8, 1.2, others between 0.2 and 3.0 daughter radiations from Y^{93}	Zr^{96}(n, α) (ValliD61, BakH65) fission (LieC39, HahO42, HahO43, KniJD59)
Sr^{94}	1.35 m (FritK61) 1.2 m (HevD64) 1.3 m (KniJD59)	λ β^- (HahO43b, HahO43) Δ −78.8 (MTW)	A chem, genet (HahO43b, HahO43) parent Y^{94} (HahO43, HahO43b, KniJD59)	β^- 2.1 max γ 1.42 (100%) daughter radiations from Y^{94}	fission (HahO43, HahO43b, DilC51, KniJD59, FritK61, HevD64)

Isotope Z A	Half-life	Type of decay ($^{A}_{Z}$; % abundance, Mass excess (Δ=M−A) MeV (C^{12}=0), Thermal neutron cross section (σ), barns	Class, Identification, Genetic relationships	Major radiations approximate energies (MeV) and intensities	Principal means of production
$_{43}Tc^{96m}$	52m (MedH50, EasH53)	☢ IT (MedH50) β^+ =0.01% (EasH53) Δ −85.8 (LHP, MTW)	B chem, excit (MedH50) chem, excit, sep isotopes (MedH52)	γ Tc X-rays e^- 0.013, 0.032 daughter radiations from Tc^{96}	Nb^{93}(α, n) (EasH53)
Tc^{97}	2.6 x 10^6 y yield (KatcS56a) others (BoydG54)	☢ EC (BoydG54) Δ −87 (MTW)	A genet (BoydG51a) chem (KatcS56a) [daughter Tc^{97m}] (BoydG51a) daughter Ru^{97} (99+%) (KatcS56a)	γ Mo X-rays	Ru^{96}(n, γ)Ru^{97}(β^-) (KatcS56a) Mo^{97}(d, 2n) (BoydG54)
Tc^{97m}	91 d (BoydG54, HelmhA41a) 90 d (MotE48b, GugP47, CacB37) 87 d (Uni359) 95 d (EdwJ47)	☢ IT (HelmhA41a, EdwJ47) Δ −87 (LHP, MTW)	A chem (PerrC37, CacB37) chem, genet (MotE47) excit, sep isotopes (MotE48b) daughter Ru^{97} (0.04%) (KatcS56a)	γ Tc X-rays e^- 0.075, 0.094	Mo^{96}(d, n) (CacB37, PerrC37, CacB39) Mo^{97}(p, n) (EdwJ47) Mo^{97}(d, 2n) (MotE48b) Ru^{96}(n, γ)Ru^{97}(β^-) (KatcS56a)
Tc^{98}	1.5 x 10^6 y sp act (OKelG56b) others (KatcS55)	☢ β^- (KatcS55) Δ −86.5 (MTW) σ_c 3 (to Tc^{99m}) (GoldmDT64)	A chem, mass spect (BoydG55)	β^- 0.30 max γ 0.66 (100%), 0.76 (100%)	Mo^{98}(p, n) (BoydG55) Ru^{96}(n, γ)Ru^{97}(β^-) Tc^{97}(n, γ) (KatcS55, KatcS56a)
Tc^{99}	2.12 x 10^5 y sp act (FrieS51) 2.15 x 10^5 y sp act (BoydG60)	☢ β^- (LincD51, SchumR51) Δ −87.33 (MTW) σ_c 22 (GoldmDT64)	A chem (LincD46, SchumR46) chem, mass spect (IngM47g) daughter Tc^{99m} (SeaG39, HahO41a) descendant Mo^{99} (MotE47a)	β^- 0.292 max γ no γ	fission (IngM47g, LincD51, SchumR51) Mo^{98}(n, γ)Mo^{99}(β^-) (MotE47a)
Tc^{99m}	6.049 h (GleG64) 6.00 h (ByeD58) others (GleL51d, BalK51, PortR60, CreT65)	☢ IT (SeaG39) Δ −87.18 (LHP, MTW)	A chem, genet (SeaG39) daughter Mo^{99} (SeaG39, SagR40a, MedH49, GleL51d, MihJ51) parent Tc^{99} (SeaG39, HahO41a)	γ Tc X-rays, 0.140 (90%) e^- 0.001, 0.119	daughter Mo^{99} (SeaG39, SagR40a, MedH49, GleL51d, MihJ51)
Tc^{100}	15.8 s (BoydG52a) 17.5 s (HouR52) 17 s (CsiG63)	☢ β^- (HouR52) Δ −85.9 (MTW)	A sep isotopes (HouR52) sep isotopes, n-capt (BoydG52a)	β^- 3.38 max γ 0.540 (strong), 0.60 (strong), 0.71, 0.81, 0.89, 1.01, 1.31, 1.49, 1.8	Tc^{99}(n, γ) (BoydG52a, OKelG58) Mo^{100}(p, n) (HouR52) Rh^{103}(n, α) (CsiG63)
Tc^{101}	14.0 m (OKelG57, MauW41, HahO41b) 14.3 m (WileDR54) 14.5 m (PerlmM48) 16.5 m (MacD48)	☢ β^- (SagR40) Δ −86.32 (MTW)	A chem, genet (SagR40) daughter Mo^{101} (BotW41, HahO41a, HahO41b, MauW41, SagR40)	β^- 1.32 max γ 0.13 (3%, complex), 0.307 (γ 92%), 0.545 (γ 8%)	Mo^{100}(n, γ)Mo^{101}(β^-) (SagR40, SagR40b, MauW41)
Tc^{102}	4.5 m (FleJ54, FleJ57)	☢ β^- (FleJ56a) Δ −85 (MTW)	B chem, genet energy levels (FleJ56a, FleJ57)	β^- 2 max γ 0.47	Ru^{102}(n, p) (FleJ57) fission (FleJ56a)
Tc^{102}	5 s (FleJ54) others (HahO41a)	☢ β^- (HahO41a) Δ −85 (MTW)	C chem, genet (HahO41a, FleJ54) daughter Mo^{102} (HahO41a, HahO41b, FleJ54)	β^- 4.4 max	daughter Mo^{102} (HahO41a, HahO41b, FleJ54)
Tc^{103}	50 s (KiePG3a, VBaeA65) 72 s (FleJ57)	☢ β^- (KiePG3b) Δ −84.9 (MTW)	B excit (FleJ57) chem, genet (KiePG3a) [parent Ru^{103}] (KiePG3a) daughter Mo^{103} (KiePG3a)	β^- 2.2 max γ 0.135 (↑ 17), 0.21 (↑ 10), 0.35	fission (KiePG3a, KiePG3b, VBaeA65) Ru^{104}(n, np) (FleJ57)
Tc^{104}	18 m (FleJ56a, KiePG2)	☢ β^- (FleJ56a, KiePG2) Δ −82.2 (MTW)	B chem (FleJ56a) chem, genet energy levels (KiePG2) daughter Mo^{104} (KiePG2)	β^- [5.8 max] (weak), 4.6 max γ 0.36, 0.53, 0.89, 1.15, 1.25, 1.37, 1.6 (complex), 1.9, 2.2 2.7, 3.2, 3.4, 3.7, 4.0, 4.4, 4.7	fission (FleJ56a, KiePG2) Ru^{104}(n, p) (FleJ57)
Tc^{105}	7.7 m (KiePG2a) 7.8 m (VBaeA65) 10 m genet (FleJ55a, FleJ56a)	☢ β^- (BornH43a) Δ −82.6 (MTW)	B chem, genet (BornH43b) parent Ru^{105}, daughter Mo^{105} (BornH43b, FleJ55a, KiePG2a) ancestor Rh^{105} (KiePG2a)	β^- 3.4 max γ 0.310 daughter radiations from Ru^{105}	fission (BornH43b, FleJ55a, FleJ56a, KiePG2a, VBaeA65)

Isotope Z A	Half-life	Type of decay (☢); % abundance, Mass excess (Δ=M−A), MeV (C^{12}=0); Thermal neutron cross section (σ), barns	Class, Identification, Genetic relationships	Major radiations approximate energies (MeV) and intensities	Principal means of production
$_{55}Cs^{135}$	3.0 x 10^6 y sp act (ZelH49) 2.1 x 10^6 y yield (SuganN49a)	☢ β^- (SuganN49a) Δ −87.8 (MTW) σ_c 8.7 (GoldmDT64)	A chem, genet (SuganN49a) chem, mass spect (IngM49) daughter Xe^{135} (SuganN49a)	β^-: 0.21 max γ: no γ	daughter Xe^{135} (SuganN49a) fission (ZelH49)
Cs^{135m}	53 m (WarhH62, HalleI64)	☢ IT (WarhH62) Δ −86.2 (MTW, LHP)	A chem, sep isotopes, cross bomb, crit abs (WarhH62) chem, mass spect (HalleI64)	γ: Cs X-rays, 0.781 (100%), 0.840 (96%) e^-: 0.745, 0.775, 0.804	Xe^{134} (d, n) (WarhH62) Xe^{132} (α, p) (WarhH62) Ba^{135} (n, p) (WarhH62) protons on Ba (HalleI64)
Cs^{136}	13.7 d (GleL49) 12.9 d (OlaJ54a) 13.5 d (WillieR60)	☢ β^- (GleL51l) Δ −86.6 (LHP, MTW)	A chem (GleL46, GleL51l) chem, excit (GleL49) chem, mass spect (OlaJ54a)	β^-: 0.657 max (7%), 0.341 max e^-: 0.116, 0.126, 0.158, 0.302 γ: Ba X-rays, 0.067 (11%), 0.086 (6%), 0.16 (36%, complex), 0.273 (18%), 0.340 (53%), 0.818 (100%), 1.05 (82%), 1.25 (20%) daughter radiations from Ba^{136m} included in above listing	La^{139} (n, α) (CamM44, GleL49, BernsH61) Ba^{136} (d, α) (GirR55, GrabZ60b)
Cs^{137}	30.0 y (weighted average by FlyK65) 29.7 y (GorbS63) 30.4 y mass spect (FarrH61, DieL63) 29.2 y mass spect (RideB63) 30.0 y sp act, mass spect (BrowF55) others (FlyK65, FleD62a, WilleDM55a, GlazM61, WilleDR53, GleL51j)	☢ β^- (MelhM41) Δ −86.9 (MTW) σ_c 0.11 (GoldmDT64)	A chem, genet (MelhM41) chem, mass spect (HaydR48a, IngM49) daughter Xe^{137} (TurA51, GleL51k) parent Ba^{137m} (TownJ48)	β^-: 1.176 max (7%), 0.514 max e^-: 0.624, 0.656 γ: Ba X-rays, 0.662 (85%) daughter radiations from Ba^{137m} included in above listing	fission (HaydR48, IngM49, GleL51j, GrumW46, FinB51c)
Cs^{138}	32.2 m (BarthR56) 32.1 m (BunkM56) others (GlasG40, WilleR60, EvaHB51, AteA39, HahO39a, GleL51k, OckD62, LangeL53a)	☢ β^- (HahO39c) Δ −83.7 (NDS, MTW)	A chem (HahO39c, HeyF39) chem, mass spect (ThuS49) descendant I^{138} (SuganN49) daughter Xe^{138} (HahO39c, HahO40, GlasG40, SeeW43a)	β^-: 3.40 max γ: 0.463 (23%), 0.55 (8%), 1.01 (25%), 1.426 (73%), 2.21 (18%), 2.63 (9%)	fission (HahO39c, HahO40a, HeyF39, HahO40, BunkM56) Ba^{138} (n, p) (WilleR60, SeeW43a)
Cs^{139}	9.5 m (SuganN50, ZhcE63) others (AteA39, HeyF39, OckD62, HahO40)	☢ β^- (HahO39c) Δ −81.1 (MTW)	A chem, genet (HahO39c, HeyF39) daughter Xe^{139} (HahO39c, HeyF39, HahO40a, HahO40) parent Ba^{139} (HahO39c, HeyF39, HahO40a, HahO40, SuganN50)	γ: 0.50, 0.63, 0.80, 1.28 (strong), 1.65 (complex), 1.90, 2.08 daughter radiations from Ba^{139}	fission (HahO39c, HeyF39, HahO40a, AteA39, SuganN50, HahO40a, HahO40, AksV62, ZhcE63, OckD62)
Cs^{140}	66 s (SuganN50) 63 s (ZhcE63)	☢ β^- (HahO40) Δ −77 (MTW)	A chem (HahO40) chem, genet (SuganN50) parent Ba^{140} (SuganN50)	γ: 0.59, 0.88, 1.14, 1.62, 1.85, 2.06, 2.32, 2.72, 3.15	fission (HahO40, SuganN50, ZhcE63)
Cs^{141}	24 s (FritK62a) 25 s (WahA62)	☢ [β^-] (BradE51)	A chem, genet (WahA62, FritK62a) parent Ba^{141} (WahA62, HahO42a) ancestor Ce^{141} (FritK62a)		fission (BradE51, DilC51a, OveR51, WahA62, FritK62a)
Cs^{142}	2.3 s (FritK62a) others (WahA62, HahO42a)	☢ [β^-] (FritK62a)	B chem, genet (FritK62a) ancestor La^{142} (FritK62a)		fission (FritK62a)
Cs^{143}	2.0 s (FritK62a)	☢ [β^-] (BradE51)	B genet (BradE51) chem, genet (FritK62a) ancestor La^{143} (FritK62a)		fission (BradE51, DilC51a)
Cs^{144}	short (DilC51, DilC51a)	☢ [β^-] (DilC51)	F genet (DilC51) (descendant Xe^{144}, ancestor Ce^{144}) (DilC51)		descendant Xe^{144} from fission (DilC51, DilC51a)
$_{56}Ba^{123}$	2.0 m (PreiI62)	☢ [β^+, EC] (PreiI62)	B chem, cross bomb, genet (PreiI62) parent Cs^{123} (PreiI62)		O^{16} on In, Sn (PreiI62) N^{14} on In (PreiI62) C^{12} on Sn (PreiI62)

Isotope Z A	Half-life	Type of decay (Ψ), % abundance; Mass excess (Δ=M−A), MeV (C^{12}=0), Thermal neutron cross section (σ), barns	Class; Identification; Genetic relationships	Major radiations: approximate energies (MeV) and intensities	Principal means of production
$_{81}Tl^{198m}$	1.87 h (JunB60) 1.90 h (FiscP56) others (OrtD49, BergI53)	Ψ IT 55%, EC 45% (JunB60) others (FiscP56, BergI53) Δ −27.0 (LHP, MTW)	A chem, excit (OrtD49, BergI53) mass spect (MicM54, JunB60) genet energy levels (FiscP56) daughter Pb^{198m} (NeumH50a, KarrD51)	Y Hg X-rays, Tl X-rays, 0.283 (30%), 0.412 (45%), 0.586 (35%), 0.635 (35%) e^- 0.033, 0.046, 0.175, 0.197, 0.246 daughter radiations from Tl^{198}	Au^{197}(α, 3n) (FiscP56, MicM54, BrinGO57)
Tl^{199}	7.4 h (JunB60a, MicM54) others (OrtD49)	Ψ EC (OrtD49) no β^+ (IserH51) Δ −28.5 (MTW)	A chem (KriR40b) chem, excit (OrtD49) mass spect (MicM54, JunB60a) daughter Pb^{199} (NeumH50a) not parent Hg^{199m} (BergI53) descendant Po^{199}, Po^{199m} (BrunC65a)	Y Hg X-rays, 0.158 (5%), 0.208 (12%), 0.247 (9%), 0.455 (14%) e^- 0.035, 0.125, 0.161, 0.193	Au^{197}(α, 2n) (VVtjR63) Hg^{199}(d, 2n) (KriR40b)
Tl^{200}	26.1 h (JansJ62) others (HerrlC57, OrtD49, MicM54)	Ψ EC (OrtD49) β^+ 0.37% (VNooB62, LHP) Δ −27.05 (MTW)	A chem, excit (OrtD49) mass spect (MicM54) daughter Pb^{200} (NeumH50a) descendant Po^{200} (BrunC65a)	Y Hg X-rays, 0.368 (88%), 0.579 (10%), 0.829 (8%), 1.21 (35%, complex), 1.364 (4%), 1.410 (1.6%), 1.517 (4%), others β^+ 1.44 max (0.06%), 1.07 max (0.3%) e^- 0.285, 0.354	deuterons on Hg (KriR40b, VNooB62, GupR60a) Au^{197}(α, n) (OrtD49) Tl^{203}(p, 4n)Pb^{200}(β^-) (SakM65)
Tl^{201}	74 h (HerrlC60) 72 h (NeumH50a) others (KriR40b)	Ψ EC (NeumH50a) Δ −27.3 (MTW)	A chem, mass spect, genet (JohaB59, HerrlC60) chem, excit, cross bomb (NeumH50a) daughter Pb^{201} (NeumH50a, JohaB59, HerrlC60) descendant Po^{201}, Po^{201m} (BrunC65a)	Y Hg X-rays, 0.135 (2%), 0.167 (8%) e^- 0.016, 0.052, 0.084	daughter Pb^{201} (NeumH50a) deuterons on Hg (KriR40b, LingdI58)
Tl^{202}	12.0 d (HameH57) others (MartIHC52, WilkG50b, FajK41a)	Ψ EC (KriR40b, MauW42) no β^+, β^- (WilkG50b) Δ −26.13 (MTW)	A chem, excit (KriR40b, FajK41a) daughter Pb^{202} (HuiJ54)	Y Hg X-rays, 0.439 (95%), 0.522 (0.1%), 0.961 (0.07%) e^- 0.356	Hg^{202}(d, 2n) (KriR40b) Hg^{201}(d, n), Tl^{203}(d, t) (BornP59)
Tl^{203}		% 29.50 (BalK50) Δ −25.75 (MTW) σ_c 11 (GoldmDT64)			
Tl^{204}	3.81 y (LeuH62) 3.80 y (HarbG63) 3.78 y (FinR59) 3.91 y (WahA59, NIIR62) 3.68 y (FlyK65a) others (EdwJ58, MerW57, TobJ55c, WyaE61, HorrD54) SpenH64)	Ψ β^- 97.9%, EC 2.1% (LeuH62) β^- 97.5%, EC 2.5% (ChrisP64) others (LidL52, DMatE52) Δ −24.34 (MTW)	A chem, n-capt (FajK40) mass spect (MicM54)	β^- 0.766 max Y Hg X-rays	Tl^{203}(n, Y) (FajK40, SerL47b)
Tl^{205}		% 70.50 (BalK50) Δ −23.81 (MTW) σ_c 0.11 (GoldmDT64)			
Tl^{206}	4.19 m (SargB53) 4.23 m (FajK40) others (PouA59, AlbuD51a, PoolM37, HeyF37)	Ψ β^- (FajK40, KriR42) Δ −22.26 (MTW)	A n-capt (PreiP35) chem, genet (BrodE47) excit, sep isotopes (NeumH50) daughter Bi^{210} (RaE) (BrodE47) daughter Bi^{210m} (NeumH50, LevyHB54) daughter Hg^{206} (NurM61, KauP62, WolfGK64)	β^- 1.52 max Y no Y	Tl^{205}(n, Y) (PreiP35, PoolM37, HeyF37, NeumH50) daughter Bi^{210m} from Bi^{209}(n, Y) (NeumH50)
Tl^{207} (AcC'')	4.79 m (SargB53) 4.76 m (CurlM31, SargB39a) others (FajK40, BretE40, BaldG46)	Ψ β^- Δ −21.01 (MTW)	A chem, genet (CurlM31) daughter Bi^{211} (AcC)	β^- 1.44 Y 0.897 (0.16%)	descendant Ac^{227} (HydE64)
Tl^{207m}	1.3 s (EccD65)	Ψ IT (EccD65) Δ −19.67 (LHP, MTW)	I excit (EccD65)	Y 0.35, 1.00	Pb^{208}(t, α) (EccD65)

Isotope Z A	Half-life	Type of decay (☢), % abundance; Mass excess (Δ=M−A), MeV (C^{12}=0), Thermal neutron cross section (σ), barns	Class; Identification, Genetic relationships	Major radiations approximate energies (MeV) and intensities	Principal means of production
$_{90}Th^{225}$	8.0 m (MeiW51)	☢: α ≈90%, EC ≈10% (MeiW51) Δ: 22.30 (MTW)	A: chem, genet (MeiW49, MeiW51) daughter U^{229}, parent Ra^{221}, parent Ac^{225} (MeiW49, MeiW51)	α: 6.80 (8%), 6.75 (6%), 6.50 (12%), 6.48 (39%), 6.44 (13%) γ: [Ac X-rays], Ra X-rays, 0.246 (5%), 0.322 (27%), 0.362 (5%), 0.45 (1%), 0.49 (1%) daughter radiations from Ra^{221}, etc	daughter U^{229} (MeiW49, MeiW51)
Th^{226}	30.9 m (StuM48)	☢: α (StuM48) β stable (cons energy) (ForB58) Δ: 23.19 (MTW)	A: chem, genet (StuM48) daughter U^{230}, parent Ra^{222} (StuM48) daughter Ac^{226} (StreK48, StreK50)	α: 6.34 (79%), 6.22 (19%) γ: Ra X-rays, 0.111 (3.4%), 0.131 (0.34%), 0.20 (0.4%, complex), 0.242 (1.2%) e^-: 0.094, 0.107 daughter radiations from Ra^{222}, Rn^{218}, etc	daughter U^{230} (HydE64)
Th^{227} (RdAc)	18.2 d (HageG54) others (PeteS49b, CuriM31)	☢: α, β stable (cons energy) (ForB58) Δ: 25.82 (MTW) σ_f: ≈1500 (GoldmDT64)	A: chem, genet (CuriM31) daughter Ac^{227}, parent Ra^{223} (AcX) daughter Pa^{227} (MeiW51, GhiA48) daughter U^{231} (CranW50)	α: 6.04 (23%), 5.98 (24%), 5.76 (21%), 5.72 (14%, doublet) γ: Ra X-rays, 0.050 (8%), 0.237 (15%, complex), 0.31 (8%, complex) e^-: 0.013, 0.026, 0.044, others daughter radiations from Ra^{223}, Rn^{219}, Po^{215}, etc	daughter Ac^{227}, from natural source or from $Ra^{226}(n,\gamma)Ra^{227}(\beta^-)$ (HydE64)
Th^{228} (RdTh)	1.910 y (KirH56) others (CuriM31)	☢: α, β stable (cons energy) (ForB58) Δ: 26.77 (MTW) σ_c: 123 (GoldmDT64) σ_f: <0.3 (GoldmDT64)	A: chem, genet (CuriM31) daughter Ac^{228} ($MsTh_2$); parent Ra^{224} (ThX); daughter U^{232} (GolJ49) daughter Pa^{228} (MeiW51)	α: 5.43 (71%), 5.34 (28%) γ: Ra L X-rays, 0.084 (1.6%), 0.132 (0.2%), 0.167 (0.1%), 0.214 (0.3%) e^-: 0.067, 0.080 daughter radiations from Ra^{224}, Rn^{220}, Po^{216}, etc.	natural source daughter U^{232} $Ra^{226}(n,\gamma)Ra^{227}(\beta^-)$ $Ac^{227}(n,\gamma)Ac^{228}(\beta^-)$ (HydE64)
Th^{229}	7340 y genet (HageF50) others (EnglA47)	☢: α; β stable (cons energy) (ForB58) Δ: 29.61 (MTW) σ_f: 32 (GoldmDT64)	A: chem, genet (EnglA47, HageF47, HageF50) daughter U^{233}, parent Ra^{225} (EnglA47, HageF47, HageF50)	α: 5.05 (7%), 4.97 (complex, 10%), 4.90 (11%), 4.84 (58%), 4.81 (11%) γ: Ra X-rays, 0.137 (≈3%, complex), 0.20 (≈10%, doublet) e^-: 0.006–0.090 daughter radiations from Ra^{225}, Ac^{225}, etc.	daughter U^{233} (HydE64)
Th^{230} (Io)	8.0×10^4 y sp act (HydE49) 7.5×10^4 y sp act (AttR62) 8.2×10^4 y genet (CuriM30) $t_{1/2}$ (SF) ≥1.5×10^{17} y (SegE52)	☢: α; β stable (cons energy) (ForB58) Δ: 30.87 (MTW) σ_c: 23 (GoldmDT64) σ_f: ≤0.001 (GoldmDT64)	A: chem, genet (CuriM31) daughter U^{234} (U_{II}), parent Ra^{226}; daughter Pa^{230} (StuM48a)	α: 4.68 (76%), 4.62 (24%) γ: Ra L X-rays, 0.068 (0.6%), 0.142 (0.07%), 0.184 (0.014%), 0.253 (0.017%) e^-: 0.051, 0.064 daughter radiations from Ra^{226}, Rn^{222}, etc.	natural source (HydE64)
Th^{231} (UY)	25.52 h (CabM58) 25.6 h (JaffAH51) 25.5 h (KniG49) others (CuriM31, GratO32, NisY38)	☢: β^-; Δ: 33.83 (MTW)	A: chem, genet (CuriM31) daughter U^{235} (AcU), parent Pa^{231}	β^-: 0.30 max e^-: 0.040, 0.054, 0.061 γ: Pa L X-rays, 0.026 (2%), 0.084 (10%, complex)	$Th^{230}(n,\gamma)$ (BaranS60, HoltzM66) daughter U^{235}
Th^{232}	1.41×10^{10} y sp act, (FarlT60) others (KovAF38, PicE56, MackR56, SenF56) $t_{1/2}$ (SF): >10^{21} y (FleG58) others (PocA55, SegE52)	☢: α; β stable (cons energy) (ForB58) %: 100 (AstF35, DempA36) Δ: 35.47 (MTW) σ_c: 7.4 (GoldmDT64) σ_f: <0.0002 (GoldmDT64)	A: chem, genet (CuriM31) parent Ra^{228} ($MsTh_1$)	α: 4.01 (76%), 3.95 (24%) γ: [Ra L X-rays] e^-: 0.042, 0.055 daughter radiations from Ra^{228}, Ac^{228}, Th^{228}, Ra^{224}, etc.	natural source (HydE64)
Th^{233}	22.12 m (JenkE55) 22.4 m (DroB57) 22.3 m (BunkM50a) 22.5 m (SeaG47) others (RutW52, GrossA41)	☢: β^- (SeaG47) Δ: 38.76 (MTW) σ_c: 1500 (GoldmDT64) σ_f: 15 (GoldmDT64)	A: chem, n-capt (MeiL38) parent Pa^{233} (MeiL38, GrossA41, SeaG41a, HahO41, SeaG47)	β^-: 1.23 max e^-: 0.009, 0.024, 0.036, 0.054, 0.067, 0.082 γ: Pa X-rays, 0.029 (2.1%), 0.087 (2.7%), 0.171 (0.7%), 0.195 (0.3%), 0.453 (1%), 0.67 (0.25%), 0.895 (0.14%)	$Th^{232}(n,\gamma)$ (MeiL38, SeaG47, SeaG41a, GrossA41).

off any other legal remedies available to a discriminatee.

[40 FR 8783, Mar. 3, 1975]

PART 20—STANDARDS FOR PROTECTION AGAINST RADIATION

GENERAL PROVISIONS

Sec.
20.1 Purpose.
20.2 Scope
20.3 Definitions
20.4 Units of radiation dose.
20.5 Units of radioactivity.
20.6 Interpretations.
20.7 Communications.
20.8 Information collection requirements: OMB approval.

PERMISSIBLE DOSES, LEVELS AND CONCENTRATIONS

20.101 Radiation dose standards for individuals in restricted areas.
20.102 Determination of prior dose.
20.103 Exposure of individuals to concentrations of radioactive materials in air in restricted areas.
20.104 Exposure of minors.
20.105 Permissible levels of radiation in unrestricted areas.
20.106 Radioactivity in effluents to unrestricted areas.
20.107 Medical diagnosis and therapy.
20.108 Orders requiring furnishing of bioassay services.

PRECAUTIONARY PROCEDURES

20.201 Surveys.
20.202 Personnel monitoring.
20.203 Caution signs, labels, signals and controls.
20.204 Same: Exceptions.
20.205 Procedures for picking up, receiving, and opening packages.
20.206 Instruction of personnel.
20.207 Storage and control of licensed materials in unrestricted areas.

WASTE DISPOSAL

20.301 General requirement.
20.302 Method for obtaining approval of proposed disposal procedures.
20.303 Disposal by release into sanitary sewerage systems.
20.305 Treatment or disposal by incineration.
20.306 Disposal of specific wastes.
20.311 Transfer for disposal and manifests.

Sec.

RECORDS, REPORTS, AND NOTIFICATION

20.401 Records of surveys, radiation monitoring, and disposal.
20.402 Reports of theft or loss of licensed material.
20.403 Notifications of incidents.
20.404 [Reserved]
20.405 Reports of overexposures and excessive levels and concentrations.
20.406 [Reserved]
20.407 Personnel monitoring reports.
20.408 Reports of personnel monitoring on termination of employment or work.
20.409 Notifications and reports to individuals.

EXCEPTIONS AND ADDITIONAL REQUIREMENTS

20.501 Applications for exemptions.
20.502 Additional requirements.

ENFORCEMENT

20.601 Violations.
APPENDIX A—PROTECTION FACTORS FOR RESPIRATORS
APPENDIX B—CONCENTRATIONS IN AIR AND WATER ABOVE NATURAL BACKGROUND
APPENDIX C
APPENDIX D—UNITED STATES NUCLEAR REGULATORY COMMISSION REGIONAL OFFICES

AUTHORITY: Secs. 53, 63, 65, 81, 103, 104, 161, 68 Stat. 930, 933, 935, 936, 937, 948, as amended (42 U.S.C. 2073, 2093, 2095, 2111, 2133, 2134, 2201); secs. 201, as amended, 202, 206, 88 Stat. 1242, as amended, 1244, 1246 (42 U.S.C. 5841, 5842, 5846).

Section 20.408 also issued under secs. 135, 141, Pub. L. 97-425, 96 Stat. 2232, 2241 (42 U.S.C. 10155, 10161).

For the purposes of sec. 223, 68 Stat. 958, as amended (42 U.S.C. 2273), §§ 20.101, 20.102, 20.103 (a), (b) and (f), 20.104 (a) and (b), 20.105(b), 20.106(a), 20.201, 20.202(a), 20.205, 20.207, 20.301, 20.303, 20.304, and 20.305 are issued under sec. 161b, 68 Stat. 948, as amended (42 U.S.C. 2201(b)); and §§ 20.102, 20.103(e), 20.401-20.407, 20.408(b) and 20.409 are issued under sec. 161o, 68 Stat. 950, as amended (42 U.S.C. 2201(o)).

SOURCE: 25 FR 10914, Nov. 17, 1960, unless otherwise noted.

GENERAL PROVISIONS

§ 20.1 Purpose.

(a) The regulations in this part establish standards for protection against radiation hazards arising out of activities under licenses issued by the Nuclear Regulatory Commission and are issued pursuant to the Atomic Energy Act of 1954, as amended, and the Energy Reorganization Act of 1974.

(b) The use of radioactive material or other sources of radiation not licensed by the Commission is not subject to the regulations in this part. However, it is the purpose of the regulations in this part to control the possession, use, and transfer of licensed material by any licensee in such a manner that the total dose to an individual (including exposures to licensed and unlicensed radioactive material and to other unlicensed sources of radiation, whether in the possession of the licensee or any other person, but not including exposures to radiation from natural background sources or medical diagnosis and therapy) does not exceed the standards of radiation protection prescribed in the regulations in this part.

(c) In accordance with recommendations of the Federal Radiation Council, approved by the President, persons engaged in activities under licenses issued by the Nuclear Regulatory Commission pursuant to the Atomic Energy Act of 1954, as amended, and the Energy Reorganization Act of 1974 should, in addition to complying with the requirements set forth in this part, make every reasonable effort to maintain radiation exposures, and releases of radioactive materials in effluents to unrestricted areas, as low as is reasonably achievable. The term "as low as is reasonably achievable" means as low as is reasonably achievable taking into account the state of technology, and the economics of improvements in relation to benefits to the public health and safety, and other societal and socioeconomic considerations, and in relation to the utilization of atomic energy in the public interest.

[25 FR 10914, Nov. 17, 1960, as amended at 40 FR 8783, Mar. 3, 1975; 40 FR 58847, Dec 19, 1975; 44 FR 32352, June 6, 1979]

§ 20.2 Scope.

The regulations in this part apply to all persons who receive, possess, use, or transfer material licensed pursuant to the regulations in Parts 30 through 35, 39, 40, 60, 61, 70, or 72 of this chapter, including persons licensed to operate a production or utilization facility pursuant to Part 50 of this chapter.

[53 FR 31680, Aug. 19, 1988]

§ 20.3 Definitions.

(a) As used in this part:

(1) *Act* means the Atomic Energy Act of 1954 (68 Stat. 919) including any amendments thereto;

(2) *Airborne radioactive material* means any radioactive material dispersed in the air in the form of dusts, fumes, mists, vapors, or gases;

(3) *Byproduct material* means any radioactive material (except special nuclear material) yielded in or made radioactive by exposure to the radiation incident to the process of producing or utilizing special nuclear material.

(4) *Calendar quarter* means not less than 12 consecutive weeks nor more than 14 consecutive weeks. The first calendar quarter of each year shall begin in January and subsequent calendar quarters shall be such that no day is included in more than one calendar quarter or omitted from inclusion within a calendar quarter. No licensee shall change the method observed by him of determining calendar quarters except at the beginning of a calendar year.

(5) *Commission* means the Nuclear Regulatory Commission or its duly authorized representatives;

(6) *Government agency* means any executive department, commission, independent establishment, corporation, wholly or partly owned by the United States of America which is an instrumentality of the United States, or any board, bureau, division, service, office, officer, authority, administration, or other establishment in the executive branch of the Government;

(7) *Individual* means any human being;

(8) *Licensed material* means source material, special nuclear material, or by-product material received, possessed, used, or transferred under a general or specific license issued by the Commission pursuant to the regulations in this chapter;

(9) *License* means a license issued under the regulations in Parts 30 through 35, 39, 40, 60, 61, 70, or Part

72 of this chapter. "Licensee" means the holder of such license;

(10)*Occupational dose* includes exposure of an individual to radiation (i) in a restricted area; or (ii) in the course of employment in which the individual's duties involve exposure to radiation, provided, that "occupational dose" shall not be deemed to include any exposure of an individual to radiation for the purpose of medical diagnosis or medical therapy of such individual.

(11)*Person* means: (i) Any individual, corporation, partnership, firm, association, trust, estate, public or private institution, group, Government agency other than the Commission or the Department (except that the Department shall be considered a person within the meaning of the regulations in this part to the extent that its facilities and activities are subject to the licensing and related regulatory authority of the Commission pursuant to section 202 of the Energy Reorganization Act of 1974 (88 Stat. 1244)), any State, any foreign government or nation or any political subdivision of any such government or nation, or other entity; and (ii) any legal successor, representative, agent, or agency of the foregoing.

(12)*Radiation* means any or all of the following: alpha rays, beta rays, gamma rays, X-rays, neutrons, high-speed electrons, high-speed protons, and other atomic particles; but not sound or radio waves, or visible, infrared, or ultraviolet light;

(13)*Radioactive material* includes any such material whether or not subject to licensing control by the Commission;

(14)*Restricted area* means any area access to which is controlled by the licensee for purposes of protection of individuals from exposure to radiation and radioactive materials. "Restricted area" shall not include any areas used as residental quarters, although a separate room or rooms in a residential building may be set apart as a restricted area;

(15)*Source material* means: (i) Uranium or thorium, or any combination thereof, in any physical or chemical form; or (ii) ores which contain by weight one-twentieth of one percent (0.05%) or more of (a) uranium, (b) thorium or (c) any combination thereof. Source material does not include special nuclear material.

(16)*Special nuclear material* means: (i) Plutonium, uranium 233, uranium enriched in the isotope 233 or in the isotope 235, and any other material which the Commission, pursuant to the provisions of section 51 of the act, determines to be special nuclear material, but does not include source material; or (ii) any material artificially enriched by any of the foregoing but does not include source material;

(17)*Unrestricted area* means any area access to which is not controlled by the licensee for purposes of protection of individuals from exposure to radiation and radioactive materials, and any area used for residential quarters.

(18)*Department* means the Department of Energy established by the Department of Energy Organization Act (Pub. L. 95-91, 91 Stat. 565, 42 U.S.C. 7101 *et seq.*) to the extent that the Department, or its duly authorized representatives, exercises functions formerly vested in the U.S. Atomic Energy Commission, its Chairman, members, officers and components and transferred to the U.S. Energy Research and Development Administration and to the Administrator thereof pursuant to sections 104 (b), (c) and (d) of the Energy Reorganization Act of 1974 (Pub. L. 93-438, 88 Stat. 1233 at 1237, 42 U.S.C. 5814) and retransferred to the Secretary of Energy pursuant to section 301(a) of the Department of Energy Organization Act (Pub. L. 95-91, 91 Stat. 565 at 577-578, 42 U.S.C. 7151).

(19)*Termination* means the end of employment with the licensee or, in the case of individuals not employed by the licensee, the end of a work assignment in the licensee's restricted areas in a given calendar quarter, without expectation or specific scheduling of reentry into the licensee's restricted areas during the remainder of that calendar quarter.

(20)*Dosimetry processor* means an individual or an organization that processes and evaluates personnel monitoring equipment in order to determine the radiation dose delivered to the equipment.

(b) Definitions of certain other words and phrases as used in this part are set forth in other sections, including:

(1)*Airborne radioactivity area* defined in § 20.203;

(2)*Radiation area* and *high radiation area* defined in § 20.202;

(3)*Personnel monitoring equipment* defined in § 20.202,

(4)*Survey* defined in § 20.201;

(5) Units of measurement of dose (rad, rem) defined in § 20.4;

(6) Units of measurement of radioactivity defined in § 20.5.

[25 FR 10914, Nov. 17, 1960, as amended at 25 FR 13953, Dec. 30, 1960, 27 FR 5905, June 22, 1962, 38 FR 22467, Aug. 21, 1973, 40 FR 8783, Mar. 3, 1975; 40 FR 42558, Sept. 15, 1975; 44 FR 32352, June 6, 1979; 45 FR 14200, Mar. 5, 1980; 46 FR 58282, Dec. 1, 1981; 47 FR 57479, Dec. 27, 1982; 52 FR 4604, Feb. 13, 1987; 52 FR 8240, Mar. 17, 1987]

§ 20.4 Units of radiation dose.

(a) "Dose," as used in this part, is the quantity of radiation absorbed, per unit of mass, by the body or by any portion of the body. When the regulations in this part specify a dose during a period of time, the dose means the total quantity of radiation absorbed, per unit of mass, by the body or by any portion of the body during such period of time. Several different units of dose are in current use. Definitions of units as used in this part are set forth in paragraphs (b) and (c) of this section.

(b) The rad, as used in this part, is a measure of the dose of any ionizing radiation to body tissues in terms of the energy absorbed per unit mass of the tissue. One rad is the dose corresponding to the absorption of 100 ergs per gram of tissue. (One millirad (mrad) = 0.001 rad.)

(c) The rem, as used in this part, is a measure of the dose of any ionizing radiation to body tissues in terms of its estimated biological effect relative to a dose of one roentgen (r) of X-rays. (One millirem (mrem) = 0.001 rem.) The relation of the rem to other dose units depends upon the biological effect under consideration and upon the conditions of irradiation. For the purpose of the regulations in this part, any of the following is considered to be equivalent to a dose of one rem:

(1) A dose of 1 r due to X or gamma radiation;

(2) A dose of 1 rad due to X, gamma, or beta radiation;

(3) A dose of 0.1 rad due to neutrons or high energy protons;

(4) A dose of 0.05 rad due to particles heavier than protons and with sufficient energy to reach the lens of the eye; If it is more convenient to measure the neutron flux, or equivalent, than to determine the neutron dose in rads, as provided in paragraph (c)(3) of this section, one rem of neutron radiation may, for purposes of the regulations in this part, be assumed to be equivalent to 14 million neutrons per square centimeter incident upon the body; or, if there exists sufficient information to estimate with reasonable accuracy the approximate distribution in energy of the neutrons, the incident number of neutrons per square centimeter equivalent to one rem may be estimated from the following table:

NEUTRON FLUX DOSE EQUIVALENTS

Neutron energy (Mev)	Number of neutrons per square centimeter equivalent to a dose of 1 rem (neutrons/cm²)	Average flux to deliver 100 millirem in 40 hours (neutrons/cm²/sec)
Thermal	970 × 10⁶	670
0.0001	720 × 10⁶	500
0.005	820 × 10⁶	570
0.02	400 × 10⁶	280
0.1	120 × 10⁶	80
0.5	43 × 10⁶	30
1.0	26 × 10⁶	18
2.5	29 × 10⁶	20
5.0	26 × 10⁶	18
7.5	24 × 10⁶	17
10	24 × 10⁶	17
10 to 30	14 × 10⁶	10

(d) For determining exposures to X or gamma rays up to 3 Mev, the dose limits specified in §§ 20.101 to 20.104 inclusive, may be assumed to be equivalent to the "air dose". For the purpose of this part "air dose" means that the dose is measured by a properly calibrated appropriate instrument in air at or near the body surface in the region of highest dosage rate.

§ 20.5 Units of radioactivity.

(a) Radioactivity is commonly, and for purposes of the regulations in this part shall be, measured in terms of disintegrations per unit time or in curies. One curie=3.7×10^{10} disintegrations per second (dps)=2.2×10^{12} disintegrations per minute (dpm). Commonly used submultiples of the curie are the millicurie and the microcurie:

(1) One millicurie (mCi) =0.001 curie (Ci) =3.7×10^{7} dps.

(2) One microcurie (μCi) =0.000001 curie=3.7×10^{4} dps.

[25 FR 10914, Nov. 17, 1960, as amended at 38 FR 29314, Oct. 24, 1973; 39 FR 23990, June 28, 1974; 40 FR 50705, Oct. 31, 1975]

§ 20.6 Interpretations.

Except as specifically authorized by the Commission in writing, no interpretation of the meaning of the regulations in this part by any officer or employee of the Commission other than a written interpretation by the General Counsel will be recognized to be binding upon the Commission.

§ 20.7 Communications.

Except where otherwise specified in this part, all communications and reports concerning the regulations in this part should be addressed to the Executive Director for Operations, U.S. Nuclear Regulatory Commission, Washington, DC 20555. Communications, reports, and applications may be delivered in person at the Commission's offices at 2120 L Street, NW., Washington, DC, or at 11555 Rockville Pike, Rockville, Maryland.

[53 FR 6139, Mar. 1, 1988, as amended at 53 FR 43420, Oct. 27, 1988]

§ 20.8 Information collection requirements: OMB approval.

(a) The Nuclear Regulatory Commission has submitted the information collection requirements contained in this part to the Office of Management and Budget (OMB) for approval as required by the Paperwork Reduction Act of 1980 (44 U.S.C. 3501 et seq.). OMB has approved the information collection requirements contained in this part under control number 3150-0014.

(b) The approved information collection requirements contained in this part appear in §§ 20.102, 20.103, 20.105, 20.106, 20.203, 20.205, 20.302, 20.311, 20.401, 20.402, 20.403, 20.405, 20.407, 20.408, and 20.409.

(c) This part contains information collection requirements in addition to those approved under the control number specified in paragraph (a) of this section. These information collection requirements and the control numbers under which they are approved are as follows:

(1) In §§ 20.101 and 20.102, Form NRC-4 is approved under control number 3150-0005.

(2) In § 20.401, Form NRC-5 is approved under control number 3150-0006.

[49 FR 19624, May 9, 1984]

PERMISSIBLE DOSES, LEVELS, AND CONCENTRATIONS

§ 20.101 Radiation dose standards for individuals in restricted areas.

(a) In accordance with the provisions of § 20.102(a), and except as provided in paragraph (b) of this section, no licensee shall possess, use, or transfer licensed material in such a manner as to cause any individual in a restricted area to receive in any period of one calendar quarter from radioactive material and other sources of radiation a total occupational dose in excess of the standards specified in the following table:

REMS PER CALENDAR QUARTER

1. Whole body; head and trunk, active blood-forming organs, lens of eyes; or gonads	1¼
2. Hands and forearms; feet and ankles	18¾
3. Skin of whole body	7½

(b) A licensee may permit an individual in a restricted area to receive a total occupational dose to the whole body greater than that permitted under paragraph (a) of this section, provided:

(1) During any calendar quarter the total occupational dose to the whole body shall not exceed 3 rems; and

(2) The dose to the whole body, when added to the accumulated occupational dose to the whole body, shall

not exceed 5 (N-18) rems where "N" equals the individual's age in years at his last birthday; and

(3) The licensee has determined the individual's accumulated occupational dose to the whole body on Form NRC-4, or on a clear and legible record containing all the information required in that form; and has otherwise complied with the requirements of § 20.102. As used in paragraph (b), "Dose to the whole body" shall be deemed to include any dose to the whole body, gonads, active blood-forming organs, head and trunk, or lens of eye.

[25 FR 10914, Nov. 17, 1960, as amended at 44 FR 32352, June 6, 1979]

§ 20.102 Determination of prior dose.

(a) Each licensee shall require any individual, prior to first entry of the individual into the licensee's restricted area during each employment or work assignment under such circumstances that the individual will receive or is likely to receive in any period of one calendar quarter an occupational dose in excess of 25 percent of the applicable standards specified in § 20.101(a) and § 20.104(a), to disclose in a written, signed statement, either: (1) That the individual had no prior occupational dose during the current calendar quarter, or (2) the nature and amount of any occupational dose which the individual may have received during that specifically identified current calendar quarter from sources of radiation possessed or controlled by other persons. Each licensee shall maintain records of such statements until the Commission authorizes their disposition.

(b) Before permitting, pursuant to § 20.101(b), any individual in a restricted area to receive an occupational radiation dose in excess of the standards specified in § 20.101(a), each licensee shall:

(1) Obtain a certificate on Form NRC-4, or on a clear and legible record containing all the information required in that form, signed by the individual showing each period of time after the individual attained the age of 18 in which the individual received an occupational dose of radiation; and

(2) Calculate on Form NRC-4 in accordance with the instructions appearing therein, or on a clear and legible record containing all the information required in that form, the previously accumulated occupational dose received by the individual and the additional dose allowed for that individual under § 20.101(b).

(c)(1) In the preparation of Form NRC-4, or a clear and legible record containing all the information required in that form, the licensee shall make a reasonable effort to obtain reports of the individual's previously accumulated occupational dose. For each period for which the licensee obtains such reports, the licensee shall use the dose shown in the report in preparing the form. In any case where a licensee is unable to obtain reports of the individual's occupational dose for a previous complete calendar quarter, it shall be assumed that the individual has received the occupational dose specified in whichever of the following columns apply:

Part of body	Column 1—Assumed exposure in rems for calendar quarters prior to Jan. 1 1961	Column 2—Assumed exposure in rems for calendar quarters beginning on or after Jan. 1 1961
Whole body, gonads, active blood forming organs, head and trunk, lens of eye	3¼	1¼

(2) The licensee shall retain and preserve records used in preparing Form NRC-4 until the Commission authorizes their disposition.

If calculation of the individual's accumulated occupational dose for all periods prior to January 1, 1961 yields a result higher than the applicable accumulated dose value for the individual as of that date, as specified in paragraph (b) of § 20.101, the excess may be disregarded.

[25 FR 10914, Nov. 17, 1960, as amended at 41 FR 18301, May 3, 1976; 44 FR 32352, June 6, 1979]

§ 20.103 Exposure of individuals to concentrations of radioactive materials in air in restricted areas.

(a)(1) No licensee shall possess, use, or transfer licensed material in such a manner as to permit any individual in a restricted area to inhale a quantity of radioactive material in any period of one calendar quarter greater than the quantity which would result from inhalation for 40 hours per week for 13 weeks at uniform concentrations of radioactive material in air specified in Appendix B, Table I, Column 1.[1,2,3] If the radioactive material is of such form that intake by absorption through the skin is likely, individual exposures to radioactive material shall be controlled so that the uptake of radioactive material by any organ from either inhalation or absorption or both routes of intake [4,5] in any calendar quarter does not exceed that which would result from inhaling such radioactive material for 40 hours per week for 13 weeks at uniform concentrations specified in Appendix B, Table I, Column 1.

(2) No licensee shall possess, use, or transfer mixtures of U-234, U-235, and U-238 in soluble form in such a manner as to permit any individual in a restricted area to inhale a quantity of such material in excess of the intake limits specified in Appendix B, Table I, Column 1 of this part. If such soluble uranium is of a form such that absorption through the skin is likely, individual exposures to such material shall be controlled so that the uptake of such material by any organ from either inhalation or absorption or both routes of intake [4] does not exceed that which would result from inhaling such material at the limits specified in Appendix B, Table I, Column 1 and footnote 4 thereto.

(3) For purposes of determining compliance with the requirements of this section the licensee shall use suitable measurements of concentrations of radioactive materials in air for detecting and evaluating airborne radioactivity in restricted areas and in addition, as appropriate, shall use measurements of radioactivity in the body, measurements of radioactivity excreted from the body, or any combination of such measurements as may be necessary for timely detection and assessment of individual intakes of radioactivity by exposed individuals. It is assumed that an individual inhales radioactive material at the airborne concentration in which he is present unless he uses respiratory protective equipment pursuant to paragraph (c) of this section. When assessment of a particular individual's intake of radioactive material is necessary, intakes less than those which would result from inhalation for 2 hours in any one day or for 10 hours in any one week at

[1] Since the concentration specified for tritium oxide vapor assumes equal intakes by skin absorption and inhalation, the total intake permitted is twice that which would result from inhalation alone at the concentration specified for H 3 S in Appendix B, Table I, Column 1 for 40 hours per week for 13 weeks.

[2] For radon-222, the limiting quantity is that inhaled in a period of one calendar year. For radioactive materials designated Sub" in the "Isotope" column of the table, the concentration value specified is based upon exposure to the material as an external radiation source. Individual exposures to these materials may be accounted for as part of the limitation on individual dose in § 20.101. These nuclides shall be subject to the precautionary procedures required by § 20.103(b)(1).

[3] Multiply the concentration values specified in Appendix B, Table I, Column 1, by 6.3×10^{4} ml to obtain the quarterly quantity limit. Multiply the concentration value specified in Appendix B, Table I, Column 1, by 2.5×10^{7} ml to obtain the annual quantity limit for Rn-222.

[4] Significant intake by ingestion or injection is presumed to occur only as a result of circumstances such as accident, inadvertence, poor procedure, or similar special conditions. Such intakes must be evaluated and accounted for by techniques and procedures as may be appropriate to the circumstances of the occurrence. Exposures so evaluated shall be included in determining whether the limitation on individual exposures in § 20.103(a)(1) has been exceeded.

[5] Regulatory guidance on assessment of individual intakes of radioactive material is given in Regulatory Guide 8.9, "Acceptable Concepts, Models, Equations and Assumptions for a Bioassay Program," single copies of which are available from the Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555, upon written request.

uniform concentrations specified in Appendix B, Table I, Column 1 need not be included in such assessment, provided that for any assessment in excess of these amounts the entire amount is included.

(b)(1) The licensee shall, as a precautionary procedure, use process or other engineering controls, to the extent practicable, to limit concentrations of radioactive materials in air to levels below those which delimit an airborne radioactivity area as defined in § 20.203(d)(1)(ii).

(2) When it is impracticable to apply process or other engineering controls to limit concentrations of radioactive material in air below those defined in § 20.203(d)(1)(ii), other precautionary procedures, such as increased surveillance, limitation of working times, or provision of respiratory protective equipment, shall be used to maintain intake of radioactive material by any individual within any period of seven consecutive days as far below that intake of radioactive material which would result from inhalation of such material for 40 hours at the uniform concentrations specified in Appendix B, Table 1, Column 1 as is reasonably achievable. Whenever the intake of radioactive material by any individual exceeds this 40-hour control measure, the licensee shall make such evaluations and take such actions as are necessary to assure against recurrence. The licensee shall maintain records of such occurrences, evaluations, and actions taken in a clear and readily identifiable form suitable for summary review and evaluation.

(c) When respiratory protective equipment is used to limit the inhalation of airborne radioactive material pursuant to paragraph (b)(2) of this section, the licensee shall use equipment that is certified or had certification extended by the National Institute for Occupational Safety and Health/Mine Safety and Health Administration (NIOSH/MSHA). The licensee may make allowance for this use of respiratory protective equipment in estimating exposures of individuals to this material provided that:

(1) The licensee selects respiratory protective equipment that provides a protection factor greater than the multiple by which peak concentrations of airborne radioactive materials in the working area are expected to exceed the values specified in Appendix B, Table I, Column 1 of this part. The equipment so selected shall be used so that the average concentration of radioactive material in the air that is inhaled during any period of uninterrupted use in an airborne radioactivity area, on any day, by any individual using the equipment, does not exceed the values specified in Appendix B, Table I, Column 1 of this part. For the purposes of this paragraph, the concentration of radioactive material in the air that is inhaled when respirators are worn may be estimated by dividing the ambient concentration in air by the protection factor specified in Appendix A of this part. If the exposure is later found to be greater than estimated, the corrected value shall be used; if the exposure is later found to be less than estimated, the corrected value may be used.

(2) The licensee maintains and implements a respiratory protection program that includes, as a minimum air sampling sufficient to identify the hazard, permit proper equipment selection and estimate exposures, surveys and bioassays as appropriate to evaluate actual exposures; written procedures regarding selection, fitting, and maintenance of respirators and testing of respirators for operability immediately prior to each use; written procedures regarding supervision and training of personnel and issuance records; and determination by a physician prior to initial use of respirators and at least every 12 months thereafter, that the individual user is physically able to use the respiratory protective equipment.

(3) A written policy statement on respirator usage shall be issued covering such things as: use of practicable engineering controls instead of respirators; routine, nonroutine, and emergency use of respirators; and periods of respirator use and relief from respirator use. The licensee shall advise each respirator user that the user may leave the area at any time for relief from respirator use in the event of equipment malfunction, physical or psychological distress, procedural or

communication failure, significant deterioration of operating conditions, or any other condition that might require such relief.

(4) The licensee uses equipment within limitations for type and mode of use and provides proper visual, communication, and other special capabilities (such as adequate skin protection) when needed.

(d) Unless otherwise authorized by the Commission, the licensee shall not assign protection factors in excess of those specified in Appendix A of this part in selecting and using respiratory protective equipment. The Commission may authorize a licensee to use higher protection factors on receipt of an application (1) describing the situation for which a need exists for higher protection factors, and (2) demonstrating that the respiratory protective equipment will provide these higher protection factors under the proposed conditions of use.

(e) Where equipment of a particular type has not been tested and certified, or had certification extended, by NIOSH/MSHA, or where there is no existing schedule for test and certification of certain equipment, the licensee shall not make allowance for this equipment without specific authorization by the Commission. An application for this authorization must include a demonstration by testing, or on the basis of reliable test information, that the material and performance characteristics of the equipment are capable of providing the proposed degree of protection under anticipated conditions of use.

(f) Only equipment that has been specifically certified or had certification extended for emergency use by NIOSH/MSHA shall be used as emergency devices.

(g) The licensee shall notify, in writing, the Regional Administrator of the appropriate Nuclear Regulatory Commission Regional Office listed in Appendix D at least 30 days before the date that respiratory protective equipment is first used under the provisions of this section.

[41 FR 52301, Nov. 29, 1976, as amended at 43 FR 29270, July 7, 1978; 47 FR 16164, Apr. 15, 1982; 52 FR 31610, Aug. 21, 1987; 53 FR 17689, May 18, 1988]

§ 20.104 Exposure of minors.

(a) No licensee shall possess, use, or transfer licensed material in such a manner as to cause any individual within a restricted area who is under 18 years of age, to receive in any period of one calendar quarter from radioactive material and other sources of radiation in the licensee's possession a dose in excess of 10 percent of the limits specified in the table in paragraph (a) of § 20.101.

(b) No licensee shall possess, use or transfer licensed material in such a manner as to cause any individual within a restricted area, who is under 18 years of age to be exposed to airborne radioactive material possessed by the licensee in an average concentration in excess of the limits specified in Appendix B, Table II of this part. For purposes of this paragraph, concentrations may be averaged over periods not greater than a week.

(c) The provisions of §§ 20.103(b)(2) and 20.103(c) shall apply to exposures subject to paragraph (b) of this section except that the references in §§ 20.103(b)(2) and 20.103(c) to Appendix B, Table I, Column 1 shall be deemed to be references to Appendix B, Table II, Column 1.

[25 FR 10914, Nov. 17, 1960, as amended at 41 FR 52302, Nov. 29, 1976]

§ 20.105 Permissible levels of radiation in unrestricted areas.

(a) There may be included in any application for a license or for amendment of a license proposed limits upon levels of radiation in unrestricted areas resulting from the applicant's possession or use of radioactive material and other sources of radiation. Such applications should include information as to anticipated average radiation levels and anticipated occupancy times for each unrestricted area involved. The Commission will approve the proposed limits if the applicant demonstrates that the proposed limits are not likely to cause any individual to receive a dose to the whole body in any period of one calendar year in excess of 0.5 rem.

(b) Except as authorized by the Commission pursuant to paragraph (a) of this section, no licensee shall possess, use or transfer licensed material in such a manner as to create in any unrestricted area from radioactive material and other sources of radiation in his possession:

(1) Radiation levels which, if an individual were continuously present in the area, could result in his receiving a dose in excess of two millirems in any one hour, or

(2) Radiation levels which, if an individual were continuously present in the area, could result in his receiving a dose in excess of 100 millirems in any seven consecutive days.

(c) In addition to other requirements of this part, licensees engaged in uranium fuel cycle operations subject to the provisions of 40 CFR Part 190, "Environmental Radiation Protection Standards for Nuclear Power Operations," shall comply with that part.

[25 FR 10914, Nov. 17, 1960, and 46 FR 18526, Mar. 25, 1981]

§ 20.106 Radioactivity in effluents to unrestricted areas.

(a) A licensee shall not possess, use, or transfer licensed material so as to release to an unrestricted area radioactive material in concentrations which exceed the limits specified in Appendix B, Table II of this part, except as authorized pursuant to § 20.302 or paragraph (b) of this section. For purposes of this section concentrations may be averaged over a period not greater than one year.

(b) An application for a license or amendment may include proposed limits higher than those specified in paragraph (a) of this section. The Commission will approve the proposed limits if the applicant demonstrates:

(1) That the applicant has made a reasonable effort to minimize the radioactivity contained in effluents to unrestricted areas; and

(2) That it is not likely that radioactive material discharged in the effluent would result in the exposure of an individual to concentrations of radioactive material in air or water exceeding the limits specified in Appendix B, Table II of this part.

(c) An application for higher limits pursuant to paragraph (b) of this section shall include information demonstrating that the applicant has made a reasonable effort to minimize the radioactivity discharged in effluents to unrestricted areas, and shall include, as pertinent:

(1) Information as to flow rates, total volume of effluent, peak concentration of each radionuclide in the effluent, and concentration of each radionuclide in the effluent averaged over a period of one year at the point where the effluent leaves a stack, tube, pipe, or similar conduit;

(2) A description of the properties of the effluents, including:

(i) Chemical composition;

(ii) Physical characteristics, including suspended solids content in liquid effluents, and nature of gas or aerosol for air effluents;

(iii) The hydrogen ion concentrations (p") of liquid effluents; and

(iv) The size range of particulates in effluents released into air.

(3) A description of the anticipated human occupancy in the unrestricted area where the highest concentration of radioactive material from the effluent is expected, and, in the case of a river or stream, a description of water uses downstream from the point of release of the effluent.

(4) Information as to the highest concentration of each radionuclide in an unrestricted area, including anticipated concentrations averaged over a period of one year:

(i) In air at any point of human occupancy; or

(ii) In water at points of use downstream from the point of release of the effluent.

(5) The background concentration of radionuclides in the receiving river or stream prior to the release of liquid effluent.

(6) A description of the environmental monitoring equipment, including sensitivity of the system, and procedures and calculations to determine concentrations of radionuclides in the unrestricted area and possible reconcentrations of radionuclides.

(7) A description of the waste treatment facilities and procedures used to reduce the concentration of radionuclides in effluents prior to their release.

(d) For the purposes of this section the concentration limits in Appendix

B, Table II of this part shall apply at the boundary of the restricted area. The concentration of radioactive material discharged through a stack, pipe or similar conduit may be determined with respect to the point where the material leaves the conduit. If the conduit discharges within the restricted area, the concentration at the boundary may be determined by applying appropriate factors for dilution, dispersion, or decay between the point of discharge and the boundary.

(e) In addition to limiting concentrations in effluent streams, the Commission may limit quantities of radioactive materials released in air or water during a specified period of time if it appears that the daily intake of radioactive material from air, water, or food by a suitable sample of an exposed population group, averaged over a period not exceeding one year, would otherwise exceed the daily intake resulting from continuous exposure to air or water containing one-third the concentration of radioactive materials specified in Appendix B, Table II of this part.

(f) The provisions of paragraphs (a) through (e) of this section do not apply to disposal of radioactive material into sanitary sewerage systems, which is governed by § 20.303.

(g) In addition to other requirements of this part, licensees engaged in uranium fuel cycle operations subject to the provisions of 40 CFR Part 190, "Environmental Radiation Protection Standard for Nuclear Power Operations," shall comply with that part.

(Secs. 161b., 161o., Pub. L. 83-703, 68 Stat. 948, 950 (42 U.S.C. 2201); sec. 201, as amended, Pub. L. 93-438, 88 Stat. 1243, Pub. L. 94-79, 89 Stat. 413, (42 U.S.C. 5841); Memorandum of Understanding between the Environmental Protection Agency and the Atomic Energy Commission, August 1973, 38 FR 24936, September 11, 1973)

[29 FR 14434, Oct. 21, 1964, as amended at 46 FR 18526, Mar. 25, 1981]

§ 20.107 Medical diagnosis and therapy.

Nothing in the regulations in this part shall be interpreted as limiting the intentional exposure of patients to radiation for the purpose of medical diagnosis or medical therapy.

§ 20.108 Orders requiring furnishing of bio-assay services.

Where necessary or desirable in order to aid in determining the extent of an individual's exposure to concentrations of radioactive material, the Commission may incorporate appropriate provisions in any license, directing the licensee to make available to the individual appropriate bio-assay services and to furnish a copy of the reports of such services to the Commission.

Precautionary Procedures

§ 20.201 Surveys.

(a) As used in the regulations in this part, "survey" means an evaluation of the radiation hazards incident to the production, use, release, disposal, or presence of radioactive materials or other sources of radiation under a specific set of conditions. When appropriate, such evaluation includes a physical survey of the location of materials and equipment, and measurements of levels of radiation or concentrations of radioactive material present.

(b) Each licensee shall make or cause to be made such surveys as (1) may be necessary for the licensee to comply with the regulations in this part, and (2) are reasonable under the circumstances to evaluate the extent of radiation hazards that may be present.

[25 FR 10914, Nov. 17, 1960, as amended at 46 FR 53648, Oct. 30, 1981]

§ 20.202 Personnel monitoring.

(a) Each licensee shall supply appropriate personnel monitoring equipment to, and shall require the use of such equipment by:

(1) Each individual who enters a restricted area under such circumstances that he receives, or is likely to receive, a dose in any calendar quarter in excess of 25 percent of the applicable value specified in paragraph (a) of § 20.101.

(2) Each individual under 18 years of age who enters a restricted area under such circumstances that he receives, or is likely to receive, a dose in any calendar quarter in excess of 5 percent of the applicable value specified in paragraph (a) of § 20.101.

(3) Each individual who enters a high radiation area.

(b) As used in this part,

(1) "Personnel monitoring equipment" means devices designed to be worn or carried by an individual for the purpose of measuring the dose received (e.g., film badges, pocket chambers, pocket dosimeters, film rings, etc.);

(2) "Radiation area" means any area, accessible to personnel, in which there exists radiation, originating in whole or in part within licensed material, at such levels that a major portion of the body could receive in any one hour a dose in excess of 5 millirem, or in any 5 consecutive days a dose in excess of 100 millirems;

(3) "High radiation area" means any area, accessible to personnel, in which there exists radiation originating in whole or in part within licensed material at such levels that a major portion of the body could receive in any one hour a dose in excess of 100 millirem.

(c) *All personnel dosimeters* (except for direct and indirect reading pocket ionization chambers and those dosimeters used to measure the dose to hands and forearms, feet and ankles) that require processing to determine the radiation dose and that are utilized by licensees to comply with paragraph (a) of this section, with other applicable provisions of 10 CFR Chapter I, or with conditions specified in a licensee's license must be processed and evaluated by a dosimetry processor:

(1) Holding current personnel dosimetry accreditation from the National Voluntary Laboratory Accreditation Program (NVLAP) of the National Bureau of Standards, and

(2) Approved in this accreditation process for the type of radiation or radiations included in the NVLAP program that most closely approximate the type of radiation or radiations for which the individual wearing the dosimeter is monitored.

[25 FR 10914, Nov. 17, 1960, as amended at 52 FR 4604, Feb. 13, 1987]

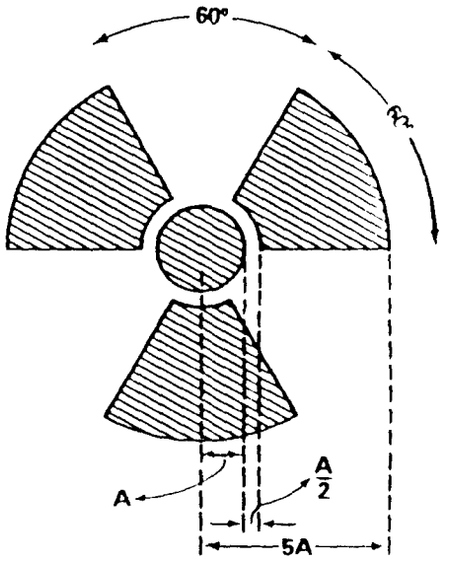
§ 20.203 Caution signs, labels, signals and controls.

(a) *General.* (1) Except as otherwise authorized by the Commission, symbols prescribed by this section shall use the conventional radiation caution colors (magenta or purple on yellow background). The symbol prescribed by this section is the conventional three-bladed design:

Radiation Symbol

1 Cross-hatched area is to be magenta or purple

2 Background is to be yellow



(2) In addition to the contents of signs and labels prescribed in this section, licensees may provide on or near such signs and labels any additional information which may be appropriate in aiding individuals to minimize exposure to radiation or to radioactive material.

(b) *Radiation areas.* Each radiation area shall be conspicuously posted with a sign or signs bearing the radiation caution symbol and the words

CAUTION [1]

RADIATION AREA

(c) *High radiation areas.* (1) Each high radiation area shall be conspicuously posted with a sign or signs bearing the radiation caution symbol and the words:

CAUTION [1]

HIGH RADIATION AREA

(2) Each entrance or access point to a high radiation area shall be:

(i) Equipped with a control device which shall cause the level of radiation to be reduced below that at which an individual might receive a dose of 100 millirems in 1 hour upon entry into the area; or

(ii) Equipped with a control device which shall energize a conspicuous visible or audible alarm signal in such a manner that the individual entering the high radiation area and the licensee or a supervisor of the activity are made aware of the entry; or

(iii) Maintained locked except during periods when access to the area is required, with positive control over each individual entry.

(3) The controls required by paragraph (c)(2) of this section shall be established in such a way that no individual will be prevented from leaving a high radiation area.

(4) In the case of a high radiation area established for a period of 30 days or less, direct surveillance to prevent unauthorized entry may be substituted for the controls required by paragraph (c)(2) of this section.

(5) Any licensee, or applicant for a license, may apply to the Commission for approval of methods not included in paragraphs (c)(2) and (4) of this section for controlling access to high radiation areas. The Commission will approve the proposed alternatives if the licensee or applicant demonstrates that the alternative methods of control will prevent unauthorized entry into a high radiation area, and that the requirement of paragraph (c)(3) of this section is met.

[1] Or "Danger".

(6) Each area in which there may exist radiation levels in excess of 500 rems in one hour at one meter from a sealed radio-active source [2] that is used to irradiate materials shall: [3]

(i) Have each entrance or access point equipped with entry control devices which shall function automatically to prevent any individual from inadvertently entering the area when such radiation levels exist; permit deliberate entry into the area only after a control device is actuated that shall cause the radiation level within the area, from the sealed source, to be reduced below that at which it would be possible for an individual to receive a dose in excess of 100 mrem in one hour; and prevent operation of the source if the source would produce radiation levels in the area that could result in a dose to an individual in excess of 100 mrem in one hour. The entry control devices required by this paragraph (c)(6) shall be established

[2] This paragraph (c)(6) does not apply to radioactive sources that are used in teletherapy, in radiography, or in completely self-shielded irradiators in which the source is both stored and operated within the same shelding radiation barrier and, in the designed configuration of the irradiator, is always physically inaccessible to any individual and cannot create high levels of radiation in an area that is accessible to any individual. This paragraph (c)(6) also does not apply to sources from which the radiation is incidental to some other use nor to nuclear reactor generated radiation other than radiation from byproduct, source, or special nuclear materials that are used in sealed sources in non-self-shielded irradiators.

[3] These requirements apply after Mar. 14, 1978. Each person licensed to conduct activities to which this paragraph (c)(6) applies and who is not in compliance with the provisions of this paragraph on Mar. 14, 1978, shall file with the Director, Office of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555, on or before June 14, 1978, information describing in detail the actions taken or to be taken to achieve compliance with this paragraph by Dec. 14, 1978, and may continue activities in conformance with present license conditions and the provisions of the previously effective § 20.2034 until such compliance is achieved. For such persons compliance must be achieved not later than Dec. 14, 1978.

in such a way that no individual will be prevented from leaving the area.

(ii) Be equipped with additional control devices such that upon failure of the entry control devices to function as required by paragraph (c)(6)(i) of this section the radiation level within the area, from the sealed source, shall be reduced below that at which it would be possible for an individual to receive a dose in excess of 100 mrem in one hour; and visible and audible alarm signals shall be generated to make an individual attempting to enter the area aware of the hazard and the licensee or at least one other individual, who is familiar with the activity and prepared to render or summon assistance, aware of such failure of the entry control devices.

(iii) Be equipped with control devices such that upon failure or removal of physical radiation barriers other than the source's shielded storage container the radiation level from the source shall be reduced below that at which it would be possible for an individual to receive a dose in excess of 100 mrem in one hour; and visible and audible alarm signals shall be generated to make potentially affected individuals aware of the hazard and the licensee or at least one other individual, who is familiar with the activity and prepared to render or summon assistance, aware of the failure or removal of the physical barrier. When the shield for the stored source is a liquid, means shall be provided to monitor the integrity of the shield and to signal, automatically, loss of adequate shielding. Physical radiation barriers that comprise permenent structural components, such as walls, that have no credible probability of failure or removal in ordinary circumstances need not meet the requirements of this paragraph (c)(6)(iii).

(iv) Be equipped with devices that will automatically generate visible and audible alarm signals to alert personnel in the area before the source can be put into operation and in sufficient time for any individual in the area to operate a clearly identified control device which shall be installed in the area and which can prevent the source from being put into operation.

(v) Be controlled by use of such administrative procedure and such devices as are necessary to assure that the area is cleared of personnel prior to each use of the source preceding which use it might have been possible for an individual to have entered the area.

(vi) Be checked by a physical radiation measurement to assure that prior to the first individual's entry into the area after any use of the source, the radiation level from the source in the area is below that at which it would be possible for an individual to receive a dose in excess of 100 mrem in one hour.

(vii) Have entry control devices required in paragraph (c)(6)(i) of this section which have been tested for proper functioning prior to initial operation with such source of radiation on any day that operations are not uninterruptedly continued from the previous day or before resuming operations after any unintended interruption, and for which records are kept of the dates, times, and results of such tests of function. No operations other than those necessary to place the source in safe condition or to effect reparis on controls shall be conducted with such source unless control devices are functioning properly. The licensee shall submit an acceptable schedule for more complete periodic tests of the entry control and warning systems to be established and adhered to as a condition of the license.

(viii) Have those entry and exit portals that are used in transporting materials to and from the irradiation area, and that are not intended for use by individuals, controlled by such devices and administrative procedures as are necessary to physically protect and warn against inadvertent entry by any individual through such portals. Exit portals for processed materials shall be equipped to detect and signal the presence of loose radiation sources that are carried toward such an exit and to automatically prevent such loose sources from being carried out of the area.

(7) Licensees with, or applicants for, licenses for radiation sources that are within the purview of paragraph (c)(6) of this section, and that must be used

in a variety of positions or in peculiar locations, such as open fields or forests, that make it impracticable to comply with certain requirements of paragraph (c)(6) of this section, such as those for the automatic control of radiation levels, may apply to the Director, Office of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555, for approval, prior to use of safety measures that are alternative to those specified in paragraph (c)(6) of this section, and that will provide at least an equivalent degree of personnel protection in the use of such sources. At least one of the alternative measures must include an entry-preventing interlock control based on a physical measurement of radiation that assures the absence of high radiation levels before an individual can gain access to an area where such sources are used.

(d) *Airborne radioactivity areas.* (1) As used in the regulations in this part "airborne radioactivity area" means (i) any room, enclosure, or operating area in which airborne radioactive materials composed wholly or partly of licensed material, exist in concentrations in excess of the amounts specified in Appendix B, Table I, Column 1 of this part; or (ii) any room, enclosure, or operating area in which airborne radioactive material composed wholly or partly of licensed material exists in concentrations which, averaged over the number of hours in any week during which individuals are in the area, exceed 25 percent of the amounts specified in Appendix B Table I, Column 1 of this part.

(2) Each airborne radioactivity area shall be conspicuously posted with a sign or signs bearing the radiation caution symbol and the words:

CAUTION [1]

AIRBORNE RADIOACTIVITY AREA

(e) *Additional requirements.* (1) Each area or room in which licensed material is used or stored and which contains any radioactive material (other than natural uranium or thorium) in an amount exceeding 10 times the quantity of such material specified in Appendix C of this part shall be conspicuously posted with a sign or signs bearing the radiation caution symbol and the words:

CAUTION [1]

RADIOACTIVE MATERIAL(S)

(2) Each area or room in which natural uranium or thorium is used or stored in any amount exceeding one hundred times the quantity specified in Appendix C of this part shall be conspicuously posted with a sign or signs bearing the radiation caution symbol and the words:

CAUTION [1]

RADIOACTIVE MATERIAL(S)

(f) *Containers.* (1) Except as provided in paragraph (f)(3) of this section, each container of licensed material shall bear a durable, clearly visible label identifying the radioactive contents.

(2) A label required pursuant to paragraph (f)(1) of this section shall bear the radiation caution symbol and the words "CAUTION, RADIOACTIVE MATERIAL" or "DANGER, RADIOACTIVE MATERIAL". It shall also provide sufficient information [2] to permit individuals handling or using the containers, or working in the vicinity thereof, to take precautions to avoid or minimize exposures.

(3) Notwithstanding the provisions of paragraph (f)(1) of this section labeling is not required:

(i) For containers that do not contain licensed materials in quantities greater than the applicable quantities listed in Appendix C of this part.

(ii) For containers containing only natural uranium or thorium in quantities no greater than 10 times the applicable quantities listed in Appendix C of this part.

[1] See footnote 1 to paragraph (b).

[1] See footnote 1 to paragraph (b).

[2] As appropriate, the information will include radiation levels, kinds of material, estimate of activity, date for which activity is estimated, mass enrichment, etc.

(iii) For containers that do not contain licensed materials in concentrations greater than the applicable concentrations listed in Appendix B, Table I, Column 2, of this part.

(iv) For containers when they are attended by an individual who takes the precautions necessary to prevent the exposure of any individual to radiation or radioactive materials in excess of the limits established by the regulations in this part.

(v) For containers when they are in transport and packaged and labeled in accordance with regulations of the Department of Transportation.

(vi) For containers which are accessible [3] only to individuals authorized to handle or use them, or to work in the vicinity thereof, provided that the contents are identified to such individuals by a readily available written record.

(vii) For manufacturing or process equipment, such as nuclear reactors, reactor components, piping, and tanks.

(4) Each licensee shall, prior to disposal of an empty uncontaminated container to unrestricted areas, remove or deface the radioactive material label or otherwise clearly indicate that the container no longer contains radioactive materials.

[25 FR 10914, Nov. 17, 1960, as amended at 31 FR 10515, Aug. 5, 1966; 34 FR 19546, Dec. 11, 1969; 35 FR 5033, Mar. 25, 1970; 42 FR 64620, Dec. 27, 1977; 43 FR 2167, Jan. 16, 1978; 43 FR 22172, May 24, 1978]

§ 20.204 Same: Exceptions.

Notwithstanding the provisions of § 20.203,

(a) A room or area is not required to be posted with a caution sign because of the presence of a sealed source provided the radiation level twelve inches from the surface of the source container or housing does not exceed five millirem per hour.

(b) Rooms or other areas in hospitals are not required to be posted with caution signs, and control of entrance or access thereto pursuant to § 20.203(c) is not required, because of the presence of patients containing byproduct material provided that there are personnel in attendance who will take the precautions necessary to prevent the exposure of any individual to radiation or radioactive material in excess of the limits established in the regulations in this part.

(c) Caution signs are not required to be posted at areas or rooms containing radioactive materials for periods of less than eight hours provided that (1) the materials are constantly attended during such periods by an individual who shall take the precautions necessary to prevent the exposure of any individual to radiation or radioactive materials in excess of the limits established in the regulations in this part and; (2) such area or room is subject to the licensee's control.

(d) A room or other area is not required to be posted with a caution sign, and control is not required for each entrance or access point to a room or other area which is a high radiation area solely because of the presence of radioactive materials prepared for transport and packaged and labeled in accordance with regulations of the Department of Transportation

[25 FR 10914, Nov. 17, 1960, as amended at 35 FR 5033, Mar. 25, 1970]

§ 20.205 Procedures for picking up, receiving, and opening packages.

(a)(1) Each licensee who expects to receive a package containing quantities of radioactive material in excess of the Type A quantities specified in paragraph (b) of this section shall:

(i) If the package is to be delivered to the licensee's facility by the carrier, make arrangements to receive the package when it is offered for delivery by the carrier; or

(ii) If the package is to be picked up by the licensee at the carrier's terminal, make arrangements to receive notification from the carrier of the arrival of the package, at the time of arrival.

(2) Each licensee who picks up a package of radioactive material from a carrier's terminal shall pick up the package expeditiously upon receipt of notification from the carrier of its arrival.

(b)(1) Each licensee, upon receipt of a package of radioactive material,

[3] For example, containers in locations such as water-filled canals, storage vaults, or hot cells.

shall monitor the external surfaces of the package for radioactive contamination caused by leakage of the radioactive contents, except:

(i) Packages containing no more than the exempt quantity specified in the table in this paragraph;

(ii) Packages containing no more than 10 millicuries of radioactive material consisting solely of tritium, carbon-14, sulfur-35, or iodine-125;

(iii) Packages containing only radioactive material as gases or in special form;

(iv) Packages containing only radioactive material in other than liquid form (including Mo-99/Tc-99m generators) and not exceeding the Type A quantity limit specified in the table in this paragraph; and

(v) Packages containing only radionuclides with half-lives of less than 30 days and a total quantity of no more than 100 millicuries.

The monitoring shall be performed as soon as practicable after receipt, but no later than three hours after the package is received at the licensee's facility if received during the licensee's normal working hours, or eighteen hours if received after normal working hours.

(2) If removable radioactive contamination in excess of 0.01 microcuries (22,000 disintegrations per minute) per 100 square centimeters of package surface is found on the external surfaces of the package, the licensee shall immediately notify the final delivering carrier and, by telephone and telegraph, mailgram or facsimile, the appropriate Nuclear Regulatory Commission Regional Office shown in Appendix D of this part.

TABLE OF EXEMPT AND TYPE A QUANTITIES

Transport group	Exempt quantity limit (in millicuries)	Type A quantity limit (in curies)
.	.01	0.001
. . .	0.1	0.050
.	1	3
. . . .	1	20
.	1	20
.	1	1000
. . . .	25,000	1000
pecial Form	1	20

(c)(1) Each licensee, upon receipt of a package containing quantities of radioactive material in excess of the Type A quantities specified in paragraph (b) of this section, other than those transported by exclusive use vehicle, shall monitor the radiation levels external to the package. The package shall be monitored as soon as practicable after receipt, but no later than three hours after the package is received at the licensee's facility if received during the licensee's normal working hours, or 18 hours if received after normal working hours.

(2) If radiation levels are found on the external surface of the package in excess of 200 millirem per hour, or at three feet from the external surface of the package in excess of 10 millirem per hour, the licensee shall immediately notify by telephone and telegraph mailgram, or facsimile, the director of the appropriate NRC Regional Office listed in Appendix D, and the final delivering carrier.

(d) Each licensee shall establish and maintain procedures for safely opening packages in which licensed material is received, and shall assure that such procedures are followed and that due consideration is given to special instructions for the type of package being opened.

[39 FR 17974, May 22, 1974, as amended at 41 FR 16445, Apr. 19, 1976; 49 FR 19624, May 9, 1984]

§ 20.206 Instruction of personnel.

Instructions required for individuals working in or frequenting any portion of a restricted area are specified in § 19.12 of this chapter.

[38 FR 22220, Aug. 17, 1973]

§ 20.207 Storage and control of licensed materials in unrestricted areas.

(a) Licensed materials stored in an unrestricted area shall be secured from unauthorized removal from the place of storage.

(b) Licensed materials in an unrestricted area and not in storage shall be tended under the constant surveillance and immediate control of the licensee.

[40 FR 26679, June 25, 1975]

WASTE DISPOSAL

§ 20.301 General requirement.

No licensee shall dispose of licensed material except:

(a) By transfer to an authorized recipient as provided in the regulations in Parts 30, 40, 60, 61, 70 or 72 of this chapter, whichever may be applicable; or

(b) As authorized pursuant to § 20.302 or Part 61 of this chapter; or

(c) As provided in § 20.303, applicable to the disposal of licensed material by release into sanitary sewerage systems, or in § 20.306 for disposal of specific wastes, or in § 20.106 (Radioactivity in effluents to unrestricted areas).

[25 FR 10914, Nov. 17, 1960, as amended at 46 FR 16234, Mar. 11, 1981; 46 FR 58282, Dec. 1, 1981; 47 FR 57479, Dec. 27, 1982]

§ 20.302 Method for obtaining approval of proposed disposal procedures.

(a) Any licensee or applicant for a license may apply to the Commission for approval of proposed procedures to dispose of licensed material in a manner not otherwise authorized in the regulations in this chapter. Each application should include a description of the licensed material and any other radioactive material involved, including the quantities and kinds of such material and the levels of radioactivity involved, and the proposed manner and conditions of disposal. The application should also include an analysis and evaluation of pertinent information as to the nature of the environment, including topographical, geological, meteorological, and hydrological characteristics; usage of ground and surface waters in the general area; the nature and location of other potentially affected facilities; and procedures to be observed to minimize the risk of unexpected or hazardous exposures.

(b) The Commission will not approve any application for a license for disposal of licensed material at sea unless the applicant shows that sea disposal offers less harm to man or the environment than other practical alternative methods of disposal.

[25 FR 10914, Nov. 17, 1960, as amended at 26 FR 352, Jan. 18, 1961; 36 FR 23138, Dec. 4, 1971; 47 FR 57479, Dec. 27, 1982]

§ 20.303 Disposal by release into sanitary sewerage systems.

No licensee shall discharge licensed material into a sanitary sewerage system unless:

(a) It is readily soluble or dispersible in water; and

(b) The quantity of any licensed or other radioactive material released into the system by the licensee in any one day does not exceed the larger of paragraphs (b)(1) or (2) of this section.

(1) The quantity which, if diluted by the average daily quantity of sewage released into the sewer by the licensee will result in an average concentration equal to the limits specified in Appendix B, Table I, Column 2 of this part; or

(2) Ten times the quantity of such material specified in Appendix C of this part; and

(c) The quantity of any licensed or other radioactive material released in any one month, if diluted by the average monthly quantity of water released by the licensee, will not result in an average concentration exceeding the limits specified in Appendix B Table I, Column 2 of this part; and

(d) The gross quantity of licensed and other radioactive material, excluding hydrogen-3 and carbon-14, released into the sewerage system by the licensee does not exceed one curie per year. The quantities of hydrogen-3 and carbon-14 released into the sanitary sewerage system may not exceed curies per year for hydrogen-3 and curie per year for carbon-14. Excreta from individuals undergoing medical diagnosis or therapy with radioactive material shall be exempt from any limitations contained in this section.

[25 FR 10914, Nov. 17, 1960, as amended at 46 FR 16234, Mar. 11, 1981]

§ 20.305 Treatment or disposal by incineration.

No licensee shall treat or dispose of licensed material by incineration except for materials listed under § 20.306 or as specifically approved by the Commission pursuant to §§ 20.106(b) and 20.302.

[46 FR 16234, Mar. 11, 1981]

§ 20.306 Disposal of specific wastes.

Any licensee may dispose of the following licensed material without regard to its radioactivity:

(a) 0.05 microcuries or less of hydrogen-3 or carbon-14, per gram of medium, used for liquid scintillation counting; and

(b) 0.05 microcuries or less of hydrogen-3 or carbon-14, per gram of animal tissue averaged over the weight of the entire animal; provided however, tissue may not be disposed of under this section in a manner that would permit its use either as food for humans or as animal feed.

(c) Nothing in this section, however, relieves the licensee of maintaining records showing the receipt, transfer and disposal of such byproduct material as specified in § 30.51 of this chapter; and

(d) Nothing in this section relieves the licensee from complying with other applicable Federal, State and local regulations governing any other toxic or hazardous property of these materials.

[46 FR 16234, Mar. 11, 1981]

§ 20.311 Transfer for disposal and manifests.

(a) *Purpose.* The requirements of this section are designed to control transfers of radioactive waste intended for disposal at a land disposal facility and establish a manifest tracking system and supplement existing requirements concerning transfers and recordkeeping for such wastes. The reporting and recordkeeping requirements contained in this section have been approved by the Office of Management and Budget; OMB approval No. 3150-0014.

(b) Each shipment of radioactive waste to a licensed land disposal facility must be accompanied by a shipment manifest that contains the name, address, and telephone number of the person generating the waste. The manifest shall also include the name, address, and telephone number or the name and EPA hazardous waste identification number of the person transporting the waste to the land disposal facility. The manifest must also indicate as completely as practicable: a physical description of the waste; the volume; radionuclide identity and quantity; the total radioactivity; and the principal chemical form. The solidification agent must be specified. Waste containing more than 0.1% chelating agents by weight must be identified and the weight percentage of the chelating agent estimated. Wastes classified as Class A, Class B, or Class C in § 61.55 of this chapter must be clearly identified as such in the manifest. The total quantity of the radionuclides H-3, C-14, Tc-99 and I-129 must be shown. The manifest required by this paragraph may be shipping papers used to meet Department of Transportation or Environmental Protection Agency regulations or requirements of the receiver, provided all the required information is included. Copies of manifests required by this section may be legible carbon copies or legible photocopies.

(c) Each manifest must include a certification by the waste generator that the transported materials are properly classified, described, packaged, marked, and labeled and are in proper condition for transportation according to the applicable regulations of the Department of Transportation and the Commission. An authorized representative of the waste generator shall sign and date the manifest.

(d) Any generating licensee who transfers radioactive waste to a land disposal facility or a licensed waste collector shall comply with the requirements in paragraphs (d)(1) through (8) of this section. Any generating licensee who transfers waste to a licensed waste processor who treats or repackages waste shall comply with the requirements of paragraphs (d)(4) through (8) of this section. A licensee shall:

(1) Prepare all wastes so that the waste is classified according to § 61.55 and meets the waste characteristics requirements in § 61.56 of this chapter;

(2) Label each package of waste to identify whether it is Class A waste, Class B waste, or Class C waste, in accordance with § 61.55 of this chapter;

(3) Conduct a quality control program to assure compliance with §§ 61.55 and 61.56 of this chapter; the program must include management evaluation of audits;

(4) Prepare shipping manifests to meet the requirements of §§ 20.311 (b) and (c) of this part;

(5) Forward a copy of the manifest to the intended recipient, at the time of shipment; or, deliver to a collector at the time the waste is collected, obtaining acknowledgement of receipt in the form of a signed copy of the manifest or equivalent documentation from the collector;

(6) Include one copy of the manifest with the shipment;

(7) Retain a copy of the manifest and documentation of acknowledgement of receipt as the record of transfer of licensed material as required by Parts 30, 40, and 70 of this chapter; and,

(8) For any shipments or any part of a shipment for which acknowledgement of receipt has not been received within the times set forth in this section, conduct an investigation in accordance with paragraph (h) of this section.

(e) Any waste collector licensee who handles only prepackaged waste shall:

(1) Acknowledge receipt of the waste from the generator within one week of receipt by returning a signed copy of the manifest or equivalent documentation;

(2) Prepare a new manifest to reflect consolidated shipments; the new manifest shall serve as a listing or index for the detailed generator manifests. Copies of the generator manifests shall be a part of the new manifest. The waste collector may prepare a new manifest without attaching the generator manifests, provided the new manifest contains for each package the information specified in paragraph (b) of this section. The collector licensee shall certify that nothing has been done to the waste which would invalidate the generator's certification;

(3) Forward a copy of the new manifest to the land disposal facility operator at the time of shipment;

(4) Include the new manifest with the shipment to the disposal site;

(5) Retain a copy of the manifest and documentation of acknowledgement of receipt as the record of transfer of licensed material as required by Parts 30, 40, and 70 of this chapter, and retain information from generator manifests until disposition is authorized by the Commission; and,

(6) For any shipments or any part of a shipment for which acknowledgement of receipt is not received within the times set forth in this section, conduct an investigation in accordance with paragraph (h) of this section.

(f) Any licensed waste processor who treats or repackages wastes shall:

(1) Acknowledge receipt of the waste from the generator within one week of receipt by returning a signed copy of the manifest or equivalent documentation;

(2) Prepare a new manifest that meets the requirements of paragraphs (b) and (c) of this section. Preparation of the new manifest reflects that the processor is responsible for the waste;

(3) Prepare all wastes so that the waste is classified according to § 61.55 and meets the waste characteristics requirements in § 61.56 of this chapter;

(4) Label each package of waste to identify whether it is Class A waste, Class B waste, or Class C waste, in accordance with §§ 61.55 and 61.57 of this chapter;

(5) Conduct a quality control program to assure compliance with §§ 61.55 and 61.56 of this chapter. The program shall include management evaluation of audits;

(6) Forward a copy of the new manifest to the disposal site operator or waste collector at the time of shipment, or deliver to a collector at the time the waste is collected, obtaining acknowledgement of receipt in the form of a signed copy of the manifest or equivalent documentation by the collector;

(7) Include the new manifest with the shipment;

(8) Retain copies of original manifests and new manifests and documentation of acknowledgement of receipt as the record of transfer of licensed material required by Parts 30, 40, and 70 of this chapter; and

(9) For any shipment or part of a shipment for which acknowledgement is not received within the times set forth in this section, conduct an investigation in accordance with paragraph (h) of this section.

(g) The land disposal facility operator shall:

(1) Acknowledge receipt of the waste within one week of receipt by returning a signed copy of the manifest or equivalent documentation to the shipper. The shipper to be notified is the licensee who last possessed the waste and transferred the waste to the operator. The returned copy of the manifest or equivalent documentation shall indicate any discrepancies between materials listed on the manifest and materials received;

(2) Maintain copies of all completed manifests or equivalent documentation until the Commission authorizes their disposition; and

(3) Notify the shipper (i.e., the generator, the collector, or processor) and the Regional Administrator of the nearest Commission Regional Office listed in Appendix D of this part when any shipment or part of a shipment has not arrived within 60 days after the advance manifest was received.

(h) Any shipment or part of a shipment for which acknowledgement is not received within the times set forth in this section, must:

(1) Be investigated by the shipper if the shipper has not received notification of receipt within 20 days after transfer; and

(2) Be traced and reported. The investigation shall include tracing the shipment and filing a report with the nearest Commission Regional Office listed in Appendix D of this part. Each licensee who conducts a trace investigation shall file a written report with the nearest Commission's Regional office within 2 weeks of completion of the investigation.

[47 FR 57479, Dec. 27, 1982, as amended at 53 FR 17689, May 18, 1988]

Records, Reports, and Notification

§ 20.401 Records of surveys, radiation monitoring, and disposal.

(a) Each licensee shall maintain records showing the radiation exposures of all individuals for whom personnel monitoring is required under § 20.202 of the regulations in this part. Such records shall be kept on Form NRC-5, in accordance with the instructions contained in that form or on clear and legible records containing all the information required by Form NRC-5. The doses entered on the forms or records shall be for periods of time not exceeding one calendar quarter.

(b) Each licensee shall maintain records in the same units used in this part, showing the results of surveys required by § 20.201(b), monitoring required by §§ 20.205(b) and 20.205(c), and disposals made under §§ 20.302, 20.303, removed § 20.304,[1] and Part 61 of this chapter.

(c)(1) Records of individual exposure to radiation and to radioactive material which must be maintained pursuant to the provisions of paragraph (a) of this section and records of bioassays, including results of whole body counting examinations, made pursuant to § 20.108, shall be preserved until the Commission authorizes disposition.

(2) Records of the results of surveys and monitoring which must be maintained pursuant to paragraph (b) of this section shall be preserved for two years after completion of the survey except that the following records shall be maintained until the Commission authorizes their disposition: (i) Records of the results of surveys to determine compliance with § 20.103(a); (ii) in the absence of personnel monitoring data, records of the results of surveys to determine external radiation dose; and (iii) records of the results of surveys used to evaluate the release of radioactive effluents to the environment.

(3) Records of disposal of licensed materials made pursuant to §§ 20.302, 20,303, removed § 20.304,[1] and Part 61 of this chapter are to be maintained until the Commission authorizes their disposition.

(4) Records which must be maintained pursuant to this part may be the original or a reproduced copy or microform if such reproduced copy or microform is duly authenticated by authorized personnel and the microform is capable of producing a clear and legible copy after storage for the period specified by Commission regulations.

(5) If there is a conflict between the Commission's regulations in this part, license condition, or technical specification, or other written Commission approval or authorization pertaining to the retention period for the same type of record, the retention period specified in the regulations in this part for such records shall apply unless the Commission pursuant to § 20.501, has granted a specific exemption from the record retention requirements specified in the regulations in this part.

[25 FR 10914, Nov. 17, 1960, as amended at 41 FR 18301, May 3, 1976; 47 FR 57480, Dec. 27, 1982]

§ 20.402 Reports of theft or loss of licensed material.

(a)(1) Each licensee shall report to the Commission, by telephone, immediately after it determines that a loss or theft of licensed material has occurred in such quantities and under such circumstances that it appears to the licensee that a substantial hazard may result to persons in unrestricted areas.

(2) Reports must be made as follows:

(i) Licensees having an installed Emergency Notification System shall make the reports to the NRC Operations Center in accordance with § 50.72 of this chapter.

(ii) All other licensees shall make reports to the Administrator of the appropriate NRC Regional Office listed in Appendix D of this part.

(b) Each licensee who makes a report under paragraph (a) of this section shall, within 30 days after learning of the loss or theft, make a report in writing to the U.S. Nuclear Regulatory Commission, Document Control Desk, Washington, DC 20555, with a copy to the appropriate NRC Regional Office listed in Appendix D of this part. The report shall include the following information:

(1) A description of the licensed material involved, including kind, quantity, chemical, and physical form;

(2) A description of the circumstances under which the loss or theft occurred;

(3) A statement of disposition or probable disposition of the licensed material involved;

(4) Radiation exposures to individuals, circumstances under which the exposures occurred, and the extent of possible hazard to persons in unrestricted areas;

(5) Actions which have been taken or will be taken, to recover the material; and

(6) Procedures or measures which have been or will be adopted to prevent a recurrence of the loss or theft of licensed material.

(c) Subsequent to filing the written report the licensee shall also report any substantive additional information on the loss or theft which becomes available to the licensee, within 30 days after he learns of such information.

(d) Any report filed with the Commission pursuant to this section shall be so prepared that names of individuals who may have received exposure to radiation are stated in a separate part of the report.

(e) For holders of an operating license for a nuclear power plant, the events included in paragraph (b) of this section must be reported in accordance with the procedures described in § 50.73 (b), (c), (d), (e), and (g) of this chapter and must include the information required in paragraph (b) of this section. Events reported in accordance with § 50.73 of this chapter need not be reported by a duplicate report under paragraph (b) of this section.

[34 FR 7500, May 9, 1969, as amended at 38 FR 1271, Jan. 11, 1973; 48 FR 33859, July 26, 1983]

§ 20.403 Notifications of incidents.

(a) *Immediate notification.* Each licensee shall immediately report any events involving byproduct, source, or special nuclear material possessed by the licensee that may have caused or threatens to cause:

(1) Exposure of the whole body of any individual to 25 rems or more of radiation; exposure of the skin of the

[1] Section 20.304 provided for burial of small quantities of licensed materials in soil. Notice of its removal appears in the Federal Register of October 30, 1980 (45 FR 71762).

[1] See footnote 1 to paragraph (b) of this section.

whole body of any individual of 150 rems or more or radiation; or exposure of the feet, ankles, hands or forearms of any individual to 375 rems or more of radiation; or

(2) The release of radioactive material in concentrations which, if averaged over a period of 24 hours, would exceed 5,000 times the limits specified for such materials in Appendix B, Table II of this part; or

(3) A loss of one working week or more of the operation of any facilities affected; or

(4) Damage to property in excess of $200,000.

(b) *Twenty-four hour notification.* Each licensee shall within 24 hours of discovery of the event, report any event involving licensed material possessed by the licensee that may have caused or threatens to cause:

(1) Exposure of the whole body of any individual to 5 rems or more of radiation; exposure of the skin of the whole body of any individual to 30 rems or more of radiation; or exposure of the feet, ankles, hands, or forearms to 75 rems or more of radiation; or

(2) The release of radioactive material in concentrations which, if averaged over a period of 24 hours, would exceed 500 times the limits specified for such materials in Appendix B, Table II of this part; or

(3) A loss of one day or more of the operation of any facilities affected; or

(4) Damage to property in excess of $2,000.

(c) Any report filed with the Commission pursuant to this section shall be prepared so that names of individuals who have received exposure to radiation will be stated in a separate part of the report.

(d) Reports made by licensees in response to the requirements of this section must be made as follows:

(1) Licensees that have an installed Emergency Notification System shall make the reports required by paragraphs (a) and (b) of this section to the NRC Operations Center in accordance with § 50.72 of this chapter.

(2) All other licensees shall make the reports required by paragraphs (a) and (b) of this section by telephone to the NRC Operations Center[1] and by telegram, mailgram, or facsimile to the Administrator of the appropriate NRC Regional Office listed in Appendix D of this part.

[27 FR 5905, June 22, 1962, as amended at 28 FR 6823, July 3, 1963; 42 FR 43965, Sept. 1, 1977; 43 FR 2719, Jan. 19, 1978; 48 FR 33859, July 26, 1983; 52 FR 33917, Sept. 9, 1987]

§ 20.404 [Reserved]

§ 20.405 Reports of overexposures and excessive levels and concentrations.

(a)(1) In addition to any notification required by § 20.403 of this part, each licensee shall make a report in writing concerning any one of the following types of incidents within 30 days of its occurrence:

(i) Each exposure of an individual to radiation in excess of the applicable limits in §§ 20.101 or 20.104(a) of this part, or the license;

(ii) Each exposure of an individual to radioactive material in excess of the applicable limits in §§ 20.103(a)(1), 20.103(a)(2), or § 20.104(b) of this part, or in the license;

(iii) Levels of radiation or concentrations of radioactive material in a restricted area in excess of any other applicable limit in the license;

(iv) Any incident for which notification is required by § 20.403 of this part; or

(v) Levels of radiation or concentrations of radioactive material (whether or not involving excessive exposure of any individual) in an unrestricted area in excess of ten times any applicable limit set forth in this part or in the license.

(2) Each report required under paragraph (a)(1) of this section must describe the extent of exposure of individuals to radiation or to radioactive material, including:

(i) Estimates of each individual's exposure as required by paragraph (b) of this section;

(ii) Levels of radiation and concentrations of radioactive material involved;

[1] Commercial telephone number of the NRC Operations Center is (202) 951-0550.

(iii) The cause of the exposure, levels or concentrations; and

(iv) Corrective steps taken or planned to prevent a recurrence.

(b) Any report filed with the Commission pursuant to paragraph (a) of this section shall include for each individual exposed the name, social security number, and date of birth, and an estimate of the individual's exposure. The report shall be prepared so that this information is stated in a separate part of the report.

(c)(1) In addition to any notification required by § 20.403 of this part, each licensee shall make a report in writing of levels of radiation or releases of radioactive material in excess of limits specified by 40 CFR Part 190, "Environmental Radiation Protection Standards for Nuclear Power Operations," or in excess of license conditions related to compliance with 40 CFR Part 190.

(2) Each report submitted under paragraph (c)(1) of this section must describe:

(i) The extent of exposure of individuals to radiation or to radioactive material;

(ii) Levels of radiation and concentrations of radioactive material involved;

(iii) The cause of the exposure, levels, or concentrations; and

(iv) Corrective steps taken or planned to assure against a recurrence, including the schedule for achieving conformance with 40 CFR Part 190 and with associated license conditions.

(d) For holders of an operating license for a nuclear power plant, the incidents included in paragraphs (a) or (c) of this section must be reported in accordance with the procedures described in § 50.73 (b), (c), (d), (e), and (g) of this chapter and must also include the information required by paragraphs (a) and (c) of this section. Incidents reported in accordance with § 50.73 of this chapter need not be reported by a duplicate report under paragraphs (a) or (c) of this section.

(e) All other licensees who make reports under paragraphs (a) or (c) of this section shall, within 30 days after learning of the overexposure or excessive level or concentration, make a report in writing to the U.S. Nuclear Regulatory Commission, Document Control Desk, Washington, D.C. 20555, with a copy to the appropriate NRC Regional Office listed in Appendix D of this part.

[25 FR 10914, Nov. 17, 1960, as amended at 35 FR 15068, Sept. 29, 1970; 46 FR 18526 Mar 25, 1981; 48 FR 33860, July 26, 1983]

§ 20.406 [Reserved]

§ 20.407 Personnel monitoring reports.

Each person described in § 20.408 of this part shall, within the first quarter of each calendar year, submit to the Director, Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission, Washington, DC 20555, the reports specified in paragraphs (a) and (b) of this section, covering the preceding calendar year.[1]

(a) A report of either (1) the total number of individuals for whom personnel monitoring was required under § 20.202(a) or § 34.33(a) of this chapter during the calendar year; or (2) the total number of individuals for whom personnel monitoring was provided during the calendar year: *Provided, however,* That such total includes at least the number of individuals required to be reported under paragraph (a)(1) of this section. The report shall indicate whether it is submitted in accordance with paragraph (a)(1) or (a)(2) of this section. If personnel monitoring was not required to be provided to any individual by the licensee under §§ 20.202(a) or 34.33(a) of this chapter during the calendar year, the licensee shall submit a negative report indicating that such personnel monitoring was not required.

(b) A statistical summary report of the personnel monitoring information recorded by the licensee for individuals for whom personnel monitoring was either required or provided, as described in paragraph (a) of this section, indicating the number of individuals whose total whole body exposure

[1] A licensee whose license expires or terminates prior to, or on the last day of the calendar year, shall submit reports at the expiration or termination of the license, covering that part of the year during which the license was in effect

recorded during the previous calendar year was in each of the following estimated exposure ranges:

Estimated whole body exposure range (rems)[1]	Number of individuals in each range
No measurable exposure	
Measurable exposure less than 0.1	
0.1 to 0.25	
0.25 to 0.5	
0.5 to 0.75	
0.75 to 1	
1 to 2	
2 to 3	
3 to 4	
4 to 5	
5 to 6	
6 to 7	
7 to 8	
8 to 9	
9 to 10	
10 to 11	
11 to 12	
12+	

[1] Individual values exactly equal to the values separating exposure ranges shall be reported in the higher range.

The low exposure range data are required in order to obtain better information about the exposures actually recorded. This section does not require improved measurements.

[43 FR 44829, Sept. 29, 1978, as amended at 49 FR 24513, June 14, 1984]

§ 20.408 Reports of personnel monitoring on termination of employment or work.

(a) This section applies to each person licensed by the Commission to:

(1) Operate a nuclear reactor designed to produce electrical or heat energy pursuant to § 50.21(b) or § 50.22 of this chapter or a testing facility as defined in § 50.2 of this chapter.

(2) Possess or use byproduct material for purposes of radiography pursuant to Parts 30 and 34 of this chapter;

(3) Possess or use at any one time, for purposes of fuel processing, fabricating, or reprocessing, special nuclear material in a quantity exceeding 5,000 grams of contained uranium-235, uranium-233, or plutonium or any combination thereof pursuant to Part 70 of this chapter;

(4) Possess high-level radioactive waste at a geologic repository operations area pursuant to Part 60 of this chapter; or

(5) Possess spent fuel in an independent spent fuel storage installation (ISFSI) or possess spent fuel or high level radioactive waste in a monitored retrievable storage installation (MRS) pursuant to Part 72 of this chapter; or

(6) Possess or use at any one time, for processing or manufacturing for distribution pursuant to Parts 30, 32, or 33 of this Chapter, byproduct material in quantities exceeding any one of the following quantities:

Radionuclide[1]	Quantity in curies
Cesium-137	1
Cobalt 60	1
Gold-198	100
Iodine-131	1
Iridium-192	10
Krypton-85	1,000
Promethium-147	10
Technetium-99m	1,000

[1] The Commission may require, as a license condition, or by rule, regulation or order pursuant to § 20.502, reports from licensees who are licensed to use radionuclides not on this list, in quantities sufficient to cause comparable radiation levels.

(7) Receive radioactive waste from other persons for disposal under Part 61 of this chapter.[1]

(b) When an individual terminates employment with a licensee described in paragraph (a) of this section, or an individual assigned to work in such a licensee's facility, but not employed by the licensee, completes the work assignment in the licensee's facility, the licensee shall furnish to the Director, Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission, Washington, DC 20555, a report of the individual's exposures to radiation and radioactive material, incurred during the period of employment or work assignment in the licensee's facility, containing information recorded by the licensee pursuant to §§ 20.401(a) and 20.108. Such report shall be furnished within 30 days after the exposure of the individual has been determined by the licensee or 90 days after the date of termination of employment or work assignment, whichever is earlier.

[43 FR 44829, Sept. 29, 1978, as amended at 46 FR 13978, Feb. 25, 1981; 46 FR 58282, Dec. 1, 1981; 47 FR 57480, Dec. 27, 1982; 49 FR 24513, June 14, 1984; 50 FR 34085, Aug. 23, 1985; 53 FR 31680, Aug. 19, 1988]

§ 20.409 Notifications and reports to individuals.

(a) Requirements for notifications and reports to individuals of exposure to radiation or radioactive material are specified in § 19.13 of this chapter.

(b) When a licensee is required pursuant to §§ 20.405 or 20.408 to report to the Commission any exposure of an individual to radiation or radioactive material, the licensee shall also notify the individual. Such notice shall be transmitted at a time not later than the transmittal to the Commission, and shall comply with the provisions of § 19.13(a) of this chapter.

[38 FR 22220, Aug. 17, 1973]

Exceptions and Additional Requirements

§ 20.501 Applications for exemptions.

The Commission may, upon application by any licensee or upon its own initiative, grant such exemptions from the requirements of the regulations in this part as it determines are authorized by law and will not result in undue hazard to life or property.

§ 20.502 Additional requirements.

The Commission may, by rule, regulation, or order, impose upon any licensee such requirements, in addition to those established in the regulations in this part, as it deems appropriate or necessary to protect health or to minimize danger to life or property.

Enforcement

§ 20.601 Violations.

An injunction or other court order may be obtained prohibiting any violation of any provision of the Atomic Energy Act of 1954, as amended, or Title II of the Energy Reorganization Act of 1974, or any regulation or order issued thereunder. A court order may be obtained for the payment of a civil penalty imposed pursuant to section 234 of the Act for violation of section 53, 57, 62, 63, 81, 82, 101, 103, 104, 107, or 109 of the Act, or section 206 of the Energy Reorganization Act of 1974, or any rule, regulation, or order issued thereunder, or any term, condition, or limitation of any license issued thereunder, or for any violation for which a license may be revoked under section 186 of the Act. Any person who willfully violates any provision of the Act or any regulation or order issued thereunder may be guilty of a crime and, upon conviction, may be punished by fine or imprisonment or both, as provided by law.

[40 FR 8784, Mar. 3, 1975]

Appendix A—Protection Factors for Respirators[1]

Description[2]	Modes[3]	Protection factors[4]		Tested and certified equipment—National Institute for Occupational Safety and Health/Mine Safety and Health Administration tests for permeability
		Particulates only	Particulates gases and vapors	
I. Air-purifying respirators[5]				
Facepiece, half-mask[6]	NP	10		30 CFR Part 11, Subpart K
Facepiece, full	NP	50		
Facepiece, half mask full or hood	PP	1,000		
II. Atmosphere-supplying respirators				
1. Air-line respirator				
Facepiece, half mask	CF		1,000	
Facepiece half mask	D		5	
Facepiece full	CF		2,000	
Facepiece full	D		5	30 CFR Part 11, Subpart J
Facepiece, full	PD		2,000	
Hood	CF		(7)	
Suit	CF		(7)	(7)
2. Self-contained breathing apparatus (SCBA)				
Facepiece, full	D		50	
Facepiece, full	PD		[8] 10,000	30 CFR Part 11, Subpart H
Facepiece, full	RD		50	

APPENDIX A—PROTECTION FACTORS FOR RESPIRATORS *—Continued

Description *	Modes *	Protection factors *		Tested and certified equipment—National Institute for Occupational Safety and Health/Mine Safety and Health Administration tests for permissibility
		Particulates only	Particulates, gases and vapors *	
Facepiece, full .. III Combination respirator. Any combination of air purifying and atmosphere-supplying respirators	PP	.. . ..	* 5 000 =	30 CFR Part 11, § 11.63(b)

* For use in the selection of respiratory protective devices to be used only where the contaminants have been identified and the concentrations (or possible concentrations) are known.

* Only for shaven faces and where nothing interferes with the seal of tightfitting facepieces against the skin. (Hoods and suits are excepted.)

* The mode symbols are defined as follows: CF = continuous flow; D = demand, NP = negative pressure (i.e., negative phase during inhalation), PD = pressure demand (i.e., always positive pressure), PP = positive pressure, RD = demand, recirculating (closed circuit), RP = positive pressure, recirculating (closed circuit).

* The protection factor is a measure of the degree of protection afforded by a respirator, defined as the ratio of the concentration of airborne radioactive material outside the respiratory protective equipment to that inside the equipment (usually inside the facepiece) under conditions of use. It is applied to the ambient airborne concentration to estimate the concentrations inhaled by the wearer according to the following formula:

Concentration inhaled = (Ambient airborne concentration)/(Protection factor)

* The protection factors apply:

(a) Only for trained individuals wearing properly fitted respirators used and maintained under supervision in a well planned respiratory protective program.

(b) For air purifying respirators only when high efficiency particulate filters (above 99.97% removal efficiency by thermally generated 0.3 μm dioctyl phthalate (DOP) test) are used in atmospheres not deficient in oxygen and not containing radioactive gas or vapor respiratory hazards.

(c) No allowance is to be made for the use of sorbents against radioactive gases or vapors.

(d) For atmosphere-supplying respirators only when supplied with adequate respirable air. Respirable air shall be provided of the quality and quantity required in accordance with NIOSH/MSHA certification (described in 30 CFR Part 11). Oxygen and air shall not be used in the same apparatus.

* Excluding radioactive contaminants that present an absorption or submersion hazard. For tritium oxide, approximately one half of the intake occurs by absorption through the skin so that an overall protection factor of less than 2 is appropriate when atmosphere-supplying respirators are used to protect against tritium oxide. If the protection factor for a device is 5, the effective protection factor for tritium is about 1.4; for devices with protection factors of 10 the effective factor for tritium oxide is about 1.7; and for devices with protection factors of 100 or more the effective factor for tritium oxide is about 1.9. Air-purifying respirators are not suitable for protection against tritium oxide. See also footnote 1 concerning supplied air suits.

* Canisters and cartridges shall not be used beyond service life limitations.

* Under-chin type only. This type of respirator is not satisfactory for use where it might be possible (e.g., if an accident or emergency were to occur) for the ambient airborne concentration to reach instantaneous values greater than 10 times the pertinent values in Table 1, Column 1 of Appendix B of this part. This type of respirator is not suitable for protection against plutonium or other high toxicity materials. The mask shall be tested for fit with irritant smoke, prior to use, each time it is donned.

* Equipment shall be operated in a manner that ensures that proper air flow-rates are maintained. A protection factor of no more than 1000 may be used for tested-and-certified supplied-air hoods when a minimum air flow of 6 cubic feet per minute is maintained and calibrated airline pressure gauges or flow measuring devices are used. A protection factor of up to 2000 may be used for tested and certified hoods only when the air flow is maintained at the manufacturer's recommended maximum rate for the equipment. (This rate is greater than 6 cubic feet per minute, and calibrated airline pressure gauges or flow measuring devices are used.)

The design of the supplied air hood or helmet (with a minimum flow of 6 cfm of air) may determine its overall efficiency and the protection it provides. For example, some hoods aspirate contaminated air into the breathing zone when the wearer works with hands over head. This aspiration may be overcome if a short cape-like extension to the hood is worn under a coat or overalls. Other limitations specified by the approval agency shall be considered before using a hood in certain types of atmospheres, such as the design and its permeability to the contaminant under conditions of use.

* Appropriate protection factors shall be determined (see 20.103(e)), taking into account the design of the suit and its permeability to the contaminant under conditions of use. There shall be a standby rescue person equipped with self contained breathing apparatus and communications equipment whenever supplied air suits are used.

* No approval schedules are currently available for this equipment. Equipment shall be evaluated by testing or on the basis of reliable test information.

* This type of respirator may provide greater protection and be used as an emergency device in unknown concentrations for protection against inhalation hazards. External radiation hazards and other limitations to permitted exposure such as skin absorption shall be taken into account in these circumstances.

* Quantitative fit testing shall be performed on each individual and no more than 0.02% leakage is allowed with this type of apparatus. Perceptible outward leakage of gas from this or any positive pressure self contained breathing apparatus is unacceptable because service life will be reduced substantially. Special training in the use of this type of apparatus shall be provided to the wearer (see footnote k).

= Protection factor for type and mode of operation as listed above.

NOTE 1: Protection factors for respirators, as may be approved by the U.S. Bureau of Mines/National Institute for Occupational Safety and Health (NIOSH) according to applicable approvals for respirators for type and mode of use to protect against airborne radionuclides, may be used to the extent that they do not exceed the protection factors listed in this table. The protection factors listed in this table may not be appropriate to circumstances where chemical or other respiratory hazards exist in addition to radiological hazards. The selection and use of respirators for these circumstances should take into account applicable approvals of the U.S. Bureau of Mines/NIOSH.

NOTE 2: Radioactive contaminants for which the concentration values in Table 1, column 1, Appendix B of this part are based on internal dose due to inhalation may, in addition, present external exposure hazards at higher concentrations. Under these circumstances, limitations on occupancy may have to be governed by external dose limits.

[47 FR 16165, Apr. 15, 1982; 47 FR 19511, May 6, 1982]

APPENDIX B—CONCENTRATIONS IN AIR AND WATER ABOVE NATURAL BACKGROUND

[See footnotes at end of Appendix B]

Element (atomic number)	Isotope *		Table I		Table II	
			Col. 1—Air (μCi/ml)	Col. 2—Water (μCi/ml)	Col. 1—Air (μCi/ml)	Col. 2—Water (μCi/ml)
Actinium (89)	Ac 227	S	2 × 10⁻¹²	6 × 10⁻⁴	8 × 10⁻¹⁴	2 × 10⁻⁵
		I	3 × 10⁻¹²	9 × 10⁻⁴	9 × 10⁻¹⁴	3 × 10⁻⁵
	Ac 228	S	8 × 10⁻⁹	3 × 10⁻⁵	3 × 10⁻¹⁰	9 × 10⁻⁷
		I	2 × 10⁻⁸	3 × 10⁻⁵	6 × 10⁻¹⁰	9 × 10⁻⁷
Americium (95)	Am 241	S	6 × 10⁻¹²	1 × 10⁻⁴	2 × 10⁻¹³	4 × 10⁻⁶
		I	1 × 10⁻¹¹	8 × 10⁻⁴	4 × 10⁻¹³	3 × 10⁻⁵
	Am 242m	S	6 × 10⁻¹²	1 × 10⁻⁴	2 × 10⁻¹³	4 × 10⁻⁶
		I	3 × 10⁻¹¹	3 × 10⁻⁴	9 × 10⁻¹³	9 × 10⁻⁶
	Am 242	S	4 × 10⁻⁸	4 × 10⁻⁴	1 × 10⁻⁹	1 × 10⁻⁵
		I	5 × 10⁻⁸	4 × 10⁻⁴	2 × 10⁻⁹	1 × 10⁻⁵
	Am 243	S	6 × 10⁻¹²	1 × 10⁻⁴	2 × 10⁻¹³	4 × 10⁻⁶
		I	1 × 10⁻¹¹	8 × 10⁻⁴	4 × 10⁻¹³	3 × 10⁻⁵
	Am 244	S	4 × 10⁻⁸	1 × 10⁻⁴	1 × 10⁻⁹	5 × 10⁻⁶
		I	2 × 10⁻⁸	1 × 10⁻⁴	8 × 10⁻¹⁰	5 × 10⁻⁶
Antimony	Sb 122	S	2 × 10⁻⁸	8 × 10⁻⁵	6 × 10⁻¹⁰	3 × 10⁻⁶
		I	1 × 10⁻⁸	8 × 10⁻⁵	5 × 10⁻¹⁰	3 × 10⁻⁶
	Sb 124	S	2 × 10⁻⁸	7 × 10⁻⁵	5 × 10⁻¹⁰	2 × 10⁻⁶
		I	2 × 10⁻⁸	7 × 10⁻⁵	7 × 10⁻¹⁰	2 × 10⁻⁶
	Sb 125	S	5 × 10⁻⁸	3 × 10⁻⁴	2 × 10⁻⁹	1 × 10⁻⁵
		I	3 × 10⁻⁸	3 × 10⁻⁴	9 × 10⁻¹⁰	1 × 10⁻⁵
Argon (18)	A 37	Sub *	6 × 10⁻⁶		1 × 10⁻⁷	
	A 41	Sub	2 × 10⁻⁸		4 × 10⁻¹⁰	
Arsenic (33)	As 73	S	2 × 10⁻⁸	1 × 10⁻⁴	7 × 10⁻¹⁰	5 × 10⁻⁶
		I	4 × 10⁻⁸	1 × 10⁻⁴	1 × 10⁻⁹	5 × 10⁻⁶
	As 74	S	3 × 10⁻⁸	2 × 10⁻⁵	1 × 10⁻⁹	5 × 10⁻⁷
		I	1 × 10⁻⁸	2 × 10⁻⁵	4 × 10⁻¹⁰	5 × 10⁻⁷
	As 76	S	1 × 10⁻⁸	6 × 10⁻⁵	4 × 10⁻¹⁰	2 × 10⁻⁶
		I	1 × 10⁻⁸	6 × 10⁻⁵	3 × 10⁻¹⁰	2 × 10⁻⁶
	As 77	S	5 × 10⁻⁸	2 × 10⁻⁴	2 × 10⁻⁹	8 × 10⁻⁶
		I	4 × 10⁻⁸	2 × 10⁻⁴	1 × 10⁻⁹	8 × 10⁻⁶
Astatine (85)	At 211	S	7 × 10⁻⁸	5 × 10⁻⁴	2 × 10⁻⁹	2 × 10⁻⁵
		I	3 × 10⁻⁸	2 × 10⁻⁴	1 × 10⁻⁹	7 × 10⁻⁶
Barium (56)	Ba 131	S	1 × 10⁻⁸	5 × 10⁻⁵	4 × 10⁻¹⁰	2 × 10⁻⁶
		I	4 × 10⁻⁸	5 × 10⁻⁵	1 × 10⁻⁹	2 × 10⁻⁶
	Ba 140	S	1 × 10⁻⁸	6 × 10⁻⁵	4 × 10⁻¹⁰	3 × 10⁻⁶
		I	4 × 10⁻⁸	7 × 10⁻⁵	1 × 10⁻⁹	2 × 10⁻⁶
Berkelium (97)	Bk 249	S	9 × 10⁻¹⁰	2 × 10⁻⁶	3 × 10⁻¹¹	6 × 10⁻⁸
		I	1 × 10⁻⁹	2 × 10⁻⁶	4 × 10⁻¹¹	6 × 10⁻⁸
	Bk 250	S	1 × 10⁻⁸	6 × 10⁻⁵	5 × 10⁻¹⁰	2 × 10⁻⁶
		I	1 × 10⁻⁸	6 × 10⁻⁵	4 × 10⁻¹⁰	2 × 10⁻⁶
Beryllium (4)	Be 7	S	6 × 10⁻⁸	5 × 10⁻⁴	2 × 10⁻⁹	2 × 10⁻⁵
		I	1 × 10⁻⁸	5 × 10⁻⁴	4 × 10⁻¹⁰	2 × 10⁻⁵
Bismuth (83)	Bi 206	S	2 × 10⁻⁸	1 × 10⁻⁴	6 × 10⁻¹⁰	4 × 10⁻⁶
		I	1 × 10⁻⁸	1 × 10⁻⁴	5 × 10⁻¹⁰	4 × 10⁻⁶
	Bi 207	S	2 × 10⁻⁸	2 × 10⁻⁴	6 × 10⁻¹⁰	6 × 10⁻⁶
		I	1 × 10⁻⁸	2 × 10⁻⁴	5 × 10⁻¹⁰	6 × 10⁻⁶
	Bi 210	S	6 × 10⁻⁹	1 × 10⁻⁴	2 × 10⁻¹⁰	4 × 10⁻⁶
		I	6 × 10⁻⁹	1 × 10⁻⁴	2 × 10⁻¹⁰	4 × 10⁻⁶
	Bi 212	S	1 × 10⁻⁸	1 × 10⁻⁴	3 × 10⁻¹⁰	4 × 10⁻⁶
		I	2 × 10⁻⁸	1 × 10⁻⁴	7 × 10⁻¹⁰	4 × 10⁻⁶
Bromine (35)	Br 82	S	1 × 10⁻⁸	8 × 10⁻⁵	4 × 10⁻¹⁰	3 × 10⁻⁶
		I	2 × 10⁻⁸	1 × 10⁻⁴	6 × 10⁻¹⁰	4 × 10⁻⁶
Cadmium (48)	Cd 109	S	5 × 10⁻⁷	5 × 10⁻³	2 × 10⁻⁸	2 × 10⁻⁴
		I	7 × 10⁻⁷	5 × 10⁻³	3 × 10⁻⁸	2 × 10⁻⁴
	Cd 115m	S	4 × 10⁻⁸	7 × 10⁻⁵	1 × 10⁻⁹	3 × 10⁻⁶
		I	4 × 10⁻⁸	7 × 10⁻⁵	1 × 10⁻⁹	3 × 10⁻⁶
	Cd 115	S	2 × 10⁻⁸	1 × 10⁻⁴	8 × 10⁻¹⁰	3 × 10⁻⁶
		I	2 × 10⁻⁸	1 × 10⁻⁴	6 × 10⁻¹⁰	4 × 10⁻⁶
Calcium (20)	Ca 45	S	3 × 10⁻⁸	3 × 10⁻⁴	1 × 10⁻⁹	9 × 10⁻⁶
		I	1 × 10⁻⁷	5 × 10⁻⁴	4 × 10⁻⁹	2 × 10⁻⁵
	Ca 47	S	2 × 10⁻⁸	1 × 10⁻⁴	6 × 10⁻¹⁰	5 × 10⁻⁶

APPENDIX B—CONCENTRATIONS IN AIR AND WATER ABOVE NATURAL BACKGROUND—Continued

[See footnotes at end of Appendix B]

Element (atomic number)	Isotope [1]		Table I		Table II	
			Col. 1—Air (μCi/ml)	Col. 2—Water (μCi/ml)	Col. 1—Air (μCi/ml)	Col. 2—Water (μCi/ml)
		I	2×10^{-7}	1×10^{-3}	8×10^{-9}	3×10^{-5}
Californium (98)	Cf 249	S	2×10^{-12}	1×10^{-3}	5×10^{-11}	4×10^{-8}
		I	1×10^{-10}	7×10^{-3}	3×10^{-12}	2×10^{-5}
	Cf 250	S	5×10^{-12}	4×10^{-3}	2×10^{-12}	1×10^{-5}
		I	1×10^{-10}	7×10^{-3}	3×10^{-12}	3×10^{-5}
	Cf 251	S	2×10^{-12}	1×10^{-3}	6×10^{-12}	4×10^{-8}
		I	1×10^{-10}	8×10^{-3}	3×10^{-12}	3×10^{-5}
	Cf 252	S	6×10^{-12}	2×10^{-3}	2×10^{-12}	7×10^{-6}
		I	3×10^{-11}	2×10^{-3}	1×10^{-12}	7×10^{-6}
	Cf 253	S	8×10^{-10}	4×10^{-3}	3×10^{-11}	1×10^{-4}
		I	6×10^{-10}	4×10^{-3}	3×10^{-11}	1×10^{-4}
	Cf 254	S	5×10^{-12}	4×10^{-6}	2×10^{-13}	1×10^{-7}
		I	5×10^{-12}	4×10^{-6}	2×10^{-13}	1×10^{-7}
Carbon (6)	C 14	S	4×10^{-6}	2×10^{-3}	1×10^{-7}	8×10^{-6}
	(CO_2)	Sub	5×10^{-7}	.....	1×10^{-6}	.....
Cerium (58)	Ce 141	S	4×10^{-7}	3×10^{-7}	2×10^{-8}	9×10^{-9}
		I	2×10^{-7}	3×10^{-7}	5×10^{-8}	9×10^{-9}
	Ce 143	S	3×10^{-7}	1×10^{-7}	9×10^{-9}	4×10^{-9}
		I	2×10^{-7}	1×10^{-7}	7×10^{-9}	4×10^{-9}
	Ce 144	S	1×10^{-8}	3×10^{-7}	3×10^{-10}	1×10^{-9}
		I	6×10^{-9}	3×10^{-7}	2×10^{-10}	1×10^{-9}
Cesium (55)	Cs 131	S	1×10^{-6}	7×10^{-6}	4×10^{-8}	2×10^{-7}
		I	3×10^{-6}	3×10^{-6}	1×10^{-7}	9×10^{-7}
	Cs 134m	S	4×10^{-7}	2×10^{-6}	1×10^{-8}	6×10^{-8}
		I	6×10^{-8}	3×10^{-6}	2×10^{-9}	1×10^{-7}
	Cs 134	S	4×10^{-8}	3×10^{-7}	1×10^{-9}	9×10^{-9}
		I	1×10^{-7}	1×10^{-7}	4×10^{-10}	4×10^{-9}
	Cs 135	S	5×10^{-7}	3×10^{-7}	2×10^{-8}	1×10^{-7}
		I	9×10^{-8}	7×10^{-7}	3×10^{-9}	2×10^{-7}
	Cs 136	S	4×10^{-7}	2×10^{-6}	1×10^{-8}	9×10^{-8}
		I	2×10^{-7}	2×10^{-6}	6×10^{-9}	6×10^{-8}
	Cs 137	S	6×10^{-8}	4×10^{-7}	2×10^{-9}	2×10^{-8}
		I	1×10^{-7}	1×10^{-6}	5×10^{-10}	4×10^{-8}
Chlorine (17)	Cl 36	S	4×10^{-7}	2×10^{-6}	1×10^{-8}	8×10^{-8}
		I	2×10^{-7}	2×10^{-6}	8×10^{-10}	6×10^{-8}
	Cl 38	S	3×10^{-6}	1×10^{-6}	9×10^{-8}	4×10^{-7}
		I	2×10^{-6}	1×10^{-6}	7×10^{-8}	4×10^{-7}
Chromium (24)	Cr 51	S	1×10^{-5}	5×10^{-5}	4×10^{-7}	2×10^{-6}
		I	2×10^{-6}	5×10^{-5}	6×10^{-8}	2×10^{-6}
Cobalt (27)	Co 57	S	3×10^{-6}	2×10^{-5}	1×10^{-7}	5×10^{-6}
		I	2×10^{-7}	1×10^{-5}	6×10^{-9}	4×10^{-6}
	Co 58m	S	2×10^{-7}	8×10^{-5}	8×10^{-9}	3×10^{-6}
		I	9×10^{-8}	6×10^{-5}	3×10^{-9}	2×10^{-6}
	Co 58	S	8×10^{-8}	4×10^{-6}	3×10^{-9}	1×10^{-7}
		I	5×10^{-7}	3×10^{-6}	2×10^{-8}	9×10^{-7}
	Co 60	S	3×10^{-8}	1×10^{-6}	1×10^{-9}	5×10^{-7}
		I	9×10^{-8}	1×10^{-6}	3×10^{-10}	3×10^{-7}
Copper (29)	Cu 64	S	2×10^{-6}	1×10^{-5}	7×10^{-8}	3×10^{-7}
		I	1×10^{-6}	8×10^{-6}	4×10^{-8}	2×10^{-7}
Curium (96)	Cm 242	S	1×10^{-10}	7×10^{-7}	4×10^{-12}	2×10^{-9}
		I	2×10^{-10}	7×10^{-7}	8×10^{-12}	2×10^{-9}
	Cm 243	S	8×10^{-12}	1×10^{-7}	2×10^{-12}	5×10^{-10}
		I	1×10^{-10}	7×10^{-7}	3×10^{-12}	2×10^{-9}
	Cm 244	S	9×10^{-12}	2×10^{-7}	3×10^{-12}	7×10^{-10}
		I	1×10^{-10}	8×10^{-7}	3×10^{-12}	3×10^{-9}
	Cm 245	S	5×10^{-12}	1×10^{-7}	2×10^{-12}	4×10^{-10}
		I	1×10^{-10}	9×10^{-7}	4×10^{-12}	3×10^{-9}
	Cm 246	S	5×10^{-12}	1×10^{-7}	2×10^{-12}	4×10^{-10}
		I	1×10^{-10}	8×10^{-7}	4×10^{-12}	3×10^{-9}
	Cm 247	S	5×10^{-12}	1×10^{-7}	2×10^{-12}	4×10^{-10}
		I	1×10^{-10}	6×10^{-7}	4×10^{-12}	2×10^{-9}
	Cm 248	S	6×10^{-13}	1×10^{-7}	2×10^{-13}	4×10^{-10}
		I	1×10^{-11}	4×10^{-7}	4×10^{-13}	1×10^{-9}
	Cm 249	S	1×10^{-5}	6×10^{-3}	4×10^{-7}	2×10^{-6}
		I	1×10^{-5}	6×10^{-3}	4×10^{-7}	2×10^{-6}

APPENDIX B—CONCENTRATIONS IN AIR AND WATER ABOVE NATURAL BACKGROUND—Continued

[See footnotes at end of Appendix B]

Element (atomic number)	Isotope [1]		Table I		Table II	
			Col. 1—Air (μCi/ml)	Col. 2—Water (μCi/ml)	Col. 1—Air (μCi/ml)	Col. 2—Water (μCi/ml)
Dysprosium (66)	Dy 165	S	3×10^{-6}	1×10^{-3}	9×10^{-8}	4×10^{-6}
		I	2×10^{-6}	1×10^{-3}	7×10^{-8}	4×10^{-6}
	Dy 166	S	2×10^{-7}	1×10^{-3}	6×10^{-9}	4×10^{-6}
		I	2×10^{-7}	1×10^{-3}	7×10^{-9}	4×10^{-6}
Einsteinium (99)	Es 253	S	8×10^{-10}	7×10^{-6}	3×10^{-11}	2×10^{-7}
		I	6×10^{-10}	7×10^{-6}	2×10^{-11}	2×10^{-7}
	Es 254m	S	5×10^{-8}	5×10^{-6}	2×10^{-10}	2×10^{-7}
		I	6×10^{-8}	5×10^{-6}	2×10^{-10}	2×10^{-7}
	Es 254	S	2×10^{-11}	4×10^{-7}	8×10^{-13}	1×10^{-7}
		I	1×10^{-10}	4×10^{-6}	4×10^{-12}	1×10^{-7}
	Es 255	S	5×10^{-10}	8×10^{-7}	2×10^{-11}	3×10^{-7}
		I	4×10^{-10}	8×10^{-7}	1×10^{-11}	3×10^{-7}
Erbium (68)	Er 169	S	6×10^{-7}	3×10^{-7}	2×10^{-8}	9×10^{-8}
		I	4×10^{-7}	3×10^{-7}	1×10^{-8}	9×10^{-8}
	Er 171	S	7×10^{-7}	3×10^{-7}	2×10^{-8}	1×10^{-7}
		I	6×10^{-7}	3×10^{-7}	2×10^{-8}	1×10^{-7}
Europium (63)	Eu 152	S	4×10^{-7}	2×10^{-7}	1×10^{-8}	6×10^{-8}
	(T1/2 = 9.2 hrs)	I	3×10^{-7}	2×10^{-7}	1×10^{-8}	6×10^{-8}
	Eu 152	S	1×10^{-6}	2×10^{-7}	4×10^{-10}	8×10^{-8}
	(T1/2 = 13 yrs)	I	2×10^{-6}	2×10^{-7}	8×10^{-10}	8×10^{-8}
	Eu 154	S	4×10^{-7}	6×10^{-7}	1×10^{-10}	2×10^{-7}
		I	7×10^{-7}	6×10^{-7}	2×10^{-10}	2×10^{-7}
	Eu 155	S	9×10^{-7}	6×10^{-7}	3×10^{-8}	2×10^{-7}
		I	7×10^{-7}	6×10^{-7}	3×10^{-8}	2×10^{-7}
Fermium (100)	Fm 254	S	6×10^{-7}	4×10^{-7}	2×10^{-8}	1×10^{-7}
		I	7×10^{-7}	4×10^{-7}	2×10^{-8}	1×10^{-7}
	Fm 255	S	2×10^{-7}	1×10^{-7}	6×10^{-10}	3×10^{-8}
		I	1×10^{-7}	1×10^{-7}	4×10^{-10}	3×10^{-8}
	Fm 256	S	3×10^{-7}	3×10^{-7}	1×10^{-10}	9×10^{-8}
		I	2×10^{-7}	3×10^{-7}	6×10^{-11}	9×10^{-8}
Fluorine (9)	F 18	S	5×10^{-7}	2×10^{-6}	2×10^{-8}	8×10^{-8}
		I	3×10^{-7}	1×10^{-6}	9×10^{-9}	5×10^{-8}
Gadolinium (64)	Gd 153	S	2×10^{-7}	6×10^{-7}	8×10^{-9}	2×10^{-7}
		I	9×10^{-8}	6×10^{-7}	3×10^{-9}	2×10^{-7}
	Gd 159	S	5×10^{-7}	2×10^{-6}	2×10^{-8}	8×10^{-8}
		I	4×10^{-7}	2×10^{-6}	1×10^{-8}	8×10^{-8}
Gallium (31)	Ga 72	S	2×10^{-7}	1×10^{-6}	8×10^{-9}	4×10^{-8}
		I	2×10^{-7}	1×10^{-6}	6×10^{-9}	4×10^{-8}
Germanium (32)	Ge 71	S	1×10^{-6}	5×10^{-6}	4×10^{-8}	2×10^{-7}
		I	6×10^{-7}	5×10^{-6}	2×10^{-8}	2×10^{-7}
Gold (79)	Au 196	S	1×10^{-6}	5×10^{-6}	4×10^{-8}	2×10^{-7}
		I	6×10^{-7}	4×10^{-6}	2×10^{-8}	1×10^{-7}
	Au 198	S	3×10^{-7}	2×10^{-6}	1×10^{-8}	5×10^{-8}
		I	2×10^{-7}	1×10^{-6}	8×10^{-9}	5×10^{-8}
	Au 199	S	1×10^{-6}	5×10^{-6}	4×10^{-8}	2×10^{-7}
		I	8×10^{-7}	4×10^{-6}	3×10^{-8}	2×10^{-7}
Hafnium (72)	Hf 181	S	4×10^{-8}	2×10^{-6}	1×10^{-8}	7×10^{-8}
		I	7×10^{-8}	2×10^{-6}	3×10^{-9}	7×10^{-8}
Holmium (67)	Ho 166	S	2×10^{-7}	9×10^{-7}	7×10^{-9}	3×10^{-8}
		I	2×10^{-7}	9×10^{-7}	6×10^{-9}	3×10^{-8}
Hydrogen (1)	H3	S	5×10^{-6}	1×10^{-3}	2×10^{-7}	3×10^{-6}
		I	5×10^{-6}	1×10^{-3}	2×10^{-7}	3×10^{-6}
		Sub	2×10^{-7}		4×10^{-7}	
Indium (49)	In 113m	S	8×10^{-7}	4×10^{-7}	3×10^{-8}	1×10^{-7}
		I	7×10^{-7}	4×10^{-7}	2×10^{-8}	1×10^{-7}
	In 114m	S	1×10^{-7}	5×10^{-7}	4×10^{-9}	2×10^{-8}
		I	2×10^{-7}	5×10^{-7}	7×10^{-10}	2×10^{-8}
	In 115m	S	2×10^{-7}	1×10^{-7}	8×10^{-9}	4×10^{-8}
		I	2×10^{-7}	1×10^{-7}	6×10^{-9}	4×10^{-8}
	In 115	S	2×10^{-7}	3×10^{-7}	9×10^{-9}	9×10^{-8}
		I	3×10^{-7}	3×10^{-7}	1×10^{-8}	9×10^{-8}
Iodine (53)	I 125	S	5×10^{-7}	4×10^{-7}	8×10^{-11}	2×10^{-7}
		I	2×10^{-7}	6×10^{-7}	6×10^{-9}	2×10^{-7}
	I 126	S	8×10^{-7}	5×10^{-7}	9×10^{-11}	3×10^{-7}
		I	3×10^{-7}	3×10^{-7}	1×10^{-8}	9×10^{-8}

APPENDIX B—CONCENTRATIONS IN AIR AND WATER ABOVE NATURAL BACKGROUND—Continued

(See footnotes at end of Appendix B)

Element (atomic number)	Isotope [1]		Table I		Table II	
			Col 1—Air (μCi/ml)	Col. 2—Water (μCi/ml)	Col 1—Air (μCi/ml)	Col 2—Water (μCi/ml)
	I 129	S	$2 \cdot 10^{-8}$	$1 \cdot 10^{-3}$	$2 \cdot 10^{-11}$	$6 \cdot 10^{-8}$
		I	$7 \cdot 10^{-8}$	$6 \cdot 10^{-8}$	$2 \cdot 10^{-9}$	$2 \cdot 10^{-7}$
	I 131	S	$9 \cdot 10^{-8}$	$6 \cdot 10^{-8}$	$1 \cdot 10^{-10}$	$3 \cdot 10^{-7}$
		I	$3 \cdot 10^{-7}$	$2 \cdot 10^{-7}$	$1 \cdot 10^{-8}$	$6 \cdot 10^{-8}$
	I 132	S	$2 \cdot 10^{-7}$	$2 \cdot 10^{-7}$	$3 \cdot 10^{-9}$	$8 \cdot 10^{-8}$
		I	$9 \cdot 10^{-7}$	$5 \cdot 10^{-7}$	$3 \cdot 10^{-8}$	$2 \cdot 10^{-7}$
	I 133	S	$3 \cdot 10^{-8}$	$2 \cdot 10^{-7}$	$4 \cdot 10^{-10}$	$1 \cdot 10^{-8}$
		I	$2 \cdot 10^{-7}$	$1 \cdot 10^{-7}$	$7 \cdot 10^{-9}$	$4 \cdot 10^{-8}$
	I 134	S	$5 \cdot 10^{-7}$	$4 \cdot 10^{-7}$	$6 \cdot 10^{-9}$	$2 \cdot 10^{-7}$
		I	$3 \cdot 10^{-6}$	$2 \cdot 10^{-6}$	$1 \cdot 10^{-7}$	$6 \cdot 10^{-7}$
	I 135	S	$1 \cdot 10^{-7}$	$7 \cdot 10^{-8}$	$1 \cdot 10^{-9}$	$4 \cdot 10^{-8}$
		I	$4 \cdot 10^{-7}$	$2 \cdot 10^{-7}$	$1 \cdot 10^{-8}$	$7 \cdot 10^{-8}$
Iridium (77)	Ir 190	S	$1 \cdot 10^{-6}$	$6 \cdot 10^{-7}$	$4 \cdot 10^{-8}$	$2 \cdot 10^{-7}$
		I	$4 \cdot 10^{-7}$	$5 \cdot 10^{-7}$	$1 \cdot 10^{-8}$	$2 \cdot 10^{-7}$
	Ir 192	S	$1 \cdot 10^{-7}$	$1 \cdot 10^{-7}$	$4 \cdot 10^{-9}$	$4 \cdot 10^{-8}$
		I	$3 \cdot 10^{-8}$	$1 \cdot 10^{-7}$	$9 \cdot 10^{-10}$	$4 \cdot 10^{-8}$
	Ir 194	S	$2 \cdot 10^{-7}$	$1 \cdot 10^{-7}$	$8 \cdot 10^{-9}$	$3 \cdot 10^{-8}$
		I	$2 \cdot 10^{-7}$	$9 \cdot 10^{-7}$	$5 \cdot 10^{-9}$	$3 \cdot 10^{-8}$
Iron (26)	Fe 55	S	$9 \cdot 10^{-7}$	$2 \cdot 10^{-6}$	$3 \cdot 10^{-8}$	$8 \cdot 10^{-7}$
		I	$1 \cdot 10^{-6}$	$7 \cdot 10^{-6}$	$3 \cdot 10^{-8}$	$2 \cdot 10^{-7}$
	Fe 59	S	$1 \cdot 10^{-7}$	$2 \cdot 10^{-7}$	$5 \cdot 10^{-9}$	$6 \cdot 10^{-8}$
		I	$5 \cdot 10^{-8}$	$2 \cdot 10^{-7}$	$2 \cdot 10^{-9}$	$5 \cdot 10^{-8}$
Krypton (36)	Kr 85m	Sub	$6 \cdot 10^{-6}$	.....	$1 \cdot 10^{-7}$	
	Kr 85	Sub	$1 \cdot 10^{-5}$	.	$3 \cdot 10^{-7}$	
	Kr 87	Sub	$1 \cdot 10^{-6}$	... .	$2 \cdot 10^{-8}$	
	Kr 88	Sub	$1 \cdot 10^{-6}$	. ...	$2 \cdot 10^{-8}$	. ...
Lanthanum (57)	La 140	S	$2 \cdot 10^{-7}$	$7 \cdot 10^{-8}$	$5 \cdot 10^{-9}$	$2 \cdot 10^{-7}$
		I	$1 \cdot 10^{-7}$	$7 \cdot 10^{-8}$	$4 \cdot 10^{-9}$	$2 \cdot 10^{-7}$
Lead (82)	Pb 203	S	$3 \cdot 10^{-6}$	$1 \cdot 10^{-7}$	$9 \cdot 10^{-8}$	$4 \cdot 10^{-7}$
		I	$2 \cdot 10^{-6}$	$1 \cdot 10^{-7}$	$6 \cdot 10^{-8}$	$4 \cdot 10^{-7}$
	Pb 210	S	$1 \cdot 10^{-10}$	$4 \cdot 10^{-9}$	$4 \cdot 10^{-12}$	$1 \cdot 10^{-7}$
		I	$2 \cdot 10^{-10}$	$5 \cdot 10^{-9}$	$8 \cdot 10^{-12}$	$2 \cdot 10^{-7}$
	Pb 212	S	$2 \cdot 10^{-7}$	$6 \cdot 10^{-8}$	$6 \cdot 10^{-10}$	$2 \cdot 10^{-7}$
		I	$2 \cdot 10^{-7}$	$5 \cdot 10^{-8}$	$7 \cdot 10^{-10}$	$2 \cdot 10^{-7}$
Lutetium (71)	Lu 177	S	$8 \cdot 10^{-7}$	$3 \cdot 10^{-7}$	$2 \cdot 10^{-8}$	$1 \cdot 10^{-7}$
		I	$5 \cdot 10^{-7}$	$3 \cdot 10^{-7}$	$2 \cdot 10^{-8}$	$1 \cdot 10^{-7}$
Manganese (25)	Mn 52	S	$2 \cdot 10^{-7}$	$1 \cdot 10^{-7}$	$7 \cdot 10^{-9}$	$3 \cdot 10^{-8}$
		I	$1 \cdot 10^{-7}$	$9 \cdot 10^{-8}$	$5 \cdot 10^{-9}$	$3 \cdot 10^{-8}$
	Mn 54	S	$4 \cdot 10^{-7}$	$4 \cdot 10^{-7}$	$1 \cdot 10^{-8}$	$1 \cdot 10^{-7}$
		I	$4 \cdot 10^{-7}$	$3 \cdot 10^{-7}$	$1 \cdot 10^{-8}$	$1 \cdot 10^{-7}$
	Mn 56	S	$8 \cdot 10^{-7}$	$4 \cdot 10^{-7}$	$3 \cdot 10^{-8}$	$1 \cdot 10^{-7}$
		I	$5 \cdot 10^{-7}$	$3 \cdot 10^{-7}$	$2 \cdot 10^{-8}$	$1 \cdot 10^{-7}$
Mercury (80)	Hg 197m	S	$7 \cdot 10^{-7}$	$6 \cdot 10^{-7}$	$3 \cdot 10^{-8}$	$2 \cdot 10^{-7}$
		I	$8 \cdot 10^{-8}$	$5 \cdot 10^{-8}$	$3 \cdot 10^{-9}$	$2 \cdot 10^{-8}$
	Hg 197	S	$1 \cdot 10^{-6}$	$9 \cdot 10^{-7}$	$4 \cdot 10^{-8}$	$3 \cdot 10^{-7}$
		I	$3 \cdot 10^{-6}$	$1 \cdot 10^{-7}$	$9 \cdot 10^{-8}$	$5 \cdot 10^{-7}$
	Hg 203	S	$7 \cdot 10^{-8}$	$5 \cdot 10^{-8}$	$2 \cdot 10^{-9}$	$2 \cdot 10^{-7}$
		I	$1 \cdot 10^{-7}$	$3 \cdot 10^{-7}$	$4 \cdot 10^{-9}$	$1 \cdot 10^{-7}$
Molybdenum (42)	Mo 99	S	$7 \cdot 10^{-7}$	$5 \cdot 10^{-7}$	$3 \cdot 10^{-8}$	$2 \cdot 10^{-7}$
		I	$2 \cdot 10^{-7}$	$1 \cdot 10^{-7}$	$7 \cdot 10^{-9}$	$4 \cdot 10^{-8}$
Neodymium (60)	Nd 144	S	$8 \cdot 10^{-11}$	$2 \cdot 10^{-8}$	$3 \cdot 10^{-11}$	$7 \cdot 10^{-8}$
		I	$3 \cdot 10^{-10}$	$2 \cdot 10^{-7}$	$1 \cdot 10^{-11}$	$8 \cdot 10^{-8}$
	Nd 147	S	$4 \cdot 10^{-7}$	$2 \cdot 10^{-7}$	$1 \cdot 10^{-8}$	$6 \cdot 10^{-8}$
		I	$2 \cdot 10^{-7}$	$2 \cdot 10^{-7}$	$8 \cdot 10^{-9}$	$6 \cdot 10^{-8}$
	Nd 149	S	$2 \cdot 10^{-6}$	$8 \cdot 10^{-7}$	$6 \cdot 10^{-8}$	$3 \cdot 10^{-7}$
		I	$1 \cdot 10^{-6}$	$8 \cdot 10^{-7}$	$5 \cdot 10^{-8}$	$3 \cdot 10^{-7}$
Neptunium (93)	Np 237	S	$4 \cdot 10^{-11}$	$9 \cdot 10^{-5}$	$1 \cdot 10^{-12}$	$3 \cdot 10^{-8}$
		I	$1 \cdot 10^{-10}$	$9 \cdot 10^{-7}$	$4 \cdot 10^{-12}$	$3 \cdot 10^{-5}$
	Np 239	S	$8 \cdot 10^{-7}$	$4 \cdot 10^{-7}$	$3 \cdot 10^{-8}$	$1 \cdot 10^{-7}$
		I	$7 \cdot 10^{-7}$	$4 \cdot 10^{-3}$	$2 \cdot 10^{-8}$	$1 \cdot 10^{-7}$
Nickel (28)	Ni 59	S	$5 \cdot 10^{-7}$	$6 \cdot 10^{-7}$	$2 \cdot 10^{-8}$	$2 \cdot 10^{-7}$
		I	$8 \cdot 10^{-7}$	$6 \cdot 10^{-7}$	$3 \cdot 10^{-8}$	$2 \cdot 10^{-7}$
	Ni 63	S	$6 \cdot 10^{-8}$	$8 \cdot 10^{-8}$	$2 \cdot 10^{-9}$	$3 \cdot 10^{-8}$
		I	$3 \cdot 10^{-7}$	$2 \cdot 10^{-7}$	$1 \cdot 10^{-8}$	$7 \cdot 10^{-8}$
	Ni 65	S	$9 \cdot 10^{-7}$	$4 \cdot 10^{-7}$	$3 \cdot 10^{-8}$	$1 \cdot 10^{-7}$

APPENDIX B—CONCENTRATIONS IN AIR AND WATER ABOVE NATURAL BACKGROUND—Continued

(See footnotes at end of Appendix B)

Element (atomic number)	Isotope [1]		Table I		Table II	
			Col 1—Air (μCi/ml)	Col 2—Water (μCi/ml)	Col 1—Air (μCi/ml)	Col 2—Water (μCi/ml)
		I	$5 \cdot 10^{-7}$	$3 \cdot 10^{-7}$	$2 \cdot 10^{-8}$	$1 \cdot 10^{-7}$
Niobium (Columbium) (41)	Nb 93m	S	$1 \cdot 10^{-7}$	$1 \cdot 10^{-7}$	$4 \cdot 10^{-8}$	$4 \cdot 10^{-7}$
		I	$2 \cdot 10^{-7}$	$1 \cdot 10^{-7}$	$5 \cdot 10^{-8}$	$4 \cdot 10^{-7}$
	Nb 95	S	$5 \cdot 10^{-7}$	$3 \cdot 10^{-7}$	$2 \cdot 10^{-8}$	$1 \cdot 10^{-7}$
		I	$1 \cdot 10^{-7}$	$3 \cdot 10^{-7}$	$3 \cdot 10^{-8}$	$1 \cdot 10^{-7}$
	Nb 97	S	$6 \cdot 10^{-6}$	$3 \cdot 10^{-7}$	$2 \cdot 10^{-7}$	$9 \cdot 10^{-7}$
		I	$5 \cdot 10^{-6}$	$3 \cdot 10^{-7}$	$2 \cdot 10^{-7}$	$9 \cdot 10^{-7}$
Osmium (76)	Os 185	S	$5 \cdot 10^{-7}$	$2 \cdot 10^{-7}$	$2 \cdot 10^{-8}$	$7 \cdot 10^{-8}$
		I	$5 \cdot 10^{-7}$	$2 \cdot 10^{-7}$	$2 \cdot 10^{-8}$	$7 \cdot 10^{-8}$
	Os 191m	S	$2 \cdot 10^{-6}$	$7 \cdot 10^{-7}$	$6 \cdot 10^{-8}$	$3 \cdot 10^{-7}$
		I	$9 \cdot 10^{-6}$	$7 \cdot 10^{-7}$	$3 \cdot 10^{-8}$	$2 \cdot 10^{-7}$
	Os 191	S	$1 \cdot 10^{-6}$	$5 \cdot 10^{-7}$	$4 \cdot 10^{-8}$	$2 \cdot 10^{-7}$
		I	$4 \cdot 10^{-7}$	$5 \cdot 10^{-7}$	$1 \cdot 10^{-8}$	$2 \cdot 10^{-7}$
	Os 193	S	$4 \cdot 10^{-7}$	$2 \cdot 10^{-7}$	$1 \cdot 10^{-8}$	$6 \cdot 10^{-8}$
		I	$3 \cdot 10^{-7}$	$2 \cdot 10^{-7}$	$9 \cdot 10^{-9}$	$5 \cdot 10^{-8}$
Palladium (46)	Pd 103	S	$1 \cdot 10^{-6}$	$1 \cdot 10^{-7}$	$5 \cdot 10^{-8}$	$3 \cdot 10^{-7}$
		I	$7 \cdot 10^{-7}$	$8 \cdot 10^{-7}$	$3 \cdot 10^{-8}$	$3 \cdot 10^{-7}$
	Pd 109	S	$6 \cdot 10^{-7}$	$3 \cdot 10^{-7}$	$2 \cdot 10^{-8}$	$9 \cdot 10^{-8}$
		I	$4 \cdot 10^{-7}$	$2 \cdot 10^{-7}$	$1 \cdot 10^{-8}$	$7 \cdot 10^{-8}$
Phosphorus (15)	P 32	S	$7 \cdot 10^{-8}$	$5 \cdot 10^{-8}$	$2 \cdot 10^{-9}$	$2 \cdot 10^{-8}$
		I	$8 \cdot 10^{-8}$	$7 \cdot 10^{-8}$	$3 \cdot 10^{-9}$	$2 \cdot 10^{-8}$
Platinum (78)	Pt 191	S	$8 \cdot 10^{-7}$	$4 \cdot 10^{-7}$	$3 \cdot 10^{-8}$	$1 \cdot 10^{-7}$
		I	$6 \cdot 10^{-7}$	$3 \cdot 10^{-7}$	$2 \cdot 10^{-8}$	$1 \cdot 10^{-7}$
	Pt 193m	S	$7 \cdot 10^{-6}$	$3 \cdot 10^{-7}$	$2 \cdot 10^{-7}$	$1 \cdot 10^{-7}$
		I	$5 \cdot 10^{-6}$	$3 \cdot 10^{-7}$	$2 \cdot 10^{-7}$	$1 \cdot 10^{-7}$
	Pt 193	S	$1 \cdot 10^{-6}$	$3 \cdot 10^{-7}$	$4 \cdot 10^{-8}$	$9 \cdot 10^{-7}$
		I	$3 \cdot 10^{-7}$	$5 \cdot 10^{-7}$	$1 \cdot 10^{-8}$	$2 \cdot 10^{-7}$
	Pt 197m	S	$6 \cdot 10^{-6}$	$3 \cdot 10^{-7}$	$2 \cdot 10^{-7}$	$1 \cdot 10^{-7}$
		I	$5 \cdot 10^{-6}$	$3 \cdot 10^{-7}$	$2 \cdot 10^{-7}$	$9 \cdot 10^{-7}$
	Pt 197	S	$8 \cdot 10^{-7}$	$4 \cdot 10^{-7}$	$3 \cdot 10^{-8}$	$1 \cdot 10^{-7}$
		I	$6 \cdot 10^{-7}$	$3 \cdot 10^{-7}$	$2 \cdot 10^{-8}$	$1 \cdot 10^{-7}$
Plutonium (94)	Pu 238	S	$2 \cdot 10^{-11}$	$1 \cdot 10^{-7}$	$7 \cdot 10^{-11}$	$5 \cdot 10^{-8}$
		I	$3 \cdot 10^{-11}$	$8 \cdot 10^{-7}$	$1 \cdot 10^{-11}$	$3 \cdot 10^{-7}$
	Pu 239	S	$2 \cdot 10^{-11}$	$1 \cdot 10^{-7}$	$6 \cdot 10^{-11}$	$5 \cdot 10^{-8}$
		I	$4 \cdot 10^{-11}$	$8 \cdot 10^{-7}$	$1 \cdot 10^{-11}$	$3 \cdot 10^{-7}$
	Pu 240	S	$2 \cdot 10^{-11}$	$1 \cdot 10^{-7}$	$8 \cdot 10^{-11}$	$5 \cdot 10^{-8}$
		I	$4 \cdot 10^{-11}$	$8 \cdot 10^{-7}$	$1 \cdot 10^{-11}$	$3 \cdot 10^{-7}$
	Pu 241	S	$9 \cdot 10^{-10}$	$7 \cdot 10^{-7}$	$3 \cdot 10^{-11}$	$2 \cdot 10^{-7}$
		I	$4 \cdot 10^{-6}$	$4 \cdot 10^{-7}$	$1 \cdot 10^{-7}$	$1 \cdot 10^{-7}$
	Pu 242	S	$2 \cdot 10^{-11}$	$1 \cdot 10^{-7}$	$8 \cdot 10^{-11}$	$5 \cdot 10^{-8}$
		I	$4 \cdot 10^{-11}$	$9 \cdot 10^{-7}$	$1 \cdot 10^{-11}$	$3 \cdot 10^{-7}$
	Pu 243	S	$2 \cdot 10^{-6}$	$1 \cdot 10^{-7}$	$8 \cdot 10^{-8}$	$3 \cdot 10^{-7}$
		I	$2 \cdot 10^{-6}$	$1 \cdot 10^{-7}$	$8 \cdot 10^{-8}$	$3 \cdot 10^{-7}$
	Pu 244	S	$2 \cdot 10^{-11}$	$1 \cdot 10^{-7}$	$6 \cdot 10^{-11}$	$4 \cdot 10^{-8}$
		I	$3 \cdot 10^{-11}$	$3 \cdot 10^{-7}$	$1 \cdot 10^{-11}$	$1 \cdot 10^{-7}$
Polonium (84)	Po 210	S	$5 \cdot 10^{-10}$	$2 \cdot 10^{-7}$	$2 \cdot 10^{-11}$	$7 \cdot 10^{-8}$
		I	$2 \cdot 10^{-10}$	$8 \cdot 10^{-7}$	$7 \cdot 10^{-11}$	$3 \cdot 10^{-7}$
Potassium (19)	K42	S	$2 \cdot 10^{-6}$	$9 \cdot 10^{-7}$	$7 \cdot 10^{-8}$	$3 \cdot 10^{-7}$
		I	$1 \cdot 10^{-6}$	$6 \cdot 10^{-7}$	$4 \cdot 10^{-8}$	$2 \cdot 10^{-7}$
Praseodymium (59)	Pr 142	S	$2 \cdot 10^{-7}$	$9 \cdot 10^{-7}$	$7 \cdot 10^{-8}$	$3 \cdot 10^{-7}$
		I	$2 \cdot 10^{-7}$	$9 \cdot 10^{-7}$	$5 \cdot 10^{-8}$	$3 \cdot 10^{-7}$
	Pr 143	S	$3 \cdot 10^{-7}$	$1 \cdot 10^{-7}$	$1 \cdot 10^{-8}$	$5 \cdot 10^{-8}$
		I	$2 \cdot 10^{-7}$	$1 \cdot 10^{-7}$	$6 \cdot 10^{-8}$	$5 \cdot 10^{-8}$
Promethium (61)	Pm 147	S	$6 \cdot 10^{-7}$	$6 \cdot 10^{-7}$	$2 \cdot 10^{-8}$	$2 \cdot 10^{-7}$
		I	$1 \cdot 10^{-6}$	$6 \cdot 10^{-7}$	$3 \cdot 10^{-8}$	$2 \cdot 10^{-7}$
	Pm 149	S	$3 \cdot 10^{-7}$	$1 \cdot 10^{-7}$	$1 \cdot 10^{-8}$	$4 \cdot 10^{-8}$
		I	$2 \cdot 10^{-7}$	$1 \cdot 10^{-7}$	$8 \cdot 10^{-9}$	$4 \cdot 10^{-8}$
Protoactinium (91)	Pa 230	S	$2 \cdot 10^{-7}$	$7 \cdot 10^{-7}$	$6 \cdot 10^{-11}$	$2 \cdot 10^{-7}$
		I	$8 \cdot 10^{-10}$	$7 \cdot 10^{-7}$	$3 \cdot 10^{-11}$	$2 \cdot 10^{-7}$
	Pa 231	S	$1 \cdot 10^{-12}$	$3 \cdot 10^{-7}$	$4 \cdot 10^{-13}$	$9 \cdot 10^{-8}$
		I	$1 \cdot 10^{-10}$	$8 \cdot 10^{-7}$	$4 \cdot 10^{-12}$	$2 \cdot 10^{-7}$
	Pa 233	S	$6 \cdot 10^{-7}$	$4 \cdot 10^{-7}$	$2 \cdot 10^{-8}$	$1 \cdot 10^{-7}$
		I	$2 \cdot 10^{-7}$	$3 \cdot 10^{-7}$	$6 \cdot 10^{-9}$	$1 \cdot 10^{-7}$
Radium (88)	Ra 223	S	$2 \cdot 10^{-8}$	$2 \cdot 10^{-7}$	$6 \cdot 10^{-11}$	$7 \cdot 10^{-8}$
		I	$2 \cdot 10^{-10}$	$1 \cdot 10^{-7}$	$8 \cdot 10^{-12}$	$4 \cdot 10^{-8}$

APPENDIX B—CONCENTRATIONS IN AIR AND WATER ABOVE NATURAL BACKGROUND—Continued

[See footnotes at end of Appendix B]

Element (atomic number)	Isotope [1]		Table I		Table II	
			Col. 1—Air (μCi/ml)	Col. 2—Water (μCi/ml)	Col. 1—Air (μCi/ml)	Col. 2—Water (μCi/ml)
	Ra 224	S	$5 \cdot 10^{-8}$	$7 \cdot 10^{-7}$	$2 \cdot 10^{-10}$	$2 \cdot 10^{-8}$
		I	$7 \cdot 10^{-10}$	$2 \cdot 10^{-7}$	$2 \cdot 10^{-11}$	$5 \cdot 10^{-9}$
	Ra 226	S	$3 \cdot 10^{-11}$	$4 \cdot 10^{-7}$	$3 \cdot 10^{-12}$	$3 \cdot 10^{-9}$
		I	$5 \cdot 10^{-11}$	$9 \cdot 10^{-7}$	$2 \cdot 10^{-12}$	$3 \cdot 10^{-9}$
	Ra 228	S	$7 \cdot 10^{-11}$	$8 \cdot 10^{-7}$	$2 \cdot 10^{-12}$	$3 \cdot 10^{-9}$
		I	$4 \cdot 10^{-11}$	$7 \cdot 10^{-7}$	$1 \cdot 10^{-12}$	$3 \cdot 10^{-9}$
Radon (86)	Rn 220	S	$3 \cdot 10^{-7}$		$1 \cdot 10^{-9}$	
	Rn 222 [1]		$3 \cdot 10^{-7}$		$3 \cdot 10^{-9}$	
Rhenium (75)	Re 183	S	$3 \cdot 10^{-6}$	$2 \cdot 10^{-5}$	$9 \cdot 10^{-8}$	$6 \cdot 10^{-7}$
		I	$2 \cdot 10^{-6}$	$8 \cdot 10^{-7}$	$5 \cdot 10^{-8}$	$3 \cdot 10^{-7}$
	Re 186	S	$6 \cdot 10^{-7}$	$3 \cdot 10^{-6}$	$2 \cdot 10^{-8}$	$9 \cdot 10^{-8}$
		I	$2 \cdot 10^{-7}$	$1 \cdot 10^{-6}$	$6 \cdot 10^{-9}$	$5 \cdot 10^{-8}$
	Re 187	S	$9 \cdot 10^{-6}$	$7 \cdot 10^{-5}$	$3 \cdot 10^{-7}$	$3 \cdot 10^{-6}$
		I	$5 \cdot 10^{-7}$	$4 \cdot 10^{-5}$	$2 \cdot 10^{-8}$	$2 \cdot 10^{-6}$
	Re 188	S	$4 \cdot 10^{-7}$	$2 \cdot 10^{-6}$	$1 \cdot 10^{-8}$	$6 \cdot 10^{-7}$
		I	$2 \cdot 10^{-7}$	$9 \cdot 10^{-7}$	$6 \cdot 10^{-9}$	$3 \cdot 10^{-7}$
Rhodium (45)	Rh 103m	S	$8 \cdot 10^{-5}$	$4 \cdot 10^{-4}$	$3 \cdot 10^{-6}$	$1 \cdot 10^{-5}$
		I	$6 \cdot 10^{-5}$	$3 \cdot 10^{-4}$	$2 \cdot 10^{-6}$	$1 \cdot 10^{-5}$
	Rh 105	S	$8 \cdot 10^{-7}$	$4 \cdot 10^{-6}$	$3 \cdot 10^{-8}$	$1 \cdot 10^{-6}$
		I	$5 \cdot 10^{-7}$	$3 \cdot 10^{-6}$	$2 \cdot 10^{-8}$	$1 \cdot 10^{-6}$
Rubidium (37)	Rb 86	S	$3 \cdot 10^{-7}$	$2 \cdot 10^{-6}$	$1 \cdot 10^{-8}$	$7 \cdot 10^{-8}$
		I	$7 \cdot 10^{-6}$	$7 \cdot 10^{-6}$	$2 \cdot 10^{-7}$	$2 \cdot 10^{-6}$
	Rb 87	S	$5 \cdot 10^{-7}$	$3 \cdot 10^{-6}$	$2 \cdot 10^{-8}$	$1 \cdot 10^{-6}$
		I	$7 \cdot 10^{-6}$	$5 \cdot 10^{-6}$	$2 \cdot 10^{-7}$	$2 \cdot 10^{-6}$
Ruthenium (44)	Ru 97	S	$2 \cdot 10^{-6}$	$1 \cdot 10^{-5}$	$8 \cdot 10^{-8}$	$4 \cdot 10^{-7}$
		I	$2 \cdot 10^{-6}$	$1 \cdot 10^{-5}$	$6 \cdot 10^{-8}$	$3 \cdot 10^{-7}$
	Ru 103	S	$5 \cdot 10^{-7}$	$2 \cdot 10^{-6}$	$2 \cdot 10^{-8}$	$8 \cdot 10^{-8}$
		I	$8 \cdot 10^{-6}$	$2 \cdot 10^{-6}$	$3 \cdot 10^{-7}$	$8 \cdot 10^{-8}$
	Ru 105	S	$7 \cdot 10^{-7}$	$3 \cdot 10^{-6}$	$2 \cdot 10^{-8}$	$1 \cdot 10^{-7}$
		I	$5 \cdot 10^{-7}$	$3 \cdot 10^{-6}$	$2 \cdot 10^{-8}$	$1 \cdot 10^{-7}$
	Ru 106	S	$8 \cdot 10^{-6}$	$4 \cdot 10^{-5}$	$3 \cdot 10^{-7}$	$1 \cdot 10^{-6}$
		I	$6 \cdot 10^{-6}$	$3 \cdot 10^{-5}$	$2 \cdot 10^{-7}$	$1 \cdot 10^{-6}$
Samarium (62)	Sm 147	S	$7 \cdot 10^{-11}$	$2 \cdot 10^{-7}$	$2 \cdot 10^{-11}$	$6 \cdot 10^{-9}$
		I	$3 \cdot 10^{-10}$	$2 \cdot 10^{-7}$	$9 \cdot 10^{-12}$	$7 \cdot 10^{-9}$
	Sm 151	S	$6 \cdot 10^{-6}$	$1 \cdot 10^{-5}$	$2 \cdot 10^{-7}$	$4 \cdot 10^{-7}$
		I	$1 \cdot 10^{-6}$	$1 \cdot 10^{-5}$	$5 \cdot 10^{-8}$	$4 \cdot 10^{-7}$
	Sm 153	S	$5 \cdot 10^{-7}$	$2 \cdot 10^{-6}$	$2 \cdot 10^{-8}$	$8 \cdot 10^{-8}$
		I	$4 \cdot 10^{-7}$	$2 \cdot 10^{-6}$	$1 \cdot 10^{-8}$	$8 \cdot 10^{-8}$
Scandium (21)	Sc 46	S	$2 \cdot 10^{-7}$	$1 \cdot 10^{-6}$	$8 \cdot 10^{-9}$	$4 \cdot 10^{-8}$
		I	$2 \cdot 10^{-6}$	$1 \cdot 10^{-6}$	$8 \cdot 10^{-8}$	$4 \cdot 10^{-8}$
	Sc 47	S	$6 \cdot 10^{-7}$	$3 \cdot 10^{-6}$	$2 \cdot 10^{-8}$	$9 \cdot 10^{-8}$
		I	$5 \cdot 10^{-7}$	$3 \cdot 10^{-6}$	$2 \cdot 10^{-8}$	$9 \cdot 10^{-8}$
	Sc 48	S	$2 \cdot 10^{-7}$	$8 \cdot 10^{-7}$	$6 \cdot 10^{-9}$	$3 \cdot 10^{-8}$
		I	$1 \cdot 10^{-7}$	$8 \cdot 10^{-7}$	$5 \cdot 10^{-9}$	$3 \cdot 10^{-8}$
Selenium 34)	Se 75	S	$1 \cdot 10^{-6}$	$9 \cdot 10^{-6}$	$4 \cdot 10^{-8}$	$3 \cdot 10^{-7}$
		I	$1 \cdot 10^{-6}$	$8 \cdot 10^{-6}$	$4 \cdot 10^{-8}$	$3 \cdot 10^{-7}$
Silicon (14)	Si 31	S	$6 \cdot 10^{-6}$	$3 \cdot 10^{-5}$	$2 \cdot 10^{-7}$	$9 \cdot 10^{-7}$
		I	$1 \cdot 10^{-6}$	$6 \cdot 10^{-6}$	$3 \cdot 10^{-8}$	$2 \cdot 10^{-7}$
Silver (47)	Ag 105	S	$6 \cdot 10^{-7}$	$3 \cdot 10^{-6}$	$2 \cdot 10^{-8}$	$1 \cdot 10^{-7}$
		I	$8 \cdot 10^{-7}$	$3 \cdot 10^{-6}$	$3 \cdot 10^{-8}$	$1 \cdot 10^{-7}$
	Ag 110m	S	$2 \cdot 10^{-7}$	$9 \cdot 10^{-7}$	$7 \cdot 10^{-9}$	$3 \cdot 10^{-8}$
		I	$1 \cdot 10^{-7}$	$9 \cdot 10^{-7}$	$3 \cdot 10^{-9}$	$3 \cdot 10^{-8}$
	Ag 111	S	$3 \cdot 10^{-7}$	$1 \cdot 10^{-6}$	$1 \cdot 10^{-8}$	$4 \cdot 10^{-8}$
		I	$2 \cdot 10^{-7}$	$1 \cdot 10^{-6}$	$8 \cdot 10^{-9}$	$4 \cdot 10^{-8}$
Sodium (11)	Na 22	S	$2 \cdot 10^{-7}$	$1 \cdot 10^{-6}$	$6 \cdot 10^{-9}$	$4 \cdot 10^{-8}$
		I	$9 \cdot 10^{-6}$	$9 \cdot 10^{-6}$	$3 \cdot 10^{-7}$	$3 \cdot 10^{-7}$
	Na 24	S	$1 \cdot 10^{-6}$	$6 \cdot 10^{-6}$	$4 \cdot 10^{-8}$	$2 \cdot 10^{-7}$
		I	$1 \cdot 10^{-7}$	$8 \cdot 10^{-7}$	$5 \cdot 10^{-9}$	$3 \cdot 10^{-8}$
Strontium (38)	Sr 85m	S	$4 \cdot 10^{-6}$	$2 \cdot 10^{-5}$	$1 \cdot 10^{-7}$	$7 \cdot 10^{-7}$
		I	$3 \cdot 10^{-6}$	$2 \cdot 10^{-5}$	$1 \cdot 10^{-7}$	$7 \cdot 10^{-7}$
	Sr 85	S	$2 \cdot 10^{-7}$	$3 \cdot 10^{-6}$	$8 \cdot 10^{-9}$	$1 \cdot 10^{-7}$
		I	$1 \cdot 10^{-7}$	$5 \cdot 10^{-7}$	$4 \cdot 10^{-9}$	$2 \cdot 10^{-8}$
	Sr 89	S	$3 \cdot 10^{-8}$	$3 \cdot 10^{-7}$	$3 \cdot 10^{-10}$	$3 \cdot 10^{-8}$
		I	$4 \cdot 10^{-8}$	$6 \cdot 10^{-7}$	$1 \cdot 10^{-9}$	$3 \cdot 10^{-8}$
	Sr 90	S	$1 \cdot 10^{-9}$	$1 \cdot 10^{-7}$	$3 \cdot 10^{-11}$	$3 \cdot 10^{-9}$

APPENDIX B—CONCENTRATIONS IN AIR AND WATER ABOVE NATURAL BACKGROUND—Continued

[See footnotes at end of Appendix B]

Element (atomic number)	Isotope [1]		Table I		Table II	
			Col. 1—Air (μCi/ml)	Col. 2—Water (μCi/ml)	Col. 1—Air (μCi/ml)	Col. 2—Water (μCi/ml)
		I	$5 \cdot 10^{-6}$	$1 \cdot 10^{-5}$	$2 \cdot 10^{-8}$	$4 \cdot 10^{-7}$
	Sr 91	S	$4 \cdot 10^{-7}$	$2 \cdot 10^{-6}$	$2 \cdot 10^{-8}$	$7 \cdot 10^{-8}$
		I	$3 \cdot 10^{-7}$	$1 \cdot 10^{-6}$	$9 \cdot 10^{-9}$	$5 \cdot 10^{-8}$
	Sr 92	S	$4 \cdot 10^{-7}$	$2 \cdot 10^{-6}$	$2 \cdot 10^{-8}$	$7 \cdot 10^{-8}$
		I	$3 \cdot 10^{-7}$	$2 \cdot 10^{-6}$	$1 \cdot 10^{-8}$	$6 \cdot 10^{-8}$
Sulfur (16)	S 35	S	$3 \cdot 10^{-7}$	$2 \cdot 10^{-6}$	$9 \cdot 10^{-9}$	$6 \cdot 10^{-8}$
		I	$3 \cdot 10^{-7}$	$8 \cdot 10^{-7}$	$9 \cdot 10^{-9}$	$3 \cdot 10^{-8}$
Tantalum (73)	Ta 182	S	$4 \cdot 10^{-8}$	$1 \cdot 10^{-7}$	$1 \cdot 10^{-9}$	$4 \cdot 10^{-9}$
		I	$2 \cdot 10^{-8}$	$1 \cdot 10^{-7}$	$7 \cdot 10^{-10}$	$4 \cdot 10^{-9}$
Technetium (43)	Tc 96m	S	$8 \cdot 10^{-6}$	$4 \cdot 10^{-5}$	$3 \cdot 10^{-7}$	$1 \cdot 10^{-6}$
		I	$3 \cdot 10^{-6}$	$3 \cdot 10^{-5}$	$1 \cdot 10^{-7}$	$1 \cdot 10^{-6}$
	Tc 96	S	$6 \cdot 10^{-7}$	$3 \cdot 10^{-6}$	$2 \cdot 10^{-8}$	$1 \cdot 10^{-7}$
		I	$2 \cdot 10^{-7}$	$1 \cdot 10^{-6}$	$8 \cdot 10^{-9}$	$5 \cdot 10^{-8}$
	Tc 97m	S	$2 \cdot 10^{-6}$	$1 \cdot 10^{-5}$	$8 \cdot 10^{-8}$	$4 \cdot 10^{-7}$
		I	$2 \cdot 10^{-6}$	$5 \cdot 10^{-6}$	$5 \cdot 10^{-8}$	$2 \cdot 10^{-7}$
	Tc 97	S	$1 \cdot 10^{-5}$	$5 \cdot 10^{-5}$	$4 \cdot 10^{-7}$	$2 \cdot 10^{-6}$
		I	$3 \cdot 10^{-7}$	$2 \cdot 10^{-6}$	$1 \cdot 10^{-8}$	$8 \cdot 10^{-8}$
	99m	S	$4 \cdot 10^{-7}$	$2 \cdot 10^{-6}$	$1 \cdot 10^{-8}$	$6 \cdot 10^{-8}$
		I	$1 \cdot 10^{-6}$	$8 \cdot 10^{-6}$	$5 \cdot 10^{-8}$	$3 \cdot 10^{-7}$
	Tc 99	S	$2 \cdot 10^{-6}$	$1 \cdot 10^{-5}$	$7 \cdot 10^{-8}$	$3 \cdot 10^{-7}$
		I	$6 \cdot 10^{-7}$	$5 \cdot 10^{-6}$	$2 \cdot 10^{-8}$	$2 \cdot 10^{-7}$
Tellurium (52)	Te 125m	S	$4 \cdot 10^{-7}$	$5 \cdot 10^{-6}$	$1 \cdot 10^{-8}$	$2 \cdot 10^{-7}$
		I	$1 \cdot 10^{-7}$	$3 \cdot 10^{-6}$	$4 \cdot 10^{-9}$	$1 \cdot 10^{-7}$
	Te 127m	S	$1 \cdot 10^{-7}$	$2 \cdot 10^{-6}$	$5 \cdot 10^{-9}$	$6 \cdot 10^{-8}$
		I	$4 \cdot 10^{-7}$	$2 \cdot 10^{-6}$	$1 \cdot 10^{-8}$	$5 \cdot 10^{-8}$
	Te 127	S	$2 \cdot 10^{-6}$	$8 \cdot 10^{-6}$	$6 \cdot 10^{-8}$	$3 \cdot 10^{-7}$
		I	$9 \cdot 10^{-7}$	$5 \cdot 10^{-6}$	$3 \cdot 10^{-8}$	$2 \cdot 10^{-7}$
	Te 129m	S	$8 \cdot 10^{-7}$	$1 \cdot 10^{-6}$	$3 \cdot 10^{-8}$	$3 \cdot 10^{-8}$
		I	$3 \cdot 10^{-7}$	$6 \cdot 10^{-7}$	$1 \cdot 10^{-8}$	$2 \cdot 10^{-8}$
	Te 129	S	$5 \cdot 10^{-6}$	$2 \cdot 10^{-5}$	$2 \cdot 10^{-7}$	$8 \cdot 10^{-7}$
		I	$4 \cdot 10^{-6}$	$2 \cdot 10^{-5}$	$1 \cdot 10^{-7}$	$8 \cdot 10^{-7}$
	Te 131m	S	$4 \cdot 10^{-7}$	$2 \cdot 10^{-6}$	$1 \cdot 10^{-8}$	$6 \cdot 10^{-8}$
		I	$2 \cdot 10^{-7}$	$1 \cdot 10^{-6}$	$6 \cdot 10^{-9}$	$4 \cdot 10^{-8}$
	Te 132	S	$2 \cdot 10^{-7}$	$9 \cdot 10^{-7}$	$7 \cdot 10^{-9}$	$3 \cdot 10^{-8}$
		I	$1 \cdot 10^{-7}$	$6 \cdot 10^{-7}$	$4 \cdot 10^{-9}$	$2 \cdot 10^{-8}$
Terbium (65)	Tb 160	S	$1 \cdot 10^{-7}$	$1 \cdot 10^{-6}$	$3 \cdot 10^{-9}$	$4 \cdot 10^{-8}$
		I	$3 \cdot 10^{-7}$	$1 \cdot 10^{-6}$	$1 \cdot 10^{-8}$	$4 \cdot 10^{-8}$
Thallium (81)	Tl 200	S	$3 \cdot 10^{-6}$	$1 \cdot 10^{-5}$	$9 \cdot 10^{-8}$	$4 \cdot 10^{-7}$
		I	$1 \cdot 10^{-6}$	$7 \cdot 10^{-6}$	$4 \cdot 10^{-8}$	$2 \cdot 10^{-7}$
	Tl 201	S	$2 \cdot 10^{-6}$	$9 \cdot 10^{-6}$	$7 \cdot 10^{-8}$	$3 \cdot 10^{-7}$
		I	$9 \cdot 10^{-7}$	$5 \cdot 10^{-6}$	$3 \cdot 10^{-8}$	$2 \cdot 10^{-7}$
	Tl 202	S	$8 \cdot 10^{-7}$	$4 \cdot 10^{-6}$	$3 \cdot 10^{-8}$	$1 \cdot 10^{-7}$
		I	$2 \cdot 10^{-7}$	$2 \cdot 10^{-6}$	$8 \cdot 10^{-9}$	$7 \cdot 10^{-8}$
	Tl 204	S	$6 \cdot 10^{-7}$	$3 \cdot 10^{-6}$	$2 \cdot 10^{-8}$	$1 \cdot 10^{-7}$
		I	$3 \cdot 10^{-6}$	$2 \cdot 10^{-5}$	$9 \cdot 10^{-8}$	$6 \cdot 10^{-7}$
Thorium (90)	Th 227	S	$3 \cdot 10^{-11}$	$5 \cdot 10^{-7}$	$1 \cdot 10^{-11}$	$2 \cdot 10^{-9}$
		I	$2 \cdot 10^{-11}$	$5 \cdot 10^{-7}$	$8 \cdot 10^{-12}$	$2 \cdot 10^{-9}$
	Th 228	S	$9 \cdot 10^{-12}$	$2 \cdot 10^{-7}$	$3 \cdot 10^{-12}$	$7 \cdot 10^{-10}$
		I	$6 \cdot 10^{-12}$	$4 \cdot 10^{-7}$	$2 \cdot 10^{-12}$	$1 \cdot 10^{-9}$
	Th 230	S	$2 \cdot 10^{-12}$	$5 \cdot 10^{-8}$	$8 \cdot 10^{-12}$	$2 \cdot 10^{-9}$
		I	$1 \cdot 10^{-12}$	$9 \cdot 10^{-8}$	$3 \cdot 10^{-12}$	$3 \cdot 10^{-9}$
	Th 231	S	$1 \cdot 10^{-6}$	$7 \cdot 10^{-6}$	$5 \cdot 10^{-8}$	$2 \cdot 10^{-7}$
		I	$1 \cdot 10^{-6}$	$7 \cdot 10^{-6}$	$4 \cdot 10^{-8}$	$2 \cdot 10^{-7}$
	Th 232	S	$3 \cdot 10^{-11}$	$5 \cdot 10^{-8}$	$1 \cdot 10^{-12}$	$2 \cdot 10^{-9}$
		I	$3 \cdot 10^{-11}$	$1 \cdot 10^{-7}$	$1 \cdot 10^{-12}$	$4 \cdot 10^{-9}$
	Th natural	S	$6 \cdot 10^{-11}$	$6 \cdot 10^{-8}$	$2 \cdot 10^{-12}$	$2 \cdot 10^{-9}$
		I	$6 \cdot 10^{-11}$	$6 \cdot 10^{-8}$	$2 \cdot 10^{-12}$	$2 \cdot 10^{-9}$
	Th 234	S	$6 \cdot 10^{-6}$	$5 \cdot 10^{-6}$	$2 \cdot 10^{-8}$	$2 \cdot 10^{-7}$
		I	$3 \cdot 10^{-6}$	$5 \cdot 10^{-6}$	$1 \cdot 10^{-8}$	$2 \cdot 10^{-7}$
Thulium (69)	Tm 170	S	$4 \cdot 10^{-7}$	$1 \cdot 10^{-6}$	$1 \cdot 10^{-8}$	$5 \cdot 10^{-8}$
		I	$3 \cdot 10^{-7}$	$1 \cdot 10^{-6}$	$1 \cdot 10^{-8}$	$5 \cdot 10^{-8}$
	Tm 171	S	$1 \cdot 10^{-7}$	$1 \cdot 10^{-6}$	$4 \cdot 10^{-9}$	$5 \cdot 10^{-8}$
		I	$2 \cdot 10^{-7}$	$1 \cdot 10^{-6}$	$8 \cdot 10^{-9}$	$5 \cdot 10^{-8}$
Tin (50)	Sn 113	S	$4 \cdot 10^{-7}$	$2 \cdot 10^{-6}$	$1 \cdot 10^{-8}$	$9 \cdot 10^{-8}$
		I	$5 \cdot 10^{-7}$	$2 \cdot 10^{-6}$	$2 \cdot 10^{-8}$	$8 \cdot 10^{-8}$

APPENDIX B—CONCENTRATIONS IN AIR AND WATER ABOVE NATURAL BACKGROUND—Continued

(See footnotes at end of Appendix B)

Element (atomic number)	Isotope [1]		Table I		Table II	
			Col 1—Air (μCi/ml)	Col 2—Water (μCi/ml)	Col 1—Air (μCi/ml)	Col 2—Water (μCi/ml)
	Sn 125	S	1 · 10 [-7]	5 · 10 [-4]	4 · 10 [-9]	2 10 [-5]
		I	8 · 10 [-8]	5 · 10 [-4]	3 · 10 [-9]	2 10 [-5]
Tungsten (Wolfram) (74)	W 181	S	2 · 10 [-6]	1 · 10 [-3]	8 10 [-9]	4 10 [-5]
		I	1 · 10 [-7]	1 · 10 [-3]	4 10 [-9]	3 · 10 [-5]
	W 185	S	8 10 [-7]	4 · 10 [-4]	3 10 [-8]	1 · 10 [-5]
		I	1 · 10 [-7]	3 · 10 [-4]	4 10 [-9]	1 10 [-5]
	W 187	S	4 10 [-7]	2 10 [-4]	2 10 [-8]	7 · 10 [-6]
		I	3 10 [-7]	2 10 [-4]	1 10 [-8]	6 10
Uranium (92)	U 230	S	3 · 10 [-10]	1 10 [-6]	1 10 [-11]	5 · 10 [-8]
		I	1 · 10 [-10]	1 10 [-6]	4 10 [-11]	5 10 [-8]
	U 232	S	1 · 10 [-10]	8 · 10 [-7]	3 · 10 [-11]	3 10 [-8]
		I	3 10 [-11]	8 · 10 [-7]	9 · 10 [-12]	3 10 [-8]
	U 233	S	5 · 10 [-10]	9 · 10 [-7]	2 · 10 [-11]	3 10 [-8]
		I	1 · 10 [-10]	9 · 10 [-7]	4 · 10 [-12]	3 · 10 [-8]
	U 234	S [3]	6 · 10 [-10]	9 · 10 [-7]	2 · 10 [-11]	3 10 [-8]
		I	1 · 10 [-10]	9 · 10 [-7]	4 10 [-11]	3 · 10 [-8]
	U 235	S [3]	5 · 10 [-10]	8 10 [-7]	2 · 10 [-11]	3 · 10 [-8]
		I	1 · 10 [-10]	8 10 [-7]	4 · 10 [-11]	3 · 10 [-8]
	U 236	S	6 · 10 [-10]	1 10 [-6]	2 10 [-11]	3 10 [-8]
		I	1 · 10 [-10]	1 · 10 [-6]	4 · 10 [-12]	3 10 [-8]
	U 238	S [3]	7 · 10 [-11]	1 10 [-6]	3 · 10 [-12]	4 · 10 [-8]
		I	1 · 10 [-10]	1 · 10 [-6]	5 · 10 [-12]	4 · 10 [-8]
	U 240	S	2 · 10 [-7]	1 · 10 [-6]	8 · 10 [-9]	3 · 10 [-8]
		I	2 · 10 [-7]	1 · 10 [-6]	6 · 10 [-9]	3 · 10 [-8]
	U natural	S [3]	1 · 10 [-10]	1 · 10 [-6]	5 · 10 [-11]	3 · 10 [-8]
		I	1 · 10 [-10]	1 · 10 [-6]	5 · 10 [-12]	3 · 10 [-8]
Vanadium (23)	V 48	S	2 · 10 [-7]	9 · 10 [-7]	6 · 10 [-9]	3 · 10 [-8]
		I	6 10 [-8]	6 · 10 [-7]	2 · 10 [-9]	3 · 10 [-8]
Xenon (54)	Xe 131m	Sub	2 · 10 [-5]	..	4 · 10 [-7]	
	Xe 133	Sub	1 · 10 [-5]	.....	3 · 10 [-7]	
	Xe 133m	Sub	1 10 [-5]	..	3 · 10 [-7]	
	Xe 135	Sub	4 · 10 [-6]	.	1 · 10 [-7]	
Ytterbium (70)	Yb 175	S	7 · 10 [-7]	3 · 10 [-5]	2 · 10 [-8]	1 · 10 [-6]
		I	6 · 10 [-7]	3 · 10 [-5]	2 10 [-8]	1 · 10 [-6]
Yttrium (39)	Y 90	S	1 · 10 [-7]	6 · 10 [-6]	4 10 [-9]	2 · 10 [-7]
		I	1 · 10 [-7]	6 · 10 [-6]	3 · 10 [-9]	2 10
	Y 91m	S	2 10 [-6]	1 10 [-4]	8 · 10 [-8]	3 10 [-6]
		I	2 · 10 [-6]	1 10 [-4]	6 10 [-8]	3 10 [-6]
	Y 91	S	4 · 10 [-8]	8 · 10 [-6]	1 · 10 [-9]	3 10 [-7]
		I	3 · 10 [-8]	8 · 10 [-6]	1 · 10 [-9]	3 10 [-7]
	Y 92	S	4 · 10 [-7]	2 · 10 [-4]	1 10 [-8]	6 10 [-6]
		I	3 · 10 [-7]	2 · 10 [-4]	1 10 [-8]	6 10 [-6]
	Y 93	S	2 · 10 [-7]	8 10 [-6]	6 10 [-9]	3 10 [-7]
		I	1 · 10 [-7]	8 · 10 [-6]	5 10 [-9]	3 · 10 [-7]
Zinc (30)	Zn 65	S	1 · 10 [-7]	3 10 [-5]	4 10 [-9]	1 10 [-6]
		I	6 · 10 [-8]	5 · 10 [-5]	2 10 [-9]	2 · 10 [-6]
	Zn 69m	S	4 · 10 [-7]	2 · 10 [-4]	1 10 [-8]	7 · 10 [-6]
		I	3 · 10 [-7]	2 · 10 [-4]	1 · 10 [-8]	6 · 10 [-6]
	Zn 69	S	7 · 10 [-6]	5 · 10 [-4]	2 · 10 [-7]	2 · 10 [-5]
		I	9 · 10 [-6]	5 · 10 [-4]	3 · 10 [-7]	2 10 [-5]
Zirconium (40)	Zr 93	S	1 · 10 [-7]	2 · 10 [-4]	4 · 10 [-9]	8 · 10 [-6]
		I	3 · 10 [-7]	2 · 10 [-4]	1 · 10 [-8]	8 · 10 [-6]
	Zr 95	S	1 · 10 [-7]	2 · 10 [-4]	4 · 10 [-9]	6 · 10 [-6]
		I	3 · 10 [-7]	2 · 10 [-4]	1 · 10 [-8]	6 · 10 [-6]
	Zr 97	S	1 · 10 [-7]	5 · 10 [-4]	4 · 10 [-9]	2 · 10 [-5]
		I	9 · 10 [-6]	5 · 10 [-4]	3 · 10 [-7]	2 · 10 [-5]
Any single radionuclide not listed above with decay mode other than alpha emission or spontaneous fission and with radioactive half life less than 2 hours		Sub	1 · 10 [-6]	....	3 · 10 [-8]	..

APPENDIX B—CONCENTRATIONS IN AIR AND WATER ABOVE NATURAL BACKGROUND—Continued

(See footnotes at end of Appendix B)

Element (atomic number)	Isotope [1]		Table I		Table II	
			Col 1—Air (μCi/ml)	Col 2—Water (μCi/ml)	Col 1—Air (μCi/ml)	Col 2—Water (μCi/ml)
Any single radionuclide not listed above with decay mode other than alpha emission or spontaneous fission and with radioactive half life greater than 2 hours			3 10 [-7]	9 10	1 · 10 [-8]	3 10 [-5]
Any single radionuclide not listed above, which decays by alpha emission or spontaneous fission			6 10 [-11]	4 · 10 [-7]	2 · 10 [-11]	7 10 [-8]

[1] Soluble (S), insoluble (I)

[2] "Sub" means that values given are for submersion in a semispherical infinite cloud of airborne material

[3] These radon concentrations are appropriate for protection from radon 222 combined with its short lived daughters Alternatively, the value in Table I may be replaced by one-third (⅓) working level (A "working level" is defined as any combination of short lived radon 222 daughters polonium 218, lead 214 bismuth 214 and polonium-214, in one liter of air, without regard to the degree of equilibrium that will result in the ultimate emission of 1 3 · 10 [5] MeV of alpha particle energy) The Table II value may be replaced by one-thirtieth (1/30) of a "working level" The limit on radon 222 concentrations in restricted areas may be based on an annual average

[4] For soluble mixtures of U-238, U-234 and U-235 in air chemical toxicity may be the limiting factor If the percent by weight-enrichment) of U-235 is less than 5, the concentration value for a 40-hour workweek Table I, is 0 2 milligrams uranium per cubic meter of air average For any enrichment, the product of the average concentration and time of exposure during a 40-hour workweek shall not exceed 8 · 10 [-1] SA μCi-hr/ml where SA is the specific activity of the uranium inhaled The concentration value for Table II is 0 007 milligrams uranium per cubic meter of air The specific activity for natural uranium is 6 77 · 10 [-7] curies per gram U The specific activity for other mixtures of U-238 U-235 and U-234, if not known shall be

SA = 3 6 · 10 [-7] curies/gram U U depleted

SA = (0 4 + 0 38 E + 0 0034 E [2]) 10 [-6] E 0 72

where E is the percentage by weight of U-235 expressed as percent

NOTE. In any case where there is a mixture in air or water of more than one radionuclide the limiting values for purposes of this Appendix should be determined as follows

1. If the identity and concentration of each radionuclide in the mixture are known the limiting values should be derived as follows: Determine, for each radionuclide in the mixture, the ratio between the quantity present in the mixture and the limit otherwise established in Appendix B for the specific radionuclide when not in a mixture The sum of such ratios for all the radionuclides in the mixture may not exceed "1 (i.e unity")

EXAMPLE If radionuclides A, B, and C are present in concentrations C_A, C_B, and C_C and if the applicable MPC s are MPC$_A$, and MPC$_B$, and MPC$_C$, respectively, then the concentrations shall be limited so that the following relationship exists

$(C_A/MPC_A) + (C_B/MPC_B) + (C_C/MPC_C) \leq 1$

2 If either the identity or the concentration of any radionuclide in the mixture is not known the limiting values for purposes of Appendix B shall be

a. For purposes of Table I Col 1—6 10 [-11]

b For purposes of Table I, Col 2—4 · 10 [-7]

c For purposes of Table II Col 1—2 10 [-11]

d For purposes of Table II Col 2—3 10 [-8]

3 If any of the conditions specified below are met the corresponding values specified below may be used in lieu of those specified in paragraph 2 above

a If the identity of each radionuclide in the mixture is known but the concentration of one or more of the radionuclides in the mixture is not known the concentration limit for the mixture is the limit specified in Appendix B for the radionuclide in the mixture having the lowest concentration limit or

b. If the identity of each radionuclide in the mixture is not known but it is known that certain radionuclides specified in Appendix B are not present in the mixture the concentration limit for the mixture is the lowest concentration limit specified in Appendix "B" for any radionuclide which is not known to be absent from the mixture or

c Element (atomic number) and isotope	Table I		Table II	
	Col 1—Air (μCi/ml)	Col 2—Water (μCi/ml)	Col 1—Air (μCi/ml)	Col 2—Water (μCi/ml)
If it is known that Sr 90, I 125 I 126, I 129, I 131 (I 133, Table II only) Pb 210, Po 210 At 211, Ra 223, Ra 224, Ra 226 Ac 227, Ra 228, Th 230 Pa 231, Th 232, Th-nat, Cm 248 Cf 254, and Fm 256 are not present		9 · 10 [-8]		3 10 [-9]
If it is known that Sr 90 I 125, I 126, I 129 (I 131 I 133, Table II only), Pb 210, Po 210, Ra 223, Ra 226, Ra 228, Pa 231 Th nat, Cm 248, Cf 254 and Fm 256 are not present		6 10 [-7]		2 10 [-8]
If it is known that Sr 90, I 129 (I 125, I 126 I 131, Table II only), Pb 210 Ra 226, Ra 228, Cm 248 and Cf 254 are not present		2 10 [-7]		6 10 [-9]
If it is known that (I 129, Table II only), Ra 226 and Ra 228 are not present		3 10 [-8]		1 10 [-9]
If it is known that alpha-emitters and Sr 90, I 129, Pb 210 Ac 227 Ra 228 Pa 230, Pu 241, and Bk 249 are not present	3 10 [-12]		1 10 [-13]	

c Element (atomic number) and isotope	Table I		Table II	
	Col. 1—Air (μCi/ml)	Col. 2—Water (μCi/ml)	Col. 1—Air (μCi/ml)	Col. 2—Water (μCi/ml)
If it is known that alpha emitters and Pb 210, Ac 227, Ra 226, and Pu 241 are not present	3×10^{-12}		1×10^{-11}	
If it is known that alpha-emitters and Ac 227 are not present	3×10^{-11}		1×10^{-10}	
If it is known that Ac 227, Th 230, Pa 231, Pu 238, Pu 239, Pu 240, Pu 242, Pu 244, Cm 248, Cf 249 and Cf 251 are not present	3×10^{-10}		1×10^{-10}	

4 If a mixture of radionuclides consists of uranium and its daughters in ore dust prior to chemical separation of the uranium from the ore, the values specified below may be used for uranium and its daughters through radium 226, instead of those from paragraphs 1, 2, or 3 above

a For purposes of Table I, Col 1—1×10^{-12} μCi/ml gross alpha activity; or 5×10^{-11} μCi/ml natural uranium or 75 micrograms per cubic meter of air natural uranium

b For purposes of Table II, Col. 1—3×10^{-12} μCi/ml gross alpha activity; 2×10^{-11} μCi/ml natural uranium or 3 micrograms per cubic meter of air natural uranium

5 For purposes of this note, a radionuclide may be considered as not present in a mixture if (a) the ratio of the concentration of that radionuclide in the mixture (C_x) to the concentration limit for that radionuclide specified in Table II of Appendix "B" (MPC_x) does not exceed 1/10, (i.e. $C_x/MPC_x \leq 1/10$) and (b) the sum of such ratios for all the radionuclides considered as not present in the mixture does not exceed 1/2 i.e.

$(C_1/MPC_1 + C_2/MPC_2 + \ldots \leq 1/2)$

[25 FR 10914, Nov. 17, 1960, as amended at 25 FR 13953, Dec. 30, 1960; 26 FR 11046, Nov. 25, 1961; 29 FR 14435, Oct. 21, 1964; 30 FR 15801, Dec. 22, 1965; 31 FR 86, Jan. 5, 1966; 37 FR 23319, Nov. 2, 1972; 38 FR 29314, Oct. 24, 1973; 39 FR 23990, June 28, 1974; 39 FR 25463, July 11, 1974; 39 FR 27121, July 25, 1974; 40 FR 50705, Oct. 31, 1975]

APPENDIX C

Material	Microcuries
Americium-241	0.1
Antimony-122	100
Antimony-124	10
Antimony-125	10
Arsenic-73	100
Arsenic-74	10
Arsenic-76	10
Arsenic-77	100
Barium-131	10
Barium-133	10
Barium-140	10
Bismuth-210	1
Bromine-82	10
Cadmium-109	10
Cadmium-115m	10
Cadmium-115	100
Calcium-45	10
Calcium-47	10
Carbon-14	100
Cerium-141	100
Cerium-143	100
Cerium-144	1
Cesium-131	1,000
Cesium-134m	100
Cesium-134	1
Cesium-135	10
Cesium-136	10
Cesium-137	10
Chlorine-36	10
Chlorine-38	10
Chromium-51	1,000
Cobalt-58m	10
Cobalt-58	10
Cobalt-60	1
Copper-64	100
Dysprosium-165	10
Dysprosium-166	100

APPENDIX C—Continued

Material	Microcuries
Erbium-169	100
Erbium-171	100
Europium-152 9.2 h	100
Europium-152 13 yr	1
Europium-154	1
Europium-155	10
Fluorine-18	1,000
Gadolinium-153	10
Gadolinium-159	100
Gallium-72	10
Germanium-71	100
Gold-198	100
Gold-199	100
Hafnium-181	10
Holmium-166	100
Hydrogen-3	1,000
Indium-113m	100
Indium-114m	10
Indium-115m	100
Indium-115	10
Iodine-125	1
Iodine-126	1
Iodine-129	0.1
Iodine-131	1
Iodine-132	10
Iodine-133	1
Iodine-134	10
Iodine-135	10
Iridium-192	10
Iridium-194	100
Iron-55	100
Iron-59	10
Krypton-85	100
Krypton-87	10
Lanthanum-140	10
Lutetium-177	100
Manganese-52	10
Manganese-54	10

APPENDIX C—Continued

Material	Microcuries
Manganese-56	10
Mercury-197m	100
Mercury-197	100
Mercury-203	10
Molybdenum-99	100
Neodymium-147	100
Neodymium-149	100
Nickel-59	100
Nickel-63	10
Nickel-65	100
Niobium-93m	10
Niobium-95	10
Niobium-97	10
Osmium-185	10
Osmium-191m	100
Osmium-191	100
Osmium-193	100
Palladium-103	100
Palladium-109	100
Phosphorus-32	10
Platinum-191	100
Platinum-193m	100
Platinum-193	100
Platinum-197m	100
Platinum-197	100
Plutonium-239	0.1
Polonium-210	0.1
Potassium-42	10
Praseodymium-142	100
Praseodymium-143	100
Promethium-147	10
Promethium-149	10
Radium-226	0.1
Rhenium-186	100
Rhenium-188	100
Rhodium-103m	100
Rhodium-105	100
Rubidium-86	10
Rubidium-87	10
Ruthenium-97	100
Ruthenium-103	10
Ruthenium-105	10
Ruthenium-106	1
Samarium-151	10
Samarium-153	100
Scandium-46	10
Scandium-47	100
Scandium-48	10
Selenium-75	10
Silicon-31	100
Silver-105	10
Silver-110m	1
Silver-111	100
Sodium-24	10
Strontium-85	10
Strontium-89	1
Strontium-90	0.1
Strontium-91	10
Strontium-92	10
Sulphur-35	100
Tantalum-182	10
Technetium-96	10
Technetium-97m	100
Technetium-97	100
Technetium-99m	100
Technetium-99	10
Tellurium-125m	10

APPENDIX C—Continued

Material	Microcuries
Tellurium-127m	10
Tellurium-127	100
Tellurium-129m	10
Tellurium-129	100
Tellurium-131m	10
Tellurium-132	10
Terbium-160	10
Thallium-200	100
Thallium-201	100
Thallium-202	100
Thallium-204	10
Thorium (natural)[2]	100
Thulium-170	10
Thulium-171	10
Tin-113	10
Tin-125	10
Tungsten-181	10
Tungsten-185	10
Tungsten-187	100
Uranium (natural)[3]	100
Uranium-233	0.1
Uranium-234—Uranium-235	0.1
Vanadium-48	10
Xenon-131m	1,000
Xenon-133	100
Xenon-135	100
Ytterbium-175	100
Yttrium-90	10
Yttrium-91	10
Yttrium-92	100
Yttrium-93	100
Zinc-65	10
Zinc-69m	100
Zinc-69	1,000
Zirconium-93	10
Zirconium-95	10
Zirconium-97	10
Any alpha emitting radionuclide not listed above or mixtures of alpha emitters of unknown composition	0.1
Any radionuclide other than alpha emitting radionuclides, not listed above or mixtures of beta emitters of unknown composition	1

[2]Based on alpha disintegration rate of Th 232 Th 230 and their daughter products.

[3]Based on alpha disintegration rate of U 238 U 234 and U-235

NOTE: For purposes of § 20.303, where there is involved a combination of isotopes in known amounts, the limit for the combination should be derived as follows: Determine, for each isotope in the combination, the ratio between the quantity present in the combination and the limit otherwise established for the specific isotope when not in combination. The sum of such ratios for all the isotopes in the combination may not exceed "1" (i.e., "unity").

[35 FR 6425, Apr. 22, 1970, as amended at 36 FR 16898, Aug. 26, 1971; 38 FR 29314, Oct. 24, 1973; 39 FR 23991, June 28, 1974; 45 FR 71763, Oct. 30, 1980]

APPENDIX D—U.S. NUCLEAR REGULATORY COMMISSION REGIONAL OFFICES

	Addresses	Telephone (24 hours)
Region I Connecticut, Delaware, District of Columbia, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont.	USNRC, 475 Allendale Road, King of Prussia, PA 19406	(215) 337-5000 (FTS) 346-5000
Region II Alabama Florida, Georgia, Kentucky, Mississippi, North Carolina, Puerto Rico, South Carolina, Tennessee, Virginia, Virgin Islands, and West Virginia	USNRC, 101 Marietta Street, NW, Suite 2900, Atlanta, GA 30323	(404) 331-4503 (FTS) 242-4503
Region III Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio, and Wisconsin	USNRC, 799 Roosvelt Road, Glen Ellyn, IL 60137.	(708) 790-5500 (FTS) 388-5500
Region IV Arkansas, Colorado, Idaho, Kansas, Louisiana, Montana, Nebraska, New Mexico, North Dakota, Oklahoma, South Dakota, Texas, Utah and Wyoming	USNRC, 611 Ryan Plaza Drive Suite 1000, Arlington, TX 76011	(817) 860-8100 (FTS) 728-8100
Region IV Field Office	USNRC, Region IV Uranium Recovery Field Office, 730 Simms Street P O Box 25325, Denver CO 80225	(303) 236-2805 (FTS) 776-2805
Region V Alaska, Arizona, California, Hawaii, Nevada, Oregon Pacific Trust Territories, and Washington	USNRC, 1450 Maria Lane, Suite 210, Walnut Creek, CA 94596	(415) 943-3700 (FTS) 463-3700

[49 FR 47823, Dec. 7, 1984, as amended at 50 FR 46631, Nov. 12, 1985; 51 FR 35500, Oct. 6, 1986; 53 FR 3862, Feb. 10, 1988; 54 FR 42288, Oct. 16, 1989]

PART 21—REPORTING OF DEFECTS AND NONCOMPLIANCE

GENERAL PROVISIONS

Sec.
21.1 Purpose.
21.2 Scope.
21.3 Definitions.
21.4 Interpretations.
21.5 Communications.
21.6 Posting requirements.
21.7 Exemptions.
21.8 Information collection requirements: OMB approval.

NOTIFICATION

21.21 Notification of failure to comply or existence of a defect.

PROCUREMENT DOCUMENTS

21.31 Procurement documents.

INSPECTIONS, RECORDS

21.41 Inspections.
21.51 Maintenance of records.

ENFORCEMENT

21.61 Failure to notify.

AUTHORITY: Sec. 161, 68 Stat. 948, as amended, sec. 234, 83 Stat. 444, as amended (42 U.S.C. 2201, 2282); secs. 201, as amended, 206, 88 Stat. 1242, as amended, 1246 (42 U.S.C. 5841, 5846).

Sec. 21.2 also issued under secs. 135, 141, Pub. L. 97-425, 96 Stat. 2232, 2241 (42 U.S.C. 10155, 10161).

For the purposes of sec. 223, 68 Stat. 958, as amended (42 U.S.C. 2273); §§ 21.6, 21.21(a) and 21.31 are issued under sec. 161b, 68 Stat. 948, as amended (42 U.S.C. 2201(b)); and §§ 21.21, 21.41 and 21.51 are issued under sec. 161o, 68 Stat. 950, as amended (42 U.S.C. 2201(o)).

SOURCE: 42 FR 28893, June 6, 1977, unless otherwise noted.

GENERAL PROVISIONS

§ 21.1 Purpose.

The regulations in this part establish procedures and requirements for implementation of section 206 of the Energy Reorganization Act of 1974. That section requires any individual director or responsible officer of a firm constructing, owning, operating or supplying the components of any facility or activity which is licensed or otherwise regulated pursuant to the Atomic Energy Act of 1954, as amended, or the Energy Reorganization Act of 1974, who obtains information reasonably indicating: (a) That the facility, activity or basic component supplied to such facility or activity fails to comply with the Atomic Energy Act of 1954, as amended, or any applicable rule, regulation, order, or license of the Commission relating to substantial safety hazards or (b) that the facility, activity, or basic component supplied to such facility or activity contains defects, which could create a substantial safety hazard, to immediately notify the Commission of such failure to comply or such defect, unless he has

actual knowledge that the Commission has been adequately informed of such defect or failure to comply.

§ 21.2 Scope.

The regulations in this part apply, except as specifically provided otherwise in Parts 31, 34, 35, 39, 40, 60, 61, 70, or 72 of this chapter, to each individual, partnership, corporation, or other entity licensed pursuant to the regulations in this chapter to possess, use, and/or transfer within the United States source material, byproduct material, special nuclear material, and/or spent fuel and high level radioactive waste, or to construct, manufacture, possess, own, operate and/or transfer within the United States, any production or utilization facility, or independent spent fuel storage installation (ISFSI) or monitored retrievable storage installation (MRS), and to each director (see § 21.3(f)) and responsible officer (see § 21.3(j)) of such a licensee. The regulations in this part apply also to each individual, corporation, partnership or other entity doing business within the United States, and each director and responsible officer of such organization that constructs (see § 21.3(c)) a production or utilization facility licensed for manufacture, construction or operation (see § 21.3(h)) pursuant to Part 50 of this chapter, an independent spent fuel storage installation (ISFSI) for the storage of spent fuel licensed pursuant to Part 72 of this chapter or a monitored retrievable storage installation (MRS) for the storage of spent fuel or high-level radioactive waste licensed pursuant to Part 72 of this chapter, or supplies (see § 21.3(l)) basic components (see § 21.3(a)) for a facility or activity licensed, other than for export, under Parts 30, 39, 40, 50, 60, 61, 70, 71, or 72 of this chapter. Nothing in these regulations should be deemed to preclude either an individual or a manufacturer/supplier of a commercial grade item (see § 21.3(a-1)) not subject to the regulations in this part from reporting to the Commission a known or suspected defect or failure to comply and, as authorized by law, the identity of anyone so reporting will be withheld from disclosure.[1]

[53 FR 31680, Aug. 19, 1988, as amended at 54 FR 52342, Dec. 21, 1989]

§ 21.3 Definitions.

As used in this part:

(a)(1) "Basic component," when applied to nuclear power reactors means a plant structure, system, component or part thereof necessary to assure (i) the integrity of the reactor coolant pressure boundary, (ii) the capability to shut down the reactor and maintain it in a safe shutdown condition, or (iii) the capability to prevent or mitigate the consequences of accidents which could result in potential offsite exposures comparable to those referred to in § 100.11 of this chapter.

(2) "Basic component," when applied to other facilities and when applied to other activities licensed pursuant to Parts 30, 40, 50, 60, 61, 70, 71, or 72 of this chapter, means a component, structure, system, or part thereof that is directly procured by the licensee of a facility or activity subject to the regulations in this part and in which a defect (see § 21.3(d)) or failure to comply with any applicable regulation in this chapter, order, or license issued by the Commission could create a substantial safety hazard (see § 21.3(k)).

(3) In all cases "basic component" includes design, inspection, testing, or consulting services important to safety that are associated with the component hardware, whether these services are performed by the component supplier or others

[1] NRC Regional Officers will accept collect telephone calls from individuals who wish to speak to NRC representatives concerning nuclear safety-related problems. The location and telephone numbers (for nights and holidays as well as regular hours) are listed below:

Region:
I (Philadelphia)... (215) 337-5000
II (Atlanta) ... (404) 331-4503
III (Chicago)... (708) 790-5500
IV (Dallas)... (817) 860-8100
IV Uranium Recovery Field Office (Denver)... (303) 236-2805
V (San Francisco)... (415) 943-3700

1910.96—IONIZING RADIATION INTERP

(a) **Definitions applicable to this section.**

(1) "Radiation" includes alpha rays, beta rays, gamma rays, X-rays, neutrons, high-speed electrons, high-speed protons, and other atomic particles; but such term does not include sound or radio waves, or visible light, or infrared or ultraviol - light.

(2) "Radioactive material" means any material which emits, by spontaneous nuclear disintegration, corpuscular or electromagnetic emanations.

(3) "Restricted area" means any area access to which is controlled by the employer for purposes of protection of individuals from exposure to radiation or radioactive materials.

(4) "Unrestricted area" means any area access to which is not controlled by the employer for purposes of protection of individuals from exposure to radiation or radioactive materials.

(5) "Dose" means the quantity of ionizing radiation absorbed, per unit of mass, by the body or by any portion of the body. When the provisions in this section specify a dose during a period of time, the dose is the total quantity of radiation absorbed, per unit of mass, by the body or by any portion of the body during such period of time. Several different units of dose are in current use. Definitions of units used in this section are set forth in subparagraphs (6) and (7) of this paragraph.

(6) "Rad" means a measure of the dose of any ionizing radiation to body tissues in terms of the energy absorbed per unit of mass of the tissue. One rad is the dose corresponding to the absorption of 100 ergs per gram of tissue (1 millirad (mrad) = 0.001 rad).

(7) "Rem" means a measure of the dose of any ionizing radiation to body tissue in terms of its estimated biological effect relative to a dose of 1 roentgen (r) of X-rays (1 millirem (mrem) =0.001 rem). The relation of the rem to other dose units depends upon the biological effect under consideration and upon the conditions for irradiation. Each of the following is considered to be equivalent to a dose of 1 rem:

(i) A dose of 1 (r) due to X- or gamma radiation;

(ii) A dose of 1 rad due to X-, gamma, or beta radiation;

(iii) A dose of 0.1 rad due to neutrons or high energy protons;

(iv) A dose of 0.05 rad due to particles heavier than protons and with sufficient energy to reach the lens of the eye;

(v) If it is more convenient to measure the neutron flux, or equivalent, than to determine the neutron dose in rads, as provided in subdivision (iii) of this subparagraph, 1 rem of neutron radiation may, for purposes of the provisions in this section be assumed to be equivalent to 14 million neutrons per square centimeter incident upon the body; or, if there is sufficient information to estimate with reasonable accuracy the approximate distribution in energy of the neutrons, the incident number of neutrons per square centimeter equivalent to 1 rem may be estimated from Table G-17:

TABLE G-17—NEUTRON FLUX DOSE EQUIVALENTS

Neutron energy (million electron volts (Mev))	Number of neutrons per square centimeter equivalent to a dose of 1 rem (neutrons/cm²)	Average flux to deliver 100 millirem in 40 hours (neutrons/cm² per sec.)
Thermal	970 × 10⁶	670
0.0001	720 × 10⁶	500
0.005	820 × 10⁶	570
0.02	400 × 10⁶	280
0.1	120 × 10⁶	80
0.5	43 × 10⁶	30
1.0	26 × 10⁶	18
2.5	29 × 10⁶	20
5.0	26 × 10⁶	18
7.5	24 × 10⁶	17
10	24 × 10⁶	17
10 to 30	14 × 10⁶	10

(8) For determining exposures to X- or gamma rays up to 3 Mev., the dose limits specified in this section may be assumed to be equivalent to the "air dose." For the purpose of this section "air dose" means that the dose is measured by a properly calibrated appropriate instrument in air at or near the body surface in the region of the highest dosage rate.

(b) Exposure of individuals to radiation in restricted areas.

(1) Except as provided in subparagraph (2) of this paragraph, no employer shall possess, use, or transfer sources of ionizing radiation in such a manner as to cause any individual in a restricted area to receive in any period of one calendar quarter from sources in the employer's possession or control a dose in excess of the limits specified in Table G-18:

TABLE G-18

	Rems per calendar quarter
Whole body: Head and trunk; active blood-forming organs; lens of eyes; or gonads	1¼
Hands and forearms; feet and ankles	18¾
Skin of whole body	7½

(2) An employer may permit an individual in a restricted area to receive doses to the whole body greater than those permitted under subparagraph (1) of this paragraph, so long as:

(i) During any calendar quarter the dose to the whole body shall not exceed 3 rems; and

(ii) The dose to the whole body, when added to the accumulated occupational dose to the whole body, shall not exceed 5 (N–18) rems, where "N" equals the individual's age in years at his last birthday; and

(iii) The employer maintains adequate past and current exposure records which show that the addition of such a dose will not cause the individual to exceed the amount authorized in this subparagraph. As used in this subparagraph, "dose to the whole body" shall be deemed to include any dose to the whole body, gonad, active bloodforming organs, head and trunk, or lens of the eye.

(3) No employer shall permit any employee who is under 18 years of age to receive in any period of one calendar quarter a dose in excess of 10 percent of the limits specified in Table G-18.

(4) "Calendar quarter" means any 3-month period determined as follows:

(i) The first period of any year may begin on any date in January: *Provided*, That the second, third, and fourth periods accordingly begin on the same date in

April, July, and October, respectively, and that the fourth period extends into January of the succeeding year, if necessary to complete a 3-month quarter. During the first year of use of this method of determination, the first period for that year shall also include any additional days in January preceding the starting date for the first period; or

(ii) The first period in a calendar year of 13 complete, consecutive calendar weeks; the second period in a calendar year of 13 complete consecutive weeks; the third period in a calendar year of 13 complete, consecutive calendar weeks; the fourth period in a calendar year of 13 complete, consecutive calendar weeks. If at the end of a calendar year there are any days not falling within a complete calendar week of that year, such days shall be included within the last complete calendar week of that year. If at the beginning of any calendar year there are days not falling within a complete calendar week of that year, such days shall be included within the last complete calendar week of the previous year; or

(iii) The four periods in a calendar year may consist of the first 14 complete, consecutive calendar weeks; the next 12 complete, consecutive calendar weeks, the next 14 complete, consecutive calendar weeks, and the last 12 complete, consecutive calendar weeks. If at the end of a calendar year there are any days not falling within a complete calendar week of that year, such days shall be included (for purposes of this section) within the last complete calendar week of the year. If at the beginning of any calendar year there are days not falling within a complete calendar week of that year, such days shall be included (for purposes of this section) within the last complete week of the previous year.

(c) Exposure to airborne radioactive material.

(1) No employer shall possess, use or transport radioactive material in such a manner as to cause any employee, within a restricted area, to be exposed to airborne radioactive material in an average concentration in excess of the limits specified in Table 1 of Appendix B to 10 CFR Part 20. The limits given in Table 1 are for exposure to the concentrations specified for 40 hours in any workweek of 7 consecutive days. In any such period where the number of hours of exposure is less than 40, the limits specified in the table may be increased proportionately. In any such period where the number of hours of exposure is greater than 40, the limits specified in the table shall be decreased proportionately.

(2) No employer shall possess, use, or transfer radioactive material in such a manner as to cause any individual within a restricted area, who is under 18 years of age, to be exposed to airborne radioactive material in an average concentration in excess of the limits specified in Table II of Appendix B to 10 CFR Part 20. For purposes of this subparagraph, concentrations may be averaged over periods not greater than 1 week.

(3) "Exposed" as used in this paragraph means that the individual is present in an airborne concentration. No allowance shall be made for the use of protective clothing or equipment, or particle size.

(d) Precautionary procedures and personal monitoring.

(1) Every employer shall make such surveys as may be necessary for him to comply with the provisions in this section. "Survey" means an evaluation of the radiation hazards incident to the production, use, release, disposal, or presence of radioactive materials or other sources of radiation under a specific set of conditions. When appropriate, such evaluation includes a physical survey of the location of materials and equipment, and measurements of levels of radiation or concentrations of radioactive material present.

(2) Every employer shall supply appropriate personnel monitoring equipment, such as

film badges, pocket chambers, pocket dosimeters, or film rings, to, and shall require the use of such equipment by:

(i) Each employee who enters a restricted area under such circumstances that he receives, or is likely to receive, a dose in any calendar quarter in excess of 25 percent of the applicable value specified in paragraph (b)(1) of this section; and

(ii) Each employee under 18 years of age who enters a restricted area under such circumstances that he receives, or is likely to receive, a dose in any calendar quarter in excess of 5 percent of the applicable value specified in paragraph (b)(1) of this section; and

(iii) Each employee who enters a high radiation area.

(3) As used in this section:

(i) "Personnel monitoring equipment" means devices designed to be worn or carried by an individual for the purpose of measuring the dose received (e.g., film badges, pocket chambers, pocket dosimeters, film rings, etc.);

(ii) "Radiation area" means any area, accessible to personnel, in which there exists radiation at such levels that a major portion of the body could receive in any 1 hour a dose in excess of 5 millirem, or in any 5 consecutive days a dose in excess of 100 millirem; and

(iii) "High radiation area" means any area, accessible to personnel, in which there exists radiation at such levels that a major portion of the body could receive in any one hour a dose in excess of 100 millirem.

(e) Caution signs, labels, and signals.

(1) General.

(i) Symbols prescribed by this paragraph shall use the conventional radiation caution colors (magenta or purple on yellow background). The symbol prescribed by this paragraph is the conventional three-bladed design:

RADIATION SYMBOL

1. Cross-hatched area is to be magenta or purple.
2. Background is to be yellow.

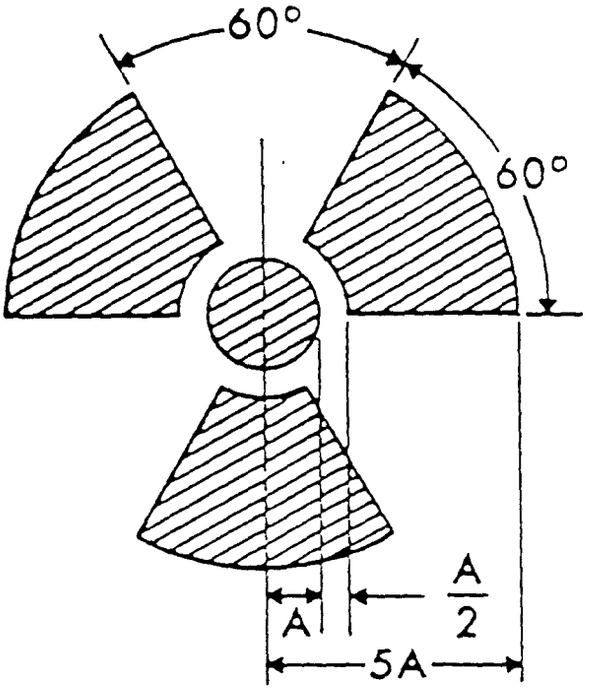


FIGURE G-10

(ii) Deleted

[43 F.R. 49746, October 24, 1978]

(2) Radiation area. Each radiation area shall be conspicuously posted with a sign or signs bearing the radiation caution symbol described in subparagraph (1) of this paragraph and the words:

CAUTION
RADIATION AREA

(3) High radiation area.

(i) Each high radiation area shall be conspicuously posted with a sign or signs bearing the radiation caution symbol and the words:

CAUTION
HIGH RADIATION AREA

(ii) Each high radiation area shall be equipped with a control device which shall either cause the level of radiation to be reduced below that at which an individual might receive a dose of 100 millirems in 1 hour upon entry into the area or shall energize a conspicuous visible or audible alarm signal in such a manner that the individual entering and the employer or a supervisor of the activity are made aware of the entry. In the case of a high radiation area established for a period of 30 days or less, such control device is not required.

(4) Airborne radioactivity area.

(i) As used in the provisions of this section, "airborne radioactivity area" means:

(a) Any room, enclosure, or operating area in which airborne radioactive materials, composed wholly or partly of radioactive material, exist in concentrations in excess of the amounts specified in column 1 of Table 1 of Appendix B to 10 CFR Part 20 or

(b) Any room, enclosure, or operating area in which airborne radioactive materials exist in concentrations which, averaged over the number of hours in any week during which individuals are in the area, exceed 25 percent of the amounts specified in column 1 of Table 1 of Appendix B to 10 CFR Part 20.

(ii) Each airborne radioactivity area shall be conspicuously posted with a sign or signs bearing the radiation caution symbol described in subparagraph (1) of this paragraph and the words:

CAUTION
AIRBORNE RADIOACTIVITY AREA

(5) Additional requirements.

(i) Each area or room in which radioactive material is used or stored and which contains any radioactive material (other than natural uranium or thorium) in any amount exceeding 10 times the quantity of such material specified in Appendix C to 10 CFR Part 20 shall be conspicuously posted with a sign or signs bearing the radiation caution symbol described in subparagraph (1) of this paragraph and the words:

CAUTION
RADIOACTIVE MATERIALS

(ii) Each area or room in which natural uranium or thorium is used or stored in an amount exceeding 100 times the quantity of such material specified in 10 CFR Part 20 shall be conspicuously posted with a sign or signs bearing the radiation caution symbol described in subparagraph (1) of this paragraph and the words:

CAUTION
RADIOACTIVE MATERIALS

(6) Containers.

(i) Each container in which is transported, stored, or used a quantity of any radioactive material (other than natural uranium or thorium) greater than the quantity of such material specified in Appendix C to 10 CFR Part 20 shall bear a durable, clearly visible label bearing the radiation caution symbol described in subparagraph (1) of this paragraph and the words:

CAUTION
RADIOACTIVE MATERIALS

(ii) Each container in which natural uranium or thorium is transported, stored, or used in a quantity greater than 10 times the quantity specified in Appendix C to 10 CFR Part 20 shall bear a durable, clearly visible label bearing the radiation caution symbol described in subparagraph (1) of this paragraph and the words:

CAUTION
RADIOACTIVE MATERIALS

(iii) Notwithstanding the provisions of subdivisions (i) and (ii) of this subparagraph a label shall not be required:

(a) If the concentration of the material in the container does not exceed that specified in column 2 of Table 1 of Appendix B to 10 CFR Part 20, or

(b) For laboratory containers, such as beakers, flasks, and test tubes, used transiently in laboratory procedures, when the user is present.

(iv) Where containers are used for storage, the labels required in this subparagraph shall state also the quantities and kinds of radioactive materials in the containers and the date of measurement of the quantities.

(f) Immediate evacuation warning signal.

(1) Signal characteristics.

(i) The signal shall be a midfrequency complex sound wave amplitude modulated at a subsonic frequency. The complex sound wave in free space shall have a fundamental frequency (f_1) between 450 and 500 hertz (Hz) modulated at a subsonic rate between 4 and 5 hertz.

(ii) The signal generator shall not be less than 75 decibels at every location where an individual may be present whose immediate, rapid, and complete evacuation is essential.

(iii) A sufficient number of signal units shall be installed such that the requirements of subdivision (ii) of this subparagraph are met at every location where an individual may be present whose immediate, rapid, and complete evacuation is essential.

(iv) The signal shall be unique in the plant or facility in which it is installed.

(v) The minimum duration of the signal shall be sufficient to insure that all affected persons hear the signal.

(vi) The signal-generating system shall respond automatically to an initiating event without requiring any human action to sound the signal.

(2) Design objectives.

(i) The signal-generating system shall be designed to incorporate components which enable the system to produce the desired signal each time it is activated within one-half second of activation.

(ii) The signal-generating system shall be provided with an automatically activated secondary power supply which is adequate to simultaneously power all emergency equipment to which it is connected, if operation during power failure is necessary, except in those systems using batteries as the primary source of power.

(iii) All components of the signal-generating system shall be located to provide maximum practicable protection against damage in case of fire, explosion, corrosive atmosphere, or other environmental extremes consistent with adequate system performance.

(iv) The signal-generating system shall be designed with the minimum number of components necessary to make it function as intended, and should utilize components which do not require frequent servicing such as lubrication or cleaning.

(v) Where several activating devices feed activating information to a central signal generator, failure of any activating device shall not render the signal-generator system inoperable to activating information from the remaining devices.

(vi) The signal-generating system shall be designed to enhance the probability that alarm occurs only when immediate evacuation is warranted. The number of false alarms shall not be so great that the signal will come to be disregarded and

shall be low enough to minimize personal injuries or excessive property damage that might result from such evacuation.

(3) Testing.

(i) Initial tests, inspections, and checks of the signal-generating system shall be made to verify that the fabrication and installation were made in accordance with design plans and specifications and to develop a thorough knowledge of the performance of the system and all components under normal and hostile conditions.

(ii) Once the system has been placed in service, periodic tests, inspections, and checks shall be made to minimize the possibility of malfunction.

(iii) Following significant alterations or revisions to the system, tests and checks similar to the initial installation tests shall be made.

(iv) Tests shall be designed to minimize hazards while conducting the tests.

(v) Prior to normal operation the signal-generating system shall be checked physically and functionally to assure reliability and to demonstrate accuracy and performance. Specific tests shall include:

(a) All power sources.

(b) Calibration and calibration stability.

(c) Trip levels and stability.

(d) Continuity of function with loss and return of required services such as AC or DC power, air pressure, etc.

(e) All indicators.

(f) Trouble indicator circuits and signals, where used.

(g) Air pressure (if used).

(h) Determine that sound level of the signal is within the limit of subparagraph (1)(ii) of this paragraph at all points that require immediate evacuation.

(vi) In addition to the initial startup and operating tests, periodic scheduled performance tests and status checks must be made to insure that the system is at all times operating within design limits and capable of the required response. Specific periodic tests or checks or both shall include:

(a) Adequacy of signal activation device.

(b) All power sources.

(c) Function of all alarm circuits and trouble indicator circuits including trip levels.

(d) Air pressure (if used).

(e) Function of entire system including operation without power where required.

(f) Complete operational tests including sounding of the signal and determination that sound levels are adequate.

(vii) Periodic tests shall be scheduled on the basis of need, experience, difficulty, and disruption of operations. The entire system should be operationally tested at least quarterly.

(viii) All employees whose work may necessitate their presence in an area covered by the signal shall be made familiar with the actual sound of the signal—preferably as it sounds at their work location. Before placing the system into operation, all employees normally working in the area shall be made acquainted with the signal by actual demonstration at their work locations.

(g) Exceptions from posting requirements.

Notwithstanding the provisions of paragraph (e) of this section:

(1) A room or area is not required to be posted with a caution sign because of the presence of a sealed source, provided the radiation level 12 inches from the surface of the source container or housing does not exceed 5 millirem per hour.

(2) Rooms or other areas in onsite medical facilities are not required to be posted with caution signs because of the presence of patients containing radioactive material, provided that there are personnel in attendance who shall take the precautions necessary to prevent the exposure of any individual to radiation or radioactive material in excess of the limits established in the provisions of this section.

(3) Caution signs are not required to be posted at areas or rooms containing radioactive materials for periods of less than 8 hours: *Provided*, That

(i) The materials are constantly attended during such periods by an individual who shall take the precautions necessary to prevent the exposure of any individual to radiation or radioactive materials in excess of the limits established in the provisions of this section; and

(ii) Such area or room is subject to the employer's control.

(h) Exemptions for radioactive materials packaged for shipment.

Radioactive materials packaged and labeled in accordance with regulations of the Department of Transportation published in 49 CFR Chapter I, are exempt from the labeling and posting requirements of this subpart during shipment, provided that the inside containers are labeled in accordance with the provisions of paragraph (e) of this section.

(i) Instruction of personnel, posting.

(1) Employers regulated by the Atomic Energy Commission shall be governed by 10 CFR Part 20 standards. Employers in a State named in paragraph (p)(3) of this section shall be governed by the requirements of the laws and regulations of that State. All other employers shall be regulated by the following:

(2) All individuals working in or frequenting any portion of a radiation area shall be informed of the occurrence of radioactive materials or of radiation in such portions of the radiation area; shall be instructed in the safety problems associated with exposure to such materials or radiation and in precautions or devices to minimize exposure; shall be instructed in the applicable provisions of this section for the protection of employees from exposure to radiation or radioactive materials; and shall be advised of reports of radiation exposure which employees may request pursuant to the regulations in this section.

(3) Each employer to whom this section applies shall post a current copy of its provisions and a copy of the operating procedures applicable to the work conspicuously in such locations as to insure that employees working in or frequenting radiation areas will observe these documents on the way to and from their place of employment, or shall keep such documents available for examination of employees upon request.

(j) Storage of radioactive materials.

Radioactive materials stored in a nonradiation area shall be secured against unauthorized removal from the place of storage.

(k) Waste disposal.

No employer shall dispose of radioactive material except by transfer to an authorized recipient, or in a manner approved by the Atomic Energy Commission or a State named in paragraph (p)(3) of this section.

(l) Notification of incidents.

(1) Immediate notification. Each employer shall immediately notify the Assistant Secretary of Labor or his duly authorized representative, for employees not protected by the Atomic Energy Commission by means of 10 CFR Part 20; paragraph (p)(2) of this section, or the requirements of the laws and

regulations of States named in paragraph (p)(3) of this section, by telephone or telegraph of any incident involving radiation which may have caused or threatens to cause:

(i) Exposure of the whole body of any individual to 25 rems or more of radiation; exposure of the skin of the whole body of any individual to 150 rems or more of radiation; or exposure of the feet, ankles, hands, or forearms of any individual to 375 rems or more of radiation; or

(ii) The release of radioactive material in concentrations which, if averaged over a period of 24 hours, would exceed 5,000 times the limit specified for such materials in Table II of Appendix B to 10 CFR Part 20.

(2) Twenty-four hour notification. Each employer shall within 24 hours following its occurrence notify the Assistant Secretary of Labor or his duly authorized representative for employees not protected by the Atomic Energy Commission by means of 10 CFR Part 20; paragraph (p)(2) of this section, or the requirements of the laws and applicable regulations of States named in paragraph (p)(3) of this section, by telephone or telegraph of any incident involving radiation which may have caused or threatens to cause:

(i) Exposure of the whole body of any individual to 5 rems or more of radiation; exposure of the skin of the whole body of any individual to 30 rems or more of radiation; or exposure of the feet, ankles, hands, or forearms to 75 rems or more of radiation; or

(m) Reports of overexposure and excessive levels and concentrations.

(1) In addition to any notification required by paragraph (1) of this section each employer shall make a report in writing within 30 days to the Assistant Secretary of Labor or his duly authorized representative, for employees not protected by the Atomic Energy Commission by means of 10 CFR Part 20; or under paragraph (p)(2) of this section, or the requirements of the laws and regulations of States named in paragraph (p)(3) of this section, of each exposure of an individual to radiation or concentrations of radioactive material in excess of any applicable limit in this section. Each report required under this subparagraph shall describe the extent of exposure of persons to radiation or to radioactive material; levels of radiation and concentration of radioactive material involved, the cause of the exposure, levels of concentrations; and corrective steps taken or planned to assure against a recurrence.

(2) In any case where an employer is required pursuant to the provisions of this paragraph to report to the U.S. Department of Labor any exposure of an individual to radiation or to concentrations of radioactive material, the employer shall also notify such individual of the nature and extent of exposure. Such notice shall be in writing and shall contain the following statement: "You should preserve this report for future reference."

(n) Records.

(1) Every employer shall maintain records of the radiation exposure of all employees for whom personnel monitoring is required under paragraph (d) of this section and advise each of his employees of his individual exposure on at least an annual basis.

(2) Every employer shall maintain records in the same units used in tables in paragraph (b) of this section and Appendix B to 10 CFR Part 20.

(o) Disclosure to former employee of individual employee's record.

(1) At the request of a former employee an employer shall furnish to the employee a report of the employee's exposure to radiation as shown in records maintained by the employer pursuant to paragraph (n)(1) of this section. Such report shall be furnished within 30 days from the time the request is made, and shall cover each calendar quarter of the individual's employment involving exposure to radiation or such lesser period as may be requested by the employee. The report shall also include the results of any calculations and analysis of radioactive material deposited in the body of the employee. The report shall be in writing and contain the following statement: "You should preserve this report for future reference."

(p) Atomic Energy Commission licensees—AEC contractors operating AEC plants and facilities—AEC agreement State licensees or registrants.

(1) Any employer who possesses or uses source material, byproduct material, or special nuclear material, as defined in the Atomic Energy Act of 1954, as amended, under a license issued by the Atomic Energy Commission and in accordance with the requirements of 10 CFR Part 20 shall be deemed to be in compliance with the requirements of this section with respect to such possession and use.

(2) AEC contractors operating AEC plants and facilities: Any employer who possesses or uses source material, byproduct material, special nuclear material, or other radiation sources under a contract with the Atomic Energy Commission for the operation of AEC plants and facilities and in accordance with the standards, procedures, and other requirements for radiation protection established by the Commission for such contract pursuant to the Atomic Energy Act of 1954 as amended (42 U.S.C. 2011 et seq.), shall be deemed to be in compliance with the requirements of this section with respect to such possession and use.

(3) AEC-agreement State licensees or registrants:

(i) Atomic Energy Act sources. Any employer who possesses or uses source material, byproduct material, or special nuclear material, as defined in the Atomic Energy Act of 1954, as amended (42 U.S.C. 2011 et seq.), and has either registered such sources with, or is operating under a license issued by, a State which has an agreement in effect with the Atomic Energy Commission pursuant to section 274(b) (42 U:S.C. 2021(b)) of the Atomic Energy Act of 1954, as amended, and in accordance with the requirements of that State's laws and regulations shall be deemed to be in compliance with the radiation requirements of this section, insofar as his possession and use of such material is concerned, unless the Secretary of Labor, after conference with the Atomic Energy Commission, shall determine that the State's program for control of these radiation sources is incompatible with the requirements of this section. Such agreements currently are in effect only in the States of Alabama, Arkansas, California, Kansas, Kentucky, Florida, Mississippi, New Hampshire, New York, North Carolina, Texas, Tennessee, Oregon, Idaho, Arizona, Colorado, Louisiana, Nebraska, Washington, Maryland, North Dakota, South Carolina, and Georgia.

(ii) Other sources. Any employer who possesses or uses radiation sources other than source material, byproduct material, or special nuclear material, as defined in the Atomic Energy Act of 1954, as amended (42 U.S.C. 2011 et seq.), and has either registered such sources with, or is operating under a license issued by a State which has an agreement in effect with the Atomic Energy Commission pursuant to section 274(b) (42 U.S.C. 2021(b)) of the Atomic Energy Act of 1954, as amended, and in accordance with the requirements of that State's laws and regulations shall be deemed to be in compliance with the radiation requirements of this section, insofar as his possession

and use of such material is concerned, provided the State's program for control of these radiation sources is the subject of a currently effective determination by the Assistant Secretary of Labor that such program is compatible with the requirements of this section. Such determinations currently are in effect only in the States of Alabama, Arkansas, California, Kansas, Kentucky, Florida, Mississippi, New Hampshire, New York, North Carolina, Texas, Tennessee, Oregon, Idaho, Arizona, Colorado, Louisiana, Nebraska, Washington, Maryland, North Dakota, South Carolina, and Georgia.

(q) [Reserved]

(r) Radiation standards for mining. Revoked

1910.97—NONIONIZING RADIATION

(a) Electromagnetic radiation.

(1) Definitions applicable to this paragraph.

(i) The term "electromagnetic radiation" is restricted to that portion of the spectrum commonly defined as the radio frequency region, which for the purpose of this specification shall include the microwave frequency region.

(ii) Partial body irradiation. Pertains to the case in which part of the body is exposed to the incident electromagnetic energy.

The following document entitled *Federal Radiation Protection Guidance for Occupational Exposure*, has been retyped from the *Federal Register* dated Tuesday, January 27, 1987 (Vol. 52, No. 17).

FEDERAL RADIATION PROTECTION GUIDANCE FOR OCCUPATIONAL EXPOSURE

This memorandum transmits recommendations that would update previous guidance to Federal agencies for the protection of workers exposed to ionizing radiation. These recommendations were developed cooperatively by the Nuclear Regulatory Commission, the Occupational Safety and Health Administration, the Mine Safety and Health Administration, the Department of Defense, the Department of Energy, the National Aeronautics and Space Administration, the Department of Commerce, the Department of Transportation, the Department of Health and Human Services, and the Environmental Protection Agency. In addition, the National Council on Radiation Protection and Measurements (NCRP), the National Academy of Sciences (NAS), the Conference of Radiation Control Program Directors (CRCPD) of the States, and the Health Physics Society were consulted during the development of this guidance.

Executive Order 10831, the Atomic Energy Act, as amended, and Reorganization Plan No. 3 of 1970 charge the Administrator of the Environmental Protection Agency (EPA) to ". . advise the President with respect to radiation matters, directly or indirectly affecting health, including guidance for all Federal agencies in the formulation of radiation standards and in the establishment and execution of programs of cooperation with States." This guidance has historically taken the form of qualitative and quantitative "Federal Radiation Protection Guidance." The recommendations transmitted here would replace those portions of previous Federal guidance (25 FR 4402), approved by President Eisenhower on May 13, 1960, that apply to the protection of workers exposed to ionizing radiation. The portions of that guidance which apply to exposure of the general public would not be changed by these recommendations.

These recommendations are based on consideration of (1) current scientific understanding of effects on health from ionizing radiation, (2) recommendations of international and national organizations involved in radiation protection, (3) proposed "Federal Radiation Protection Guidance for Occupational Exposure" published on January 23, 1981 (46 FR 7836) and public comments on that proposed guidance, and (4) the collective experience of the Federal agencies in the control of occupational exposure to ionizing radiation. A summary of the considerations that led to these recommendations is provided below. Public comments on the previously proposed guidance and a response to those comments are contained in the document "Federal Radiation Protection Guidance for Occupational Exposure-Response to Comments" (EPA 520/1-84-011). Single copies of this report are available from the Program Management Office (ANR-458), Office of Radiation Programs, U.S. Environmental Protection Agency, Washington, D.C. 20460; telephone (202) 475-8388.

Background

A review of current radiation protection guidance for workers began in 1974 with the formation of a Federal interagency committee by EPA. As a result of the deliberations of that committee, EPA published an "Advance Notice of Proposed Recommendations and Future Public Hearings" on September 17, 1979 (44 FR 53785). On January 23, 1981, EPA published "Federal Radiation Protection Guidance for Occupational Exposures; Proposed Recommendations, Request

for Written Comments, and Public Hearings" (46 FR 7836). Public hearings were held in Washington, D.C. (April 20-23, 1981); Houston, Texas (May 1-2, 1981); Chicago, Illinois (May 5-6, 1981), and San Francisco, California (May 8-9, 1981) (46 FR 15205). The public comment period closed July 6, 1981 (46 FR 26557). On December 15, 1982, representatives of the ten Federal agencies noted above, the CRCPD and NCRP convened under the sponsorship of the EPA to review the issues raised in public comments and to complete development of these recommendations. The issues were carefully considered during a series of meetings, and the conclusions of the working group have provided the basis for these recommendations for revised Federal guidance.

EPA has also sponsored or conducted four major studies in support of this review of occupational radiation protection guidance. First, the Committee on the Biological Effects of Ionizing Radiations, National Academy of Sciences-National Research Council reviewed the scientific data on health risks of low levels of ionizing radiation in a report transmitted to EPA on July 22, 1980: "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation: 1980," National Academy Press, Washington, D.C. 1980. Second, EPA has published two studies of occupational radiation exposure: "Occupational Exposure to Ionizing Radiation in the United States: A Comprehensive Summary for the Year 1975" (EPA 520/4-80-001) and "Occupational Exposure to Ionizing Radiation in the United States: A Comprehensive Review for the Year 1980 and Summary of Trends for the Years 1960-1985" (EPA 520/1-84-005). Third, the Agency sponsored a study to examine the changes in previously derived concentration limits for intake of radionuclides from air or water that result from use of up-to-date dosimetric and biological transport models. These are presented in Federal Guidance Report No. 10, "The Radioactivity Concentration Guides: A New Calculation of Derived Limits for the 1960 Radiation Protection Guides Reflecting Updated Models for Dosimetry and Biological Transport" (EPA 520/1-84-010). Finally, the cost of implementing the changes in Federal guidance proposed on January 23, 1981 was surveyed and the findings published in the two-volume report: "Analysis of Costs for Compliance with Federal Radiation Protection Guidance for Occupational Exposure: Volume I-Cost of Compliance" (EPA 520/1-83-013-1) and "Volume II-Case Study Analysis of the Impacts" (EPA 520/1-83-013-2). These EPA reports are available from National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161.

The interagency review of occupational radiation protection has confirmed the need for revising the previous Federal guidance, which was promulgated in 1960. Since that time knowledge of the effects of ionizing radiation on humans has increased substantially. We now have a greatly improved ability to estimate risk of harm due to irradiation of individual organs and tissues. As a result, some of the old numerical guides are now believed to be less and some more protective than formerly. Other risks, specifically those to the unborn, are now considered to be more significant and were not addressed by the old guidance. These disparities and omissions should be corrected. Drawing on this improved knowledge, the International Commission on Radiological Protection (ICRP) published, in 1977, new recommendations on radiation protection philosophy and limits for occupational exposure. These recommendations are now in use, in whole or substantial part, in most other countries. We have considered these recommendations,

among others, and believe that it is appropriate to adopt the general features of the ICRP approach in radiation protection guidance to Federal agencies for occupational exposure. These recommendations are now in use, in whole or substantial part, in most other countries. We have considered these recommendations, among others, and believe that it is appropriate to adopt the general features of the ICRP approach in radiation protection guidance to Federal agencies for occupational exposure. In two cases, protection of the unborn and the management of long-term exposure to internally deposited radioactivity, we have found it advisable to make additions.

There are four types of possible effects on health from exposure to ionizing radiation. The first of these is cancer. Cancers caused by radiation are not different from those that have been historically observed, whether from known or unknown causes. Although radiogenic cancers have been observed in humans over a range of higher doses, few useful data are available for defining the effect of doses at normal occupational levels of exposure. The second type of effect is the induction of hereditary effects in descendants of exposed persons. The severity of hereditary effects ranges from inconsequential to fatal. Although such effects have been observed in experimental animals at high doses, they have not been confirmed in studies of humans. Based on extensive but incomplete scientific evidence, it is prudent to assume that at low levels of exposure the risk of incurring either cancer or hereditary effects is linearly related to the dose received in the relevant tissue. The severity of any such effect is not related to the amount of dose received. That is, once a cancer or an hereditary effect has been induced, its severity is independent of the doses. Thus, for these two types of effects, it is assumed that there is no completely risk-free level of exposure.

The third type includes a variety of effects for which the degree of damage (i.e., severity) appears to depend on the amount of dose received and for which there is an effective threshold below which clinically observable effects do not occur. An example of such an effect is radiation sickness syndrome, which is observed at high doses and is fatal at very high doses. Examples of lesser effects include opacification of the lens of the eye, erythema of the skin, and temporary impairment of fertility. All of these effects occur at relatively high doses. At the levels of dose contemplated under both the previous Federal guidance and these recommendations, clinically observable examples of this third type of effect are not known to occur.

The fourth type includes effects on children who were exposed *in utero*. Not only may the unborn be more sensitive than adults to the induction of malformations, cancer, and hereditary effects, but recent studies have drawn renewed attention to the risk of severe mental retardation from exposure of the unborn during certain periods of pregnancy. The risk of less severe mental retardation appears to be similarly elevated. Although it is not yet clear to what extent the frequency of retardation is proportional to the amount of dose (the data available at occupational levels of exposure are limited), it is prudent to assume that proportionality exists.

The risks to health from exposure to low levels of ionizing radiation were reviewed for EPA by the NAS in reports published in 1972 and in 1980. Regarding cancer there continues to be divided opinion on how to interpolate between the absence of radiation effects at zero dose and

the observed effects of radiation (mostly at high doses) to estimate the most probable effects of low doses. Some scientists believe that available data best support use of a linear model for estimating such effects. Others, however, believe that other models, which usually predict somewhat lower risks, provide better estimates. These differences of opinion have not been resolved to date by studies of the effects or radiation in humans, the most important of which are those of the Hiroshima and Nagasaki atom bomb survivors. Studies are now underway to reassess radiation dose calculations for these survivors and in turn to provide improved estimates of risk. It will be at least several years before these reassessments and estimates are completed, and it is not likely that they will conclusively resolve uncertainties in estimating low dose effects. EPA is monitoring the progress of this work. When it is completed we will initiate reviews of the risks of low levels of radiation, in order to provide the basis for any indicated reassessment of this guidance.

In spite of the above uncertainties, estimates of the risks from exposure to low levels of ionizing radiation are reasonably well bounded, and the average worker is believed to incur a relatively small risk of harm from radiation. This situation has resulted from a system of protection which combines limits on maximum dose with active application of measures to minimize doses within these limits. These recommendations continue that approach. Approximately 1.3 million workers were employed in occupations in which they were potentially exposed to radiation in 1980, the latest year for which we have comprehensive assessments. About half of these workers received no measurable occupational dose. In that year the average worker measurably exposed to external radiation received an occupational dose equivalent of 0.2 rem to the whole body, based on the readings of individual dosimeters worn on the surface of the body. We estimate (assuming a linear non-threshold model) the increased risk of premature death due to radiation-induced cancer for such a dose is approximately 2 to 5 in 100,000 and that the increased risk of serious hereditary effects is somewhat smaller. To put these estimated risks in perspective with other occupational hazards, they are comparable to the observed risk of job-related accidental death in the safest industries, wholesale and retail trades, for which the annual accidental death rate averaged about 5 per 100,000 from 1980 to 1984. The U.S. average for all industries was 11 per 100,000 in 1984 and 1985.

These recommendations are based on the assumption that risks of injury from exposure to radiation should be considered in relation to the overall benefit derived from the activities causing the exposure. This approach is similar to that used by the Federal Radiation Council (FRC) in developing the 1960 Federal guidance. The FRC said then, "Fundamentally, setting basic radiation protection standards involves passing judgment on the extent of the possible health hazard society is willing to accept in order to realize the known benefits of radiation." This leads to three basic principles that have governed radiation protection of workers in recent decades in the United States and in most other countries. Although the precise formulation of these principles has evolved over the years, their intent has continued unchanged. The first is that any activity involving occupational exposure should be determined to be useful enough to society to warrant the exposure of workers; i.e., that a finding be made that the activity is "justified". This same principle applies to virtually any human endeavor which involves some risk of injury. The second is that, for justified activities, exposure of the work force should be

as low as reasonably achievable (commonly designated by the acronym "ALARA"); this has most recently been characterized as "optimization" of radiation protection by the International Commission on Radiological Protection (ICRP). Finally, to provide an upper limit on risk to individual workers, "limitation" of the maximum allowed individual dose is required. This is required above and beyond the protection provided by the first two principles because their primary objective is to minimize the total harm from occupational exposure in the entire work force; they do not limit the way that harm is distributed among individual workers.

The principle that activities causing occupational exposure should produce a net benefit is important in radiation protection even though the judgement of net benefit is not easily made. The 1960 guidance says: "There should not be any man-made radiation exposure without the expectation of benefit resulting from such exposure . . ." And "It is basic that exposure to radiation should result from a real determination of its necessity." Advisory bodies other than the FRC have used language which has essentially the same meaning. In its most recent revision of international guidance (1977) the ICRP said ". . . no practice shall be adopted unless its introduction produces a positive net benefit," and in slightly different form the NCRP, in its most recent statement (1975) on this matter, said ". . . all exposures should be kept to a practicable minimum; . . . this principle involves value judgments based upon perception of compensatory benefits commensurate with risks, preferably in the form of realistic numerical estimates of both benefits and risks from activities involving radiation and alternative means to the same benefits."

This principle is set forth in these recommendations in a simple form: "There should not be any occupational exposure of workers to ionizing radiation without the expectation of an overall benefit from the activity causing the exposure." An obvious difficulty in making this judgement is the difficulty of quantifying in comparable terms cost (including risks) and benefits. Given this situation, informed value judgements are necessary and are usually all that is possible. It is perhaps useful to observe, however, that throughout history individuals and societies have made risk-benefit judgements, with their success usually depending upon the amount of accurate information available. Since more is known about radiation now than in previous decades, the prospect is that these judgments can now be better made than before.

The preceding discussion has implicitly focused on major activities, i.e., those instituting or continuing a general practice involving radiation exposure of workers. This principle also applies to detailed management of facilities and direct supervision of workers. Decisions on whether or not particular tasks should be carried out (such as inspecting control systems or acquiring specific experimental data) require judgments which can, in the aggregate, be as significant for radiation protection as those justifying the basic activities these tasks support.

The principle of reduction of exposure to levels that are "as low as reasonably achievable" (ALARA) is typically implemented in two different ways. First, it is applied to the engineering design of facilities so as to reduce, prospectively, the anticipated exposure of workers. Second, it is applied to actual operations; that is, work practices are designed and carried out to reduce

the exposure of workers. Both of these applications are encompassed by these recommendations.* The principle applies both to collective exposures of the work force and to annual and cumulative individual exposures. Its application may therefore require complex judgments, particularly when tradeoffs between collective and individual doses are involved. Effective implementation of the ALARA principle involves most of the many facets of an effective radiation protection program: education of workers concerning the health risks of exposure to radiation; training in regulatory requirements and procedures to control exposure; monitoring, assessment, and reporting of exposure levels and doses; and management and supervision of radiation protection activities, including the choice and implementation of radiation control measures. A comprehensive radiation protection program will also include, as appropriate, properly trained and qualified radiation protection personnel; adequately designed, operated, and maintained facilities and equipment; and quality assurance and audit procedures. Another important aspect of such programs is maintenance of records of cumulative exposures of workers and implementation of appropriate measures to assure that lifetime exposure of workers repeatedly exposed near the limits is minimized.

The types of work and activity which involve worker exposure to radiation vary greatly and are administered by many different Federal and State agencies under a wide variety of legislative authorities. In view of this complexity, Federal radiation protection guidance can address only the broad prerequisites of an effective ALARA program, and regulatory authorities must ensure that more detailed requirements are identified and carried out. In doing this, such authorities may find it useful to establish or encourage the use of 1) administrative control levels specifying, for specific categories of workers or work situations, dose levels below the limiting numerical values recommended in this guidance; 2) reference levels to indicate the need for such actions as recording, investigation, and intervention; and 3) local goals for limiting individual and collective occupational exposures. Where the enforcement of a general ALARA requirement is not practical under an agency's statutory authority, it is sufficient that an agency endorse and encourage ALARA, and establish such regulations which result from ALARA findings as may be useful and appropriate to meet the objectives of this guidance.

The numerical radiation protection guidance which has been in effect since 1960 for limiting the maximum allowed dose to an individual worker is based on the concept of limiting the dose to the most critically exposed part of the body. This approach was appropriate, given the limitations of scientific information available at the time, and resulted in a set of five independent numerical guides for maximum exposure of a) the whole body, head and trunk,

---

* The recommendation that Federal agencies, through their regulations, operational procedures and other appropriate means, maintain doses ALARA is not intended to express, and therefore should not be interpreted as expressing, a view whether the ALARA concept should constitute a duty of care in tort litigation. Implementation of the ALARA concept requires a complex, subjective balancing of scientific, economic and social factors generally resulting in the attainment of average dose levels significantly below the maximum permitted by this guidance.

active blood-forming organs, gonads, and lens of eye; b) thyroid and skin of the whole body; c) hands and forearms, feet and ankles; d) bone, and e) other organs. A consequence of this approach when several different parts of the body are exposed simultaneously is that only the part that receives the highest dose relative to its respective guide is decisive for limiting the dose.

Current knowledge permits a more comprehensive approach that takes into account the separate contributions to the total risk from each exposed part of the body. These recommendations incorporate the dose weighting system introduced for this purpose by the ICRP in 1977. That system assigns weighting factors to the various parts of the body for the risks of lethal cancer and serious prompt genetic effects (those in the first two generations); these factors are chose so that the sum of weighted dose equivalents represents a risk the same as that from a numerically equal dose equivalent to the whole body. The ICRP recommends that the effective (i.e. weighted) dose equivalent incurred in any year be limited to 5 rems. Based on the public response to the similar proposal published by EPA in 1981 and Federal experience with comparable exposure limits, the Federal agencies concur. These recommendations therefore replace the 1960 whole body numerical guides of 3 rems per quarter and 5(N-18) rems cumulative dose equivalent (where N is the age of the worker) and associated critical organ guides with a limiting value of 5 rems effective dose equivalent incurred in any year. Supplementary limiting values are also recommended to provide protection against those health effects for which an effective threshold is believed to exist.

In recommending a limiting value of 5 rems in any single year, EPA has had to balance a number of considerations. Public comments confirmed that, for some beneficial activities, occasional doses approaching this value are not reasonably avoidable. On the other hand, continued annual exposures at or near this level over substantial portions of working lifetime would, we believe, lead to unwarranted risks. For this reason such continued annual exposures should be avoided, and these recommendations provide such guidance. As noted earlier, these recommendations also continue a system of protection which combines limiting values for maximum dose with a requirement for active application of measures to minimize doses-the ALARA requirement. This has resulted in steadily decreasing average annual doses to workers (most recently to about one-fiftieth of the recommended limiting value) and, to date, only a few hundred out of millions of workers have received planned cumulative doses that are a substantial fraction of the maximum previously permitted cumulative dose over and occupational lifetime. EPA anticipates that the continued application of the ALARA requirement, combined with new guidance on avoidance of large cumulative doses, will result in maintaining risks to all workers at low levels. EPA will continue to review worker doses with a view to initiating recommendations for any further modifications of the dose limitation system that are warranted by future trends in worker exposure.

Certain radionuclides, if inhaled or ingested, may remain in and continue to irradiate the body for many years. These recommendations provide that radionuclides should be contained so as to minimize intake, to the extent reasonably achievable. When avoidance of situations that may result in such intake is not practical, the recommendations distinguish between pre-exposure and

post-exposure situations. With respect to the former, Federal agencies should base control of prospective internal exposure to radionuclides (e.g. facility design, monitoring, training, and operating procedures) upon the entire future dose that may result from any intake (the committed dose), not just upon the dose accrued in the year of intake. This is to assure that, prior to exposure to such materials, proper account is taken of the risk due to doses in future years.

With respect to post-exposure situations, most significant internal exposure to radionuclides occurs as the result of inadvertent intakes. In the case of some long-lived radionuclides, it may also be difficult to measure accurately the small quantities corresponding to the recommended numerical guidance for control of committed doses. In such cases, when workers are inadvertently exposed or it is not otherwise possible to avoid intakes in excess of these recommendations for control of committed dose, it will be necessary to take appropriate corrective action to assure control has been reestablished and to properly manage future exposure of the worker. In regard to the latter requirement, provision should be made to continue to monitor the annual dose received from radionuclides in the body as long as they remain in sufficient amount to deliver doses significant compared to the limiting values for annual dose. These recommendations extend those of the ICRP, because it is appropriate to maintain active management of workers who exceed the guidance for committed dose in order that individual differences in retention of such materials in the body be monitored, and to assure, whenever possible, conformance to the limiting values for annual dose.

These recommendations also incorporate guidance for limiting exposure of the unborn as a result of occupational exposure of female workers. It has long been suspected that the embryo and fetus are more sensitive to a variety of effects of radiation than are adults. Although our knowledge remains incomplete, it has now become clear that the unborn are especially subject to the risk of mental retardation from exposure to radiation at a relatively early phase of total development. Available scientific evidence appears to indicate that this sensitivity is greatest during the period near the end of the first trimester and the beginning of the second trimester of pregnancy, that is, the period from 8 weeks to about 15 weeks after conception. Accordingly, when a woman has declared her pregnancy, this guidance recommends not only that the total exposure of the unborn be more limited than that of adult workers, but that the monthly rate of exposure be further limited in order to provide additional protection. Due to the incomplete state of knowledge of the transfer of radionuclides from the mother to the unborn (and the resulting uncertainty in dose to the unborn), in those few work situations where intake of radionuclides could normally be possible it may also be necessary to institute measures to avoid such intakes by pregnant women in order to satisfy these recommendations.

The health protection objectives of this guidance for the unborn should be achieved in accordance with the provisions of Title VII of the Civil Rights Act of 1964, as amended, with respect to discrimination in employment practices.** The guidance applies only to situations

---

** The Civil Rights Act of 1964, as amended provides that "It shall be an unlawful employment practice for an employer (1) to fail or refuse to hire or to discharge any individual,

in which the worker has voluntarily made her pregnancy known to her employer. Protection of the unborn may be achieved through such measures as temporary job rotation, worker self-selection, or use of protective equipment. The guidance recognizes that protection of the unborn is a joint responsibility of the employer and worker. Workers should be informed of the risks involved and encouraged to voluntarily make pregnancies known as early as possible so that any temporary arrangements necessary to modify exposures can be made. Conversely, employers should make such arrangements in a manner that minimizes the impact on the worker.

The recommended numerical guidance for limiting dose to workers applies to the sum of dose from external and internal sources of radiation. This procedure is recommended so as to provide a single limit on the total risk from radiation exposure. Therefore, in those cases where both kinds of radiation sources are present, decisions about to control of dose from internal sources should not be made without equal consideration of their implication for dose from external sources.

The guidance emphasizes the importance of recordkeeping for annual, committed, and cumulative (lifetime) doses. Such recordkeeping should be designed to avoid burdensome requirements for cases in which doses are insignificant. Currently, regulatory records are not generally required for doses small compared to regulatory limits for annual external and internal doses. Under this guidance such regulatory practices would continue to be appropriate if due consideration is given to the implications of summing internal and external doses and to recordkeeping needs for assessing cumulative doses. To the extent reasonable such records should be established on the basis of individual dosimetry rather than on monitoring of exposure condition.

In summary, many of the important changes from the 1960 guidance are structural. These include introduction of the concept of risk-based weighting of doses to different parts of the body and the use of committed dose as the primary basis for control of internal exposure. The numerical values of the guidance for maximum radiation doses are also modified. These changes bring this guidance into general conformance with international recommendations and practice. In addition, guidance is provided for protection of the unborn, and increased emphasis is placed on eliminating unjustified exposure and on keeping justified exposure as low as reasonable achievable, both long-standing tenets of radiation protection. The guidance emphasizes the importance of instruction of workers and their supervisors, monitoring and

---

or otherwise to discriminate against any individual with respect to his compensation, terms, conditions or privileges of employment, because of such individual's sex . . . or (2) to limit, segregate, or classify his employees or applicants for employment in any way which would deprive or tend to deprive any individual of employment opportunities or otherwise adversely affect his status as an employee, because of such individual's . . . sex . . ." [42 U.S.C. 2000e(a)]. The Pregnancy Discrimination Act of 1978 defines "because of sex" to include because of or on the basis of pregnancy, childbirth, or related medical conditions [42 U.S.C. 2000 e(k)].

recording of doses to workers, and the use of administrative control and reference levels for carrying out ALARA programs.

These recommendations apply to workers exposed to other than normal background radiation on the job. It is sometimes hard to identify such workers because everyone is exposed to natural sources of radiation and many occupational exposures are small. Workers or workplaces subject to this guidance will be identified by the responsible implementing agencies. Agencies will have to use care in determining when exposure of workers does not need to be regulated. In making such determinations agencies should consider both the collective dose which is likely to be avoided through regulation and the maximum individual doses possible.

Implementation of these recommendations will require changes that can reasonably be achieved only over a period of time. It is expected that Federal agencies will identify any problem areas and provide adequate flexibility and the necessary transition periods to avoid undue impacts, while at the same time assuring reasonable prompt implementation of this new guidance.

Upon implementing these recommendations, occupational exposure should be reduced. It is not possible to quantify the overall exposure reduction that will be realized because it cannot be predicted how efficiently these recommendations will be implemented or how much of existing exposure in unnecessary. These recommendations reduce the maximum whole body dose that works may receive in any one year by more than half (i.e., from 3 rems per quarter to 5 rems per year), require that necessary exposure to internal radioactivity be controlled on the basis of committed dose, require that internal and external doses be considered together rather than separately, and provide increased protection of the unborn. We also expect the strengthened and more explicit recommendations for maintaining occupational exposure "as low as reasonably achievable" will improve the radiation protection of workers. Finally, these recommendations would facilitate the practice of radiation protection by introducing a self-consistent system of limits in accordance with that in practice internationally.

Recommendations

The following recommendations are made for the guidance of Federal agencies in their conduct of programs for the protection of workers from ionizing radiation.

1. There should not be any occupational exposure of workers to ionizing radiation without the expectation of an overall benefit from the activity causing the exposure. Such activities may be allowed provided exposure of workers is limited in accordance with these recommendations.

2. No exposure is acceptable without regard to the reason for permitting it, and it should be general practice to maintain doses from radiation to levels below the limiting values specified in these recommendations. Therefore, it is fundamental to radiation protection that a sustained effort be made to ensure that collective doses, as well as annual,

committed, and cumulative lifetime individual doses, are maintained as low as reasonably achievable (ALARA), economic and social factors being taken into account.

3. In addition to the above recommendations, radiation doses received as a result of occupational exposure should not exceed the *limiting values for assessed dose to individual workers* specified below. These are given separately for protection against different types of effect on health and apply to the sum of doses from external and internal sources of radiation. For cancer and genetic effect, the limiting value is specified in terms of a derived quantity called the effective dose equivalent. For other health effects, the limiting values are specified in terms of the dose equivalent[1] to specific organs or tissues.

Cancer and Genetic Effects. The effective dose equivalent, H_E, received in any year by an adult worker should not exceed 5 rems (0.05 sievert).[2] The effective dose equivalent is defined as:

$$H_E = \sum_T w_T H_T$$

where w_T is a weighting factor and H_T is the annual dose equivalent averaged over organ or tissue T. Values of w_T and their corresponding[3] organs and tissues are:

Gonads	0.25
Breasts	0.15
Red bone marrow	0.12
Lungs	0.12
Thyroid	0.03
Bone surfaces	0.03
Remainder	0.30

[1] "Dose equivalent" is the product of the absorbed dose, a quality factor which varies with the energy and type of radiation, and other modifying factors, as defined by the International Commission on Radiation Units and Measurements.

[2] The unit of dose equivalent in the system of special quantities for ionizing radiation currently in use in the United States is the "rem". In the recently-adopted international system (SI) the unit of dose equivalent is the "sievert". One sievert = 100 rems.

[3] "Remainder" means the five other organs (such as liver, kidneys, spleen, brain, thymus, adrenals, pancreas, stomach, small intestine, upper large intestine, and lower large intestine, but excluding skin, lens of the eye, and extremities) with the highest doses. The weighting factor for each such organ is 0.06.

For the case of uniform irradiation of the whole body, where H_T may be assumed the same for each organ or tissue, the effective dose equivalent is equal to the dose equivalent to the whole body.

Other Health Effects. In addition to the limitation on effective dose equivalent, the dose equivalent, H_T , received in any year by an adult worker should not exceed 15 rems (0.15 sievert) to the lens of the eye, and 50 rems (0.5 sievert) to any other organ, tissue (including the skin), or extremity[4] of the body.

Additional limiting values which apply to the control of dose from internal exposure to radionuclides in the workplace are specified in Recommendation 4. Continued exposure of a worker at or near the limiting values for dose received in any year over substantial portions of a working lifetime should be avoided. This should normally be accomplished through application of appropriate radiation protection practices established under Recommendation 2.

4. As the primary means for controlling internal exposure to radionuclides, agencies should require that radioactive materials be contained, to the extent reasonable achievable, so as to minimize intake. In controlling internal exposure consideration should also be given to concomitant eternal exposure.

The control of necessary exposure of adult workers to radioactive materials in the workplace should be designed, operated, and monitored with sufficient frequency to ensure that, as the result of intake of radionuclides in a year, the following *limiting values for control of the workplace* are satisfied: (a) the anticipated magnitude of the committed effective dose equivalent from such intake plus any annual effective dose equivalent from eternal exposure will not exceed 5 rems (0.05 sievert), and (b) the anticipated magnitude of the committed dose equivalent to any organ or tissue from such intake plus any annual dose equivalent from external exposure will not exceed 50 rems (0.5 sievert). The committed effective dose equivalent from internal sources of radiation, $H_{E,50}$ is defined as:

$$H_{E,50} = \sum_T w_T H_{T,50}$$

where w_T is defined as in Recommendation 3 and the committed dose equivalent, $H_{T,50}$, is the sum of all dose equivalents to organ or tissue T that may accumulate over an individual's anticipated remaining lifetime (taken as 50 years) from radionuclides that are retained in the body. These conditions on committed doses should provide the primary basis for the control of internal exposure to radioactive materials.[5]

---

[4] "Extremity" means the forearms and hands, or the lower legs and feet.

[5] When these conditions on intake of radioactive materials have been satisfied, it is not necessary to assess contributions from such intakes to annual doses in future years, and, as an

In circumstances where assessment of actual intake for an individual worker shows the above conditions for control of intake have not been met, agencies should require that appropriate corrective action be taken to assure control has been reestablished and that future exposure of the worker is appropriately managed. Provision should be made to assess annual dose equivalents due to radionuclides retained in the body from such intake for as long as they are significant for ensuring conformance with the limiting values specified in Recommendation 3.

5. Occupational dose equivalents to individuals under the age of eighteen should be limited to one-tenth of the values specified in Recommendations 3 and 4 for adult workers.

6. Exposure of an unborn child should be less than that of adult workers. Workers should be informed of current knowledge of risks to the unborn[6] from radiation and of the responsibility of both employers and workers to minimize exposure of the unborn. The dose equivalent to an unborn as a result of occupational exposure of a woman who has declared that she is pregnant should be maintained as low as reasonably achievable, and in any case should not exceed 0.5 rem (0.005 sievert) during the entire gestation period. Efforts should be made to avoid substantial variation above the uniform monthly exposure rate that would satisfy this limiting value. The limiting value for the unborn does not create a basis for discrimination, and should be achieved in conformance with the provision of Title VII of the Civil Rights Act of 1964, as amended, regarding discrimination in employment practices, including hiring, discharge, compensation, and terms, conditions, or privileges of employment.

7. Individuals occupationally exposed to radiation and managers of activities involving radiation should be instructed on the basic risks to health from ionizing radiation and on basic radiation protection principles. This should, as a minimum, include instruction on the somatic (including *in utero*) and genetic effects of ionizing radiation, the recommendations set forth in Federal radiation protection guidance for occupational exposure and applicable regulations and operating procedures which implement this guidance, the general levels of risk and appropriate radiation protection practices for their work situations, and the responsibilities of individual worker to avoid and minimize exposure. The degree and type of instruction that is appropriate will depend on the potential radiation exposures involved.

8. Appropriate monitoring of workers and the work place should be performed and records kept to ensure conformance with these recommendations. The types and accuracy of monitoring methods and procedures utilized should be periodically reviewed to assure that appropriate techniques are being competently applied.

---

operational procedure, such doses may be assigned to the year of intake for the purpose of assessing compliance with Recommendation 3.

[6] The term "unborn" is defined to encompass the period commencing with conception and ending with birth.

Maintenance of a cumulative record of lifetime occupational doses for each worker is encouraged. For doses due to intake of radioactive materials, the committed effective dose equivalent and the quantity of each radionuclide in the body should be assessed and recorded, to the extend practicable. A summary of annual, cumulative, and committed effective dose equivalents should be provided each worker on no less than an annual basis; more detailed information concerning his or her exposure should be made available upon the worker's request.

9. Radiation exposure control measures should be designed, selected, utilized, and maintained to ensure that anticipated and actual doses meet the objectives of this guidance. Establishment of administrative control levels[7] below the limiting values for control may be useful and appropriate for achieving this objective. Reference levels[8] may also be useful to determine the need to take such actions as recording, investigation, and interventions. Since such administrative control and reference levels will often involve ALARA considerations, they may be developed for specific categories of workers or work situations. Agencies should encourage the establishment of measures by which management can assess the effectiveness of ALARA efforts, including, where appropriate, local goals for limiting individual and collective occupational doses. Supervision should be provided on a part-time, full-time, or task-by-task basis as necessary to maintain effective control over the exposure of workers.

10. The numerical values recommended herein should not be deliberately exceeded except during emergencies, or under unusual circumstances for which the Federal agency having jurisdiction has carefully considered the reasons for doing so in light of these recommendations. If Federal agencies authorize dose equivalents greater than these values for unusual circumstances, they should make any generic procedures specifying conditions under which such exposures may occur publicly available or make specific instances in which such authorization has been given a matter of public record.

The following notes are provided to clarify application of the above recommendations:

1. Occupational exposure of workers does not include that due to normal background radiation and exposure as a patient of practitioners of the healing arts.

2. The existing Federal guidance (34 FR 576 and 36 FR 12921) for limiting exposure for underground miners to radon decay products applies independently of, and is not changed by, these recommendations.

---

[7] Administrative control levels are requirements determined by a competent authority of the management of an institution or facility. They are not primary limits, and may therefore be exceeded, upon approval of competent authority or management as situations dictate.

[8] Reference levels are not limits, and may be expressed in terms of any useful parameter. They are used to determine a course of action, such as recording, investigation, or intervention, when the value of a parameter exceeds, or is projected to exceed, the reference level.

3. The values specified by the International Commission on Radiological Protection (ICRP) for quality factors and dosimetric conventions for the various types of radiation, the models for reference persons, and the results of their dosimetric methods and metabolic models may be used for determining conformance to these recommendations.

4. "Annual Limits on Intake" (ALIs) and/or "Derived Air Concentrations" (DACs) may be used to limit radiation exposure from intake of or immersion in radionuclides. The ALI or DAC for a single radionuclide is the maximum intake in a year or average air concentration for a working year, respectively, for a reference person that, in the absence of any external dose, satisfies the conditions on committed effective dose equivalent and committed dose equivalent of Recommendation 4. ALIs and DACs may be derived from different chemical or physical forms of radioactive materials.

5. The numerical values provided by these recommendations do not apply to workers responsible for the management of or response to emergencies.

These recommendations would replace those portions of current Federal Radiation Protection Guidance (25 FR 4402) that apply to the protection of workers from ionizing radiation. It is expected that individual Federal agencies, on the basis of their knowledge of specific worker exposure situations, will use this new guidance as the basis upon which to revise or develop detailed standards and regulations to the extent that they have regulatory or administrative jurisdiction. The Environmental Protection Agency will keep informed of Federal agency actions to implement this guidance, and will issue any necessary clarifications and interpretations required to reflect new information, so as to promote the coordination necessary to achieve an effective Federal program of worker protection.

June 1974

U.S. ATOMIC ENERGY COMMISSION

REGULATORY GUIDE

DIRECTORATE OF REGULATORY STANDARDS

REGULATORY GUIDE 1.86

TERMINATION OF OPERATING LICENSES FOR NUCLEAR REACTORS

A. INTRODUCTION

Section 50.51, "Duration of license, renewal," of 10 CFR Part 50, "Licensing of Production and Utilization Facilities," requires that each license to operate a production and utilization facility be issued for a specified duration. Upon expiration of the specified period, the license may be either renewed or terminated by the Commission. Section 50.82, "Applications for termination of licenses," specifies the requirements that must be satisfied to terminate an operating license, including the requirement that the dismantlement of the facility and disposal of the component parts not be inimical to the common defense and security or to the health and safety of the public. This guide describes methods and procedures considered acceptable by the Regulatory staff for the termination of operating licenses for nuclear reactors. The Advisory Committee on Reactor Safeguards has been consulted concerning this guide and has concurred in the regulatory position.

B. DISCUSSION

When a licensee decides to terminate his nuclear reactor operating license, he may, as a first step in the process, request that his operating license be amended to restrict him to possess but not operate the facility. The advantage to the licensee of converting to such a possession-only license is reduced surveillance requirements in that periodic surveillance of equipment important to the safety of reactor operation is no longer required. Once this possession-only license is issued, reactor operation is not permitted. Other activities related to cessation of operations such as unloading fuel from the reactor and placing it in storage (either onsite of offsite) may be continued.

A licensee having a possession-only license must retain, with the Part 50 license, authorization for special nuclear material (10 CFR Part 70, "Special Nuclear Material"), byproduct material (10 CFR Part 30, "Rules of General Applicability to Licensing of Byproduct Material"), and source material (10 CFR Part 40, "Licensing of Source Material"), until the fuel, radioactive components, and sources are removed from the facility. Appropriate administrative controls and facility requirements are imposed by the Part 50 license and the technical specifications to assure that proper surveillance is performed and that the reactor facility is maintained in a safe condition and not operated.

A possession-only license permits various options and procedures for decommissioning, such as mothballing, entombment, or dismantling. The requirements imposed depend on the option selected.

Section 50.82 provides that the licensee may dismantle and dispose of the component parts of a nuclear reactor in accordance with existing regulations. For research reactors and critical facilities, this has usually meant the disassembly of a reactor and its shipment offsite, sometimes to another appropriately licensed organization for further use. The site from which a reactor has been removed must be decontaminated, as necessary, and inspected by the Commission to determine whether unrestricted access can be approved. In the case of nuclear power reactors, dismantling has usually been accomplished by shipping fuel offsite, making the reactor inoperable, and disposing of some of the radioactive components.

Radioactive components may be either shipped offsite for burial at an authorized burial ground or secured

USAEC REGULATORY GUIDES

Regulatory Guides are issued to describe and make available to the public methods acceptable to the AEC Regulatory staff of implementing specific parts of the Commission's regulations, to delineate techniques used by the staff in evaluating specific problems or postulated accidents, or to provide guidance to applicants. Regulatory Guides are not substitutes for regulations and compliance with them is not required. Methods and solutions different from those set out in the guides will be acceptable if they provide a basis for the findings requisite to the issuance or continuance of a permit or license by the Commission.

Published guides will be revised periodically as appropriate to accommodate comments and to reflect new information or experience.

Copies of published guides may be obtained by request indicating the divisions desired to the U.S. Atomic Energy Commission, Washington, D.C. 20545, Attention: Director of Regulatory Standards. Comments and suggestions for improvements in these guides are encouraged and should be sent to the Secretary of the Commission, U.S. Atomic Energy Commission, Washington, D.C. 20545, Attention: Chief, Public Proceedings Staff.

The guides are issued in the following ten broad divisions.

1. Power Reactors
2. Research and Test Reactors
3. Fuels and Materials Facilities
4. Environmental and Siting
5. Materials and Plant Protection
6. Products
7. Transportation
8. Occupational Health
9. Antitrust Review
10. General

on the site. Those radioactive materials remaining on the site must be isolated from the public by physical barriers or other means to prevent public access to hazardous levels of radiation. Surveillance is necessary to assure the long term integrity of the barriers. The amount of surveillance required depends upon (1) the potential hazard to the health and safety of the public from radioactive material remaining on the site and (2) the integrity of the physical barriers. Before areas may be released for unrestricted use, they must have been decontaminated or the radioactivity must have decayed to less than prescribed limits (Table I).

The hazard associated with the retired facility is evaluated by considering the amount and type of remaining contamination, the degree of confinement of the remaining radioactive materials, the physical security provided by the confinement, the susceptibility to release of radiation as a result of natural phenomena, and the duration of required surveillance.

C. REGULATORY POSITION

1. APPLICATION FOR A LICENSE TO POSSESS BUT NOT OPERATE (POSSESSION-ONLY LICENSE)

A request to amend an operating license to a possession-only license should be made to the Director of Licensing, U.S. Atomic Energy Commission, Washington, D.C. 20545. The request should include the following information.

a. A description of the current status of the facility.

b. A description of measures that will be taken to prevent criticality or reactivity changes and to minimize releases of radioactivity from the facility.

c. Any proposed changes to the technical specifications that reflect the possession-only facility status and the necessary disassembly/retirement activities to be performed.

d. A safety analysis of both the activities to be accomplished and the proposed changes to the technical specifications.

e. An inventory of activated materials and their location in the facility.

2. ALTERNATIVES FOR REACTOR RETIREMENT

Four alternatives for retirement of nuclear reactor facilities are considered acceptable by the Regulatory staff. These are:

a. **Mothballing.** Mothballing of a nuclear reactor facility consists of putting the facility in a state of protective storage. In general, the facility may be left intact except that all fuel assemblies and the radioactive fluids and waste should be removed from the site. Adequate radiation monitoring, environmental surveillance, and appropriate security procedures should be established under a possession-only license to ensure that the health and safety of the public is not endangered.

b. **In-Place Entombment.** In-place entombment consists of sealing all the remaining highly radioactive or contaminated components (e.g., the pressure vessel and reactor internals) within a structure integral with the biological shield after having all fuel assemblies, radioactive fluids and wastes, and certain selected components shipped offsite. The structure should provide integrity over the period of time in which significant quantities (greater than Table I levels) of radioactivity remain with the material in the entombment. An appropriate and continuing surveillance program should be established under a possession-only license.

c. **Removal of Radioactive Components and Dismantling.** All fuel assemblies, radioactive fluids and waste, and other materials having activities above accepted unrestricted activity levels (Table I) should be removed from the site. The facility owner may then have unrestricted use of the site with no requirement for a license. If the facility owner so desires, the remainder of the reactor facility may be dismantled and all vestiges removed and disposed of.

d. **Conversion to a New Nuclear System or a Fossil Fuel System.** This alternative, which applies only to nuclear power plants, utilizes the existing turbine system with a new steam supply system. The original nuclear steam supply system should be separated from the electric generating system and disposed of in accordance with one of the previous three retirement alternatives.

3. SURVEILLANCE AND SECURITY FOR THE RETIREMENT ALTERNATIVES WHOSE FINAL STATUS REQUIRES A POSSESSION-ONLY LICENSE

A facility which has been licensed under a possession-only license may contain a significant amount of radioactivity in the form of activated and contaminated hardware and structural materials. Surveillance and commensurate security should be provided to assure that the public health and safety are not endangered.

a. Physical security to prevent inadvertent exposure of personnel should be provided by multiple locked barriers. The presence of these barriers should make it extremely difficult for an unauthorized person to gain access to areas where radiation or contamination levels exceed those specified in Regulatory Position C.4. To prevent inadvertent exposure, radiation areas above 5 mR/hr, such as near the activated primary system of a power plant, should be appropriately marked and should not be accessible except by cutting of welded closures or the disassembly and removal of substantial structures

and/or shielding material. Means such as a remote readout intrusion alarm system should be provided to indicate to designated personnel when a physical barrier is penetrated. Security personnel that provide access control to the facility may be used instead of the physical barriers and the intrusion alarm systems.

b. The physical barriers to unauthorized entrance into the facility, e.g., fences, buildings, welded doors, and access openings, should be inspected at least quarterly to assure that these barriers have not deteriorated and that locks and locking apparatus are intact.

c. A facility radiation survey should be performed at least quarterly to verify that no radioactive material is escaping or being transported through the containment barriers in the facility. Sampling should be done along the most probable path by which radioactive material such as that stored in the inner containment regions could be transported to the outer regions of the facility and ultimately to the environs.

d. An environmental radiation survey should be performed at least semiannually to verify that no significant amounts of radiation have been released to the environment from the facility. Samples such as soil, vegetation, and water should be taken at locations for which statistical data has been established during reactor operations.

e. A site representative should be designated to be responsible for controlling authorized access into and movement within the facility.

f. Administrative procedures should be established for the notification and reporting of abnormal occurrences such as (1) the entrance of an unauthorized person or persons into the facility and (2) a significant change in the radiation or contamination levels in the facility or the offsite environment.

g. The following reports should be made:

(1) An annual report to the Director of Licensing, U.S. Atomic Energy Commission, Washington, D.C. 20545, describing the results of the environmental and facility radiation surveys, the status of the facility, and an evaluation of the performance of security and surveillance measures.

(2) An abnormal occurrence report to the Regulatory Operations Regional Office by telephone within 24 hours of discovery of an abnormal occurrence. The abnormal occurrence will also be reported in the annual report described in the preceding item.

h. Records or logs relative to the following items should be kept and retained until the license is terminated, after which they may be stored with other plant records:

(1) Environmental surveys,

(2) Facility radiation surveys,

(3) Inspections of the physical barriers, and

(4) Abnormal occurrences

4 DECONTAMINATION FOR RELEASE FOR UNRESTRICTED USE

If it is desired to terminate a license and to eliminate any further surveillance requirements, the facility should be sufficiently decontaminated to prevent risk to the public health and safety. After the decontamination is satisfactorily accomplished and the site inspected by the Commission, the Commission may authorize the license to be terminated and the facility abandoned or released for unrestricted use. The licensee should perform the decontamination using the following guidelines:

a. The licensee should make a reasonable effort to eliminate residual contamination.

b. No covering should be applied to radioactive surfaces of equipment or structures by paint, plating, or other covering material until it is known that contamination levels (determined by a survey and documented) are below the limits specified in Table I. In addition, a reasonable effort should be made (and documented) to further minimize contamination prior to any such covering.

c. The radioactivity of the interior surfaces of pipes, drain lines, or ductwork should be determined by making measurements at all traps and other appropriate access points, provided contamination at these locations is likely to be representative of contamination on the interior of the pipes, drain lines, or ductwork. Surfaces of premises, equipment, or scrap which are likely to be contaminated but are of such size, construction, or location as to make the surface inaccessible for purposes of measurement should be assumed to be contaminated in excess of the permissable radiation limits.

d. Upon request, the Commission may authorize a licensee to relinquish possession or control of premises, equipment, or scrap having surfaces contaminated in excess of the limits specified. This may include, but is not limited to, special circumstances such as the transfer of premises to another licensed organization that will continue to work with radioactive materials. Requests for such authorization should provide:

(1) Detailed, specific information describing the premises, equipment, scrap, and radioactive contaminants and the nature, extent, and degree of residual surface contamination.

(2) A detailed health and safety analysis indicating that the residual amounts of materials on surface areas, together with other considerations such as the prospective use of the premises, equipment, or scrap, are unlikely to result in an unreasonable risk to the health and safety of the public.

e. Prior to release of the premises for unrestricted use, the licensee should make a comprehensive radiation survey establishing that contamination is within the limits specified in Table 1. A survey report should be filed with the Director of Licensing, U.S. Atomic Energy Commission, Washington, D.C. 20545, with a copy to the Director of the Regulatory Operations Regional Office having jurisdiction. The report should be filed at least 30 days prior to the planned date of abandonment. The survey report should:

(1) Identify the premises;

(2) Show that reasonable effort has been made to reduce residual contamination to as low as practicable levels;

(3) Describe the scope of the survey and the general procedures followed; and

(4) State the finding of the survey in units specified in Table 1.

After review of the report, the Commission may inspect the facilities to confirm the survey prior to granting approval for abandonment.

5. REACTOR RETIREMENT PROCEDURES

As indicated in Regulatory Position C.2, several alternatives are acceptable for reactor facility retirement. If minor disassembly or "mothballing" is planned, this could be done by the existing operating and maintenance procedures under the license in effect. Any planned actions involving an unreviewed safety question or a change in the technical specifications should be reviewed and approved in accordance with the requirements of 10 CFR §50.59.

If major structural changes to radioactive components of the facility are planned, such as removal of the pressure vessel or major components of the primary system, a dismantlement plan including the information required by §50.82 should be submitted to the Commission. A dismantlement plan should be submitted for all the alternatives of Regulatory Position C.2 except mothballing. However, minor disassembly activities may still be performed in the absence of such a plan, provided they are permitted by existing operating and maintenance procedures. A dismantlement plan should include the following:

a. A description of the ultimate status of the facility.

b. A description of the dismantling activities and the precautions to be taken.

c. A safety analysis of the dismantling activities including any effluents which may be released.

d. A safety analysis of the facility in its ultimate status.

Upon satisfactory review and approval of the dismantling plan, a dismantling order is issued by the Commission in accordance with §50.82. When dismantling is completed and the Commission has been notified by letter, the appropriate Regulatory Operations Regional Office inspects the facility and verifies completion in accordance with the dismantlement plan. If residual radiation levels do not exceed the values in Table 1, the Commission may terminate the license. If these levels are exceeded, the licensee retains the possession-only license under which the dismantling activities have been conducted or, as an alternative, may make application to the State (if an Agreement State) for a byproduct materials license.

TABLE I

ACCEPTABLE SURFACE CONTAMINATION LEVELS

NUCLIDE[a]	AVERAGE[b c]	MAXIMUM[b d]	REMOVABLE[b e]
U-nat, U-235, U-238, and associated decay products	5,000 dpm α/100 cm^2	15,000 dpm α/100 cm^2	1,000 dpm α/100 cm^2
Transuranics, Ra-226, Ra-228, Th-230, Th-228, Pa-231, Ac-227, I-125, I-129	100 dpm/100 cm^2	300 dpm/100 cm^2	20 dpm/100 cm^2
Th-nat, Th-232, Sr-90, Ra-223, Ra-224, U-232, I-126, I-131, I-133	1000 dpm/100 cm^2	3000 dpm/100 cm^2	200 dpm/100 cm^2
Beta-gamma emitters (nuclides with decay modes other than alpha emission or spontaneous fission) except Sr-90 and others noted above.	5000 dpm β-γ/100 cm^2	15,000 dpm β-γ/100 cm^2	1000 dpm β-γ/100 cm^2

[a]Where surface contamination by both alpha- and beta-gamma-emitting nuclides exists, the limits established for alpha- and beta-gamma-emitting nuclides should apply independently.

[b]As used in this table, dpm (disintegrations per minute) means the rate of emission by radioactive material as determined by correcting the counts per minute observed by an appropriate detector for background, efficiency, and geometric factors associated with the instrumentation.

[c]Measurements of average contaminant should not be averaged over more than 1 square meter. For objects of less surface area, the average should be derived for each such object.

[d]The maximum contamination level applies to an area of not more than 100 cm^2.

[e]The amount of removable radioactive material per 100 cm^2 of surface area should be determined by wiping that area with dry filter or soft absorbent paper, applying moderate pressure, and assessing the amount of radioactive material on the wipe with an appropriate instrument of known efficiency. When removable contamination on objects of less surface area is determined, the pertinent levels should be reduced proportionally and the entire surface should be wiped.

NOV 4 1983

DISTRIBUTION
RECunningham
BSinger
VLMiller
LCRouse
CEMacDonald
WTCrow
FCUF R/F
NMSS R/F
DRChapell
JGlenn, RI
JPotter, RII
BMallett, RIII
JEverett, RIV
RThomas, RV
FC Central File

MEMORANDUM FOR: Regional Administrators
Branch Chiefs
Division of Fuel Cycle and Material Safety, NMSS

FROM: Richard E. Cunningham, Director
Division of Fuel Cycle and Material Safety, NMSS

SUBJECT: POLICY AND GUIDANCE DIRECTIVE FC 83-23: TERMINATION OF BYPRODUCT, SOURCE AND SPECIAL NUCLEAR MATERIAL LICENSES

The enclosed final rule specifies licensee responsibility and requirements for terminating a license issued under 10 CFR Parts 30, 40 and 70. Among other things, a licensee is required to submit on or before the expiration date a radiation survey report to confirm the absence of radioactive materials or to specify existing levels of residual radioactive contamination present from past operations. A survey report is not required if a licensee can demonstrate the absence of radioactive contamination in some other manner, such as the use only of sealed sources that never showed evidence of leakage. If detectable levels of residual radioactive contamination attributable to licensed operations are found, the license continues in force until the Commission notifies the licensee in writing that the license is terminated. The purpose of this memorandum is to provide guidance to the Regions and Headquarters staff on the findings that need to be made before written notification is given that the license is terminated.

Review Procedure

Before terminating a license where residual radioactive material contamination is present from past licensed operations, NRC should determine whether:

1. a reasonable effort has been made to eliminate residual contamination, and

2. residual radioactive contamination is acceptably low to permit unrestricted release of the affected facilities.

If the levels of residual radioactive contamination on surfaces and in soil are a small fraction of those normally acceptable for unrestricted release (see Section below), it is not necessary for the licensee to describe the efforts he has made to reduce contamination levels.

Policy and Guidance Directive FC 83-3: Standard Review Plan (SRP) for Termination of Special Nuclear Material Licenses for Fuel Cycle Facilities, contains information that is generally useful for terminating any byproduct, source or special nuclear material license.

OFFICE							
SURNAME					NOV 1 0 1983		
DATE							

OFFICIAL RECORD COPY

In most cases involving short half-life radionuclides or operations involving only sealed sources, an independent confirmatory survey by NRC will not be necessary. Confirmatory surveys should always be made if the licensee's survey report appears suspect or past licensee operations involved the chemical processing of hundreds of milligrams of plutonium, tens of kilograms of enriched uranium 235 or hundreds of kilograms of source material. For materials licensees which used and processed hundreds of millicuries of long half-life radionuclides (> 1 yr), confirmatory surveys should also be made in all cases. If it is determined that a confirmatory survey will be made, a notice should be sent to the licensee informing him that the equipment and facilities should be held for NRC inspection. Discretion may be exercised as to whether a confirmatory survey is to be made if there is information available, such as inspection reports, which provides a basis for acceptance of the licensee's survey.

Contamination Levels Generally Acceptable for Unrestricted Release

- Surface Contamination - See Enclosure 2
- Soil Contamination - See Enclosure 3
- Water Contamination - If surface or groundwater contamination is below EPA's National Interim Primary Drinking Water Regulations (EPA 570-9-76-003), the contamination is acceptable for unrestricted release.

If the levels of contamination exceed the levels discussed above and a judgment is made that further efforts to reduce the contamination is not necessary for termination of the license, an environmental impact assessment should be made to support the termination. Such cases should be brought to the attention of the Director of the Division of Fuel Cycle and Material Safety, NMSS, before the termination is dispatched.

Original Signed by
D. R. Chapell

Richard E. Cunningham, Director
Division of Fuel Cycle and
Material Safety, NMSS

Enclosures:
1. Final Rule: Amendments to 10 CFR Parts 30, 40 and 70 Specifying Licensee Responsibility for Nuclear Materials and Procedures for Termination of Specific Licenses

FC
DRChapell
11/4/83

2. Guidelines for Decontamination of Facilites and Equipment Prior to Release for Unrestricted Use or Termination of Licenses for Byproduct, Source, or Special Nuclear Material

*See previous concurrence sheets

OFFICE	FCUP*	FCUF*	FCAF*	FCML	FCTC*	FCMC*	FC
SURNAME	WTCrow	RGPage/as	LCRouse	VLMiller	CEMacDonald	BSinger	RECunningham
DATE	8/8/83	8/8/83	8/8/83	11/3/83	8/12/83	8/12/83	11/4/83

Table on Acceptable Soil Contamination Levels

OFFICIAL RECORD COPY

Acceptable Soil Contamination Levels

	Kind of Material	Soil Concentration Level for unrestricted area
i)	Natural Uranium (U-238 + U-234) with daughters present and in equilibrium	10 (pCi/gm of soil)
ii)	Depleted Uranium or Natural Uranium that has been separated from its daughters Soluble or Insoluble	35 (pCi/gm of soil)
iii)	Natural Thorium (Th-232 + Th-228) with daughters present and in equilibrium	10 (pCi/gm of soil)
iv)	Enriched Uranium Soluble or Insoluble	30 (pCi/gm of soil)
v)	Plutonium (Y) or (W) compounds	25 (pCi/gm of soil)
vi)	Am-241 (W) compounds	30 (pCi/gm of soil)
vii)	All Byproduct Material	Soil concentrations shall be determined on a case by case basis
viii)	External Radiation	10 microroentgens/hr above background measured at one meter from the ground surface

ENCLOSURE 3

Revision 2
December 1987

U.S. NUCLEAR REGULATORY COMMISSION

REGULATORY GUIDE

OFFICE OF NUCLEAR REGULATORY RESEARCH

REGULATORY GUIDE 8.13
(Task OP 031-4)

INSTRUCTION CONCERNING PRENATAL RADIATION EXPOSURE

A. INTRODUCTION

Section 19.12, "Instructions to Workers," of 10 CFR Part 19, "Notices, Instructions, and Reports to Workers, Inspections," requires that all individuals working in or frequenting any portion of a restricted area[1] be instructed in the health protection problems associated with exposure to radioactive materials or radiation, in precautions or procedures to minimize exposure, and in the regulations that they are expected to observe. The present 10 CFR Part 20, "Standards for Protection Against Radiation," has no special limit for exposure of the embryo/fetus.[2] This guide describes the instructions an employer should provide to workers and supervisors concerning biological risks to the embryo/fetus exposed to radiation, a dose limit for the embryo/fetus that is under consideration, and suggestions for reducing radiation exposure.

This regulatory guide takes into consideration a proposed revision to 10 CFR Part 20, which incorporates the radiation protection guidance for the embryo/fetus approved by the President in January 1987 (Ref. 1). This revision to Part 20 was issued in January 1986 for comment as a proposed rule. Comments on the guide as it pertains to the proposed Part 20 are encouraged. If the new Part 20 is codified, this regulatory guide will be revised to conform to the new regulation and will incorporate appropriate public comments.

Any information collection activities mentioned in this regulatory guide are contained as requirements in 10 CFR Parts 19 or 20, which provide the regulatory basis for this guide. The information collection requirements in 10 CFR Parts 19 and 20 have been cleared under OMB Clearance Nos 3150-0044 and 3150-0014, respectively.

B. DISCUSSION

It has been known since 1906 that cells that are dividing very rapidly and are undifferentiated in their structure and function are generally more sensitive to radiation. In the embryo stage, cells meet both these criteria and thus would be expected to be highly sensitive to radiation. Furthermore, there is direct evidence that the embryo/fetus is radiosensitive. There is also evidence that it is especially sensitive to certain radiation effects during certain periods after conception, particularly during the first 2 to 3 months after conception when a woman may not be aware that she is pregnant.

Section 20.104 of 10 CFR Part 20 places different radiation dose limits on workers who are minors than on adult workers. Workers under the age of 18 are limited to one-tenth of the adult radiation dose limits. However, the present NRC regulations do not establish dose limits specifically for the embryo/fetus.

The NRC's present limit on the radiation dose that can be received on the job is 1,250 millirems per quarter (3 months).[3] Working minors (those under 18) are limited to a dose equal to one-tenth that of adults, 125 millirems per quarter. (See § 20.101 of 10 CFR Part 20.)

Because of the sensitivity of the unborn child, the National Council on Radiation Protection and Measurements (NCRP) has recommended that the dose equivalent

[1] Restricted area means any area that has controlled access to protect individuals from being exposed to radiation and radioactive materials.

[2] In conformity with the proposed revision to 10 CFR Part 20, the term "embryo/fetus" is used throughout this document to represent all stages of pregnancy.

[3] The limit is 3,000 millirems per quarter if the worker's occupational dose history is known and the average dose does not exceed 5,000 millirems per year.

USNRC REGULATORY GUIDES

Regulatory Guides are issued to describe and make available to the public methods acceptable to the NRC staff of implementing specific parts of the Commission's regulations, to delineate techniques used by the staff in evaluating specific problems or postulated accidents, or to provide guidance to applicants. Regulatory Guides are not substitutes for regulations, and compliance with them is not required. Methods and solutions different from those set out in the guides will be acceptable if they provide a basis for the findings requisite to the issuance or continuance of a permit or license by the Commission.

This guide was issued after consideration of comments received from the public. Comments and suggestions for improvements in these guides are encouraged at all times, and guides will be revised, as appropriate, to accommodate comments and to reflect new information or experience.

Written comments may be submitted to the Rules and Procedures

The guides are issued in the following ten broad divisions:

1. Power Reactors
2. Research and Test Reactors
3. Fuels and Materials Facilities
4. Environmental and Siting
5. Materials and Plant Protection
6. Products
7. Transportation
8. Occupational Health
9. Antitrust and Financial Review
10. General

Copies of issued guides may be purchased from the Government Printing Office at the current GPO price. Information on current GPO prices may be obtained by contacting the Superintendent of Documents, U.S. Government Printing Office, Post Office Box 37082, Washington, DC 20013-7082, telephone (202)275-2060 or (202)275-2171.

Issued guides may also be purchased from the National Technical

to the unborn child from occupational exposure of the expectant mother be limited to 500 millirems for the entire pregnancy (Ref. 2). The 1987 Presidential guidance (Ref. 1) specifies an effective dose equivalent limit of 500 millirems to the unborn child if the pregnancy has been declared by the mother, the guidance also recommends that substantial variations in the rate of exposure be avoided. The NRC (in § 20.208 of its proposed revision to Part 20) has proposed adoption of the above limits on dose and rate of exposure.

In 1971, the NCRP commented on the occupational exposure of fertile women (Ref. 2) and suggested that fertile women should be employed only where the annual dose would be unlikely to exceed 2 or 3 rems and would be accumulated at a more or less steady rate. In 1977, the ICRP recommended that, when pregnancy has been diagnosed, the woman work only where it is unlikely that the annual dose would exceed 0.30 of the dose-equivalent limit of 5 rems (Ref. 3). In other words, the ICRP has recommended that pregnant women not work where the annual dose might exceed 1.5 rem.

C. REGULATORY POSITION

Instructions on radiation risks should be provided to workers, including supervisors, in accordance with § 19.12 of 10 CFR Part 19 before they are allowed to work in a restricted area. In providing instructions on radiation risks, employers should include specific instructions about the risks of radiation exposure to the embryo/fetus.

The instructions should be presented both orally and in printed form, and the instructions should include, as a minimum, the information provided in Appendix A (Instructor's Guide) to this guide. Individuals should be given the opportunity to ask questions and in turn should be questioned to determine whether they understand the instructions. An acceptable method of ensuring that the information is understood is to give a simple written test covering the material included in Appendix B (Pregnant Worker's Guide). This approach should highlight for instructors those parts of the instructions that cause difficulties and thereby lead to appropriate modifications in the instructional curriculum.

D. IMPLEMENTATION

The purpose of this section is to provide information to applicants and licensees regarding the NRC staff's plans for using this regulatory guide.

Except in those cases in which an applicant or licensee proposes an acceptable alternative method for complying with specified portions of the Commission's regulations, the NRC will use the material described in this guide to evaluate the instructional program presented to individuals, including supervisors, working in or frequenting any portion of a restricted area.

APPENDIX A

INSTRUCTOR'S GUIDE

EFFECTS ON THE EMBRYO/FETUS OF EXPOSURE TO RADIATION AND OTHER ENVIRONMENTAL HAZARDS

In order to decide whether to continue working while exposed to ionizing radiation during her pregnancy, a woman should understand the potential effects on an embryo/fetus, including those that may be produced by various environmental risks such as smoking and drinking. This will allow her to compare these risks with those produced by exposure to ionizing radiation.

Table 1 provides information on the potential effects resulting from exposure of an embryo/fetus to radiation and nonradiation risks. The second column gives the rate at which the effect is produced by natural causes in terms of the number per thousand cases. The fourth column gives the number of additional effects per thousand cases believed to be produced by exposure to the specified amount of the risk factor.

The following section discusses the studies from which the information in Table 1 was derived. The results of exposure of the embryo/fetus to the risk factors and the dependence on the amount of the exposure are explained.

1. RADIATION RISKS

1.1 Childhood Cancer

Numerous studies of radiation-induced childhood cancer have been performed, but a number of them are controversial. The National Academy of Science (NAS) BEIR report reevaluated the data from these studies and even reanalyzed the results. Some of the strongest support for a causal relationship is provided by twin data from the Oxford survey (Ref. 4). For maternal radiation doses of 1,000 millirems, the excess number of deaths (above those occurring from natural causes) was found to be 0.6 death per thousand children (Ref. 4).

1.2 Mental Retardation and Abnormal Smallness of the Head (Microcephaly)

Studies of Japanese children who were exposed while in the womb to the atomic bomb radiation at Hiroshima and Nagasaki have shown evidence of both small head size and mental retardation. Most of the children were exposed to radiation doses in the range of 1 to 50 rads. The importance of the most recent study lies in the fact that investigators were able to show that the gestational age (age of the embryo/fetus after conception) at the time the children were exposed was a critical factor (Ref. 7). The approximate risk of small head size as a function of gestational age is shown in Table 1. For a radiation dose of 1,000 millirems at 4 to 7 weeks after conception, the excess cases of small head size was 5 per thousand; at 8 to 11 weeks, it was 9 per thousand (Ref. 7).

In another study, the highest risk of mental retardation occurred during the 8 to 15 week period after conception (Ref. 8). A recent EPA study (Ref. 16) has calculated that excess cases of mental retardation per live birth lie between 0.5 and 4 per thousand per rad.

1.3 Genetic Effects

Radiation-induced genetic effects have not been observed to date in humans. The largest source of material for genetic studies involves the survivors of Hiroshima and Nagasaki, but the 77,000 births that occurred among the survivors showed no evidence of genetic effects. For doses received by the pregnant worker in the course of employment considered in this guide, the dose received by the embryo/fetus apparently would have a negligible effect on descendants (Refs. 17 and 18).

2. NONRADIATION RISKS

2.1 Occupation

A recent study (Ref. 9) involving the birth records of 130,000 children in the State of Washington indicates that the risk of death to the unborn child is related to the occupation of the mother. Workers in the metal industry, the chemical industry, medical technology, the wood industry, the textile industry, and farms exhibited stillbirths or spontaneous abortions at a rate of 90 per thousand above that of workers in the control group, which consisted of workers in several other industries.

2.2 Alcohol

It has been recognized since ancient times that alcohol consumption had an effect on the unborn child. Carthaginian law forbade the consumption of wine on the wedding night so that a defective child might not be conceived. Recent studies have indicated that small amounts of alcohol consumption have only the minor effect of reducing the birth weight slightly, but when consumption increases to 2 to 4 drinks per day, a pattern of abnormalities called the fetal alcohol syndrome (FAS) begins to appear (Ref. 11). This syndrome consists of reduced growth in the unborn child, faulty brain function, and abnormal facial features. There is a syndrome that has the same symptoms as full-blown FAS that occurs in children born to mothers who have not consumed alcohol. This naturally occurring syndrome occurs in about 1 to 2 cases per thousand (Ref. 10).

TABLE 1

EFFECTS OF RISK FACTORS ON PREGNANCY OUTCOME

Effect	Number Occurring from Natural Causes	Risk Factor	Excess Occurrences from Risk Factor
		RADIATION RISKS	
		Childhood Cancer	
Cancer death in children	1 4 per thousand (Ref. 5)	Radiation dose of 1000 millirems received before birth	0.6 per thousand (Ref. 4)
		Abnormalities	
		Radiation dose of 1000 millirads received during specific periods after conception.	
Small head size	40 per thousand (Ref. 6)	4-7 weeks after conception	5 per thousand (Ref. 7)
Small head size	40 per thousand (Ref. 6)	8-11 weeks after conception	9 per thousand (Ref. 7)
Mental retardation	4 per thousand (Ref. 8)	Radiation dose of 1000 millirads received 8 to 15 weeks after conception	4 per thousand (Ref. 8)
		NONRADIATION RISKS	
		Occupation	
Stillbirth or spontaneous abortion	200 per thousand (Ref. 9)	Work in high-risk occupations (see text)	90 per thousand (Ref. 9)
		Alcohol Consumption (see text)	
Fetal alcohol syndrome	1 to 2 per thousand (Ref. 10)	2-4 drinks per day	100 per thousand (Ref. 11)
Fetal alcohol syndrome	1 to 2 per thousand (Ref. 10)	More than 4 drinks per day	200 per thousand (Ref. 11)
Fetal alcohol syndrome	1 to 2 per thousand (Ref. 10)	Chronic alcoholic (more than 10 drinks per day)	350 per thousand (Ref. 12)
Perinatal infant death (around the time of birth)	23 per thousand (Refs. 13, 14)	Chronic alcoholic (more than 10 drinks per day)	170 per thousand (Ref. 15)
		Smoking	
Perinatal infant death	23 per thousand (Refs 13, 14)	Less than 1 pack per day	5 per thousand (Ref. 13)
Perinatal infant death	23 per thousand (Refs 13, 14)	One pack or more per day	10 per thousand (Ref. 13)

For mothers who consume 2 to 4 drinks per day, the excess occurrences number about 100 per thousand, and for those who consume more than 4 drinks per day, excess occurrences number 200 per thousand. The most sensitive period for this effect of alcohol appears to be the first few weeks after conception, before the mother-to-be realizes she is pregnant (Refs. 10 and 11). Also, 17% or 170 per thousand of the embryo/fetuses of chronic alcoholics develop FAS and die before birth (Ref. 15). FAS was first identified in 1973 in the United States where less than full-blown effects of the syndrome are now referred to as fetal alcohol effects (FAE) (Ref. 12).

2.3 Smoking

Smoking during pregnancy causes reduced birth weights in babies amounting to 5 to 9 ounces on the average. In addition, there is an increased risk of 5 infant deaths per thousand for mothers who smoke less than one pack per day and 10 infant deaths per thousand for mothers who smoke one or more packs per day (Ref. 13).

2.4 Miscellaneous

Numerous other risks affect the embryo/fetus, only a few of which are touched upon here. Most people are familiar with the drug thalidomide (a sedative given to some pregnant women), which causes children to be born with missing limbs, and the more recent use of the drug diethylstilbestrol (DES), a synthetic estrogen given to some women to treat menstrual disorders, which produced vaginal cancers in the daughters born to women who took the drug. Living at high altitudes also gives rise to an increase in the number of low-birth-weight children born, while an increase in Down's Syndrome (mongolism) occurs in children born to mothers who are over 35 years of age. The rapid growth in the use of ultrasound in recent years has sparked an ongoing investigation into the risks of using ultrasound for diagnostic procedures (Ref. 19).

APPENDIX B

PREGNANT WORKER'S GUIDE

POSSIBLE HEALTH RISKS TO CHILDREN OF WOMEN WHO ARE EXPOSED TO RADIATION DURING PREGNANCY

During pregnancy, you should be aware of things in your surroundings or in your style of life that could affect your unborn child. For those of you who work in or visit areas designated as Restricted Areas (where access is controlled to protect individuals from being exposed to radiation and radioactive materials), it is desirable that you understand the biological risks of radiation to your unborn child.

Everyone is exposed daily to various kinds of radiation: heat, light, ultraviolet, microwave, ionizing, and so on. For the purposes of this guide, *only* ionizing radiation (such as x-rays, gamma rays, neutrons, and other high-speed atomic particles) is considered. Actually, everything is radioactive and all human activities involve exposure to radiation. People are exposed to different amounts of natural "background" ionizing radiation depending on where they live. Radon gas in homes is a problem of growing concern. Background radiation comes from three sources:

	Average Annual Dose
Terrestrial - radiation from soil and rocks	50 millirem
Cosmic - radiation from outer space	50 millirem
Radioactivity normally found within the human body	25 millirem
	125 millirem*
Dosage range (geographic and other factors)	75 to 5,000 millirem

The first two of these sources expose the body from the outside, and the last one exposes it from the inside. The average person is thus exposed to a total dose of about 125 millirems per year from natural background radiation.

In addition to exposure from normal background radiation, medical procedures may contribute to the dose people receive. The following table lists the average doses received by the bone marrow (the blood-forming cells) from different medical applications.

X-Ray Procedure	Average Dose*
Normal chest examination	10 millirem
Normal dental examination	10 millirem
Rib cage examination	140 millirem
Gall bladder examination	170 millirem
Barium enema examination	500 millirem
Pelvic examination	600 millirem

*Variations by a factor of 2 (above and below) are not unusual.

*Radiation doses in this document are described in two different units. The rad is a measure of the amount of energy absorbed in a certain amount of material (100 ergs per gram). Equal amounts of energy absorbed from different types of radiation may lead to different biological effects. The rem is a unit that reflects the biological damage done to the body. The millirad and millirem refer to 1/1000 of a rad and a rem, respectively.

NRC POSITION

NRC regulations and guidance are based on the conservative assumption that any amount of radiation, no matter how small, can have a harmful effect on an adult, child, or unborn child. This assumption is said to be conservative because there are no data showing ill effects from small doses; the National Academy of Sciences recently expressed "uncertainty as to whether a dose of, say, 1 rad would have any effect at all." Although it is known that the unborn child is more sensitive to radiation than adults, particularly during certain stages of development, the NRC has not established a special dose limit for protection of the unborn child. Such a limit could result in job discrimination for women of child-bearing age and perhaps in the invasion of privacy (if pregnancy tests were required) if a separate regulatory dose limit were specified for the unborn child. Therefore, the NRC has taken the position that special protection of the unborn child should be *voluntary* and should be based on decisions made by workers and employers who are well informed about the risks involved.

For the NRC position to be effective, it is important that both the employee and the employer understand the risk to the unborn child from radiation received as a result of the occupational exposure of the mother. This document tries to explain the risk as clearly as possible and to compare it with other risks to the unborn child during pregnancy. It is hoped this will help pregnant employees balance the risk to the unborn child against the benefits of employment to decide if the risk is worth taking. This document also discusses methods of keeping the dose, and therefore the risk, to the unborn child as low as is reasonably achievable.

RADIATION DOSE LIMITS

The NRC's present limit on the radiation dose that can be received on the job is 1,250 millirems per quarter (3 months).* Working minors (those under 18) are limited to a dose equal to one-tenth that of adults, 125 millirems per quarter. (See § 20.101 of 10 CFR Part 20.)

Because of the sensitivity of the unborn child, the National Council on Radiation Protection and Measurements (NCRP) has recommended that the dose equivalent to the unborn child from occupational exposure of the expectant mother be limited to 500 millirems for the entire pregnancy (Ref. 2). The 1987 Presidential guidance (Ref. 1) specifies an effective dose equivalent limit of 500 millirems to the unborn child if the pregnancy has been declared by the mother; the guidance also recommends that substantial variations in the rate of exposure be avoided. The NRC (in § 20.208 of its proposed revision to Part 20) has proposed adoption of the above limits on dose and rate of exposure.

ADVICE FOR EMPLOYEE AND EMPLOYER

Although the risks to the unborn child are small under normal working conditions, it is still advisable to limit the radiation dose from occupational exposure to no more than 500 millirems for the total pregnancy. Employee and employer should work together to decide the best method for accomplishing this goal. Some methods that might be used include reducing the time spent in radiation areas, wearing some shielding over the abdominal area, and keeping an extra distance from radiation sources when possible. The employer or health physicist will be able to estimate the probable dose to the unborn child during the normal nine-month pregnancy period and to inform the employee of the amount. If the predicted dose exceeds 500 millirems, the employee and employer should work out schedules or procedures to limit the dose to the 500-millirem recommended limit.

It is important that the employee inform the employer of her condition as soon as she realizes she is pregnant if the dose to the unborn child is to be minimized.

INTERNAL HAZARDS

This document has been directed primarily toward a discussion of radiation doses received from sources outside the body. Workers should also be aware that there is a risk of radioactive material entering the body in workplaces where unsealed radioactive material is used. Nuclear medicine clinics, laboratories, and certain manufacturers use radioactive material in bulk form, often as a liquid or a gas. A list of the commonly used materials and safety precautions for each is beyond the scope of this document, but certain general precautions might include the following:

1. Do not smoke, eat, drink, or apply cosmetics around radioactive material.
2. Do not pipette solutions by mouth.
3. Use disposable gloves while handling radioactive material when feasible.
4. Wash hands after working around radioactive material.
5. Wear lab coats or other protective clothing whenever there is a possibility of spills.

Remember that the employer is required to have demonstrated that it will have safe procedures and practices before the NRC issues it a license to use radioactive material. Workers are urged to follow established procedures and consult the employer's radiation safety officer or health physicist whenever problems or questions arise.

*The limit is 3,000 millirems per quarter if the worker's occupational dose history is known and the average dose does not exceed 5,000 millirems per year.

REFERENCES

1. "Federal Radiation Protection Guidance for Occupational Exposure," *Federal Register*, p. 2822, January 27, 1987.

2. National Council on Radiation Protection and Measurements, "Basic Radiation Protection Criteria," NCRP Report No 39, 1971

3. International Commission on Radiological Protection, "Recommendations of the International Commission on Radiological Protection," ICRP Publication No. 26, Vol 1, No 3, 1977.

4. National Academy of Sciences, "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation (BEIR III)," National Academy Press, Washington, DC, 1980.

5 J L. Young and R W. Miller, "Incidence of Malignant Tumors in U.S. Children," *Journal of Pediatrics*, pp. 254-258, 1975.

6. W. J. Blot, "Growth and Development Following Prenatal and Childhood Exposure to Atomic Radiation," *Journal of Radiation Research* (Supplement), pp. 82-85, 1975.

7. R W. Miller and J. J. Mulvihill, "Small Head Size After Atomic Radiation," *Teratology*, Vol. 14, pp. 355-358, 1976.

8. M. Otake and W. J. Schull, "In Utero Exposure to A-bomb Radiation and Mental Retardation; a Reassessment," *The British Journal of Radiology*, Vol. 57, pp. 409-414, 1984.

9. T. L. Vaughan et al., "Fetal Death and Maternal Occupation," *Journal of Occupational Medicine*, Vol. 26, No. 9, pp. 676-678, 1984.

10. J. W. Hanson, A. P. Streissguth, and D. W. Smith, "The Effects of Moderate Alcohol Consumption During Pregnancy on Fetal Growth and Morphogenesis," *Journal of Pediatrics*, Vol. 92, pp. 457-460, 1978.

11 D W Smith, "Alcohol Effects on the Fetus," *Progress in Clinical and Biological Research*, Vol. 36, pp. 73-82, 1980

12 L. E Robe, "Alcohol and Pregnancy," The American Medical Association, Box 10946, Chicago, 1984

13 M. B. Meyer and J. A Tonascia, "Maternal Smoking, Pregnancy Complications, and Perinatal Mortality," *American Journal of Obstetrics and Gynecology*, Vol. 128, No. 5, pp. 494-502, 1977

14. R H Mole, "Radiation Effects on Pre-Natal Development and Their Radiological Significance," *The British Journal of Radiology*, Vol 52, No. 614, pp. 89-101, February 1979.

15. D A Roe, *Alcohol and the Diet*, AVI Publishing Company Inc., Westport, Connecticut, 1979.

16. Environmental Protection Agency, "Radionuclides," Background Information Document EPA 520/1-84-022-1, pp. 8-56 - 8-63.

17. G. W. Beebe, "The Atomic Bomb Survivors and the Problem of Low-Dose Radiation Effects," *American Journal of Epidemiology*, Vol 114, No. 6, pp. 761-783, 1981.

18. W. J. Blot et al., "Reproductive Potential of Males Exposed in Utero or Prepubertally to Atomic Radiation," in *Atomic Bomb Casualty Commission Technical Report* TR-39-72, Radiation Effects Research Foundation, Hiroshima, Japan, 1972.

19. National Council on Radiation Protection and Measurements, "Protection in Nuclear Medicine and Ultrasound Diagnostic Procedures in Children," NCRP Report No. 73, 1983.

VALUE/IMPACT STATEMENT

A draft value/impact statement was published with the proposed Revision 2 to Regulatory Guide 8.13 (Task OP 031-4) when the draft guide was published for public comment in August 1981. No changes were necessary, so a separate value/impact statement for the final guide has not been prepared. A copy of the draft value/impact statement is available for inspection and copying for a fee at the Commission's Public Document Room at 1717 H Street NW., Washington, DC, under Task OP 031-4.

•U.S. G.P.O. 1987-202-292:60018

DARCOM-P 385-1

Fundamentals of Health Physics for the Radiation Protection Officer

EXEMPT AR 335-15, PARAGRAPH 5-2D

HQ. U.S. ARMY MATERIEL DEVELOPMENT AND READINESS COMMAND SEPTEMBER 1983

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

PACIFIC NORTHWEST LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC06-76RLO 1830

FUNDAMENTALS OF HEALTH PHYSICS FOR THE RADIATION PROTECTION OFFICER

B. L. Murphy
R. J. Traub
R. L. Gilchrist
J. C. Mann
L. H. Munson
E. H. Carbaugh
J. L. Baer

Contributors:
L. W. Brackenbush
T. H. Essig
D. E. Hadlock
W. N. Herrington
M. P. Moeller
D. W. Murphy
J. M. Selby
J. E. Tanner
J. M. Taylor
C. M. Unruh

March 1983

Prepared for the U.S. Department of the Army

Pacific Northwest Laboratory
Richland, Washington 99352

DEPARTMENT OF THE ARMY
HEADQUARTERS, US ARMY MATERIEL DEVELOPMENT AND READINESS COMMAND
5001 Eisenhower Avenue, Alexandria, VA 22333

DARCOM PAMPHLET
NO. 385-1

18 April 1984

Safety

FUNDAMENTALS OF HEALTH PHYSICS FOR THE RADIATION PROTECTION OFFICER

1. Purpose. This pamphlet provides the fundamentals of health physics for radiation protection officers.

2. Applicability. This pamphlet is applicable to elements who possess and use radioactive materials.

3. Explanatory. A consolidated "contents" page appears on page iv; "contents" pages appear at the beginning of each chapter.

The proponent of this pamphlet is the US Army Materiel Development and Readiness Command. Users are invited to send comments and suggested improvements on DA Form 2028 (Recommended Changes to Publications and Blank Forms) to Commander, DARCOM (DRCSF-P), 5001 Eisenhower Avenue, Alexandria, VA 22333.

FOR THE COMMANDER:

OFFICIAL:

CLAUDE M. KICKLIGHTER
Major General, USA
Chief of Staff

for DONNA H. BARTHLE 1LT, GS Asst HQ ADJ
CPT, GS
HQ Adjutant

DISTRIBUTION
HQDA (DASG-PSP-E) WASH DC 20310 (3)
Initial Distr (78) 1 ea HQ Dir/Actv/Staff Ofc)
A Pub Distr (50)
DRXAM-ABS Stock (50)
B LEAD Distr (2,279): Safety officers ONLY 2 ea
Cdr, Belvoir R&D Center (STRBE-VR), Ft Belvoir, VA 22060 (200)

CONTENTS

CHAPTER 1. PROPERTIES OF RADIOACTIVE MATERIALS 1.1

CHAPTER 2. RADIATION INSTRUMENTATION 2.1

CHAPTER 3. RADIATION PROTECTION PROGRAM 3.1

CHAPTER 4. RADIATION SURVEY PROGRAMS 4.1

CHAPTER 5. INTERNAL EXPOSURE 5.1

CHAPTER 6. EXTERNAL EXPOSURE 6.1

CHAPTER 7. DECONTAMINATION 7.1

CHAPTER 8. SELECTION AND DESIGN OF RADIATION FACILITIES . . . 8.1

CHAPTER 9. TRANSPORTATION OF RADIOACTIVE MATERIALS 9.1

CHAPTER 10. MANAGEMENT OF LOW-LEVEL RADIOACTIVE WASTE . . . 10.1

CHAPTER 11. RADIATION ACCIDENTS AND EMERGENCY PREPAREDNESS . . . 11.1

CHAPTER 12. TRAINING 12.1

CHAPTER 13. RECORDKEEPING 13.1

CHAPTER 14. QUALITY ASSURANCE PROGRAM 14.1

CHAPTER 15. APPRAISAL OF RADIATION PROTECTION PROGRAMS . . . 15.1

CHAPTER 16. REFERENCE DATA 16.1

Appendix A A-1

CHAPTER 1. PROPERTIES OF RADIOACTIVE MATERIALS

1.1 ATOMIC STRUCTURE 1.5

1.1.1 The Nucleus 1.6

1.1.2 Electrons 1.8

1.2 RADIOACTIVITY AND RADIOACTIVE DECAY 1.9

1.2.1 Characterization of Radionuclides 1.10

A. Rate of Decay 1.10

B. Energy of Decay 1.11

C. Type of Radiation Emitted 1.15

1.2.2 Decay Pathways 1.19

1.2.3 Quantification of Radioactivity 1.20

1.3 INTERACTIONS OF RADIATION WITH MATTER 1.21

1.3.1 Alpha and Beta Particles 1.21

A. Energy Transfer Processes 1.21

B. Alpha Particle Interactions 1.22

C. Beta Particle Interactions 1.23

1.3.2 Photons 1.24

A. Energy Transfer Processes 1.25

B. Photon Interactions 1.26

1.3.3 Neutrons 1.26

A. Energy Transfer Processes 1.27

B. Neutron Interactions 1.28

1.4 RADIATION QUANTITIES AND UNITS 1.29

1.4.1 Exposure 1.29

1.4.2 Absorbed Dose 1.30

1.4.3 Relative Biological Effectiveness 1.31

1.4.4 Dose Equivalent 1.31

1.5 BIOLOGICAL EFFECTS OF RADIATION 1.33

1.5.1 Genetic Effects 1.34

1.5.2 Somatic Effects 1.34

A. Prompt Effects 1.34

B. Delayed Effects 1.34

C. Relationship Between Exposure and Delayed Effects . 1.36

1.5.3 Environmental Dose and Occupational Dose Limits . . . 1.36

1.6 PROPERTIES OF RADIOACTIVE MATERIALS IMPORTANT IN THE DEVELOPMENT OF RADIATION PROTECTION PROCEDURES 1.38

1.6.1 External Versus Internal Exposure 1.38

A. External Exposure 1.38

B. Internal Exposure 1.38

1.6.2 Dispersibility 1.39

A. Nondispersible 1.39

B. Limited Dispersibility 1.39

C. Dispersible 1.40

D. Highly or Readily Dispersible 1.40

1.6.3 Chemical Toxicity 1.40

1.6.4 Radiotoxicity 1.41

1.6.5 Criticality 1.41

A. The Double-Contingency Rule 1.43

B. Factors That Affect Criticality 1.44

REFERENCES 1.46

APPENDIX A - DECAY SCHEMES 1.47

FIGURES

1.1 Numbers of Neutrons and Protons in Stable Nuclides . . . 1.7

1.2 Schematic Diagram of an Atom Showing Nucleus and Electron Shells 1.8

1.3 Number of ^{198}Au Atoms Present as a Function of Half-Lives Elapsed 1.11

1.4 Energy-Velocity Relationships for Alpha and Beta Particles . . 1.13

1.5 The Electromagnetic Spectrum 1.14

1.6 Relative Importance of the Photoelectric Effect, the Compton Effect, and Pair Production 1.25

TABLES

1.1 Radiation Characteristics 1.16

1.2 Effect of Common Decay Types on the Parent Nucleus . . . 1.17

1.3 Classification of Neutrons 1.27

1.4 Relationship of LET and Quality Factor 1.32

1.5 Recommended Values of Q for Different Types of Radiation 1.32

1.6 Dose-Effect Relationship for Acute Whole-Body Irradiation . . 1.35

1.7 Dose-Effect Relationship for Acute Partial-Body Irradiation . 1.35

1.8 U.S. General-Population Dose Estimates (1978) 1.37

1.9 Maximum Dose Equivalent Per Calendar Quarter 1.37

1.10 Radiotoxicity of Various Nuclides 1.42

1.11 Fissionable Materials 1.43

CHAPTER 1. PROPERTIES OF RADIOACTIVE MATERIALS

The world around us is composed of elements and combinations of elements, each with its own unique chemical properties. Only about 100 elements are known to man. Some examples are hydrogen, oxygen, carbon, gold, and silver. Substances such as water, wood, rock, rubber, coal, and hundreds of thousands more are combinations of the comparatively few elements. These combinations are called compounds.

Each element can be denoted by a one- or two-letter chemical symbol; for example, H is the symbol for hydrogen, O is the symbol for oxygen, and Au is the symbol for gold. Compounds are denoted by combinations of element symbols and numbers that refer to the proportion of each element in the compound. Water, for example, which has two units of hydrogen for every unit of oxygen, is designated H_2O. A list of all of the known elements and the chemical symbol for each can be found in Chapter 16, "Reference Data."

Some atoms are unstable and undergo transitions that result in the formation of a more stable atom and the release of some energy. This process is called radioactive decay, and substances that are unstable and subject to decay are called radioactive materials.

This chapter provides a review of the fundamental characteristics of radioactivity. The initial portion covers basic information about atomic structure and radioactive decay. The properties of ionizing radiation are then reviewed, followed by a discussion of radiation quantities and units. Information on the biological effects of radiation is presented. The chapter concludes with the presentation of concepts important to the development of radiation protection procedures.

Section 1.1 ATOMIC STRUCTURE

The smallest unit of an element is the atom. An atom consists of a small, dense, positively charged nucleus surrounded by a cloud of negatively charged electrons.

1.1.1 The Nucleus

The nucleus consists of two fundamental particles, protons and neutrons. The proton is a positively charged particle that has a unit charge of 1.6×10^{-19} coulombs. The mass of a proton is 1.67×10^{-24} gram. The number of protons in the nucleus, the atomic number, Z, is unique for each element; for example, if a nucleus contains six protons, the atom is a carbon atom; on the other hand, if a nucleus contains eight protons, the atom is an oxygen atom.

The neutron is a particle that has no electrical charge and has a mass slightly greater than that of a proton. The nuclei of the atoms that make up a given element may contain varying numbers of neutrons. The number of neutrons in the nucleus, the neutron number, N, influences the stability of the nucleus; that is, it determines whether the atom is radioactive. If the N number of a nucleus is plotted as a function of the Z number of the nucleus, as shown in Figure 1.1, stable, or nonradioactive, nuclei tend to be clustered about a line called the line of stability. In the case of nuclei of low Z, the most stable nuclei have approximately equal numbers of protons and neutrons. In the case of very heavy nuclei (those with many protons, or high Z), the nucleus is most stable if the number of neutrons in the nucleus is about 1.5 times the number of protons.

Isotopes are atoms of one element that have the same atomic number but that differ in neutron number. The isotopes of a given element have the same chemical properties and cannot be separated by chemical methods. However, the nuclear characteristics of the isotopes may be quite different; for example, some isotopes of an element may be radioactive while others are not. Isotopes of a given element are identified by their mass number, A, which is the total number of protons plus neutrons in the nucleus; that is, $A = Z + N$.

Individual atoms are called nuclides; the radioactive forms are called radionuclides. An isotope or nuclide may be identified by its chemical symbol, with the atomic number, Z, as a presubscript and the mass number, A, as a presuperscript: ${}^{A}_{Z}X$, where X represents the chemical symbol. Because the atomic number, Z, is unique to a given element, it is often omitted from this notation. Sometimes a nuclide is designated by the full name of the element,

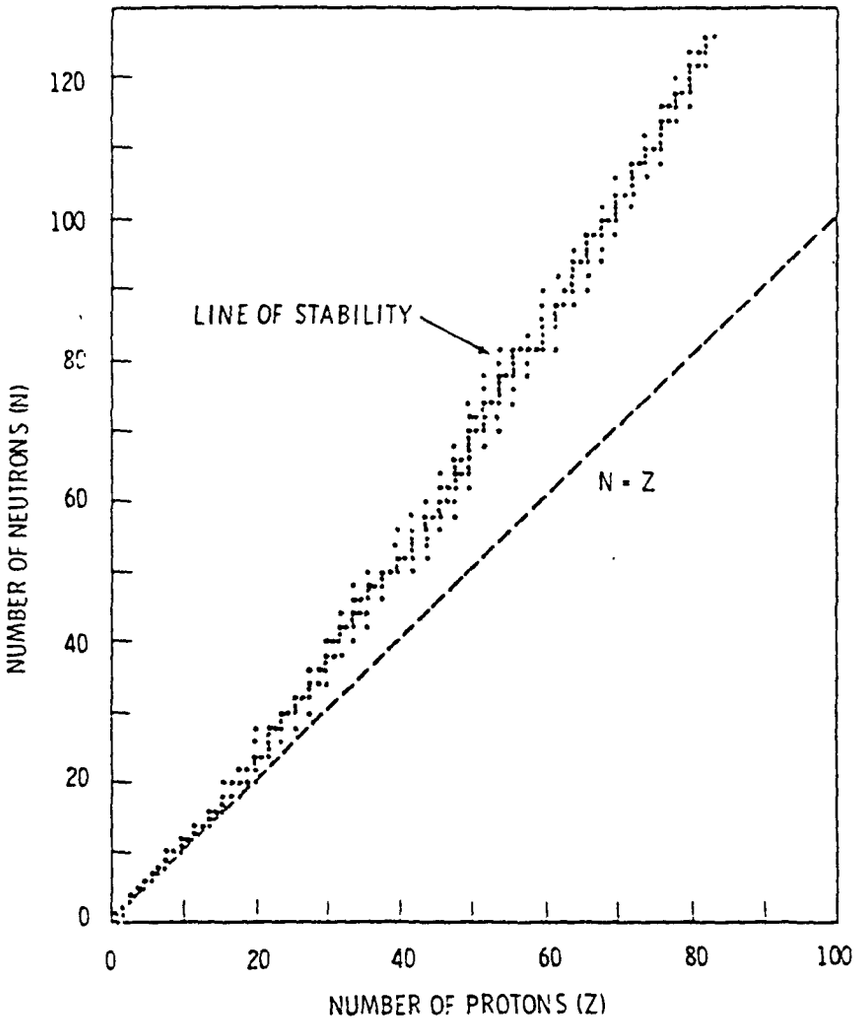


FIGURE 1.1. Numbers of Neutrons and Protons in Stable Nuclides

or its chemical symbol, followed by a hyphen and the A number. Thus, ^{12}C, $^{12}_{6}C$, C-12, and carbon-12 are four ways of designating the same nuclide. In the past, the A number was written with the chemical symbol as a postsuperscript, C^{12}.

The natural elements of the earth's crust or atmosphere are composed of mixtures of the isotopes of each element. The isotopes vary in their percent natural abundance; that is, they do not all occur in equal amounts. For example, of all the oxygen atoms that occur on earth, 99.756% are ^{16}O, 0.034%

are ^{17}O, and 0.205% are ^{18}O. The relative abundance of stable isotopes remains fairly constant over a wide geographic range.

1.1.2 Electrons

The nucleus is surrounded by electrons, which have a negative charge that is equal in magnitude, but opposite in sign, to that of the proton. In the neutral, uncharged atom, there is one electron outside the nucleus for every proton in the nucleus. The electrons can be thought of as occupying orbits, or shells, as shown in Figure 1.2. Because the photons give the nucleus a positive charge and the electrons have a negative charge, and because opposite charges tend to attract each other, there is an attractive force between an atom's nucleus and its electrons. The shells represent the strength of the attractive force between the nucleus and the electrons, not the exact location of the electrons.

The shells form a series of energy or quantum levels. The diameters of the shells are large in comparison with the diameter of the nucleus. The

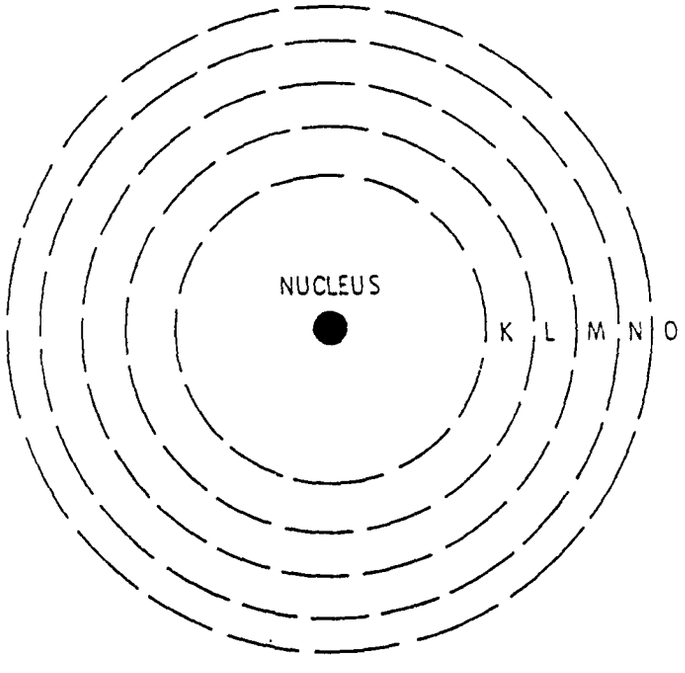


FIGURE 1.2. Schematic Diagram of an Atom Showing Nucleus and Electron Shells

shells are identified by either a letter (K, L, M, N, O, P, Q) or a quantum number (1, 2, 3, 4, 5, 6, 7). The energy state of each electron in a shell is completely described by four independent quantum letters (n, l, m, and s), and the Pauli Exclusion Principle sets an upper limit on the number of possible electrons in each shell.

Because of the attractive force between the nucleus and the electrons, it takes a certain amount of energy to remove the electrons from the atom. The amount of energy required to completely remove an electron from the atom is called the electron binding energy. This energy is different for each shell in the atom of any one element, and different for the same shell in different elements. The electrons closest to the nucleus, in the K shell, have a greater attraction to the nucleus than electrons farther from the nucleus. The electron binding energy associated with an inner shell is therefore greater than that of an outer shell.

If an electron is removed from an inner shell, a vacancy, or "hole," is formed in that shell. An electron from one of the outer shells may then "jump" or "fall" into the vacancy. When this happens, energy equal to the difference between the electron binding energies of the two shells is emitted from the atom in the form of electromagnetic radiation. This radiation is called characteristic radiation because the amount of energy released is characteristic of a given element. Characteristic radiation may be given off in the form of light, heat, or x rays, depending upon its energy.

Section 1.2 RADIOACTIVITY AND RADIOACTIVE DECAY

Radioactivity is the tendency of unstable nuclides to undergo radioactive decay. Radioactive decay is defined as a spontaneous, energy-releasing atomic transition that involves a change in the state of the nucleus of an atom. This change means that the atom changes from one nuclide (the parent) into a second nuclide (the daughter) or from one nuclear energy level to a lower energy level. The difference in the energy levels determines the amount of energy released by the transition. The transition must be spontaneous, that is, free from the influence of outside forces. It is possible to use machines

such as cyclotrons, linear accelerators, or even nuclear reactors to change the nucleus of an atom; however, such transitions are not considered radioactive decay.

1.2.1 Characterization of Radionuclides

A radioactive nuclide, or radionuclide, can be characterized by its rate of decay, the energy released during the decay, and the type of radiation emitted by the decay.

A. Rate of Decay. All radionuclides do not decay at the same rate. Some decay very quickly, in a matter of a few seconds. Others may take days, weeks, or millions of years to decay. The rate of decay of a radionuclide is measured in terms of a half-life.

The half-life of a radionuclide, symbolized $t_{1/2}$, is the time required for the number of radioactive atoms present to decrease by one half. After one half-life, 50% of the original radioactive atoms remain; after two half-lives, 25% of the original radioactive atoms remain; etc. Figure 1.3 illustrates the concept of half-life using ^{198}Au, an isotope of gold, as an example. The half-life of a particular radionuclide may be found in the Table of Isotopes (Lederer and Shirley 1978) or the Radiological Health Handbook (1970).

The rate of radioactive decay can also be expressed in terms of the decay constant, λ, of the radionuclide. The decay constant indicates the fraction of radioactive atoms present that will undergo radioactive decay in a given period of time. It is numerically equal to the natural logarithm of 2 (0.693) divided by the half-life of the radionuclide. That is,

$$\lambda = (\ln 2)/t_{1/2} = 0.693/t_{1/2} \qquad (1.1)$$

The decay constant is used when calculating the number of radioactive atoms present in a sample at any time, using the equation

$$N = N_0 e^{-\lambda t} \qquad (1.2)$$

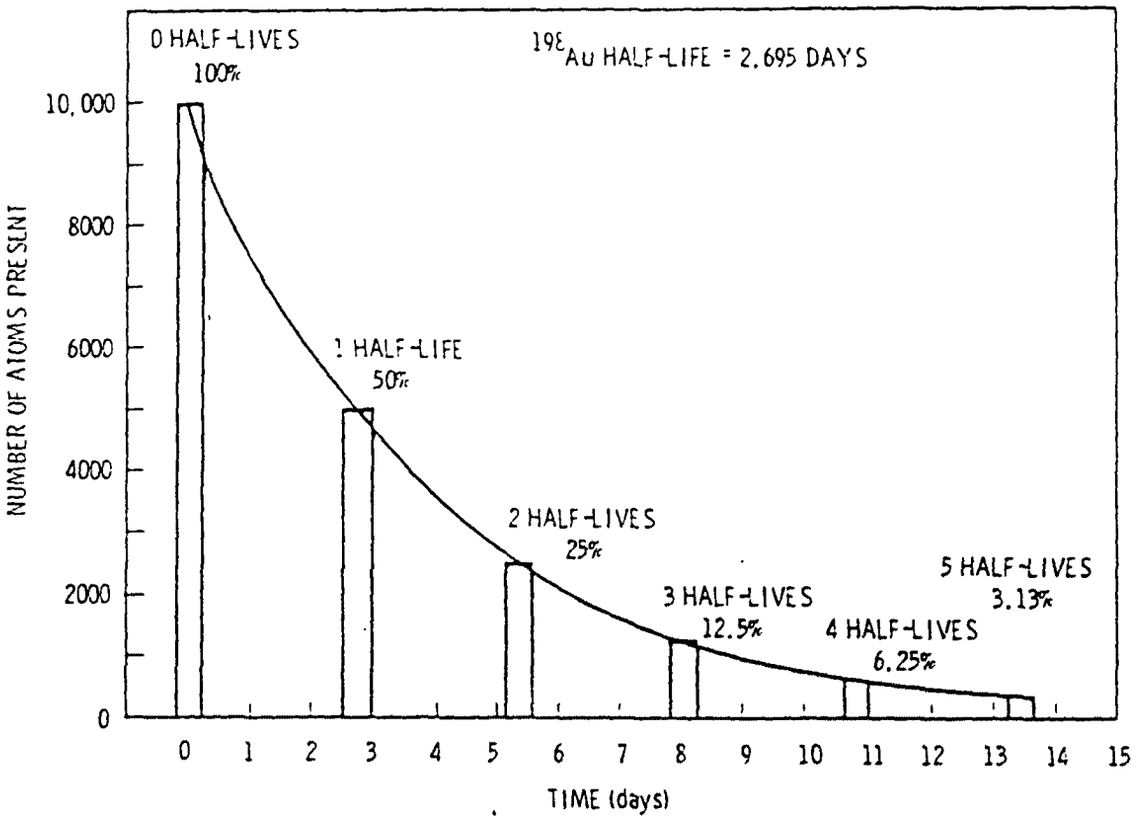


FIGURE 1.3. Number of ^{198}Au Atoms Present as a Function of Half-Lives Elapsed

where N = the number of radioactive atoms present at time t

N_0 = the number of radioactive atoms originally present

e = the base of the natural logarithms (2.71828)

λ = the decay constant of the given radionuclide

$= (\ln 2)/t_{1/2} = 0.693/t_{1/2}$

t = the time elapsed.

The half-life and decay constant are inversely related. A radionuclide with a long half-life has a small decay constant; a radionuclide with a short half-life has a relatively large decay constant.

B. Energy of Decay. The unit of energy used in radioactive decay is the electron volt (eV). The electron volt, which is the energy acquired by an electron when it falls through a potential difference of 1 volt, is equal to

about 1.6×10^{-19} joules. Multiples of the electron volt, such as the kilo-electron volt (keV) and the millionelectron volt (MeV), are also used. One keV equals 1000 eV and 1 MeV equals 1,000,000 eV.

The energy of radioactive decay is observed as the kinetic energy of particulate radiation, electromagnetic radiation, or as both.

(1) Kinetic Energy of Particles. Radioactive decay can change the state of an atom's nucleus through the emission of particles from the nucleus. These particles have kinetic energy, or energy of motion. The kinetic energy (T) of a particle is a function of its mass (m) and its velocity (v). According to classical physics,

$$T = \frac{1}{2} mv^2 \qquad (1.3)$$

From this equation we learn that, if two particles have the same velocity, their kinetic energies are related by a simple ratio of their masses. Conversely, two particles of equal kinetic energy have velocities that are related to the square root of their masses. That is, a light particle has a velocity greater than that of a heavy particle of equal kinetic energy.

Equation (1.3) is valid if the velocity of the particle is not comparable to the velocity of light. When the speed of the particle becomes faster than one-tenth the speed of light, the mass of the particle increases, and the equation cannot be used. Particles traveling at velocities comparable to the speed of light are said to be traveling at relativistic velocities, and the equation relating the kinetic energy of a particle and its velocity is then

$$T = m_o c^2 \left[\frac{1}{\sqrt{1 - \beta^2}} - 1 \right] \qquad (1.4)$$

where T = the kinetic energy of the particle
m_o = the mass of the particle
c = the velocity of light
β = v/c
v = the velocity of the particle.

An important consequence of this equation is that no particle, whatever its energy, can travel faster than the speed of light in a vacuum. Figure 1.4 illustrates the energy-velocity relationship for alpha and beta particles.

(2) Electromagnetic Energy. The energy released from a decaying radionuclide can also take the form of oscillating (vibrating) electric and magnetic fields, or electromagnetic radiation. This radiation travels in the form of waves that have a characteristic frequency, υ, and wavelength, λ. The frequency of electromagnetic radiation is expressed in terms of cycles per second, or hertz (Hz). The wavelengths of various electromagnetic radiations are expressed in units of measure appropriate to their length. For example, wavelengths of ultraviolet radiation are measured in nonometers or meters, whereas radio waves are measured in centimeters or meters. All electromagnetic radiations travel at the velocity of light, which is about 3×10^8 meters per second (m/sec) in a vacuum. The wavelength times the frequency is equal to the the velocity of light. The electromagnetic wave spectrum consists of wavelengths ranging from

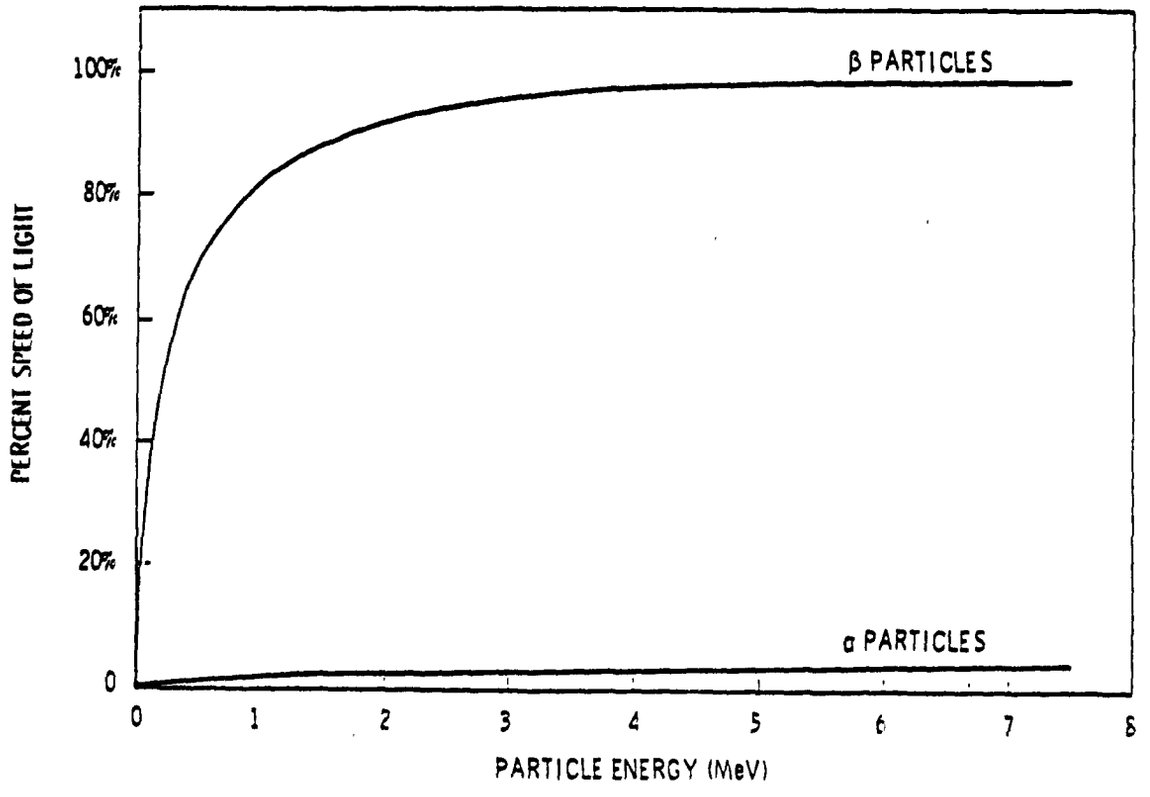


FIGURE 1.4. Energy-Velocity Relationships for Alpha and Beta Particles

several kilometers to a small fraction of a nanometer (10^{-9} m). Between these limits lies a continuous range of electromagnetic waves.

Figure 1.5 shows the electromagnetic spectrum. This spectrum is divided into a number of regions, each representing wavelength intervals within which there is a common state-of-the-art in radiation sources and detectors. All of these regions overlap; that is, the characteristics of the radiation change slowly with the change in frequency, and it is difficult to know exactly where one region ends and the next begins. Examples of electromagnetic radiation include radio waves and microwaves, infrared and visible light, and x and gamma radiation.

Electromagnetic radiation exists as waves; however, when discussing the energy of electromagnetic radiation, it is often convenient to think of the

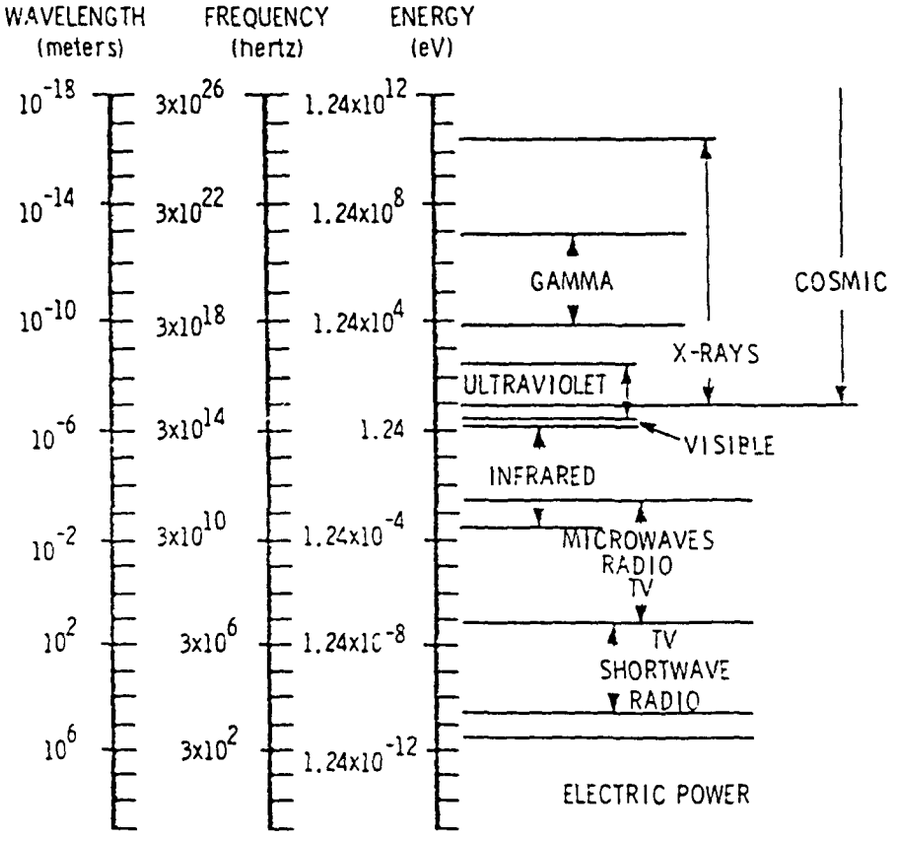


FIGURE 1.5. The Electromagnetic Spectrum

waves as existing in the form of wave packets, called quanta or photons. At high energies, these wave packets or photons behave as if they were small particles. This phenomenon of electromagnetic radiation acting like particles or particles acting like waves is called the wave-particle duality of electromagnetic radiation.

The energy of a single photon or quantum is related to the frequency of the radiation and ranges from very small values at low frequencies to very large values at high frequencies. That is,

$$E = h\upsilon \tag{1.5}$$

where E = the energy associated with a photon of electromagnetic radiation

h = Planck's constant (4.136×10^{-15} eV·sec)

υ = the frequency.

C. Type of Radiation Emitted. When particulate or electromagnetic radiation has an energy greater than about 30 eV, it is able to strip an electron from a molecule in a process called ionization. Photon energy is sufficient to cause ionization at frequencies greater than that of light. Radiation with this high an energy level is called ionizing radiation. The most important characteristic of ionizing radiation is its localized release of large amounts of energy, approximately 33 eV per ionizing event. This amount of energy is more than enough to break a strong chemical bond; for example, the energy associated with a C=C bond, commonly found in body tissues, is 4.9 eV. The ability to break chemical bonds makes ionizing radiation of concern because it can disrupt the function of living cells.

Radioactive decay results in five types of ionizing radiation: alpha particles, beta particles, gamma rays, x rays, and neutrons. These types of radiation can be distinguished by their physical characteristics, such as mass, electrical charge, and path length or range, as shown in Table 1.1. The two major modes of decay result in the emission of alpha particles or beta particles. Both of these decay modes can also be accompanied by the emission of gamma rays. The five types of ionizing radiation and the types of decay that produce them are described below.

TABLE 1.1. Radiation Characteristics

Radiation	Mass (g)	Charge[a]	Path Length	
			Air	Solid
Alpha particles	6.64×10^{-24}	+2	5-10 cm	25-40 μm
Beta particles	9.11×10^{-27}	±1	0-18 m	0-1 cm
Gamma rays and x rays	---	0	0.1-100 m[+(b)]	1 mm-1 m[+(b)]
Neutrons	1.67×10^{-24}	0	0-100 m	0-100 cm

(a) The unit charge is approximately 1.6×10^{-19} coulombs.
(b) There is no real endpoint for electromagnetic radiation; however, its intensity is reduced as it travels farther and passes through materials.

(1) Alpha Particles. Alpha particles are emitted only from very heavy nuclei that have an atomic number, Z, of 82 or more, except in some artificially produced nuclides. An alpha particle (α) is a helium nucleus. It has two protons and two neutrons and a net charge of +2. When a parent nucleus decays by alpha emission, the atomic number of the daughter nucleus is two less than that of the parent, and the mass number, A, of the daughter nucleus is four less than that of the parent. This reaction is summarized in Table 1.2.

(2) Beta Particles. Beta particles result when a proton is converted to a neutron or a neutron is converted to a proton in the nucleus. These transitions help an unstable nucleus establish a more favorable neutron-proton ratio. After such a transition, two types of particles are ejected from the nucleus: a neutrino and a beta particle. A neutrino, symbolized υ, has no charge and essentially no mass and travels at the velocity of light. The neutrino does not easily interact with matter and presents no radiation hazard. A beta particle can have either positive or negative charge, depending on the type of transition in the nucleus. If the beta particle is negatively charged, it is an electron; if positively charged, it is a positron.

When the nucleus has an excess number of neutrons, it undergoes a neutron-to-proton transition, and a negatively charged beta particle, or electron, is

TABLE 1.2. Effect of Common Decay Types on the Parent Nucleus

Decay Type	Change from Parent to Daughter Nucleus: Atomic Number, Z	Neutron Number, N	Mass Number, A	Reaction Summary[a]
Alpha	-2	-2	-4	$^{A}_{Z}X \rightarrow {}^{4}_{2}\alpha + {}^{A-4}_{Z-2}X + h\nu$
Beta negative (electron)	+1	-1	No change	$^{A}_{Z}X \rightarrow \beta^{-} + {}^{A}_{Z+1}X + h\nu$
Beta positive (positron)	-1	+1	No change	$^{A}_{Z}X \rightarrow \beta^{+} + {}^{A}_{Z-1}X - h\nu$
Electron capture	-1	+1	No change	$^{A}_{Z}X + e^{-} \rightarrow {}^{A}_{Z-1}X + h\nu$

(a) $h\nu$ = energy of protons (see Equation (1.5)).

ejected. As shown in Table 1.2, this beta negative decay results in the atomic number, Z, of the nucleus increasing by one. The mass number, A, remains constant.

Proton-to-neutron transition occurs when the nucleus has an excess number of protons. In this case, a positively charged beta particle, or positron, is ejected in what is called beta positive decay or positron decay. As a result of this decay, the atomic number Z decreases by one while the mass number A remains constant.

Sometimes a nucleus has an excess number of protons but is unable to emit a positron. In this case, the nucleus captures an orbiting electron, which combines with a proton to form a neutron. This process is called electron capture decay, and the resulting nuclear change is identical to that of positron emission: the atomic number decreases by one and the mass number remains constant. Because an electron has been removed from its orbit, x rays are produced as the electrons become rearranged (see Section (4) below).

Beta particles are emitted from the nucleus with a spectrum of energies. The beta particle and the neutrino are emitted together and share a given

amount of energy, but the sharing is not in a constant ratio. The beta particle may therefore be ejected from the nucleus with essentially no kinetic energy, or with a high kinetic energy. The average energy of the beta particles emitted is about one-third of the highest kinetic energy for beta particles. Tables of beta energies indicate the highest energy level for betas, but only a small fraction of beta particles possess this highest energy level.

(3) Gamma Rays. When radioactive decay results in the emission of a particle from the nucleus, the nucleus is often left in an excited state. The excited nucleus then releases its excess energy in the form of gamma rays (photons, or wave packets of electromagnetic radiation) until the ground energy state of the nucleus has been reached. Sometimes the energy is emitted in one jump; at other times it is emitted in a series of jumps. The number and energy of gamma rays given off following particle emission is characteristic of a given radionuclide.

Gamma rays are usually emitted immediately after the particle is ejected, but sometimes the nucleus remains in a high-energy state for a measurable period of time, up to several hours. The excited nucleus is then in an unstable, transient condition and is called an isomer of the ground-state nucleus. Isomers are nuclei that are identical to each other in all respects except for their energy state The excited state is designated by writing "m" after the mass number of the nuclide; for example, ^{99m}Tc is an isomer of technetium-99 and decays to ^{99}Tc by releasing a gamma ray.

(4) X Rays. The capture of an orbital electron by a nucleus with excess protons (electron capture decay) results in a vacancy in the shell that the electron occupied. The shell most commonly vacated is the K shell, that closest to the nucleus. Because an electron from an outer shell jumps down to fill the vacancy, electron capture is always accompanied by the emission of characteristic radiation in the form of x rays. Like gamma rays, x rays are photons, or quanta of electromagnetic radiation.

(5) Neutrons. Neutrons are not emitted from the more common radionuclides. Some of the heavier radionuclides emit neutrons by spontaneous fission, or splitting of the nucleus. The most common example of a spontaneously fissioning radionuclide is californium-252 (^{252}Cf). Other sources of neutrons are listed below.

1. Some isotopes of boron, beryllium, lithium, sodium, fluorine, and other elements with a low atomic number emit neutrons when irradiated by alpha particles or gamma rays. These neutron sources are prepared by mixing a radioactive nuclide and a finely divided powder of the target substance. Examples of neutron sources are the mixed powders ^{241}Am:Be (americium and beryllium) and ^{210}Po:Be (polonium and beryllium), and the chemical compound $^{239}PuF_4$ (plutonium fluoride). Neutron sources are kept in sealed metal containers, and the neutrons emitted have a spectrum of energies.
2. When high-speed charged particles irradiate a suitable target material, the resulting nuclear reactions yield neutrons. These high-speed particles, or accelerator sources, can be used to produce neutrons of nearly the same energy.
3. The fission process in nuclear reactors produces large numbers of neutrons with a spectrum of energies.

1.2.2 Decay Pathways

A radionuclide can undergo radioactive decay via more than one decay pathway. Each decay pathway consists of the emission of a particle followed, in most cases, by the emission of one or more gamma rays. Pathways differ in the manner in which the energy of decay is distributed among the particle emitted and the subsequent gamma rays. For example, radium-226 (^{226}Ra) can decay by five pathways. The most common pathway is the emission of an alpha particle with 4.78 MeV of kinetic energy; the resulting (daughter) nucleus, radon-222 (^{222}Rn), is not in an excited state, so no gamma is emitted. The next most common pathway is the emission of an alpha particle with a kinetic energy of 4.60 MeV. The ^{222}Rn daughter nucleus is in an excited state, and a gamma ray is emitted. For three additional pathways with alpha energies of

4.34, 4.19, and 4.16 MeV, the emission of gamma rays follows. A single nucleus can decay by only one of the various pathways, but because there are five potential pathways, it is sometimes said that ^{226}Ra has five alphas, or five potential alpha energies. Appendix A contains a more detailed discussion of decay pathways.

1.2.3 Quantification of Radioactivity

Radioactive materials are not always measured by their mass or the number of atoms present. They are usually measured by the number of nuclear decays or disintegrations occurring in a sample at any time. The number of disintegrations occurring in a sample per unit time is the activity of the sample. The traditional unit of activity is the curie, abbreviated Ci. One curie is the amount of material undergoing 3.7×10^{10} disintegrations per second (dps). Several fractions of the curie are in common usage: the microcurie, abbreviated μCi, is one millionth of a curie (3.7×10^{4} dps), and the picocurie, abbreviated pCi, is 3.7×10^{-2} dps or 2.22 disintegrations per minute (dpm). The international system (SI) unit of activity, the becquerel, abbreviated Bq, is 1 dps.

A radionuclide's activity, A, is related to its decay constant, λ, and the number of radioactive atoms present, N, by the equation $A = \lambda N$. Remember that $\lambda = (\ln 2)/t_{1/2}$. From this equation, we learn that for a given sample activity, fewer radioactive atoms are present if the half-life is short than if the half-life is long.

The activity represents the disintegration rate of the sample; for every disintegration, one or more radiations may be emitted. As a result, two samples of equal activity may emit different amounts of radiation. For example, each disintegration of cobalt-60 (^{60}Co) involves the emission of one electron followed by two gammas, whereas each disintegration of ^{3}H and ^{14}C involves the emission of only one electron, without gammas.

The activity of a radioactive sample is directly related to the number of radioactive atoms present. For this reason, the activity of the sample decreases exponentially as the number of radioactive atoms present decreases. That is, the activity of a sample of a radionuclide can be determined at any time using the following equation:

$$A = A_0 e^{-\lambda t} \qquad (1.6)$$

where A = the activity present at time t

A_0 = the activity originally present

e = the base of the natural logarithms (2.71828)

λ = the decay constant of the radionuclide = $(\ln 2)/t_{1/2}$

= $0.693/t_{1/2}$

t = the elapsed time.

The specific activity is defined as the activity of 1 gram of radioactive material and is usually expressed as Ci/g of the material. The specific activity of a radionuclide is inversely proportional to its half-life; that is, a radionuclide that has a short half-life will have a higher specific activity than a radionuclide that has a long half-life.

Section 1.3 INTERACTIONS OF RADIATION WITH MATTER

All radiation, whether particulate or electromagnetic, possesses energy. The reduction of this energy, or of the radiation's intensity, as it passes through some matter is called attenuation. Attenuation is a combination of two processes, absorption and scattering. Absorption involves the dissipation of the radiation energy into the absorbing medium; scattering involves the deflection of the radiation from its original path. The mechanisms of radiation attenuation are described in this section.

1.3.1 Alpha and Beta Particles

The transfer of energy from radiation to the atoms of an absorbing material can occur by several processes. Alpha and beta particles transfer energy primarily by the absorption processes of excitation and ionization.

A. Energy Transfer Processes. Excitation is the raising of an electron in an atom or molecule of the absorbing material to a higher energy level without the electron being ejected from the atom or molecule. The electron

then returns to its original energy state, at the same time releasing electromagnetic radiation in the form of light or x rays.

Ionization involves the transfer of sufficient energy to an electron to remove it from the electronic structure of the atom or molecule. Depending on the degree of the interaction, the ejected electron may possess anywhere from a negligible up to a very large amount of kinetic energy. If the electron is given sufficient kinetic energy as it is ejected, it may cause excitation and ionization in other atoms of the absorbing material it is passing through; it is then termed a delta ray. The isolated electron and the remaining atom together are called an ion pair. The average number of ion pairs formed by radiation per unit length of the matter it passes through is called the specific ionization of the radiation.

As alpha and beta radiations move through an absorbing medium and their energy of motion is transferred to the orbiting electrons of the absorbing medium by excitation and ionization, the alpha and beta particles gradually lose all kinetic energy until virtually no energy is left. The rate of energy loss as the radiation traverses a material is called the linear energy transfer (LET) of the radiation and is measured in joules per meter (J/m). (Historically, LET has also been expressed in terms of keV/um.) In general, the higher the LET of the radiation, the shorter its range (the distance it travels) and the greater the biological hazard it presents because all its energy is deposited over a smaller volume of tissue.

B. Alpha Particle Interactions. An alpha particle is emitted from the nucleus of a radioactive atom with a velocity about one-twentieth that of light. Because of its low velocity and double positive charge, the alpha particle interacts readily with atomic electrons by excitation and ionization, and has a very high specific ionization and LET. The alpha particle loses kinetic energy very rapidly, so it has a low penetrating ability and travels only a few centimeters in air. (Refer back to Table 1.1.) An alpha particle can usually be stopped by several sheets of paper or a sheet of aluminum foil. After an alpha particle loses all of its energy, it attracts two electrons and becomes a helium atom.

The range of an alpha particle in tissue is 35 to 70 um, depending on its original energy. Because this range is about the same as the thickness of the dead skin layers on the human body, an alpha-emitting radionuclide is considered to present little hazard outside of the body. There are a few exceptions to this general rule. First, if the skin is broken, living tissue may be irradiated. Second, in the case of the eye, the living tissues are very close to the surface and can be harmed by alpha radiation.

The greatest biological hazard due to alpha-emitting radionuclides occurs when the material enters the body by inhalation or ingestion. In this case, there are no dead cells to absorb the energy, and living tissue is irradiated.

C. Beta Particle Interactions. Beta particles are emitted from the nucleus with a velocity much greater than that of alpha particles, even approaching the velocity of light. Beta particles are more penetrating than alpha particles and can travel up to 18 meters in air, depending on their energy; however, they can be stopped by a few millimeters of materials such as plastic, aluminum, and iron.

Beta particles lose their energy primarily by interacting with the electrons of the absorbing medium. Beta particles can also slow down in the electrical field of atomic nuclei to produce x rays. The x rays produced in these interactions are called bremsstrahlung (from the German word for "braking," so named because this radiation results from the slowing down of beta particles). The energy of the bremsstrahlung may range from negligible up to the energy of the beta particle. The probability of this interaction occurring is greater for radionuclides that emit high-energy beta particles, such as phosphorus-32 (^{32}P) and yttrium-90 (^{90}Y), and for absorbing materials with a high atomic number, such as iron or lead, than for radionuclides that emit beta particles with lower energies and for absorbing materials with a low atomic number. The radiation produced is identical in all respects to gamma or x radiation of the same energy. Bremsstrahlung photons can present a significant radiation hazard when radionuclides that emit high-energy beta particles are stored in metallic containers. In order to reduce the production of bremsstrahlung, emitters of high-energy beta particles should be kept in thick-walled plastic containers. The plastic containers may then be placed in iron or lead

containers to protect against any photons other than bremsstrahlung that may be emitted. Bremsstrahlung is not produced in any significant amount in biological materials because the elements of which human tissues are composed have low atomic numbers.

The LET of beta particles is much lower than that of alpha particles because betas have only a single charge and travel at high velocities. In many cases, beta radiation is considered to be only a slight hazard outside the body, because even though betas with an energy higher than 70 keV can penetrate to living skin tissue, they still cannot reach the major organs of the body. However, beta particles can cause severe damage to the skin and the eye. Thus we can say that beta particles present more of an external hazard than do alpha particles.

Inside the body, beta radiation is less hazardous than alpha radiation. Because the LET of beta particles is less than that of alpha particles, the energy deposited by the beta radiation is dissipated over a larger volume than is the energy deposited by alpha radiation.

After a negatively charged beta particle (an electron) loses all of its kinetic energy, it becomes attached to a positive ion, becoming an orbital electron. A postively charged beta particle (or positron), on the other hand, is antimatter and cannot exist for long in nature. After it loses all of its kinetic energy, it fuses (coalesces) with an electron, the two particles annihilate each other, and their mass is converted into energy. This energy is observed as two photons, called annihilation radiation, each of which has 0.511 MeV of energy. The two photons are emitted in opposite directions.

1.3.2 Photons

Gamma rays and x rays are both forms of electromagnetic radiation and they have identical properties. The only difference between them is that gamma rays are emitted from the nucleus and x rays arise from processes outside the nucleus. X rays produced as a result of radioactive decay tend to have lower energies than gamma rays, while x rays produced by x-ray machines can have energies much higher than the energies of gamma rays.

A. Energy Transfer Processes. Ionizing photons interact with matter by three major mechanisms: the photoelectric effect, the Compton effect, and pair production. Which interaction takes place depends on the photon energy and on the atomic number, Z, of the absorbing medium. Figure 1.6 shows the relative importance of these interactions as a function of Z and photon energy. The end result of all three interactions is the production of high-energy electrons, which interact with matter in the same way beta particles do.

The photoelectric effect is an interaction between a photon and an orbital electron. In this process, the photon ceases to exist and its energy is transferred to the electron, which is ejected from the atom with a kinetic energy equal to the energy of the photon minus the binding energy of the electron. The photoelectric interaction is dependent on the energy of the photon and strongly dependent on the atomic number of the absorbing material. It is most likely to occur in high-Z materials, such as iron and lead, and at low photon energies, less than 100 keV (0.1 MeV). The photoelectric effect is not an important interaction in biological systems, which are made up primarily

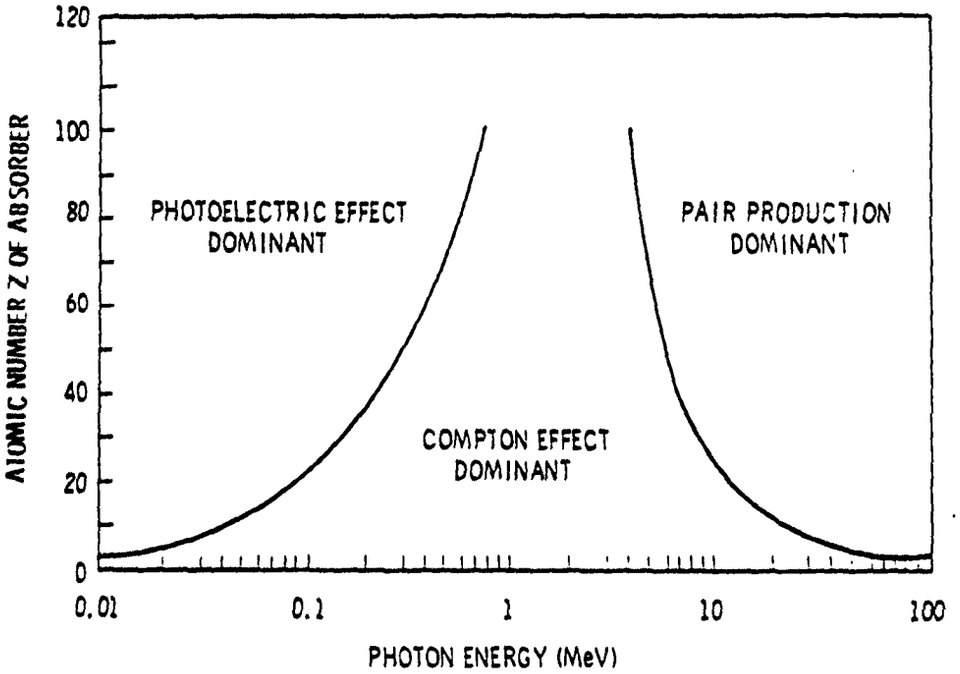


FIGURE 1.6. Relative Importance of the Photoelectric Effect, the Compton Effect, and Pair Production

of carbon, oxygen, hydrogen, and nitrogen, all low-Z elements. However, it is important in high-Z materials and is useful for identifying and quantifying gamma-emitting radionuclides.

The Compton effect (or Compton scattering) is the predominant interaction between biological materials and photons from 30 keV (0.03 MeV) to 10 MeV. In the Compton interaction, the photon interacts with an orbital electron that is not tightly bound to the nucleus. The photon transfers part of its energy to the electron, which is ejected from the atom. The photon is then scattered by (deflected from) the atom at reduced energy. The scattered photon can go on to interact with electrons of other atoms.

High-energy photons can interact with the electrical field of the atom's nucleus via pair production. In this process, when a photon passes close to the nucleus of an atom, the photon ceases to exist, and 1.02 MeV of energy is converted into an electron (negatron) and a positron. If the original photon had an energy greater than 1.02 MeV, the remaining energy is shared by the electron and the positron in the form of kinetic energy. This interaction, which does not occur if the original photon energy is less than 1.02 MeV, is of greatest importance in high-Z materials and does not often occur in biological tissue.

B. Photon Interactions. Photon-emitting radionuclides outside the body can present a severe hazard for several reasons. First, photons can penetrate through thick layers of lead and concrete, so it is difficult to shield the body against them. Second, they can penetrate great distances through air and may therefore constitute a hazard even far from a source of radiation. Finally, photons can easily penetrate the skin and can irradiate organs within the body; in fact, they can irradiate the whole body. However, photons are less of an internal hazard than either alpha or beta radiation because they have a low LET and distribute their energy throughout the body rather than concentrating it in one small area.

1.3.3 Neutrons

Neutrons, like photons, are very penetrating. Because they have no electrical charge, neutrons, unlike other types of radiation, do not interact with electrons. They do interact with atomic nuclei, yielding charged particles

that can then deposit energy in an absorbing medium by excitation and ionization. Neutrons are not stable outside the nucleus. They have a half-life of 10.6 min and decay to a proton and an electron.

Neutrons can be classified by their energies; one such classification scheme is shown in Table 1.3. All neutrons are fast neutrons when produced. Neutrons that have lost most of their energy are called thermal neutrons. Thermal neutrons receive their name from the fact that they are in approximate thermal equilibrium with their environment.

A. Energy Transfer Processes. To a large extent, the type of interaction that a neutron undergoes depends on its energy. Most fast neutrons lose their energy by colliding with nuclei in what are termed elastic collisions or "billiard ball" collisions. For neutrons with energies between 100 keV and 20 MeV, this is the predominant interaction with biological materials. When incident neutrons collide with the nucleus of an atom of the absorbing material, part of the neutron's kinetic energy is transferred to the nucleus and part is retained by the deflected neutron, which may then undergo additional collisions until it has lost virtually all of its energy.

Fast neutrons may also lose their energy by inelastic scatter. In this process, a neutron transfers part of its kinetic energy to the nucleus of an atom. The nucleus is then in an excited state and emits a gamma ray to return to its ground state. Inelastic scatter is a phenomenon more closely associated with high-Z absorbers, such as iron or lead, than with low-Z absorbers, such as hydrogen or carbon.

TABLE 1.3. Classification of Neutrons

Neutron Classification	Energy
Thermal neutrons	$\leq$0.025 eV
Slow neutrons	0.025 eV to 100 eV
Intermediate neutrons	100 eV to 10 keV
Fast neutrons	$\geq$10 keV

A neutron may enter the nucleus of an atom and undergo radiative capture. The resultant nucleus, one mass unit heavier than the original, is in an excited state and emits a gamma ray. Because the gamma rays arising from this type of interaction may have energies up to several MeV, they contribute to the shielding difficulties encountered with neutrons.

In radiative capture with particle emission, a neutron may be captured by a nucleus that subsequently ejects a charged particle, for example, a proton or an alpha particle. This interaction is used to infer the presence of neutrons and to produce radioactive isotopes.

The capture of a neutron by certain heavy nuclei may result in fission, the splitting of the nucleus into two lighter nuclei of approximately equal mass, called fission fragments. As the nucleus disintegrates, an average of two or three neutrons is emitted. If one of these causes a subsequent fission, a steady-state chain reaction may take place. Some nuclei undergo fission after absorbing a thermal neutron, others after absorbing a fast neutron. Fission fragments are radioactive and present a radiation hazard of their own.

B. Neutron Interactions. In soft tissues of the body, the predominant interaction is collisions between incident neutrons and hydrogen nuclei, which are single protons. This interaction is important because a large fraction of the neutron energy is transferred to the proton, since its mass is almost the same as that of the neutron. Furthermore, hydrogen is the most abundant atom in the tissues. The protons that are set into motion by this process lose energy by the excitation and ionization of atoms as they pass through biological material. These protons have a high LET and can produce significant biological damage.

At kinetic energies below a few hundred keV, radiative capture of neutrons becomes important. The capturing nuclei are primarily those of hydrogen and nitrogen. Neutron capture by hydrogen, ^{1}H, results in the emission of a 2.2-MeV gamma ray; at the same time, the ^{1}H nucleus is converted to a ^{2}H nucleus. Neutron capture by a ^{14}N nucleus leads to the emission of a 660-keV proton and the transformation of the ^{14}N nucleus to a ^{14}C nucleus. The probability of neutron capture by other elements in the body is small.

If the body is exposed to a high concentration of neutrons, two reactions occur that can be used to estimate the neutron exposure: sodium in the tissues and blood is converted from ^{23}Na to ^{24}Na, and sulfur in the hair changes from ^{32}S to ^{32}P. The radiation dose from these radioactive nuclides is small compared to the radiation dose received from the large number of neutrons required to activate an appreciable number of target atoms.

Section 1.4 RADIATION QUANTITIES AND UNITS

Radiation measurements and units of radiation dose are based primarily on the energy deposited by radiation as it travels through matter. The International Commission on Radiation Units and Measurements (ICRU) selects and defines the units and quantities of radiation. Information provided in this section is based on ICRU Report 33, Radiation Quantities and Units (ICRU 1980).

1.4.1 Exposure

The term "exposure" has two levels of meaning. The first level is that of an object or person being subjected to the action of radiation. It is in this context that the word is most commonly employed, especially by the public. For example, a person might say "I was exposed to neutrons." In radiation protection, on the other hand, the term exposure is used to quantify the amount of x or gamma radiation present. In a given situation, the meaning of the word is determined from the context in which it is used.

In the context of radiation protection, exposure is a measure of the ionization produced by x or gamma radiation in air. The ionization is measured by collecting all the electrons liberated by the photons through photoelectric, Compton, and pair production interactions. Note that exposure, in this sense of the word, is defined only for x and gamma radiation, and that the measurement must be made in air. In practice, exposure is difficult to measure precisely when the photon energies involved are below a few keV or above a few MeV.

The special unit for exposure is the roentgen (R). One roentgen is equal to 2.58×10^{-4} coulomb/kg of air. This seemingly arbitrary value is equivalent to 1 electrostatic unit of electricity (esu) per cubic centimeter of air at standard temperature and pressure (STP), which was the original definition of the roentgen. One roentgen results in the production of 2.08×10^{9} ion pairs/cc of dry air at STP. The energy required to produce these ion pairs is approximately 87.7 ergs/g of air.

1.4.2 Absorbed Dose

The absorbed dose describes the quantity of radiation energy transferred to any absorbing material (tissue, air, shielding, etc.). The ICRU has defined absorbed dose, symbolized D, as

$$D = \frac{d\bar{\varepsilon}}{dm} \tag{1.7}$$

where $d\bar{\varepsilon}$ is the mean energy imparted by ionizing radiation to matter of mass dm. The advantage of absorbed dose as a measure, as compared with exposure, is that absorbed dose can be applied to any radiation and any absorbing medium. The unit of absorbed dose is called the rad and is equal to 100 ergs/g of the absorbing material. In the international system of units (the SI unit), the absorbed dose is the gray (Gy) and is equal to 1 joule/kg.

$$1 \text{ rad} = 100 \text{ ergs/g} = 10^{-2} \text{ J/kg} = 0.01 \text{ Gy}$$

For x and gamma rays, the exposure (expressed in units of roentgens) can be related to the absorbed dose in tissue (expressed in rad) by the equation

$$D_{tissue} \cong 0.97 \, X \tag{1.8}$$

where X is the exposure in roentgens. This equation holds for x or gamma radiation of energies from 0.1 to 10 MeV. From this equation, the absorbed dose, in rad, to an individual exposed to x or gamma radiation can be determined by measuring the exposure, in roentgens, at the location where the

individual was exposed. Potential radiation doses to individuals working with sources of x or gamma radiation can also be estimated, as will be discussed in subsequent chapters.

1.4.3 Relative Biological Effectiveness

Because radiations interact with matter in varying ways, equal doses of different types of radiation do not always produce equal biological effects. When comparing the effects of different radiations, it is customary to use 250-kV x rays as the standard. This radiation was chosen as a standard because its effects were well documented and it was the only type of radiation widely available at the time this convention was adapted.

The formal definition of relative biological effectiveness (RBE) is as follows: the RBE of a test radiation is defined by the ratio D_{250}/D_r, where D_{250} is the absorbed dose of 250-kV x rays and D_r is the absorbed dose of the test radiation required to produce an equal biological effect.

The RBE is often used in radiation biology, but the concept has limited usefulness in radiation protection because the RBE of a given radiation is influenced by the specific conditions of the experiment. The dose rate used, the dose fractionation (or the number of increments in which the dose is received), the biological tissue irradiated, and the radiation effect measured all affect the RBE.

1.4.4 Dose Equivalent

The results of biological experiments have shown that the absorbed dose by itself is insufficient for predicting either the probability of deleterious health effects from irradiation under unspecified conditions, or the severity of such effects. The RBE of radiation is also not useful, primarily because of the many factors that can influence it. Consequently, an additional quantity has been defined.

This quantity, a quality factor, Q, accounts for the different biological effects that result from the ways various types of radiation distribute energy. The values of Q are defined as a function of the radiation's LET in water and are based on relevant values of RBE. Table 1.4 shows the recommended values

TABLE 1.4. Relationship of LET and Quality Factor

LET (keV/um)	Q
≤3.5	1
7	2
23	5
53	10
175	20

of Q as a function of LET in water. It is possible to find exact quality factors based on the LET by interpolating the values given in the table. However, it is common practice to use the recommended values for different types of radiation, as given in Table 1.5.

The absorbed dose and the quality factor are incorporated into a third quantity, called the dose equivalent. The dose equivalent, H, at a point in tissue is given by the equation

TABLE 1.5. Recommended Values of Q for Different Types of Radiation(a)

Radiation	Q
X rays, gamma rays, and electrons	1
Neutrons, protons, and singly charged particles with a rest mass greater than 1 atomic mass unit and with an unknown energy	10
Alpha particles and multiply-charged particles (and particles of unknown charge) with an unknown energy	20

(a) Based on Report No. 39 of the National Council on Radiation Protection and Measurements (NCRP 1971).

$$H = DQN \qquad (1.9)$$

where H = dose equivalent (rem)
D = absorbed dose (rad)
Q = quality factor
N = modifying factors.

The numerical value of N is generally considered equal to 1. The special name for the unit of dose equivalent is the rem. The SI unit for dose equivalent is the sievert (Sv), which equals 1 J/kg. If the absorbed dose is given in units of gray, then the dose equivalent is in units of sievert.

The dose equivalent is a valuable term because the varying biological effects of different types of radiation are accounted for through the quality factor, Q. Therefore, the effect of 1 rem (or 0.01 Sv) of radiation is nearly the same for all types of radiation. This equivalence permits the addition of dose equivalents when several radiations are involved.

Section 1.5 BIOLOGICAL EFFECTS OF RADIATION

Just as atoms are the basic building blocks of elements, cells are the basic unit of the human body. The body is composed of millions of cells, each with a specific job to do to keep us alive and well. When radiation transfers energy to cells, primarily by the processes of excitation and ionization, it can disturb the cells so they can no longer perform their original functions.

The cells that make up the various tissues of the body do not have identical functions or appearances. For example, the cells that make up nerve tissue look and act differently from those that make up muscle tissue. Each type of cell may react differently to radiation. Some cells are more radiosensitive than others (that is, susceptible to radiation injury). In the body, the most radiosensitive cells are the blood-producing and the reproductive cells. Muscle, nerve, and bone cells are the least radiosensitive. Radiation has two main types of effects on biological systems: genetic effects and somatic effects.

1.5.1 Genetic Effects

Genetic effects are biological effects of raciation that result in mutations, or changes, in the genes of reproductive cells and that are expressed in the descendants of the exposed individual. Mutations occur in all living organisms. They can be induced by agents such as radiation or chemicals, or they can occur spontaneously, without any outside alteration in the physical or chemical environment. Genetic effects of radiation appear as birth defects in the offspring of the irradiated individual and in succeeding generations, as demonstrated in experiments involving thousands of irradiated animals. These effects have not been observed in human populations, perhaps because few people have received the high doses thought to cause such effects.

1.5.2 Somatic Effects

Somatic effects are biological effects of radiation that are expressed in the exposed individual. The somatic effects of radiation can be divided into prompt effects and delayed effects.

A. Prompt Effects. Prompt effects are observed shortly after an individual receives an acute radiation dose, a very large dose received in a very short time period. Prompt effects are generally associated with a threshold; that is, if the radiation dose is below a certain level, no effect is noticed, but if the dose exceeds that level, most people suffer an effect. Prompt effects tend to be short-term. The short-term effects of acute exposure to high levels of ionizing radiation are well known from observations of individuals exposed during atomic warfare, medical treatments, or industrial accidents. These effects may include nausea, fatigue, blood disorders, intestinal problems, temporary loss of hair, skin burns, and in extreme cases, death. Table 1.6 shows the effect of an acute whole-body exposure in relation to dose, and Table 1.7 shows the effect of partial-body irradiation in selected organs. Note that whole-body irradiations are much more dangerous than partial-body irradiations. If radiation safety standards are met, there is no reason for any individual to experience prompt radiation effects.

B. Delayed Effects. Delayed effects can result from an acute raciation dose and are the major effects of a chronic radiation dose. A chronic radiation dose is the continuous or repeated subjection of an individual to

TABLE 1.6. Dose-Effect Relationship for Acute Whole-Body Irradiation

Acute Dose (rem)	Nature of Effect
5-23	Minimal dose detectable by chromosome analysis or other specialized analysis
25-125	Slight blood changes
75-125	Minimal acute dose likely to produce vomiting in about 10% of people so exposed
150-200	Temporary disability, blood changes
300-500	Mean lethal dose

TABLE 1.7. Dose-Effect Relationship for Acute Partial-Body Irradiation

Acute Dose (rad)	Organ	Effect in Relevant Organs
50	Testis	Temporary sterility
200	Ovary	Temporary amenorrhea, sterility
500	Skin	Temporary reddening and loss of hair
800	Testis	Permanent sterility
	Ovary	Permanent menopause, sterility
2000	Liver	Hepatitis
2500	Skin	Temporary ulceration and permanent loss of hair

radiation at low dose rates over a long period of time. The primary delayed somatic effects are the development of cancer and, to a lesser extent, the production of cataracts. As opposed to prompt effects of radiation, delayed effects are associated not with thresholds but with probabilities of occurrence: as the radiation dose increases, the likelihood of observing an effect increases. A relationship between radiation dose and cancer induction has been shown from studies of 1) Japanese survivors of the atom bomb; 2) the Marshall

Islanders, who were exposed to fallout from weapons tests; 3) uranium miners; and 4) radiation therapy patients who received excessive doses in the early part of the century. These situations all involved much higher radiation doses than those today's radiation workers can legally receive.

C. Relationship Between Exposure and Delayed Effects. The exact relationship between chronic low-level exposure and delayed effects is difficult to establish for two reasons. First, effects such as cancer can be caused not only by radiation, but also by other agents in the environment, such as cigarette smoke or chemical pollutants. Second, long periods of time may elapse between an exposure to radiation and the observation of any effects.

We do not yet know how radiation causes cancer. However, most diseases are caused by the interaction of a variety of factors, including general physical condition, inherited traits, age, sex, and exposure to outside agents. It is impossible to know whether a given cancer is caused by radiation or some other agent. However, we do know that an increased incidence of cancer is observed in groups of highly exposed people. Although several studies have been performed, there is no firm evidence that exposure to radiation at currently accepted levels results in an increased incidence of cancer.

1.5.3 Environmental Dose and Occupational Dose Limits

Individuals who work with radiation receive a radiation dose from the environment as well as from their workplace. Table 1.8 shows the estimated average individual dose in millirem from natural background radiation and other sources. The table indicates that the average individual in the United States receives a dose of about 200 mrem of radiation each year from sources that are part of our natural and man-made environment.

The standards of radiation dose suitable to the workplace are set by federal regulations. Table 1.9 lists the dose standards for various parts of the body. These standards do not represent boundaries between safe conditions and harmful or lethal conditions. Rather, they represent dose levels for which regulators consider there is sufficiently small probability of radiation effects. Because the likelihood of causing an effect increases gradually with increasing dose, it is wise to keep the actual radiation dose as low as is reasonably achievable (ALARA).

TABLE 1.8. U.S. General-Population Dose Estimates (1978)[a]

Source	Average Individual Dose (mrem/yr)
Natural background	100
Medical	90
Release of radioactive material by mining, milling, etc.	5
Nuclear weapons development (primarily fallout)	5 to 8
Nuclear energy	0.28
Consumer products	0.03
TOTAL	200 mrem/yr

(a) Interagency Task Force on the Health Effects of Ionizing Radiation, 1979.

TABLE 1.9. Maximum Dose Equivalent Per Calendar Quarter[a]

Organ	Amount (rem)
Whole body; head and trunk; active blood-forming organs; lens of eyes; gonads	1.25
Hands and forearms; feet and ankles	18.75
Skin of whole body	7.50

(a) AR 40-14.

Section 1.6. PROPERTIES OF RADIOACTIVE MATERIALS IMPORTANT IN THE DEVELOPMENT OF RADIATION PROTECTION PROCEDURES

Several properties of radioactive materials play a key role in the development of radiation protection procedures. These include the distinction between external and internal exposure, and the properties of dispersibility, chemical toxicity, radiotoxicity, and criticality.

1.6.1 External Versus Internal Exposure

The extent to which radiation causes biological effects depends in part on whether the body is exposed externally or internally, and on the types of radiation involved in the exposure.

A. External Exposure. External exposure results from exposure to a source of ionizing radiation outside the body. Sources of external exposure can be divided into two classes: penetrating and nonpenetrating radiations. Penetrating radiations--gamma rays, x rays, and neutrons--have sufficient energy to pass through the surface of the skin and interact with internal body tissues. Nonpenetrating radiations--alpha particles and low-energy beta particles--interact only with the skin surface. Therefore, from the standpoint of external exposure, penetrating radiation is a greater hazard than nonpenetrating radiation.

The principles and procedures that minimize external exposure, and the calculation of external dose, are discussed in Chapter 6.

B. Internal Exposure. Radioactive materials can be taken into the body by ingestion, inhalation, and absorption through pores of the skin or through breaks in the skin. Once in the body, these materials may be deposited in various organs and constitute a source of internal exposure.

A stable isotope and a radioactive isotope of the same element have identical chemical behavior in the body. The chemical characteristics of an isotope or nuclide determine the organ in which it is deposited as well as the rate at which it is excreted from the body. If a radionuclide has no stable counterpart in the body, it follows the metabolism and excretion pattern of another element with similar chemical properties. For example, strontium is

not normally found in large quantities within the body. However, the chemical properties of strontium are similar to those of calcium. Thus, strontium that enters the body behaves much as calcium does and may be deposited in the bone.

The radiological hazard associated with internal exposure depends upon the type of radiation emitted by a radionuclide, the radiosensitivity of the organ in which it is deposited, and the physical properties of the radionuclide (e.g., its solubility and particle size). Of the various types of radiation, alpha particles are usually considered the greatest internal hazard.

The calculation of internal dose is discussed in Chapter 5 along with two principles that are important in making those calculations, the principles of maximum permissible concentration (MPC) and the critical organ. Procedures for minimizing internal exposure to radiation are also discussed in Chapter 5.

1.6.2 Dispersibility

The physical form of a radioactive material and its intended use influence how much it will scatter, or disperse. For example, a radioactive powder has a greater chance of being scattered over a wide area than does a sealed source. Conditions of use under which various forms of radioactive material are nondispersible, of limited dispersibility, dispersible, or highly dispersible are listed below. Engineered safeguards and administrative controls for each of these types of materials are discussed throughout the manual.

A. Nondispersible

1. nondestructive use of encapsulated or sealed sources
2. storage of nonflammable, nonexplosive radioactive materials in sealed containers especially designed for such storage.

B. Limited Dispersibility[a]

1. simple operations that can result only in fractional releases of material from a radiation area during credible accidents

(a) Criteria used to classify radionuclides in this category are subjective and thus depend in part upon experience and judgment.

2. use of radioactive materials that are strongly bound in a solid matrix or biological system.

C. Dispersible

1. use of unsealed, noncombustible, nonexplosive liquids or compact solids in standard chemical processes or operations.

D. Highly or Readily Dispersible

1. use of radionuclides in hazardous or complex chemical operations
2. use of radioactive powders, gases, vapors, or other aerosols
3. use of radioactive materials in combustible or explosive procedures
4. dry, dusty operations
5. high-temperature or high-pressure operations that may increase the probability of producing radioactive aerosols
6. use of radioactive materials that can ignite spontaneously.

1.6.3 Chemical Toxicity

Chemical toxicity refers to the harm that can be caused by an element because of its chemical nature. Many elements are toxic and can cause severe illness if ingested. Examples of toxic elements include arsenic, which damages blood vessels; cadmium, which is a kidney poison; mercury, which in large doses is a kidney poison and in chronic situations affects the nervous system; and lead, which also affects the nervous system. A radionuclide may be hazardous both because of its chemical nature and because of the radiation it emits. Uranium, for example, is a kidney poison and is also radioactive (it has no stable isotopes). In the case of long-lived isotopes of uranium, it is the chemical rather than the radiation hazard that limits the amount that may safely be ingested. Other radioactive materials, such as plutonium, have negligible chemical toxicity but are considered hazardous because of the amount of radiation damage they can produce. These materials are called radiotoxins.

1.6.4 Radiotoxicity

The term radiotoxicity indicates the relative radiological hazard associated with internally deposited radionuclides. Nuclides that are highly radiotoxic, such as those that emit alpha particles or high-energy beta particles, present the greatest relative health hazard when deposited internally. The level of radiotoxicity strongly dictates the degree of control required in work with radioactive materials. A listing of the relative radiotoxicity of some radionuclides is given in Table 1.10. Note that Group I radionuclides are the least radiotoxic and Group 8 the most radiotoxic.

1.6.5 Criticality

Fission occurs when a heavy nucleus (with an atomic number, Z, of 90 or more) absorbs a neutron and splits into two lighter nuclei, each with about half the mass of the original nucleus. Each fission can also result in the emission of up to eight neutrons, with two and one-half neutrons being the average. A nuclide that is capable of undergoing fission is called a fissionable nuclide. Examples of fissionable nuclides are ^{235}U and ^{238}U. Some nuclides, such as ^{238}U, undergo fission only when they absorb a fast neutron. Other nuclides, such as ^{235}U and ^{239}Pu, undergo fission when they absorb a thermal or slow neutron, and are called fissile nuclides. Materials that contain such nuclides are fissile materials. Natural uranium, which is a combination of ^{235}U and ^{238}U, is a fissile material. Some nuclides, such as ^{235}U and ^{239}Pu, also undergo spontaneous fission; that is, they can split without first having been irradiated by neutrons. Table 1.11 lists some of the more common fissionable nuclides.

After a fission, the neutrons that are released have three possible fates. They may 1) completely escape from the fissile material, 2) be absorbed by nonfissile atoms, or 3) be captured by fissile atoms. If they are captured by fissile atoms, more fissions can occur and more neutrons may be released. The continuing process of fission, release of neutrons, capture of neutrons, and subsequent fission is called a chain reaction.

If the neutrons released by a fissioning atom cause, on the average, less than one subsequent fission, then no chain reaction is possible and the reaction is said to be subcritical. When the neutrons released by each fission cause

TABLE 1.10. Radiotoxicity of Various Nuclides[a]

Radionuclides Grouped by Relative Radiotoxicity	Activity in Curies of Single Inhalation that Results in 15-rem Dose(b) to Critical Organ	to Lung(c)
Group I		
^{3}H	6.15×10^{-2}	---
^{14}C	2.88×10^{-2}	---
Group II		
^{51}Cr	8.84×10^{-2}	5.30×10^{-3}
^{55}Fe	2.17×10^{-3}	2.30×10^{-3}
Group III		
^{35}S	7.23×10^{-4}	6.90×10^{-4}
^{198}Au	7.25×10^{-4}	5.30×10^{-4}
^{47}Ca	2.59×10^{-4}	4.60×10^{-4}
^{132}I	4.50×10^{-4}	---
^{141}Ce	7.06×10^{-4}	4.20×10^{-4}
^{85}Sr	2.00×10^{-3}	2.70×10^{-4}
^{140}La	4.20×10^{-4}	2.60×10^{-4}
^{95}Nb	3.60×10^{-3}	2.30×10^{-4}
^{65}Zn	2.60×10^{-4}	1.50×10^{-4}
^{58}Co	8.40×10^{-3}	1.30×10^{-4}
^{59}Fe	3.00×10^{-4}	1.30×10^{-4}
Group IV		
^{181}Hf	9.94×10^{-5}	1.92×10^{-4}
^{147}Pm	8.90×10^{-5}	2.30×10^{-4}
^{32}P	8.70×10^{-5}	2.10×10^{-5}
^{140}Ba	1.40×10^{-4}	8.60×10^{-5}
^{234}Ba	8.50×10^{-5}	7.30×10^{-5}
^{85}Kr	6.90×10^{-4}	5.80×10^{-5}
^{192}Ir	3.20×10^{-5}	6.90×10^{-5}
^{36}Cl	2.70×10^{-5}	5.30×10^{-5}
^{91}Y	5.00×10^{-4}	7.30×10^{-5}
^{182}Ta	1.10×10^{-5}	5.00×10^{-4}
^{45}Ca	4.30×10^{-5}	2.60×10^{-5}
^{89}Sr	4.00×10^{-9}	8.50×10^{-5}
^{137}Cs	2.60×10^{-5}	2.20×10^{-5}
^{60}Co	2.60×10^{-5}	1.50×10^{-5}
^{144}Ce	1.40×10^{-5}	1.50×10^{-4}
^{126}I	1.40×10^{-5}	7.30×10^{-4}
^{154}Eu	1.30×10^{-5}	1.60×10^{-5}
Group IV (contd)		
^{131}I	1.20×10^{-5}	7.30×10^{-4}
^{170}Tm	3.80×10^{-5}	7.30×10^{-5}
^{82}Br	7.47×10^{-3}	---
Group V		
^{129}I	2.30×10^{-6}	1.60×10^{-4}
^{99}Tc	9.10×10^{-6}	
Group VI		
^{233}Ra	3.90×10^{-6}	5.30×10^{-7}
^{210}Po	1.30×10^{-6}	5.00×10^{-7}
^{227}Th	5.50×10^{-7}	4.60×10^{-7}
^{90}Sr	3.90×10^{-7}	1.30×10^{-5}
^{210}Pb	3.20×10^{-7}	5.30×10^{-7}
^{242}Cm	3.00×10^{-7}	4.60×10^{-7}
^{233}U	7.00×10^{-7}	2.70×10^{-7}
^{235}U (+ 1% ^{234}U)	1.10×10^{-6}	2.60×10^{-7}
^{238}U & U Nat	1.90×10^{-7}	3.00×10^{-8}
^{232}Th & Th Nat	2.25×10^{-9}	2.60×10^{-8}
Group VII		
^{147}Sm	7.70×10^{-8}	6.90×10^{-7}
^{144}Nd	7.70×10^{-8}	7.30×10^{-7}
^{226}Ra	4.90×10^{-8}	1.50×10^{-8}
^{244}Cm	1.10×10^{-8}	2.30×10^{-7}
Group VIII		
^{243}Am	7.60×10^{-9}	2.70×10^{-7}
^{241}Am	6.60×10^{-9}	2.70×10^{-7}
^{237}Np	5.20×10^{-9}	2.70×10^{-7}
^{227}Ac	3.00×10^{-9}	6.90×10^{-8}
^{230}Th	2.80×10^{-9}	2.30×10^{-8}
^{242}Pu	2.50×10^{-9}	8.50×10^{-8}
^{238}Pu	2.20×10^{-9}	8.50×10^{-8}
^{239}Pu	2.00×10^{-9}	8.50×10^{-9}
^{240}Pu	2.00×10^{-9}	8.50×10^{-8}

(a) Brodsky 1965.
(b) Insoluble materials.
(c) 50-year cumulative dose.

TABLE 1.11. Fissionable Materials

Capable of Chain Reaction with Fast and Thermal Neutrons		Capable of Chain Reaction with Fast Neutrons Only
^{233}U	^{243}Cm	^{237}Np
^{235}U	^{245}Cm	^{241}Am
^{239}Pu	^{247}Cm	^{244}Cm
^{241}Pu	^{249}Cf	^{238}Pu
^{242}Am	^{251}Cf	^{240}Pu
		^{242}Pu
		^{238}U

one additional fission, then the reaction is self-perpetuating and the chain reaction is said to be critical. Finally, if the neutrons released from a fissioning atom cause, on the average, more than one subsequent fission, the reaction is said to be supercritical. An unplanned supercritical chain reaction is called a criticality accident.

Criticality accidents are extremely serious because very high levels of gamma and neutron radiation can be produced. That is, lethal doses of radiation can be received in a very short time. For this reason, special efforts are made to reduce the chances of a criticality accident to a very low level. Particularly important is the design of facilities. "Safe-by-geometry" is the best rule to remember in reducing the probability of a criticality accident.

A. The Double-Contingency Rule. One of the most generally accepted approaches to preventing a criticality accident is the double-contingency rule. This rule assumes that a sufficient number of limits and controls exists to ensure that, before a criticality is possible, at least two unlikely, independent, and concurrent changes must occur in one or more of the conditions specified as essential to nuclear safety. This rule calls for controls which ensure that no single mishap can lead to a criticality accident, regardless of the probability that that mishap might occur.

B. Factors That Affect Criticality. Nine physical factors affect the likelihood that an accumulation of fissile material will sustain a chain reaction. Criticality safety programs take account of these factors and employ safeguards based on them to prevent criticality accidents.

(1) Amount. The amount of fissionable material needed to support a chain reaction is the critical mass. If the amount of fissionable material present is small enough, criticality cannot occur no matter what the condition of the other eight physical factors. On the other hand, the greater the amount of fissile material present, the more difficult it is to avoid criticality. Limiting the amount of material present helps ensure a subcritical state. Many safeguards are designed to limit the total amount of fissile material that can be assembled in one place.

(2) Geometry. The size and shape of fissile materials have an important effect on the probability of a chain reaction occurring. Decreasing the distance that neutrons travel within the fissile material decreases the chance that the neutrons will interact to cause a subsequent fission. For this reason, a thin slab of fissile material is unlikely to support fission reactions, but a sphere is most conducive to criticality.

(3) Density. If the density of fissile materials is increased, the fissile atoms are more tightly packed together. This packing reduces the chance that a neutron will escape from the material; thus, the higher the density of the material and the atoms in it, the higher the probability that a fissile atom will capture a neutron in the material and undergo fission.

(4) Moderation. The speed of a neutron affects its chances of being captured by a fissile atom. The faster a neutron travels, the less likely it is to be captured. Thus, the fast neutrons produced by a fission are not likely to cause more fissions until they slow down.

Fast neutrons are slowed down when they collide with, but are not absorbed by, the nuclei of atoms. This slowing-down process is called thermalization, or moderation. Moderation of a neutron increases its chances of being captured and causing a fission. Graphite and hydrogen-containing materials such as paraffin, oil, and water are good moderators. Human tissues are 70% water and thus are good moderators also.

(5) Reflection. Neutrons that escape from fissile materials without causing additional fissions or being absorbed by atoms continue to move away from the materials unless they hit something in their path. Anything placed close to fissile material will tend to bounce (reflect) a few of the neutrons back into the material and give the fissile atoms another chance to absorb them.

Materials that have a low atomic number are good reflectors; in fact, many moderators are also very good reflectors. Human tissues are both good moderators and good reflectors.

(6) Enrichment. Naturally occurring uranium is mostly nonfissile ^{238}U and less than 1% fissile ^{235}U. If the world's entire supply of natural uranium ore were collected into a giant sphere and covered with drinking water, it would not be critical. However, uranium can be enriched. Uranium is said to be enriched when the percentage of ^{235}U atoms has been increased above the percentage found in natural uranium. As the enrichment increases, the number of fissile atoms that can capture neutrons and then undergo fission increases, and fewer nonfissile atoms are available to capture neutrons and prevent the fissioning process. Therefore, the greater the level of enrichment, the easier it is for an accumulation of fissile material to attain criticality.

(7) Interaction. The escape of neutrons from one accumulation or "pile" of fissile material, and their subsequent entrance into another accumulation that can cause more fissions, is called interaction. Interaction can occur if accumulations of fissile material are close enough together. For this reason, accumulations of fissile material must be stored far enough apart to prevent interaction. Keeping accumulations of fissile material at preestablished distances apart is a commonly used criticality control technique.

(8) Type of Material. Each type of fissile material has different nuclear properties. For example, the amount of ^{235}U needed to support a chain reaction is about 1 kg, whereas the amount of ^{239}Pu needed is only about 1/2 kg.

(9) Nuclear Poisons. Nuclear poisons are materials that absorb neutrons without undergoing fission. This absorption decreases the number of neutrons available to cause a fission. Examples of nuclear poisons include cadmium, boron, and samarium.

The nine factors mentioned above can interact and make the problem of determining safe handling procedures for fissile materials very complex. Because of this complexity, a criticality safety expert should be consulted whenever questions arise concerning criticality safety.

REFERENCES

Brodsky, A. 1965. "Determining Industrial Hygiene Requirements for Installations Using Radioactive Materials." Amer. Ind. Hyg. Ass. J. 26:294-310.

International Commission on Radiation Units and Measurements (ICRU). 1980. Radiation Quantities and Units. ICRU 33, Washington, D.C.

Interagency Task Force on Health Effects of Ionizing Radiation. 1979. Report of the Interagency Task Force on the Health Effects of Ionizing Radiation. U.S. Department of Health, Education and Welfare, Washington, D.C.

Lederer, C. M., and V. S. Shirley, eds. 1978. Table of Isotopes. John Wiley and Sons, New York.

National Council or Radiation Protection and Measurements (NCRP). 1971. Basic Radiation Protection Criteria. NCRP 39, Washington, D.C.

Radiological Health Handbook. 1970. U.S. Department of Health, Education and Welfare, Bureau of Radiological Health. Available from U.S. Government Printing Office, Washington, D.C.

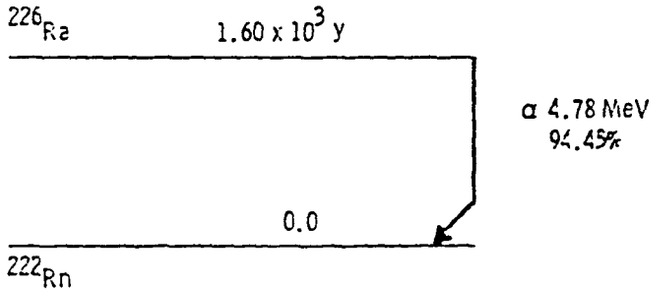
U.S. Department of the Army and Defense Logistics Agency. Medical Services - Control and Recording Procedures for Exposure to Ionizing Radiation and Radioactive Materials. AR 40-14, DLAR 1000.2E, Washington, D.C.

APPENDIX A

DECAY SCHEMES

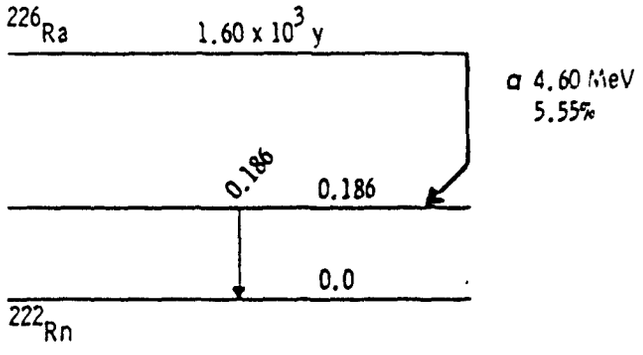
Decay schemes are diagrammatic representations of radioactive decay pathways. The chemical symbol, mass number, and half-life of the parent nuclide appear on the uppermost horizontal line. Decay leading to an increase in the N/Z ratio (alpha emission, positron emission, and electron capture) is indicated by a bent arrow leading to the lower left; decay leading to a decrease in the N/Z ratio (electron emission) is drawn with an arrow leading to the lower right. These arrows terminate on horizontal lines that represent the nuclear energy levels of the daughter nucleus. If the daughter nucleus formed is in an excited state, then gamma rays are emitted until the ground, or unexcited, state is reached. Gamma rays are represented by vertical lines that may be either straight or wavy. The maximum kinetic energy of the emitted particle or the energy of the gamma ray is indicated near the appropriate arrow. If more than one pathway may be followed, the fractional or percentage occurrence of each pathway is indicated.

As mentioned in Section 1.2.2, radium-226 (which has a half-life of 1600 years, or 1.60×10^3 years) can undergo radioactive decay by five pathways. The first and most common pathway consists of the emission of an alpha particle that has 4.78 MeV of kinetic energy. In this case, the daughter nucleus, radon-222, is not in an excited state, so no gamma ray is emitted. A decay scheme showing this pathway is shown below:



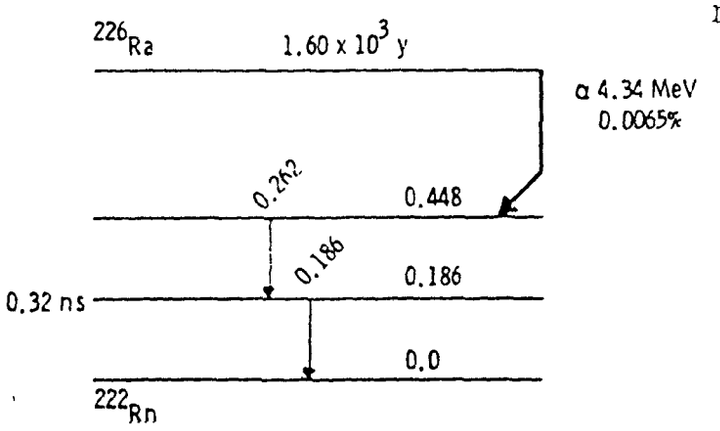
This scheme indicates that of all the decays of ^{226}Ra to ^{222}Rn, 94.45% proceed by the emission of only a 4.78-MeV alpha particle.

The next most common pathway for the decay of ^{226}Ra is the emission of an alpha particle that has a kinetic energy of 4.60 MeV. The daughter nucleus, ^{222}Rn, is in an excited state, and a gamma ray of 0.186 MeV is emitted. The scheme for this pathway is shown below.

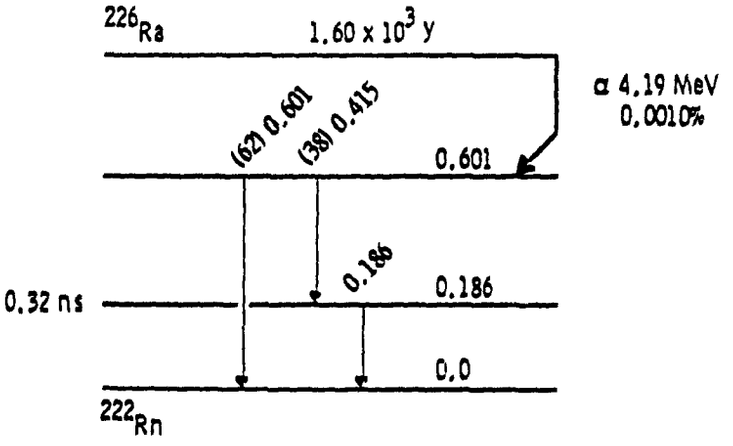


This scheme shows that, of all the decays of ^{226}Ra, 5.55% decay by this pathway. The numbers to the right of the horizontal lines represent the energy level of the daughter nucleus, in MeV. The straight vertical line between the 0.186 line and the 0.0 line represents a gamma ray that has an energy of 0.186 MeV (shown by the numbers above the gamma ray).

A third pathway by which ^{226}Ra decays is the emission of a 4.34-MeV alpha particle. The ^{222}Rn daughter nucleus is left in an excited state and loses energy by the emission of two gamma rays, one that has 0.262 MeV and a second that has 0.186 MeV of energy. The two gamma rays are emitted in quick succession, the 0.262-MeV gamma first, followed by the 0.186-MeV gamma. The 0.186-MeV level of ^{222}Rn has a half-life of 0.32 nsec (3.2×10^{-10} sec). This amount of time is not long enough for this energy level to be considered an isomer of ^{222}Rn. The decay scheme is shown on the next page.

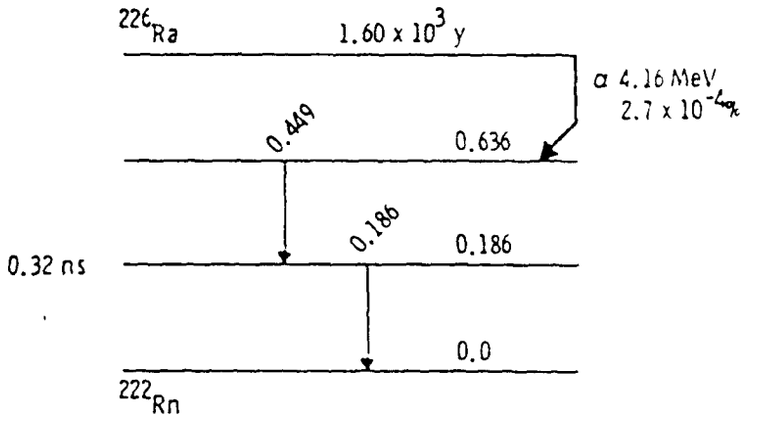


The fourth pathway by which ^{226}Ra decays is the emission of an alpha particle that has 4.19 MeV of kinetic energy. The ^{222}Rn daughter nucleus is in an excited state and releases its extra energy in two ways: 62% of the time, a single gamma ray with 0.601 MeV of energy is emitted; 38% of the time, two gamma rays are emitted, one following the other in a cascade. The total energy of the two gamma rays (0.415 and 0.186 MeV) is equal to the energy of the single emitted gamma ray. The scheme may be drawn as follows:

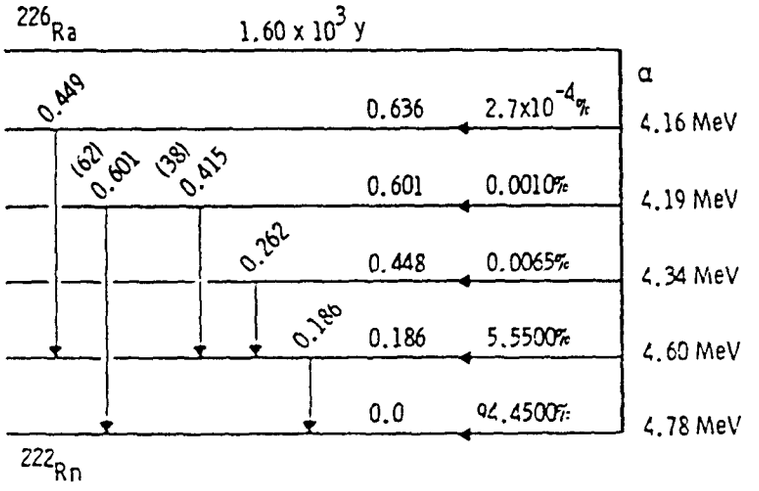


The (62) and (38) preceding the 0.601-MeV-level gamma rays indicate the percent of gamma rays following each pathway.

The final decay pathway that ^{226}Ra can follow is the emission of an alpha particle that has a kinetic energy of 4.16 MeV. The pathway is followed infrequently, by only 2.7×10^{-4}% of all decays. The ^{222}Rn daughter nucleus is an excited state and releases 0.636 MeV of energy in the form of two gamma rays of 0.449 and 0.186 MeV. These gamma rays are emitted in a cascade. The decay scheme for this pathway can be drawn as follows:

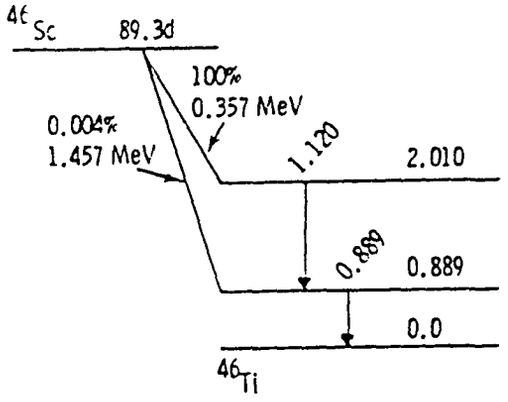


When a radionuclide follows multiple decay pathways, as does ^{226}Ra, the various pathways are all shown on one diagram rather than as several different schemes. When the complete decay scheme is complex, the method of drawing the arrows is altered to save space. Thus, the complete decay scheme for ^{226}Ra would be drawn as below:

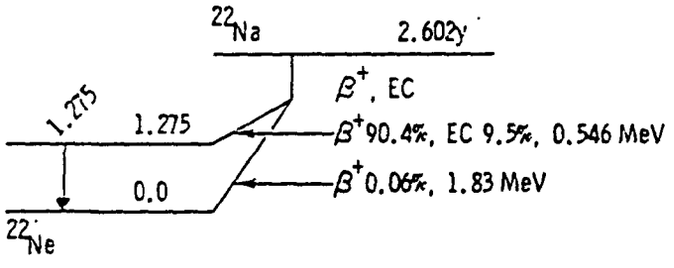


This diagram is one way of presenting the decay scheme information. Notice that the gamma ray resulting from the de-excitation of the 0.186-MeV nuclear energy level follows the 4.60-MeV alpha, the 4.34-MeV alpha, the 4.19-MeV alpha, and the 4.16-MeV alpha.

A decay scheme for beta negative emission, in the decay of scandium-46 to titanium-46, is shown below:



The decay of sodium-22, a positron emitter, to neon-22 is drawn below:



Each publisher has a slightly different method of presenting the data. For example, some publishers number the gamma rays and list the frequency of occurrence and energy in a separate table. The publisher may identify the alpha emissions by the nuclear energy level of the emission (e.g., the 0.635-MeV energy level or the 0.6007-MeV energy level) and may list the information concerning frequency of occurrence and energy in a separate table. In other words, when consulting a decay scheme, the reader should be familiar with the method of presentation used by the publishers.

Information on decay schemes can also be found in tabular form in several references, including the Table of Isotopes (Lederer and Shirley 1978) and the Radiological Health Handbook.

CHAPTER 2. RADIATION INSTRUMENTATION

2.1 BASIC CONCEPTS IN RADIATION DETECTION AND MEASUREMENT . . . 2.5

2.1.1 Characteristics of Instruments 2.5

2.1.2 Source Characteristics 2.8

2.2 RADIATION PROTECTION INSTRUMENTS AND HOW THEY WORK . . . 2.9

2.2.1 Gas Ionization Detectors 2.9

A. Principles of Operation 2.9

B. Ionization Chambers 2.14

C. Proportional Counters 2.16

D. Geiger-Mueller Counters 2.19

2.2.2 Scintillation Detectors 2.20

A. Principles of Operation 2.21

B. Inorganic Scintillators 2.22

C. Organic Scintillators 2.23

2.2.3 Semiconductor Detectors 2.26

2.3 CALIBRATION OF INSTRUMENTS 2.29

2.3.1 Calibration Sources 2.29

2.3.2 Calibration Facilities 2.30

2.3.3 Instrument Characteristics That Affect Calibration and Calibration Frequency 2.31

2.4 FACTORS THAT AFFECT THE SELECTION AND USE OF RADIATION-MONITORING INSTRUMENTS 2.33

2.4.1 Detection Versus Measurement 2.33

2.4.2 Type of Radiation 2.33

2.4.3 Radiation Energy and Instrument Energy Dependence . . 2.34

2.4.4 Nonuniform Fields 2.34

2.4.5 Angular Dependence 2.34

2.4.6 Calibration 2.35

2.4.7 Unwanted Response 2.35

2.5 TYPES OF RADIATION-MONITORING INSTRUMENTS 2.35

2.5.1 Portable Survey Meters 2.35

A. Portable Detection Instruments 2.36

B. Portable Measurement Instruments 2.36

2.5.2 Laboratory Counting Instruments 2.37

2.5.3 Air-Monitoring Equipment 2.39

A. Air Samplers 2.39

B. Air Monitors 2.40

C. Principles of Operation 2.41

2.5.4 Other Fixed Instruments 2.42

A. Remote Area Monitors 2.42

B. Continuous Air Monitors 2.42

2.6 PERSONNEL DOSIMETERS 2.43

2.6.1 Photographic Film 2.43

A. Principles of Operation 2.44

B. Dosimeter Design 2.44

C. Effects of Environment 2.44

D. Processing Techniques 2.45

E. Interpretation and Calibration 2.45

2.6.2 Nuclear Track Emulsions 2.46

2.6.3 Thermoluminescence Dosimeters 2.46

A. Principles of Operation 2.46

B. Advantages and Limitations 2.47

C. Interpretation and Calibration 2.48

D. Practical Applications 2.48

2.7 STATISTICS AND ERROR DETERMINATION 2.49

2.7.1 Systematic and Random Errors of Measurement . . . 2.49

2.7.2 Basic Statistical Distributions for Radioactive Decay . 2.49

2.8 RECORDS 2.52

REFERENCES 2.52

FIGURES

2.1 Simplified Version of a Chamber Used to Collect Ions . . . 2.9

2.2 Relationship Between Applied Voltage and the Number of Electrons Collected on the Anode 2.12

2.3 Plateaus for Typical Proportional Counter 2.18

2.4 Diffused p-n Junction Detector 2.28

2.5 Frequency of Occurrence of Count Rates for a Long-Lived Sample 2.50

2.6 Normal Distribution Function Showing Standard Deviations and Mean 2.51

TABLES

2.1 Portable Survey Instruments 2.37

2.2 Laboratory Counters 2.38

CHAPTER 2. RADIATION INSTRUMENTATION

Ionizing radiation cannot be detected by unaided human senses; instrumentation must be used to detect and measure it. This chapter describes the fundamental characteristics of radiation detection and measurement instruments and their principles of operation, their application, and their limitations. Included in the chapter are an introduction to measurement concepts; a review of instruments used in the field of radiation protection and how they work; information on the calibration of instruments; factors that affect the selection of radiation-monitoring instruments; the types of monitoring instruments and personnel dosimeters available for use; and a brief discussion of statistics and error determination.

Section 2.1 BASIC CONCEPTS IN RADIATION DETECTION AND MEASUREMENT

Numerous types of instruments are used for a wide variety of purposes in the field of radiation protection. Some instruments simply detect the presence of radiation; others give a quantitative measurement of the dose rate or exposure rate produced by the radiation.

Detection and measurement instruments have two basic components, a sensing element and an indicating element. The sensing element, called the detector, responds to the radiation and through various means provides a measurable signal to the indicating element. Common types of indicating elements include meters, recorders, counting scalers, and speakers. Intermediate electronic circuitry may be used to amplify the signal from the detector so that it can be more readily observed in the indicating element.

2.1.1 Characteristics of Instruments

Instruments can be characterized by how radiation interacts with the detector. Several instruments depend for their operation on the ionization of matter by radiation. Other detection systems depend largely upon the excitation of electrons rather than on ionization. Both ionization and excitation

result either directly or indirectly in the formation of electrical charges within the sensitive volume of the detector or its associated circuitry. If an electric field is applied across the sensitive volume of the detector, the electrical charges can be collected because negative charges travel to the positive pole of the electric field and positive charges travel to the negative pole. The collection of the electrical charges causes a build-up of charge that flows through an external circuit.

A second way of distinguishing types of instruments is by whether the flow of charge is recorded as a pulse or a current. An instrument that operates in the pulse mode records an output pulse for each individual interaction between the detector and a particle or photon of radiation. An instrument that operates in the current mode records an average of many individual interactions and subsequent pulse fluctuations. An advantage of the pulse mode is that, for many instruments, the amplitude (size or height) of each individual pulse carries valuable information about the type and energy of the radiation that caused the pulse; in the current mode, information on individual pulses, and thus on individual radiations, is lost. Pulse detectors also have a greater sensitivity than detectors that operate in the current mode; that is, they detect more of the incoming radiation. Because of these advantages, the pulse mode is more commonly used for radiation detection instruments.

A third distinction among instruments is how those that operate in the pulse mode record the pulses. Rate meters record a pulse rate, with readouts in counts per minute (cpm), mR/hr, mrem/hr, etc. Integrating instruments have a digital counting accessory that tallies the pulses for the duration of the measurement, with readouts given in counts, mR, mrad, etc.

Counting devices that accept pulses may have fixed or variable discriminators. The pulse amplitude must be of a certain size to pass the discriminator level and be counted; otherwise it is rejected. If the discriminator level can be varied, information can be obtained about the amplitude distribution of the pulses, and therefore about the types and energies of the radiations.

In nearly all detector systems, a minimum amount of time is required between two interactions in order for them to be registered as two separate

pulses. This interval is called the dead time of the system. Immediately after a pulse, the detector is insensitive to radiation and is unable to respond to other ionizing events. If an ionizing event occurs during this time, it does not produce a pulse. The important consequence of dead time is that a detector in a high-radiation field may indicate less radiation than is actually present. Counts that are recorded can be corrected for dead-time losses, and many laboratory counters have a meter that indicates the percentage of time the counter is dead.

The object of many applications of radiation detectors is to identify the energy distribution of the incident radiation. The ability of a detection system to distinguish between or separate two pulses of slightly different sizes is called its energy resolution. The resolution capabilities of various instruments are discussed later in this chapter.

If a detector counts every particle or photon of radiation that enters its sensitive volume, it has a counting efficiency of 100%. Practically speaking, however, counting efficiencies of 100% are rarely achieved. It is always possible, especially with gamma rays and neutrons, that some radiation will pass through the detector without interacting with it. In order to relate the number of pulses counted to the actual number of radiations incident on the detector, the detector's counting efficiency must be calculated. The absolute efficiency is calculated using Equation (2.1).

$$\text{absolute efficiency} = \frac{\text{number of pulses recorded}}{\text{number of radiations emitted by source}} \qquad (2.1)$$

If the absolute efficiency of the detection system is known and a given number of pulses are recorded for a given time, this equation can be used to determine the activity of the radioactive source (i.e., the number of radiations emitted per unit time).

Another type of efficiency accounts for the fact that all of the radiations emitted by the source may not reach the detector. The intrinsic efficiency of the detector is calculated using Equation (2.2).

$$\text{intrinsic efficiency} = \frac{\text{number of pulses recorded}}{\text{number of radiations incident on detector}} \qquad (2.2)$$

2.1.2 Source Characteristics

In the detection and measurement of radiation, consideration must also be given to characteristics of the radioactive source. The emission of radiation from a radioactive source is generally assumed to be isotropic; that is, radiation is emitted by the source in all directions with equal intensity. In order for all of the radiation emitted by the source to be detected, the source must be completely enclosed within the sensitive volume of the detector. This type of counting arrangement is called 4- geometry (because the solid angle subtended by the detector at the source position is 4π steradians). Most detection systems do not achieve 4π geometry because the source is placed outside the detector and only a fraction of the emitted radiation is directed toward the sensitive volume. The geometry factor is the fraction of the source sphere that actually intercepts the detector. It can be used to determine the actual number of radiations being emitted by the source.

Other source factors that must be considered are self-absorption, radiation attenuation, and the inverse-square law. When a radioactive source produces radiation, there is a finite probability that the radiation will lose its energy within the source itself. This process, called self-absorption, occurs most frequently with encapsulated alpha and beta sources because the energy of the particles is absorbed by the capsule material. Radiation may also lose its energy in the air between the source and the detector, or in the shielding of the detector before it reaches the sensitive volume, and this attenuation must be considered when attempting to determine the activity of the source. Finally, assuming that the radioactive source is a point source (very small compared to the distance to the detector) and that particles or photons radiate outward from it, the number of radiations in a unit area falls off with distance. The greater the distance between the source and the detector, the fewer the radiations entering the sensitive volume of the detector and therefore the lower the count rate. A complete discussion of this principle, called the inverse-square law, is presented in Chapter 6.

Section 2.2 RADIATION PROTECTION INSTRUMENTS AND HOW THEY WORK

Instruments used for radiation protection are of three general types: gas ionization detectors, scintillation detectors, and semiconductor detectors. The principles on which these detectors work and the types of detectors in each group are described in this section.

2.2.1 Gas Ionization Detectors

As radiation passes through a gas, it gives energy to orbital electrons, causing ionization and excitation of the gas atoms through the mechanisms described in Chapter 1. Gas ionization detectors use the process of ionization to detect the presence of radiation.

A. Principles of Operation. A simplified diagram of a gas ionization detector is shown in Figure 2.1. The detector assembly usually consists of a power supply and a closed, electrically conductive cylinder or chamber that is filled with gas. The chamber walls are usually made of metal, which can be

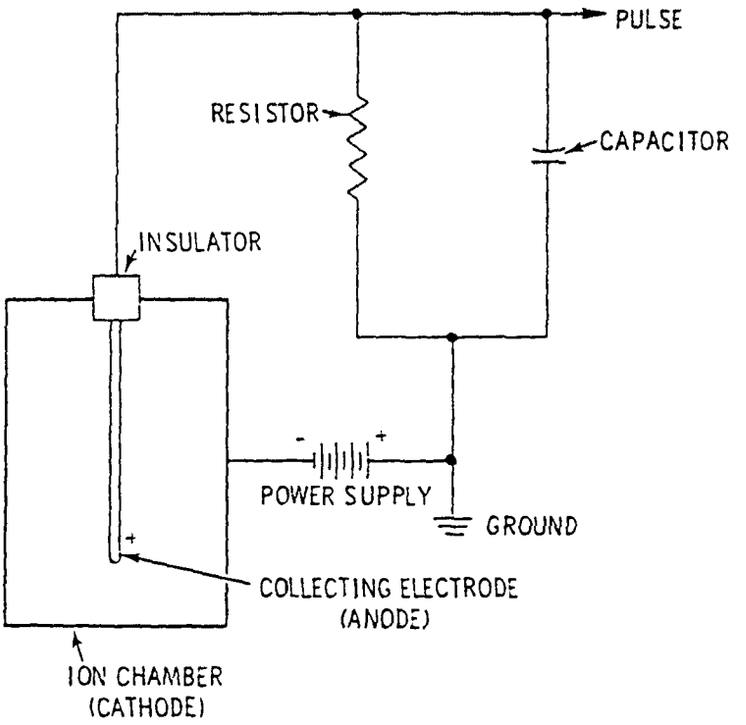


FIGURE 2.1. Simplified Version of a Chamber Used to Collect Ions

penetrated by photons and some high-energy beta particles. The chamber may have a "window" made of a material such as mylar, which can be easily penetrated by alpha particles and lower-energy beta particles.

The positive and negative poles of the power supply are called electrodes. A thin wire in the center of the chamber is connected to the positive electrode of the power supply and is called the central collecting electrode, or anode. The chamber wall is connected to the negative electrode of the power supply and is called the cathode. As radiation passes through the gas that fills the chamber, it gives energy to the orbital electrons of the gas atoms and may cause them to be removed from the originally neutral gas atoms. This ionization process results in the formation of a free electron (negative ion) and a positive gas atom (positive ion), which together are called an ion pair. Repeated interactions between radiation and the fill gas in a closed chamber gradually cause the degradation of the gas until eventually the detector loses its effectiveness, and either the degraded gas is removed from the chamber and replaced with new gas, or the entire detector is replaced.

The number of ion pairs created in a given volume of the chamber's fill gas depends on the type of gas used and the type and energy of the radiation. A dense gas has more atoms for the radiation to interact with than does a less dense gas and thus leads to the creation of more ion pairs. Alpha particles, which are relatively heavy and slow and have a double positive charge, create many ion pairs within a very short distance as they travel through the fill gas. They typically give up all of their energy to the gas within a few centimeters. Beta particles, which are much smaller and faster than alpha particles, do not interact as readily with the orbital electrons and thus create fewer ion pairs. Gamma rays and x rays, which are uncharged and have negligible mass, interact indirectly with the gas (see Chapter 1) and produce even fewer ion pairs. If an alpha particle, a beta particle, and a gamma ray with identical energies passed through the same volume of a fill gas, the alpha particle would create tens of thousands of ion pairs, the beta particle a few hundred ion pairs, and the gamma ray just a few ion pairs per centimeter of gas. The number of ion pairs created also depends on the energy of the radiation. On the average, one ion pair is produced for every 30 to 35 eV of energy transferred

to the gas. Thus, a single 1-MeV radiation that loses all of its energy in a gas creates approximately 30,000 ion pairs; a 2-MeV particle creates 60,000 ion pairs.

When voltage is applied across the chamber, the ion pairs produced in the gas by the incident radiation move toward their respective electrodes: the negatively charged electrons move rapidly to the positively charged anode, and the positively charged ions, which are much heavier, move very slowly toward the negatively charged chamber wall. The electrons that collect on the anode produce a build-up of charge. The collected charge flows through the external circuit as a pulse or surge of current. Each pulse represents the interaction of one particle or photon of radiation with the gas. The pulses flowing through the external circuit of the instrument can be recorded in one of two ways, depending on the type of electronic circuit used. If a nonintegrating, or differential, circuit is used, each individual pulse can be tallied, which gives a record of the total number of ionizing radiations entering the chamber; if an integrating circuit is used, the total current flow over a given period of time can be measured. The total current flow is proportional to the degree of ionization in the chamber.

The magnitude of the voltage applied to the electrodes is another factor that affects the number of electrons collected on the anode and the resulting charge. Figure 2.2 shows the relationship between the applied voltage and the pulse height in the circuit. In this figure, six regions can be observed: 1) the recombination region, 2) the ionization chamber region, 3) the proportional region, 4) the limited-proportional region, 5) the Geiger region, and 6) the continuous-discharge region.

(1) Recombination Region. In this region, the voltage across the electrodes is relatively low, and the force of attraction between the ions and the electrodes is not great. Therefore, most of the positive and negative ions produced by the radiation are attracted to each other, rather than to the electrodes, and they recombine. As the voltage applied to the electrodes is increased, fewer ions recombine. However, no radiation detectors operate in this region.

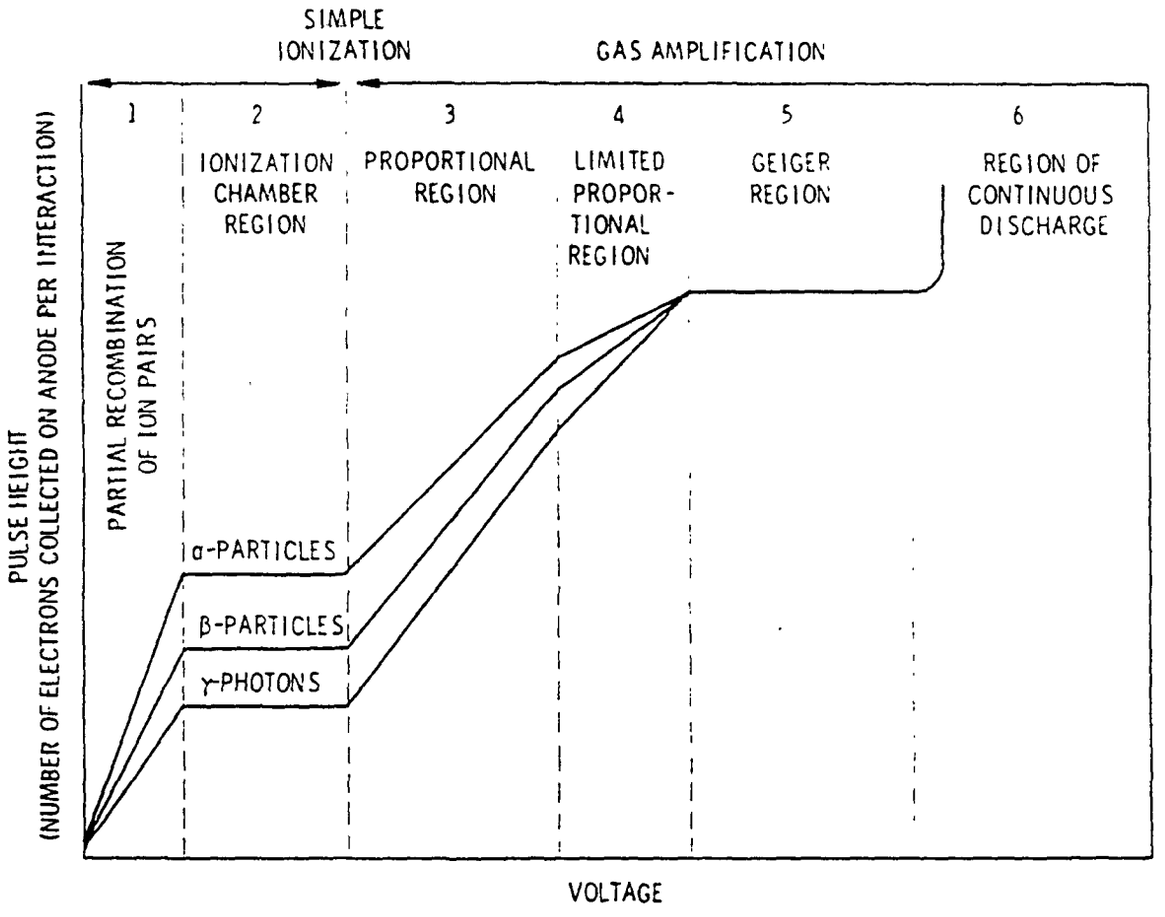


FIGURE 2.2. Relationship Between Applied Voltage and the Number of Electrons Collected on the Anode

(2) Ionization Chamber Region. At a certain voltage, the force of attraction between the ions and the electrodes is sufficient to cause all of the electrons produced by the incident radiation to be collected on the anode. Subsequent moderate increases in the voltage do not create any further increase in the electron current: a saturation voltage has been reached. (For this reason, the ionization chamber region is also called the saturation region.) The number of electrons collected at the anode is a function of the amount of ionization occurring in the chamber.

Figure 2.2 shows three curves in the ionization chamber region, one each for alpha particles, beta particles, and gamma rays (photons). Because alpha particles create a larger number of ion pairs per path length than the other

radiations do, more electrons are collected on the anode and a larger pulse is produced in the external circuit. The pulse height for beta particles, which create fewer ion pairs than alphas, is slightly smaller, and the pulse height for gamma rays is the smallest. Thus, in the ionization chamber region, the different types of radiations can be distinguished from each other because of the different pulse heights produced in the external circuit.

(3) Proportional Region. If the voltage between the anode and the cathode is increased, the number of ion pairs collected is larger than the number of primary ion pairs (those initially formed by the incident radiation). At high voltages, the primary negative ions (i.e., electrons) are accelerated toward the anode fast enough to cause additional ionization of the gas, creating secondary ion pairs. The secondary electrons that are then accelerated toward the anode may also have enough energy to cause even further ionization of the gas. This multiplication or avalanche of electrons moving toward the anode is called gas amplification, and in the proportional region the avalanche is restricted to the vicinity of the primary ionizations. The gas amplification factor, or multiplication factor, is a measure of the number of secondary electrons produced by one primary electron. Thus, if one primary electron causes 10,000 secondary electrons to be produced, the multiplication factor is 10,000. (In the ionization chamber region, the multiplication factor is 1 because the relatively low voltage across the electrodes does not result in an avalanche, or multiplication effect.) In the proportional region, the total number of ion pairs eventually formed is proportional to the number of primary ion pairs formed by the incident radiation, and the multiplication factor is constant over small voltage ranges within the region. Detectors operating in the proportional region have multiplication factors up to 10^6, depending on the applied voltage, but the typical factor is 10^4. These detectors, like those operating in the ionization chamber region, can distinguish between alpha, beta, and gamma radiations.

(4) Limited Proportional Region. At the upper range of the proportional region, the gas amplification factor is no longer constant for a given voltage range but can change markedly with small changes in the applied voltage. This region is called the limited-proportional region and, in general, has no useful purpose for radiation measurement.

(5) Geiger Region. A further increase in voltage leads to the Geiger region. The gas amplification in this region is so extensive that an avalanche of electrons spreads along the entire length of the instrument's anode, and all pulses are the same size, regardless of the type of radiation that initiated the ionization. Thus, a detector operated in the Geiger region cannot distinguish between the different types of radiation. The pulses in the Geiger region are much larger than those in any of the previous regions. In fact, the production of only one primary ion pair results in an easily measurable pulse (~1 V).

As positive ions approach the cathode wall of the detector, they have so much energy (because of the high voltage in the Geiger region) that they attract electrons from the wall and become neutral atoms. During this process, a low-energy x ray is often emitted that can cause further ionization. If this additional ionization were allowed to proceed, the detector would remain in a continual state of discharge and would not count a second pulse. To terminate, or quench, the perpetual ionization in the detector, a small amount of quenching gas is added to the chamber. The quenching gas transfers its electrons to the positive ions, and the electrons and positive ions combine to create neutral gas atoms. Without its electrons, the quenching gas has a positive charge; it migrates to the cathode and collects electrons to become neutralized. The energy produced in this process goes into the dissociation of the gas molecule rather than the production of an x ray. Bromine, chlorine, ethanol, and methane are typically used as quenching gases.

(6) Continuous-Discharge Region. If the voltage is increased still further, arcing occurs across the electrodes, and pulses are registered continuously even if no radiation is present. Instruments operated in this region can be permanently damaged in a short time.

The three types of ionization instruments commonly used by radiation protection personnel--ionization chambers, proportional counters, and Geiger-Mueller counters--correspond to the three regions of the pulse height-voltage curve in which radiations can be detected.

B. Ionization Chambers. Instruments designed to operate in the ionization chamber region of Figure 2.2 are called ionization chambers, or ion chambers. They can be passive or active detectors.

(1) Passive Ion Chambers. In a passive ion chamber, a voltage is placed across the electrodes in a process called charging. The chamber is then separated from the charger and placed in a radiation field. The ions formed by the incident radiation neutralize the charge, and the subsequent drop in voltage can be measured and correlated to the amount of radiation that was present. Two types of passive ion chambers are pocket ionization chambers and condenser chambers.

Pocket ionization chambers, also called pencil dosimeters, are integrating instruments that record the total current flow, or true charge, produced by the radiation entering the chamber. These dosimeters have a metal-coated quartz fiber that is attached at one end to a rigid metal electrode and suspended in a small gas-filled chamber. When a positive charge is placed on the electrode, the charge is also transferred to the fiber, and because like charges repel, the fiber moves away from the electrode. When radiation ionizes the fill gas in the chamber, the resulting negatively-charged electrons combine with and neutralize some of the positive charges on the fiber and electrode (the fiber and electrode are said to discharge). This results in a decrease in voltage between the two, and the fiber moves closer to the electrode. How far it moves depends on the number of electrons formed by the radiation; thus, the distance between the electrode and the fiber indicates how much radiation the dosimeter was exposed to.

Self-reading pencil dosimeters are equipped with a built-in microscope and a scale that enables the wearer to read the exposure at any time. When the dosimeter is fully charged, the fiber lies on the zero point on the scale. As the fiber discharges in response to ionizing radiations, it moves along the scale. Non-self-reading pencil dosimeters must be inserted into a specially designed voltmeter to be read. If a dosimeter is dropped or subjected to other sudden motions, it may discharge and incorrectly indicate a very high exposure.

Another type of passive ion chamber, the condenser chamber or condenser R-meter, is used to make highly accurate and precise measurements. Condenser chambers are similar to non-self-reacing pocket ionization chambers but are very carefully constructed and have walls of uniform thickness so that the

energies of incident photons can be measured. These instruments also respond to beta rays with energies higher than 1 MeV. If the inside of a condenser chamber is coated with boron, it also responds to thermal (low-energy) neutrons.

(2) Active Ion Chambers. Active ion chambers have a built-in voltage source. The circuits in these chambers can be nonintegrating, registering a pulse for each particle or photon of radiation that interacts with the fill gas, or integrating, measuring the total current produced by the ionizations.

The most popular use of active ionization chambers is as portable instruments to survey for beta and gamma radiation. These instruments come in various forms, shapes, and sizes, but the most common type is the pistol-shaped, portable rate meter known as the "Cutie Pie." Most of these survey instruments are thin-window ionization chambers that have a removable shield over the window end of a cylindrical chamber. When the shield is removed, the instrument responds to both beta and gamma radiations, but when the shield is in place, only the gamma rays can penetrate it to enter the chamber. Therefore, to get a correct beta reading, it is necessary to take two readings, one with the shield on and one with it off. The shield-on reading is then subtracted from the shield-off reading to give the beta reading.

Active ion chambers can also be used to measure alpha particles. A chamber for this purpose is usually designed so that the alpha source can be placed inside the cylindrical chamber. Because the chamber completely surrounds the source, which is emitting particles uniformly in all directions, all of the alpha particles emitted from the source deposit their energy within the chamber. This type of counting system is an illustration of 4π geometry and results in a near-100% counting efficiency.

C. Proportional Counters. A proportional counter is a gas ionization detector that is operated in the proportional region of the pulse height-voltage curve (see Figure 2.2). The anode, or collecting electrode, is a loop of very thin wire (approximately 0.025 mm) that is usually made of fine, clean tungsten with minimal surface irregularities. The cathode, or outer sheath of

the cylindrical chamber, is either metallic or metal- or carbon-coated glass. Detectors operating in the proportional region can have either nonintegrating or integrating circuits.

A mixture of 10% methane and 90% argon, known as P-10 gas, is commonly used as the fill gas in proportional counters. A mixture of 4% isobutylene and 96% helium can also be used. These gases provide stable operation and high gas amplification. Air is rarely used as the fill gas because oxygen easily captures electrons before they reach the anode, reducing gas amplification.

The proportional counters used today are either gas-flow or sealed. In gas-flow proportional counters, gas flows through the counting chamber at a very low rate, removing the degraded gas and any contaminants. Because of the continual replacement of the fill gas, these detectors have a long life. Sealed proportional counters have a finite life because the fill gas, which is sealed inside the counting chamber, degrades over time as incoming radiations interact with it. However, the chamber can be emptied and completely refilled with new counting gas.

(1) Gas-Flow Proportional Counters. Before a gas-flow proportional counter is operated, residual air and contaminants must be removed with a brief, large flow of counting gas. This process is called purging. The chamber of a simple gas-flow proportional chamber is hemispherical or sometimes cylindrical. The radiation source is typically positioned at the bottom of a hemispherical chamber or in the middle of a cylindrical chamber. If the source is suspended in the chamber, 4π geometry is achieved. If the source is positioned at the bottom of the chamber, the device is referred to as a 2π counter.

Windowless gas-flow counters are used to count alpha and beta particles. Because alpha particles have a much higher specific ionization than beta particles (they form many more ion pairs per path length as they move through the fill gas), the large pulses of electronic charge that result from alpha interactions with the fill gas can be electronically distinguished from the smaller beta pulses by adjusting the operating voltage. If the count rate versus the operating voltage is plotted, two plateaus are observed (see

Figure 2.3). At low voltages, only the alpha particles produce pulses because they are more energetic and more highly ionizing than the beta particles. This portion of the curve is called the alpha plateau. If the applied voltage is increased past the alpha plateau, the counting rate begins to increase as gas amplification is caused by increasing numbers of beta particles. After a transition region, another plateau is reached that represents the pulse created by alpha and beta particles together. This plateau is often referred to as the beta plateau. Because beta particles vary widely in their energies, the beta plateau is not as flat as the alpha plateau.

Alpha particles on surfaces can be detected using a specially designed gas-flow proportional counter. The detector is flat and has a window made of aluminized mylar. The counting gas is frequently propane, which is attached to the counter in small, interchangeable metal bottles. This survey instrument is especially useful in areas where alpha surveys are required and gamma radiation levels are high (50 to 500 mR/hr), because it can discriminate against the smaller pulses produced by gamma rays.

(2) Sealed Proportional Counters. A specially designed sealed proportional counter can be used to detect and measure low-energy (thermal) neutrons. Neutrons do not interact directly with the orbital electrons of the

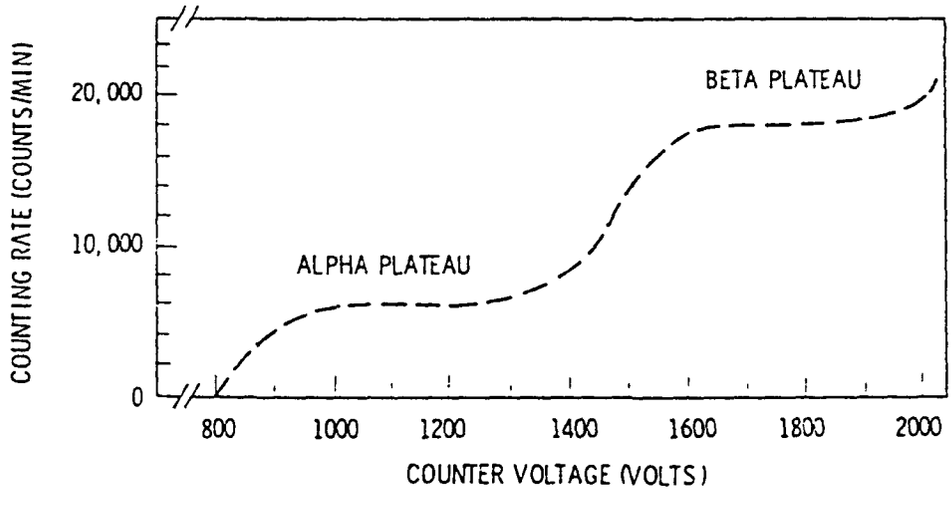


FIGURE 2.3. Plateaus for Typical Proportional Counter

fill gas (they are not directly ionizing radiation--see Chapter 1). Therefore, the detection and measurement of neutrons relies on the interaction of the neutrons with some material capable of causing ionizations. The boron trifluoride (BF_3) gas proportional counter is the most commonly used instrument for this purpose. Low-energy neutrons interact with the boron to form alpha particles, which can then ionize the gas. The BF_3 counter can also be used to measure high-energy (fast) neutrons. For this, the chamber is wrapped in polyethylene, paraffin, or some other hydrogen-containing material that slows down (reduces the energy of) the incident neutrons. These instruments, often referred to as rem meters, have the advantage of being insensitive to most other types of radiation. The small pulses produced by gamma rays can be discriminated out electronically.

D. Geiger-Mueller Counters. Geiger-Mueller (GM) counters are gas ionization detectors designed to operate in the Geiger region of the curve in Figure 2.2. They can be used as pulse counters in the laboratory or as portable survey instruments to detect alpha, beta, and gamma radiation. However, they cannot be used to distinguish between the different types of radiation because all of the pulses produced in the Geiger region of the pulse height-voltage curve are the same size.

The detector itself is a stainless-steel tube that contains the fill gas (usually argon) and the anode and that may have an end or side window. Pulses are electronically transmitted to a counter or a meter, and the readout is generally given in cpm. Some GM instruments are designed to read out in mR/hr to R/hr in response to gamma rays with energies between 60 keV and 1.5 MeV. However, these instruments should not be used as dose rate or exposure rate meters because they produce pulses of the same size regardless of the energy of the phtons causing the ionization. True dose rate meters give a response that is related to the energy of the photons.

Wall and window thicknesses, which are expressed in mg/cm^2,(a) range from 30 mg/cm^2 (for counting gamma rays and high-energy beta particles) down to 0.4 to 1.4 mg/cm^2 (for counting alpha particles and low-energy beta

(a) Thickness (mg/cm^2) = density of the material (mg/cm^3) x linear thickness (cm).

particles). One of the more popular GM survey meters uses a tube (10 cm long and 2 cm in diameter) encased in a stainless-steel housing that contains a window. The window can be opened to admit beta particles and gamma rays, or closed to admit only gamma rays. Thus, the beta contribution to the radiation field can be determined with this instrument.

For monitoring alpha and beta radiation, a "pancake" GM tube is used. The detector is a flat, round cylinder with a large window that is approximately 5 cm in diameter and 16 cm^2 in total areas. The thickness of the window is 1.4 to 2.0 mg/cm^2. The detector is sensitive to alpha radiation with energies above 3 MeV and to beta radiation with energies above 40 keV. In addition, the detector has a shield (usually made of tungsten) over all surfaces except at the window location, to reduce the influence of gamma radiation. To protect the thin window, a wire screen is sometimes provided.

Portable GM survey meters can be equipped with either a head set containing ear phones, or a speaker attached to the instrument case. Each time a pulse is recorded in the counting circuit, a click is heard. These devices are extremely useful in surveying for radiation because their response is much faster than the meter indication. The audible circuit is separate from the meter circuit and does not fail even if the device saturates and the meter indicates zero.

Geiger-Mueller counters are probably the most widely used and versatile instruments for detecting radiation. They are inexpensive, easy to operate, sensitive, and reliable. However, their use in or near very high radiation fields requires caution because most counters saturate in such a field. The incident radiation enters the sensitive volume of the tube at such a rate that the tube is in a state of continuous discharge, and the count rate circuit fails to function properly. As a result, the meter begins to respond but then falls off and reads near zero rather than off the high end of the scale. A person entering a very high radiation area might not realize it because the GM had failed.

2.2.2 Scintillation Detectors

Shortly after x rays were discovered, researchers found that certain materials fluoresce, or emit visible light, when struck by radiation. These

materials are referred to as phosphors, or scintillators. Scintillation detectors were among the earliest instruments for detecting and measuring ionizing radiation and they are still widely used today.

A. Principles of Operation. As radiation enters and passes through a phosphor, it gives up its energy to electrons in the phosphor by both ionization and excitation. Excited electrons move into defects, or gaps, in the atomic structure of the phosphor, called traps. When the electrons escape from the traps to return to lower energy levels, the excess energy is released in the form of visible light. This process is called scintillation, and the light flashes produced are called scintillations.

The light flashes generated in the phosphor can be detected and related to the incident radiation by means of a photomultiplier tube, which is a combination of a photocathode and an electron multiplier. A photocathode converts flashes of light (light photons) into electrons by the photoelectric effect (see Chapter 1). An electron multiplier multiplies the number of electrons using a series of electrodes, called dynodes, which are positively charged. The electrons from the photocathode are accelerated to the first dynode by the application of enough voltage to cause multiple emission of secondary electrons at the first dynode. The secondary electrons are then accelerated to subsequent dynodes, resulting in further multiplications. The typical voltage between each multiplying stage is 50 to 250 V, with each dynode having a more positive voltage than the preceding one. After the last multiplying stage, the electrons are collected at the anode of the photomultiplier tube and fed to an external circuit in the form of a pulse. Photomultiplier tubes typically have a gain, or multiplication, of 10^6. That is, the number of electrons released by the photocathode is multiplied a million times by the time all of the electrons reach the last dynode.

The output current from the photomultiplier tube is then detected and analyzed by the electronic circuit. The extent of the electronic circuitry depends upon the application of the system. A simple circuit, used simply to detect radiation, consists of a battery-operated power supply and an amplifier with a pulse shaper and a rate meter. However, when the device is used for analyzing the energies of the photons emitted by a radioactive material, the

circuit includes a pulse height analyzer, a scaler, and other equipment. A pulse height analyzer sorts the detector signals, or pulses, by size and stores them in appropriate pulse height channels. The size of a detector signal, and thus the channel to which it is assigned, corresponds to the energy of the incident photon.

A single-channel analyzer can analyze only one channel at a time; that is, it can count the number of pulses within a size limit that is manually set (using upper- and lower-level discriminators) on the face of the analyzer. If, for example, the lower-level discriminator is set to reject pulses below 50 kV and the upper-level discriminator is set to reject pulses above 60 kV, only those pulses within the 50- to 60-kV range will be counted. By starting at the lower end of the scale and going upward, an operator can identify which channels have the greatest number of counts, or peaks. Each peak corresponds to photons of a specific energy, which in turn correspond to specific radionuclides. This process is called spectrometry.

A multichannel analyzer has up to several hundred or several thousand single-channel analyzers automatically sorting pulses into specific channels. The data that is accumulated is displayed as a plot with channel number (or photon energy) on the x axis versus the number of counts in a specific channel on the y axis. This plot is called a spectrum. Display modes include oscilloscope screens, x-y plotters, and electric typewriters, which type out channel numbers versus counts. Because each radionuclide has its own distinct spectrum, spectrometry can be used to identify unknown radionuclides.

B. Inorganic Scintillators. Inorganic scintillators are inorganic (not carbon-containing) salts that form regular crystalline lattices. These lattices contain small amounts of impurities that activate the scintillation process (that is, they cause the crystal to emit light when it is exposed to radiation).

Crystals of the alkali halides (e.g., sodium iodide) are the most widely used class of scintillators. Sodium iodide (NaI) is a dense material with which gamma rays interact readily. Crystals of this material are activated for scintillation by the deliberate inclusion of a trace amount of thallium (Tl). These crystals, which can be used to detect gamma and x radiation, can

be produced in a solid cylinder or shaped like a well. The well shape is formed from a crystal with a hole drilled part way into it; small vials or cylindrical samples that are placed in the well are, in effect, surrounded by the crystal, a configuration that results in the detection of most of the emitted radiation.

Sodium iodide crystals are very effective for high-efficiency analysis of gamma-ray spectra. However, these crystals have a relatively poor energy resolution; that is, they cannot easily distinguish between, or separate, photon peaks of slightly different sizes. They are therefore of limited use in distinguishing between radionuclides that emit gamma rays of very similar energies.

Zinc sulfide (ZnS), another inorganic salt, is activated for scintillation by the inclusion of silver (Ag) and is used to detect and measure heavy charged particles, such as alpha particles. A zinc sulfide crystal must be about 20 μm thick in order to detect alpha particles. If the material is thicker or thinner than this, its detection efficiency decreases. In portable alpha survey meters, the zinc sulfide can be applied to the back of a thin window or sometimes painted right on the face of the photomultiplier itself.

When large areas or large volumes of a scintillator are needed, as in whole-body counters, the use of inorganic crystals involves high cost and considerable handling problems because the crystals must be protected from thermal and mechanical shock. These problems can be minimized by the use of organic scintillating materials.

C. Organic Scintillators. Organic scintillators contain carbon, which combines readily with hydrogen and oxygen. These scintillators have a low atomic number and a relatively low density, which makes them suitable for beta counting and, in the case of liquid organics, for alpha counting (the density is too low for high-efficiency counting of gamma rays). Organic scintillators can take the form of solid crystals, liquids, or plastics because the scintillation process arises from a transition in the energy level of a single molecule, and the transition does not depend on the physical state of the scintillator material.

(1) Organic Crystals. The two most common organic crystalline scintillators are anthracene ($C_{14}H_{10}$) and stilbene ($C_{14}H_{14}$). Anthracene has the highest efficiency for light output of any organic scintillator, but both materials are fragile and difficult to obtain in large sizes. They can be used to detect high-energy beta particles, but low-energy betas are either self-absorbed or absorbed by the surroundings before they can interact with the crystal. To overcome this problem, liquid organics can be used.

(2) Liquid Organic Scintillators. Liquid scintillators are made by dissolving an organic scintillator material, called the solute, in an organic solvent. The radioactive source, or sample, is then dissolved in the solution. Because all the radiations emitted by the sample must pass through some portion of the scintillator solution, counting efficiencies can approach 100%. This method is particularly advantageous for counting low-energy beta emitters, such as ^{3}H and ^{14}C, and can also be used for alpha emitters.

The scintillator solution, which is often called a cocktail, consists of the radioactive sample, the organic solvent, a primary scintillator solute (primary fluor), and sometimes a secondary solute (secondary fluor) and a solubilizing agent (diluent). The solvent, which is often toluene, xylene, or dioxane, absorbs most of the energy of the beta particles through particle interactions (see Chapter 1) and transfers it to the primary fluor. The primary fluor is made up of large organic molecules, such as p-terphenyl or PPO (chemical name: 2,5-diphenyloxazole), that scintillate after they have received the excitation energy from the solvent. The concentration of the primary fluor in the cocktail is usually about 1%. The secondary fluor absorbs the light emitted by the primary fluor and re-emits it at a somewhat longer wavelength, which is closer to the wavelength needed for optimum operation of the photomultiplier tube. A diluent such as a hydrocarbon, ether, or alcohol may be added to the cocktail if the radioactive sample does not readily dissolve in the solvent.

Although diluents favorably change the character of the solvent, they also decrease the counting efficiency by interfering with the transmission of light to the photomultiplier, as does the introduction of the radioactive sample itself. This interference, known as quenching, may limit the amount of

a radioactive sample that can be effectively incorporated into the solution. Examples of diluents that are effective but that have a strong quenching action are phenols, amines, aldehydes, and nitro- and iodo-compounds (compounds containing NO_2 or iodine), as well as colored substances. All modern instruments for liquid scintillation counting have electronic circuitry to assist in estimating the degree of correction needed to account for quenching.

After a cocktail is prepared, it is enclosed in a glass or plastic vial. Glass vials should have a low potassium content to reduce the background counts produced by naturally occurring ^{40}K, which is radioactive (it emits beta particles). To further reduce the ^{40}K background, glass vials should be very thin (and should therefore be handled carefully). Plastic vials are popular because plastic contains no potassium, and the vials therefore have a lower radioactive background than glass vials. They also have a slightly higher efficiency for ^{3}H counting. The disadvantages of plastic vials are that they are permeable to toluene, a commonly used solvent; therefore, counting rooms or laboratories in which plastic vials are used should be well ventilated. Some plastics also swell with time, which may preclude counting a sample again at a later date.

Vials containing the cocktail are placed in a lightproof enclosure containing one or more photomultiplier tubes. Quenching effects, and the fact that this counting method typically involves low-energy radiations, may produce pulses that correspond to no more than a few electrons in the photomultiplier tube. Noise (pulses arising from sources other than the radioactive sample) may also interfere with accurate and reproducible counting of the sample. Significant sources of noise include photoelectrons that are generated by heat production within the photocathode, and chemiluminescence, or additional scintillations caused by chemical reactions in the cocktail.

Sources of noise can produce extraneous photoelectrons that are included in the pulse and are difficult to discriminate against when the primary pulse (from the radioactive sample) is produced by only a few photoelectrons. The practical counting efficiency of a liquid scintillation counter is determined by its ability to distinguish between the primary pulse and the noise.

The counting interference caused by noise from the photomultiplier tube can be eliminated by using two photomultiplier tubes placed on different sides of the scintillator vial, and counting only those pulses that are observed at the same time by both tubes. Pulses arising from only one tube, which would be noise, are not counted.

Because of the efficiency and uniform geometry of liquid scintillation counting, its most common application with respect to alpha particles is for counting low-activity environmental samples. The relatively high-energy alphas have a much higher light output than the low-energy betas, and noise interference is not a problem. The energy resolution, however, is poor compared with the resolution that can be achieved using the semiconductor diode detectors discussed below.

(3) Plastic Scintillators. Plastic scintillators are solid organic solutions that are sometimes used for beta counting. They can be made much larger than organic crystal scintillators and are easily handled and shaped. A disadvantage that limits their use, however, is that they have much lower counting efficiencies than organic crystals of equal size.

2.2.3 Semiconductor Detectors

A semiconductor, or solid-state detector, is a solid crystalline material that has an electrical conductivity between that of insulators (nonconducting) and good conductors such as metals. The electrical conductivity of the semiconductor changes, however, when it is exposed to radiation, and the degree of change is related to the radiation exposure. The semiconductor detector operates on the same principle as the gas ionization detector; that is, ionizations produced within the sensitive volume of the detector cause a voltage pulse within the detector, which is then amplified and counted on a scaler system. In the semiconductor detector, a solid replaces the fill gas of the gas ionization detector, and the phenomenon of gas amplification (the production of secondary ions) does not occur. However, the voltage pulse from a gas-filled detector is smaller than the pulse from a semiconductor detector because the solid material in a semiconductor produces 10 times as many primary ion pairs as does the gas in a gas-filled chamber.

The atoms of semiconductor materials usually have four electrons in their outermost shell (i.e., four valence electrons); examples of these materials are germanium and silicon crystals. In the production of semiconductor detectors, other elements are added to the semiconductor materials. These elements are called impurities because the semiconductor crystal is no longer pure after they are added. The introduction of impurities such as lithium, aluminum, or boron, which have three valence electrons, produces a total of seven valence electrons. An atom with eight valence electrons is very stable. A material with a configuration of seven valence electrons has a space, or hole; because it wants to accept one more electron, it is called a positive or p-type material. If an impurity with five valence electrons, such as arsenic, is added to the semiconductor material, the result is nine valence electrons, or one more than the stable configuration of eight. In this case, the resulting material wants to give up its extra electron to become stable and is called a negative or n-type material, or an electron donor.

When n-type and p-type materials are combined, the extra electrons in the n-type materials combine with the holes in the p-type materials, creating electron-hole pairs and forming an electrical potential across the junction. This small potential difference is then enhanced by applying an external electric field to oppose the natural motion of the electrons and holes. This "reverse bias" is applied by connecting the positive pole of a battery to the n side and the negative pole to the p side. The depletion layer that is thus set up is the sensitive volume of the detector (see Figure 2.4). When a charged particle (alpha or beta particle) loses its energy within this depletion region, electrons are released and are attracted to the positive electrode. This movement produces a current pulse that can then be amplified and electronically measured with considerable accuracy. The diffused p-n junction detector is not useful for detecting photons because the depletion layer is only a few millimeters deep.

The germanium-lithium detector, or GeLi detector (pronounced "jelly"), and the silicon-lithium detector, or SiLi detector (pronounced "silly") are two examples of semiconductor detectors that operate on the same principle as diffused junction detectors but that have a much larger sensitive volume,

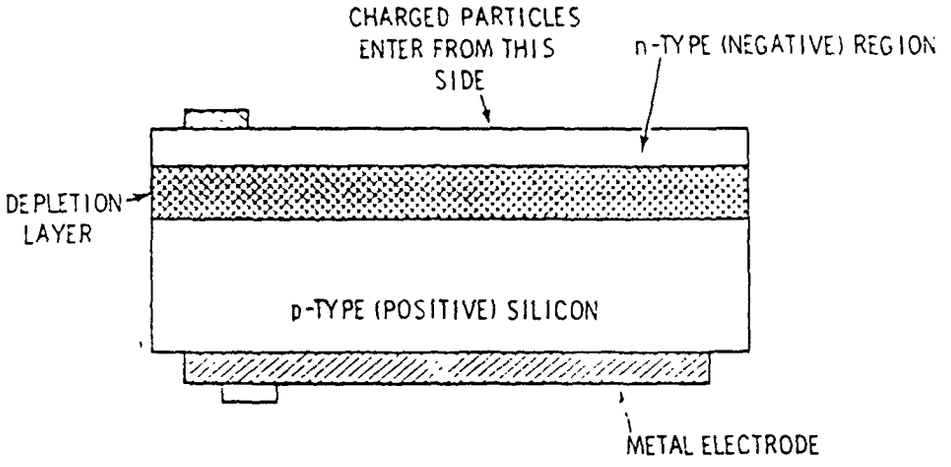


FIGURE 2.4. Diffused p-n Junction Detector

which makes them suitable for gamma counting. Lithium is drifted into a p-type germanium or silicon crystal by heating the crystal and applying a reverse bias across it. A wide layer, called the intrinsic or compensated layer, is formed where the lithium, which denotes one valence electron, exactly compensates the p-type material. This is the sensitive volume of the detector, and thicknesses of more than 1 cm can be achieved. GeLi detectors must be kept cold using liquid nitrogen (the detectors are designed to hold this coolant) because the lithium tends to "redrift" if the crystal is allowed to warm up to room temperature. SiLi detectors can be operated at room temperature but they have a relatively low counting efficiency compared with GeLi detectors because of their lower density.

Semiconductor detectors of the GeLi and SiLi type are most frequently used for gamma-ray spectroscopy. They have the ability to differentiate, with a high degree of resolution, among various energy peaks. Semiconductor detectors have a lower counting efficiency than sodium iodide crystals. However, their energy resolution is far better than that of sodium iodide detectors because of the long sequence of events that takes place in the sodium iodide detector to convert the radiation to light and then to an electrical signal. Semiconductors detectors are relatively expensive, and because of their fragile nature and design, they cannot be decontaminated.

Section 2.3 CALIBRATION OF INSTRUMENTS

The performance and accuracy of radiation detection and measurement instruments depend on the design characteristics of each instrument and on proper calibration and reliability checks made during its use. Calibration is the evaluation of an instrument's response to the type and energy of radiation it was designed to detect or measure, as well as to any other radiation that may be present and contribute to the radiation reading. Calibration also involves examination of the instrument's electrical and mechanical integrity. The AN/UDM-2 calibrator, which is intended to calibrate tactical instruments, should not be used to calibrate instruments used for radiation safety.

The extent of a radiological calibration operation at an installation depends largely on the requirements of the radiation protection organization. The funds available to a radiation protection office may limit the availability of facilities, calibration sources, and technical staff for radiological calibrations. If, for any of these reasons, an office is unable to provide a proper calibration program, the RPO should seek outside assistance from another command or from a commercial calibration service, rather than permitting the quality of the calibration services provided to be compromised.

2.3.1 Calibration Sources

The foundation of a good calibration program is the use of standard radiation sources that have well-defined properties and are traceable to the National Bureau of Standards (NBS). Such sources can be obtained in three ways:

1. They can be purchased from a vendor.
2. In certain cases, the installation's own sources (e.g., small neutron sources) can be shipped to NBS for direct calibration. Because of the time, cost, and complication in transportation, this procedure is not frequently used.
3. An intercomparison transfer standard can be obtained by sending an ionization chamber to NBS for direct calibration with their primary standard. The NBS "certifies" the calibration and accuracy of the instrument as a

"secondary standard." The chamber, which is referred to as directly traceable to NBS, is then used to calibrate radiation sources at its home facility, and the calibrated sources are used to calibrate the facility's instruments. Sources and instruments calibrated against a secondary standard are assigned an allowable error that is larger than that of the secondary standard.

The types of radioactive sources used to calibrate instruments and dosimeters vary depending upon the needs of the radiation protection program. To ensure that the proper sources are being selected, one of the following standards documents should be referred to when calibration facilities are being designed and when calibration frequencies and the types and strengths of radionuclides suitable for the instrument calibration process are being determined: American National Standards Institute (ANSI) Standards N323-1978, N42.3-1949, and N13.11-1978.

As part of a routine quality assurance program (see Chapter 15), the activity of sources should be checked periodically. Verifying the activity of a source that will be used as a radiation standard requires absolute counting methods and the use of accurate detectors with known counting efficiencies. Sources that emit alpha and beta particles can be verified by placing the source in a gas-flow proportional counter, thus providing 4π geometry for the counting. A well-type ionization chamber (in which the source is completely surrounded by the detector) is frequently used for standardizing short-lived gamma-ray sources.

2.3.2 Calibration Facilities

Radiation calibration facilities should be located where the radiation background is low, the radiation field is well known, and conditions are stable. Facilities should be constructed of a material that minimizes scatter and should be large enough to allow for good geometry when calibrating instruments that measure photons and neutrons. General criteria for facility design are discussed in Chapter 8.

2.5.3 Instrument Characteristics That Affect Calibration and Calibration Frequency

Under certain conditions, the ability of health physics instrumentation to measure radiation accurately is limited by the equipment and its operating characteristics. Some of these conditions create a relatively small error while others could, if not recognized, put the radiation protection staff and radiation workers in jeopardy. For example, as discussed earlier, a GM detector saturates and reads zero in a high-radiation field. As another example, a standard ionization chamber often produces a false reading when used around a source with a three-phase alternating current (e.g., a three-phase x-ray machine). An ionization chamber that is compensated for radio frequency must be used to avoid this problem.

The size of a source and the distance between the source and the instrument also affect measurement accuracy. If the source is not a point source and the distance between the source and the detector varies, corrections for source size and source-to-detector distance need to be developed and used. Curves illustrating these corrections are supplied by some instrument manufacturers upon request. If they are not available, they can be generated by a qualified health physicist. An effective calibration program should include the assignment of proper correction factors for each instrument type used in the radiation protection program. The correction factors should be based on the range of sizes of radiation fields and the source-to-detector configurations commonly used for each instrument type.

One of the primary factors affecting the accuracy of any measurement (either in calibrations or in field use) is the position of the source relative to the position of the sensitive volume of the detector, that is, whether the entire sensitive volume is being irradiated. It it is not, then geometry correction factors must be applied to the instrument readings. Part of the contribution to geometry errors is the difference in the radiation field during actual use and during calibration. Exposure rate instruments are usually calibrated in a radiation field of nearly uniform intensity. However, in many actual field situations, these detectors are used in nonuniform fields (i.e., close to a source) or are not entirely exposed. In either of these

actual-use situations, the response of the instrument can be low by a factor of 50. Under normal conditions, underestimation factors of 10 and above may occur.

Limitations associated with the ability of an instrument to accurately measure both high and low radiation energies are known as the energy dependence of the instrument. Energy dependence can be caused by many factors. If high-energy radiation causes photoelectrons to be emitted from the detector wall and the instrument reads them, then the total instrument reading is high. If low-energy radiation is absorbed by the detector wall, then the instrument reads low. The energy dependence of an instrument can be evaluated by exposing it to identical exposure rates from NBS-traceable sources that emit different photon energies. An instrument correction factor for a given energy can be calculated by dividing the measured exposure rate by the true exposure rate. Curves of correction factors versus radiation energy are usually available from the instrument manufacturer.

If the measurements made with an instrument vary significantly when the instrument's position is rotated through a radiation field, the instrument is considered to have angular dependence. Angular dependence may cause serious discrepancies in instrument readings, particularly if the instrument is not properly positioned in the radiation field. If angular dependence appears to be a problem for an instrument, the instrument should be calibrated at 15° increments in a full 360° plane perpendicular to the source.

During the calibration process, portable survey meters should be tested to ensure that they respond only to the type of radiation they are designed to detect. That is, alpha or neutron monitors should be verified to be insensitive to photon radiation. Similarly, photon monitors such as ionization chambers should be insensitive to other forms of penetrating radiation such as neutrons. Also, scintillation detectors should be closely checked with a high-intensity light source to verify the absence of light leaks that could produce a false count.

The frequency and extent of routine instrument calibrations are governed by many factors, including the rate at which components in each instrument age or become damaged. The ANSI standards listed earlier in this section describe

the process used in establishing calibrations frequencies. They also describe procedures for simple constancy checks to be used between calibrations.

Section 2.4 FACTORS THAT AFFECT THE SELECTION AND USE OF RADIATION-MONITORING INSTRUMENTS

Individuals who are selecting instruments for radiation monitoring should know the purpose for which the instrument will be used, the degree of accuracy needed, the type of radiation to be detected or measured, the energy of the radiation, the source form (whether solid, liquid, or gaseous), and the intensity and uniformity of the field to be measured. Knowledge of these parameters and of the limitations of various types of radiation detection and measurement devices will ensure the selection of the best instrument for each application. Each facility should have on hand a list of available radiation survey instruments, including the types of instruments available and, for each type, the number available, the radiation it detects, its sensitivity and range, the thickness of any windows, and the general use it was designed for. This listing, together with the calibration date on each instrument, can assist in the selection of the best available instrument for each situation.

Several of the factors that should be considered in the selection and use of radiation monitoring instruments are discussed briefly below.

2.4.1 Detection Versus Measurement

The purpose for which an instrument will be used and the accuracy required dictate which instrument should be selected. An instrument designed only for detection should not be used to measure radiation dose rate or exposure rate.

2.4.2 Type of Radiation

A principle factor in the selection of an instrument is the type of radiation to be detected or measured. For example, a specially designed GM counter can detect alpha, beta, and gamma radiation, but a portable alpha counter that is property calibrated should not measure gamma radiation. A standard ion chamber measures beta and gamma radiation but does not detect neutrons. A rem meter detects neutrons but does not detect external alpha particles. If an

instrument is sensitive to several types of radiation, either mechanical devices (shields or filters) or electronic discriminators can be used to distinguish between the various types of radiation.

2.4.3 Radiation Energy and Instrument Energy Dependence

The instrument selected must be capable of measuring the radiation in question. Most instruments are designed to respond to a wide energy spectrum (e.g., 150 eV to 3 MeV). However, a GM counter or an ionization chamber cannot monitor a substance such as tritium; the weak beta radiation (18.6 keV) emitted by tritium requires measurement by liquid scintillation methods or special windowless counters.

The most reliable method of determining whether an instrument operates accurately in the energy range of a specific radionuclide is to attempt to calibrate it against the radionuclide. Because each instrument will respond differently, it is useful to provide calibration curves, especially for beta calibration.

2.4.4 Nonuniform Fields

The quantification of radiation exposure rates from nonuniform fields may require special calculations and the use of correction factors. Nonuniform fields can be expected when measuring 1) dose rates at the surfaces of materials, 2) plane circular sources that are smaller than the diameter of the detection chamber, 3) surface-contaminated cylinders such as rods, pipes, and cables, and 4) radiation beams smaller than the diameter of the detection chamber. Correction factors for these special conditions may range from 1 to over 100 depending upon the condition, the type and energy of the radiation, and the particular instrument being used. Special studies and consultation with experienced health physicists may be needed.

2.4.5 Angular Dependence

If the direction from which radiation arrives at an instrument differs significantly from the directions used in the calibration field, correction may be necessary. Instrument response may be extremely directional for some instruments and radiations; for others, directional effects may be relatively

insignificant. Radiation protection personnel should be alert to the potential for directional response and should provide corrections if necessary.

2.4.6 Calibration

The selection of an instrument should be based on the instrument's demonstrated capabilities, including its ability to be calibrated. Before any instrument is placed in field service, a thorough calibration and operational check should be performed, including verifying that batteries are fully charged.

2.4.7 Unwanted Response

A portable survey instrument's response to stimuli other than the radiation it is supposed to measure constitutes what is called unwanted response. Instruments may respond to heat, light, radio frequency radiation, and mechanical shock. When used near operating equipment, particularly vehicles with generators or alternators, survey instruments may respond to induced electrical fields. In some instances, components of an instrument (other than the detector itself) may respond to radiation, causing measurement errors. This response is called extracameral sensitivity.

Section 2.5 TYPES OF RADIATION-MONITORING INSTRUMENTS

Radiation-monitoring instruments are generally classed in one of four areas, depending upon their particular application: 1) portable survey meters; 2) laboratory counting instruments; 3) air-monitoring equipment; and 4) other fixed instruments. The uses of these four classes are discussed below.

2.5.1 Portable Survey Meters

Portable survey meters are instruments small and light enough to carry from place to place. Some are used for detecting radiation and radioactive materials, and others for quantitatively measuring radiation levels. In both cases, some degree of accuracy and precision must be sacrificed to provide the light weight, small size, and ruggedness necessary for portable instruments.

For measurements of very low levels of activity, such as many measurements of environmental samples, or for measurements requiring a high level of accuracy, laboratory conditions and laboratory counting equipment should be used.

A. Portable Detection Instruments. Portable survey meters for detecting radiation or radioactive materials (e.g., GM counters) should be selected based upon the type, energy, and intensity of the radiation to be encountered. Most portable detection instruments are count rate instruments. They frequently incorporate a meter display and an aural output, using earphones or a speaker or both. For surveys of areas, equipment, or personnel, the aural output should be used if it is available because the aural circuitry of these instruments responds more rapidly to radiation increases than does the meter circuitry. Small radioactive spots or beams can be more readily detected by sound than by observing the meter movement. In addition, the aural circuitry does not fail if the device saturates and the meter indicates zero.

Even though portable survey instruments are relatively small and rugged, they must be handled and used carefully to prevent damaging them while still effectively detecting radioactivity. Most instrument detectors or probes have a very thin window or covering over the sensitive detector area or the probe. Puncturing this window may cause an implosion in some detectors (GM tubes) or light leaks that lead to erratic response in others (scintillation detectors). For this reason, most detectors have a screen or grid protector over the window. This screen helps protect the window, but it also reduces the sensitive window area.

B. Portable Measurement Instruments. Portable survey instruments for measuring exposure or exposure rate are generally small, portable ionization chambers. Like portable detection instruments, portable measurement instruments are selected based on the type, energy, and intensity of the radiation to be measured, and the degree of accuracy needed. The technical specifications of an instrument should be reviewed to determine whether it is appropriate for a particular use. In addition, the methods and radioisotopes used to calibrate the instrument, the calibration curves, and the necessary correction factors all affect the suitability of an instrument. Table 2.1 summarizes the kinds of portable survey instruments available for both detection and measurement of radiation.

TABLE 2.1. Portable Survey Instruments

Instrument	Range of Counting Rate	Radiations Detected	Typical Uses
Air proportional counter with probe	0 to 100,000 dpm over 100 cm^2	α, photons	Surfaces, hands, clothing
Gas-flow proportional counter with probe	0 to 100,000 dpm over 100 cm^2	α, photons	Surfaces, hands, clothing
Portable scintillation counter with probe	0 to 100,000 dpm over 100 cm^2	α, β, γ	Surfaces, hands, clothing
Portable count rate meter (thin-window GM counter)	0 to 1,000,000 cpm	β, γ (α-sensitive with appropriate detector probe)	Surfaces, hands clothing
Portable count rate meter (BF_3 tube)	0 to 500,000 cpm	Neutron	Area, beams

2.5.2 Laboratory Counting Instruments

Field assessments of radioactive contamination are generally qualitative rather than quantitative, and even when portable measurement instruments are used, they cannot measure levels of radioactivity as low as the levels laboratory counters can measure. To precisely quantify levels of activity, laboratory conditions and laboratory counting instruments are required. Laboratory counters may include GM tube detectors in heavily shielded chambers with scaler readouts, scintillation counters, proportional counters, semiconductor detectors, and multichannel spectrometers with computer analysis capabilities. The counter selected for a specific application depends on the type, energy, and level of radiation to be measured, and on the accuracy and precision required. Certain laboratory counting instruments (e.g., NaI crystals) can be used to determine the particular radionuclides in a sample as well as to measure the activity of each radionuclide.

Table 2.2 lists some of the available laboratory counters and their sensitivities, as documented in Report 57 of the National Council on Radiation Protection and Measurements (NCRP 1978). Most samples analyzed as part of radiation protection programs contain very small amounts of activity. The

TABLE 2.2. Laboratory Counters[a]

Instrument	Radiations Detected	Sample Sensitivity (μCi)
GM counter	β	10^{-4}
	γ	10^{-2}
Gas-flow proportional counter	β	10^{-5}
Gamma scintillation counter		
Well	γ	5×10^{-5}
Probe		10^{-2}
Liquid scintillation counter	β	10^{-5}
Alpha scintillation counter	α	5×10^{-4}
Semiconductor	α	<1 dpm
	γ	5×10^{-5}

(a) NCRP 1978.

counting instruments used should therefore be highly sensitive, and the effect of natural background radiation levels on the detectors should be kept as low as possible. Facilities used for laboratory counting should be located in areas of low background. Room or detector shielding may be required to reduce instrument background levels.

Extra precautions should be taken to assure that laboratory counters are not contaminated by the samples being counted. Because these instruments are highly sensitive to radiation, very small amounts of contamination bias their counting results. Frequent verification of background counting levels is necessary. In counters that have reusable sample holders, or planchets, the empty sample holders should be counted periodically to ensure that they have not become contaminated.

2.5.3 Air-Monitoring Equipment

Instruments used to monitor gaseous or particulate radioactivity in air should be highly sensitive because the amount of activity to be detected or measured is usually small. The type of equipment used depends upon the type, energy, and half-life of the radiation to be detected, whether it is in gaseous or particulate form, and whether sampling or monitoring is to be done.

Air sampling and air monitoring are both performed to determine the presence or amount of radioactivity in air. An air sampler either collects the air (for sampling radioactive gases) or pulls the air through a filter (for sampling radioactive particulates in air). In either case, the sample is removed for later analysis. An air monitor, on the other hand, analyzes the air in question as it is collected.

A. Air Samplers. Air sampling is performed in the following circumstances: when the probability for airborne contamination is low; as part of a long-term environmental program; where a high level of background radiation or excessive contamination prohibits air monitoring; when the consequences of airborne contamination are known not to be of immediate concern to the personnel in the area; as a check on the monitoring program; where great sensitivity for radionuclide identification is required; and where surrounding conditions (e.g., potentially explosive atmospheres) do not allow the use of monitoring equipment. The advantage of an air-sampling system is that the sample can be taken to an area of low background radiation, where it can be evaluated or held for the decay of natural radioactivity, if desired, and where various sample-processing steps can be performed and sophisticated equipment can be used to analyze the sample.

A general-purpose air-sampling system consists of a collector (filter or sorbent), collector holder, flow-measuring device, flow rate controller, and air mover. Some gas-sampling systems use evacuated flasks, cold condensate traps, or specially treated traps (e.g., activated charcoal for sampling radon gas). Most sampling systems have the advantage of being small and portable.

In some areas, small battery-operated samplers (lapel samplers) can be carried or worn by individuals to provide an integrated sample of the

contaminants in the individual's breathing zone (the air directly surrounding the face). Fixed samplers can also be selectively located to provide long-term integrated samples, which are useful in establishing the average concentration of contaminants near probable points of release and throughout the work area.

Grab samples are usually high-volume samples collected over a short time (i.e., from 2 to 20 minutes) and used for determining the level of particulate contamination in air. A portable air suction pump containing a filter paper holder is located at the point of interest, and a large volume of air (2 to 100 m^3) is drawn through the filter. The filter is then removed to a counting room or laboratory for rapid analysis. Low-volume air samplers are used in environmental programs because they can be operated continuously for weeks or months at a time. When analyzed, the filters from these samplers indicate the total release from a specific site over a given period.

B. Air Monitors. Air monitoring is performed when the sampling results are needed immediately; when a real-time monitor is required to indicate the need for immediate evacuation of a work area; to provide a continuous reading for trend analysis; to monitor releases to the environment (as in stack monitoring); and to measure immersion doses from gaseous releases.

An air-monitoring system is basically the same as an air-sampling system except that an appropriate counter (e.g., a proportional counter) or other evaluation instrument is placed near the collecting medium (filter paper or sample chamber). Air monitors are often equipped with strip-chart recorders, air activity meters (which indicate, for example, cpm per liter of air), check sources, and visual and audible alarms. The advantage of an air-monitoring system is its continuous and immediate indication of activity levels.

Most air monitors cannot detect low levels of radioactivity; therefore, these monitors are most useful where the potential for large radioactive releases is highest. For example, an alpha air monitor is relatively ineffective for measuring airborne depleted uranium (DU). By the time an alpha monitor detected DU and sounded an alarm, the airborne activity would be several times above acceptable limits.

Some airborne activity, such as low-energy beta particles from tritium, can be measured using a Kanne chamber, an ionization chamber through which the air flows. The beta particles are drawn into the chamber, where the ionization must occur if it is to be detected. However, these chambers are also sensitive to higher-energy background radiation, and some compensation for background is normally required.

C. Principles of Operation. Air sampling and monitoring involve collecting a sample of air or a material removed from the air and determining by analysis what the contaminant is (if that is not already known) and the quantity of it. Accurate determination of the activity in a sample requires accurate measurement of the volume of air sampled. For gaseous samples, this may be as simple as knowing the volume of the chamber in the sampler used. However, a system for sampling particulates requires accurate measurement of 1) the rate at which air flows through a filter medium and 2) the time over which the sample is taken. The system must have an air mover capable of moving the air at the rate desired, a method of ensuring that the air flow is constant for the sampling period, and calibration of the air sampler.

Many variables must be considered in establishing a quantitative air sampler. The type of filter paper or sorbent medium should be selected to effectively remove from the air the contaminants of interest. The collection efficiency of the medium should be established, taking into account the size of the particles collected and the air velocity during collection. Isokinetic sampling of ducts and effluent stacks should be used. This means that the opening of the sampling device should be set perpendicular to the direction of air flow, and the sample flow rate should be adjusted so that the linear air speed into the sampler is the same as that of the approaching air stream. Anisokinetic conditions may cause an over- or underestimation of particulate air concentrations in the air stream. In addition, the representativeness of the sample at the collecting point may be affected by materials becoming deposited on the sampling lines or passages, a condition called plateout. Attention must be given to limiting the length of a sample line, the degree of curvature of bends in the line, and the temperature gradients between the air being sampled and the line.

Instrumentation used to measure the activity of the collected sample is selected based on several factors: whether the instrument is to be used as part of a continuous monitor or whether it is in a counting room or laboratory; the type and energy of the radiation being detected; and the sensitivity required. Geiger-Mueller counters, gas proportional counters, scintillation counters, or semiconductor counters can be used to measure the activity of air samples.

2.5.4 Other Fixed Instruments

In addition to the radiation detection and measurement instruments previously discussed, special-purpose instruments can be used. These instruments include remote area monitors and continuous air monitors.

A. Remote Area Monitors. Remote area monitors (RAMs) are usually GM detectors or ionization chambers used to monitor direct exposures to photon radiation. These monitors are usually permanently positioned and have visual or audible alarms or both. They are often connected to other RAMs in a network, with the results displayed in a central control room. These monitors usually have a variable alarm setting so that the alert level can be altered.

In addition to the alarm function, RAMs may incorporate a continuous recorder so that a historical record of radiation levels is provided and radiological conditions and trends can be followed and evaluated.

B. Continuous Air Monitors. Continuous air monitors (CAMs) are similar to remote area monitors in function, but they always monitor the radioactivity concentrations in air continuously. This type of air monitor can be fixed in place, with sample lines to the instrument from the area being monitored, or it can be semiportable (usually a relatively heavy cart on wheels) and can be moved to the area to be monitored. Depending upon the type of radiation to be measured and whether it is in gaseous or particulate form, CAMS may use GM, gas proportional, semiconductor, or ionization chamber detectors. The complete CAM unit includes an air mover, air flow controls, the appropriate electronics for the detector being used, an alarm, and usually a recorder. Those fixed in place may also be wired for a meter readout, a strip chart recording, and an alarm at some remote or central location.

The factors that affect other air-sampling and air-monitoring systems also affect CAMs. In addition, CAM units can be affected by changes in ambient radiation levels, the fluctuations of unregulated power, and contamination from outside the area being sampled.

To avoid a long-term buildup of radioactivity and dust on filter media, fixed CAMs require frequent filter changes. Other CAM units use a moving filter tape. An advantage of the moving-filter CAM is the capability of providing a delayed counting sequence to allow for the decay of natural background radioactivity. Instruments of this type can be provided with duplicate detectors, one instantaneous and one delayed, and electronic circuitry to allow background compensation and alarm functions for both instantaneous releases and long-term buildups of radioactivity.

Section 2.6. PERSONNEL DOSIMETERS

A radiation dosimeter, loosely defined, is any instrument or system capable of measuring radiation dose. Dosimeters are typically used to provide a quantitative estimation of the radiation dose actually received by personnel. Their response should be reproducible, precise, and accurate, and the instruments should be able to measure all ionizing radiations encountered by personnel. They should be simple and convenient to use, small, easy to handle, and low in cost. Because personnel dosimeters record only the dose they have received, it is extremely important that personnel be trained in their proper use. One type of dosimeter, the pocket ionization chamber or pencil dosimeter, was already discussed in Section 2.2.1. Three other types--photographic film, nuclear track emulsions, and thermoluminescence dosimeters--are discussed below.

2.6.1 Photographic Film

Photographic film is measurably darkened by radiation, and can therefore provide a useful estimation of personnel exposure. The response of photographic film depends on the type, energy, and amount of the radiation reaching the film.

A. Principles of Operation. The sensitivity of film is defined as the amount of darkening produced by a specified radiation exposure. Photographic films, or emulsions, consist of a layer of tiny silver halide crystals embedded in a gelatin matrix. The emulsion is spread across a thin sheet of plastic or glass plates. The thickness of the emulsion can range from 10 to 2000 μm, depending on the sensitivity desired. The thicker the emulsion, the greater the sensitivity of the film.

When ionizing radiation travels through photographic emulsions, the radiation imparts a small amount of energy to the silver halide crystals, causing some of the silver ions to be reduced to free atomic silver. These silver atoms form traps capable of capturing electrons, which can in turn reduce more silver ions and create a microscopic aggregate of silver atoms. These silver aggregates are frequently referred to as latent image centers. Chemical treatment of the film causes the latent image centers to be reduced to metallic silver, which appears to the eye as a blackening of the film. The degree or density of darkening can then be related to radiation exposure.

B. Dosimeter Design. Photographic films are incorporated into the so-called film badge. The modern film badge is designed so that radiation can reach the film either directly through an open window, or through filters. The filters are disks made of metals, such as lead, tin, copper, cadmium, silver, or aluminum, and are used to distinguish between different types and energies of radiation. For example, thin filters of a low-atomic-number (low-Z) material, such as aluminum, can be used to distinguish between gamma rays and high-energy beta particles. Other metallic filters can help identify the contribution of different components of the gamma-ray spectrum. Most film wrappers stop beta particles with an energy less than about 150 keV. Thus, film cannot be used to monitor radiation exposures from low-energy beta emitters such as ^{3}H and ^{14}C.

C. Effects of Environment. Photographic film degrades with age. Under normal conditions, dosimeter films usually last for several months before they begin to deteriorate. However, the latent image centers and the overall response of the film can be adversely affected by environmental conditions. The latent image fades if the film is subjected to high temperatures, high humidity, or oxygen. Of all these influences, relative humidity is the

dominant factor. Film packets should not be used or handled by unqualified personnel. Films should be kept in their lightproof packages to reduce the possibility of light leaking in, which could ruin the film.

D. Processing Techniques. The process used for developing film dosimeters is basically the same as that used for developing medical x-ray films. Specifically, a film is placed first in a developer solution and then in a fixer, which stops the development process by dissolving the unused silver halide crystals. How long the film is left in the developer solution, the amount of agitation of the solution, and the temperature and age of the solution all affect the first step of the process. How long the film is left in the fixer affects the quality and permanence of the image on the film. When the film is removed from the fixer (after approximately 10 minutes), it is washed and then dried at room temperature.

E. Interpretation and Calibration. Once the film has been processed, it is read and interpreted. To reduce the probability of error in the reading of the film, unexposed control films are processed along with the exposed films. Unexposed films produce a density or darkening during processing known as the base fog. By processing control (unexposed) dosimeters along with the exposed dosimeters, it is possible to subtract the degree of darkening of the base fog from the degree of darkening on the exposed dosimeters.

The processed film is analyzed using a densitometer, a device that measures the degree of film darkening. Interpretation of the densitometer reading is then related to exposure, depending on the density value under each of the filters in the badge. Doses should be interpreted only by personnel who are highly skilled in evaluating photographic film. Even with properly designed filters and film badge holders, the accuracy of photographic film is limited because its response is dependent on the radiation energy and the inherent variability in films. In mixed radiation fields (fields that include both high- and low-energy radiation), low energies can result in errors of ±50% to ±200%. However, with properly designed film badges and properly controlled usage, photographic films can achieve an accuracy of ±25% in most personnel dosimetry situations.

Photographic film dosimeters are not absolute devices and therefore must be calibrated against a known source in order to relate the film density to the exposure delivered. The calibration of dosimeters should be performed under carefully controlled laboratory situations using sources traceable to NBS.

2.6.2 Nuclear Track Emulsions

Standard photographic film badges are not designed to respond to neutrons. However, nuclear track emulsion (NTA) film, which is thicker than standard photographic film, can be used to monitor for neutrons. The neutrons reaching the NTA film interact in a variety of ways with the atoms in the emulsion, charged particles are produced, and the charged particles in turn interact with the silver atoms of the NTA film to form tracks that are visible after the film is developed. The tracks can be counted and related to neutron dose.

Nuclear track emulsions are even more sensitive to latent image fading than are the standard films. Therefore, the wearing interval for NTA film dosimeters normally does not exceed 2 months, and 2 weeks is the preferred wearing time in a high-humidity climate. Fading can be reduced and the wearing time increased if the NTA film is sealed into a moisture-proof package in a nitrogen atmosphere.

2.6.3 Thermoluminescence Dosimeters

Some crystals emit light when they are heated after exposure to ionizing radiation; this process, known as thermoluminescence, is similar to the scintillation process described earlier and is the basis for another type of personnel dosimeter.

A. Principles of Operation. The crystals most commonly used in thermoluminescence dosimeters today include lithium fluoride (LiF), calcium fluoride (CaF_2), calcium sulfate ($CaSO_4$), and lithium borate ($Li_2B_4O_7$). When one of these crystals is exposed to ionizing radiation, many of the free electrons within the crystal become excited and are caught in imperfections of the crystal, or traps. The exposed crystal can be stored at room temperature for long periods without a significant number of the electrons escaping from the

traps. However, when the crystal is heated to higher temperatures, the trapped electrons escape and lose their excess energy by the emission of visible light (thermoluminescence). Because the amount of light released from a heated crystal is proportional to the energy or radiation dose absorbed within the crystal, the phenomenon of thermoluminescence can be used in radiation dosimetry. A dosimeter that uses this phenomenon is called a thermoluminescence dosimeter (TLD).

A TLD reader, which has a controlled heating element, is used to determine how much light is emitted during the heating of a dosimeter crystal. The light intensity is plotted as a function of temperature, and the resulting graph is called a glow curve. The glow curve normally has several peaks at various temperatures. The area under any peak can be used as a measure of the dose received by the TLD.

When a TLD has been irradiated and read on a TLD reader, it can be annealed and reused. Annealing is a slow heating process that completely empties the traps and restores the crystal to its original state. After the crystal has been allowed to cool, it is ready to be reused.

B. Advantages and Limitations. The TLD has a wide dose-response range (1 mrad to 10^5 rad) and a very low energy dependence. The most popular TLD material, LiF, has an effective atomic number very close to that of human muscle tissue. Thus, it is considered by most users to respond much as tissue would and is frequently considered "tissue equivalent."

Other advantages of TLDs are that they are very small, quite rugged, and essentially unaffected by environmental variables. Because TLDs show very limited fading (unlike film dosimeters), the wearing interval for the TLD can be a year or longer. The advantage of the longer wearing period is a reduction in the error produced by numerous processings throughout the year. The reported accuracy of most TLDs under controlled laboratory conditions is ±1%. An accuracy of ±10% is fairly easily achieved in the field.

Thermoluminescence dosimeters are essentially unaffected by their orientation in the radiation field and by the rate of exposure. However, the badge

or device that is designed to hold the thermoluminescent material may adversely affect the accuracy of the dosimeter. Therefore, proper badge design is essential in the correct use of TLDs.

A major limitation of TLDs is that, after they have been processed, their exposure information is erased; film, on the other hand, retains the information as a permanent record.

C. Interpretation and Calibration. Interpreting the results of a glow curve produced from an irradiated TLD requires establishing a relationship between the glow curve and a known exposure level. The best procedure is to obtain a large batch of dosimeters with well-matched responses and to run a calibration curve over the exposure range of interest, using a known radiation field.

The use of properly calibrated dosimeters is critical to a good health physics program. An installation that has a small radiation protection staff should procure the services provided by the Army or a commercial calibration company. Calibration companies should maintain their traceability to NBS through a periodic direct intercomparison.

D. Practical Applications. Thermoluminescence dosimeters can be used in any situation where film dosimeters are currently being used. They are preferred to film for extremity dosimeters (e.g., ring and wrist badges), for personnel monitoring where radiation energies are below about 100 keV, and for environmental monitoring. However, TLDs do not provide a permanent record of exposure, as film dosimeters do.

Unlike film dosimeters, TLDs can also be used to measure the neutron radiation to which an individual is exposed. Thermoluminescent materials are more sensitive to thermal (slow) neutrons than to fast neutrons. Thermal neutrons interact with a TLD as they pass through it to the wearer. Some thermal neutrons may be reflected back to the TLD from the irradiated individual and may interact with the dosimeter then also. Fast neutrons, on the other hand, do not interact with the TLD as they pass through it. These fast neutrons interact with the hydrogen in the wearer's tissues, where they lose their energy (become thermal). Many are then reflected back toward and interact

with the dosimeter. The reflected thermal neutrons are called albedo neutrons. Correct interpretation of albedo dosimetry requires that the radiation source, the dosimeter, and the irradiated individual be in line and that the original energy of the neutrons be known. The neutron energy or a description of the radiation source should be given to the dosimetry service interpreting the response.

Section 2.7 STATISTICS AND ERROR DETERMINATION

The spontaneous emission of radiation by nuclear processes occurs randomly in time, and all measurement and detection instruments must respond to these statistically random events. This means that the interpretation of instrument response must take into account the random nature of radioactive decay. We tend to assume that a measurement is an absolute indication of the activity of the source. However, this is usually not the case. It is more likely that only a fraction of the radiation can be detected. This error must be corrected using statistics and geometry correction factors.

2.7.1 Systematic and Random Errors of Measurement

The errors associated with radiation measurements can be divided into two types: systematic and random. Systematic errors are created in the measurement process or in the interpretation of measurement data. They are frequently caused by faults within the electronic systems of instruments. For example, low batteries or faulty electronic components could bias measurements, and the results would be considered to contain a systematic error. The primary source of random errors is radioactive decay.

2.7.2 Basic Statistical Distributions for Radioactive Decay

If a long-lived radionuclide of low activity was counted many times, and if a plot was made showing the number of times a given count rate occurred versus the count rate, the plot would be similar to the one shown in Figure 2.5. This curve is called a normal, or Gaussian, distribution and represents the distribution of count rate values obtained in successive counts.

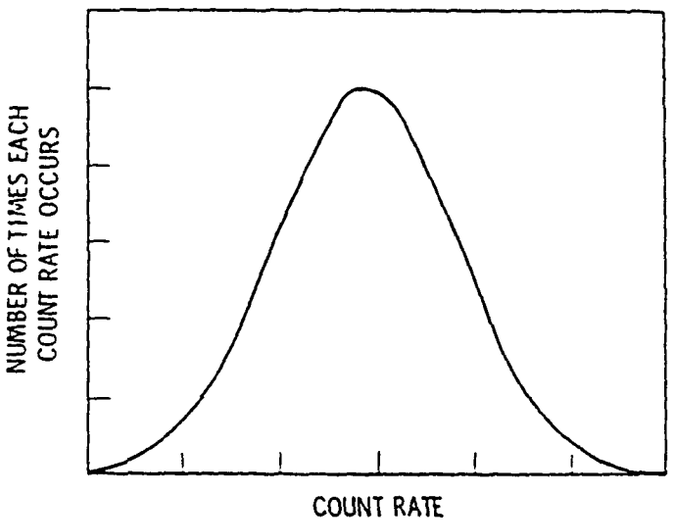


FIGURE 2.5. Frequency of Occurrence of Count Rates for a Long-Lived Sample

The normal distribution curve can be described mathematically by calculating the mean and the standard deviation of all the count rates used to prepare the curve. The mean, or the arithmetic average of the count rates, describes where on the curve the greatest number of counts occurs. It is calculated by summing all of the count rates and dividing by the number of counts taken. Written in mathematical terms, the equation appears as follows:

$$\bar{n} = \frac{1}{N} \sum_{i}^{N} n_i \qquad (2.3)$$

where $\bar{n}$ = the mean of the count rates

N = the number of times the sample was counted

n_i = the value of the ith count rate

$\sum_{i}^{N} n_i$ = the sum of all the count rates.

The individual measurements taken in any radiation survey are distributed about this sample mean.

The standard deviation (σ), a measure of variability, describes the width of the curve and is a useful indication of how extensively the count rates

vary from the average value. The square of the standard deviation is called the variance and can be approximated using the expression

$$\sigma^2 = \frac{1}{N-1} \sum_{i}^{N} (\bar{n} - n_i)^2 \qquad (2.4)$$

where σ^2 = the variance

σ = the standard deviation

N = the number of times the sample was counted

$\bar{n}$ = the mean of the count rates

n_i = the value of the ith count rate

$\sum_{i}^{N} (\bar{n} - n_i)^2$ = the sum of all the squared deviations from the mean.

When only a few measurements have been taken (fewer than 20), a best estimate of the standard deviation can be derived as follows: $\sigma = \sqrt{n}$. When more than 20 measurements have been taken, the previous method for calculating the variance and the standard deviation should be used.

Figure 2.6 shows a plot of the normal distribution curve with several features indicated. In a normal distribution, 68.3% of all counts are within

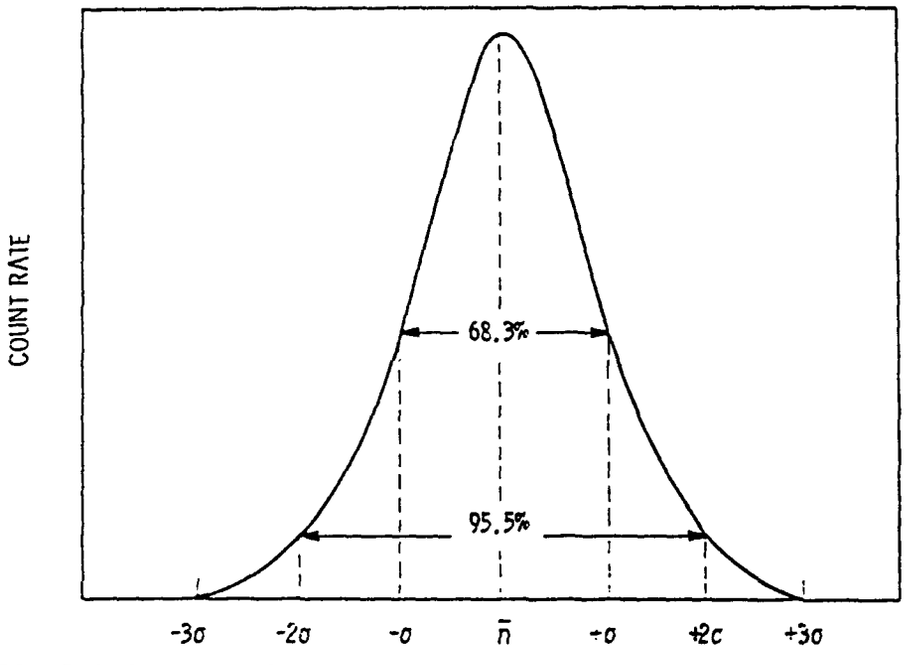


FIGURE 2.6. Normal Distribution Function Showing Standard Deviations and Mean

±1 standard deviation of the mean value, 95.5% within ±2 standard deviations of the mean, and 99.7% within ±3 standard deviations of the mean. For example, if a sample is counted 100 times, the mean value obtained is 1000 cpm, and the standard deviation is 100, then we can say, with a 68.3% chance of being correct, that the mean count rate is between 900 and 1,100. Thus, the specification of activity is a "probabilistic event"; that is, we specify with a certain statistical accuracy that the mean activity lies within a range of values.

For statistical purposes, when the results of a series of measurements are recorded, both the mean and the standard deviation should be specified.

Section 2.8 RECORDS

Records are needed to verify the availability and use of appropriate radiation detection and measure instruments, the adequacy of their calibration and maintenance, the proper interpretation and use of the resulting data, and compliance with regulatory requirements. A complete discussion of instrument recordkeeping procedures is presented in Chapter 13.

REFERENCES

American National Standards Institute (ANSI). 1949. Standard Test Procedure for Geiger-Mueller Counters. ANSI N42.3, New York.

American National Standards Institute (ANSI). 1978. Criteria for Testing Personnel Dosimetry Performance. ANSI N13.11-1978, New York.

American National Standards Institute (ANSI). 1978. Radiation Protection Instrumentation Test and Calibration. ANSI N323-1978, New York.

National Council on Radiation Protection and Measurements (NCRP). 1978. A Handbook of Radioactivity Measurements Procedures. NCRP 57, Washington, D.C.

CHAPTER 3. RADIATION PROTECTION PROGRAM

3.1 REGULATIONS 3.3

3.1.1 Department of the Army 3.3

3.1.2 Federal 3.4

3.1.3 International 3.5

3.2 RADIATION PROTECTION STANDARDS 3.5

3.2.1 Radiation Exposure Standards 3.5

A. Occupational Exposure 3.6

B. Occupational Exposure to Women 3.6

C. Occasional Exposure 3.7

D. Exposure of Minors 3.7

E. Emergency Exposure 3.7

F. Nonoccupational Exposure 3.8

G. Alternate Exposure Standards 3.8

3.2.2 Administration Limits and Action Levels 3.8

3.2.3 The ALARA Philosophy 3.9

3.3 ELEMENTS OF A RADIATION PROTECTION PROGRAM 3.9

3.3.1 Licenses, Authorizations, and Permits 3.10

3.3.2 ALARA Program 3.10

A. Management Commitment 3.10

B. Assignment of ALARA Responsibility and Authority . . 3.11

3.3.3 Surveillance and Monitoring Programs 3.13

3.3.4 Radiological Design 3.13

3.3.5 Radioactive-Material Control and Waste Management . . 3.14

3.3.6 Emergency Planning 3.14

3.3.7 Personnel Selection, Qualification, and Training . . 3.15

3.3.8 Recordkeeping 3.15

3.3.9 Quality Assurance Program 3.15

3.4 ADMINISTRATION OF THE RADIATION PROTECTION PROGRAM . . . 3.16

3.4.1 Ionizing Radiation Control Committee 3.17

3.4.2 Radiation Protection Officer 3.18

REFERENCES 3.19

APPENDIX A - REVIEW OF PROPOSALS FOR RADIATION USE 3.21

TABLES

3.1 Regulations Applicable to Army Activities 3.4

3.2 Radiation Protection Standards 3.6

CHAPTER 3. RADIATION PROTECTION PROGRAM

The objectives of a radiation protection program are to reduce exposures to a level as low as is reasonably achievable within the occupational dose-equivalent limits set by the federal government and the Department of the Army (DA) and to minimize the potential for accidental exposures. The components of an effective radiation protection program are common to all installations where radioactive materials are used or stored. However, the magnitude and complexity of the program may vary from one installation to another. This chapter describes briefly the principles and practices that should be considered in the establishment of a radiation protection program. These practices are covered in greater detail in later chapters of this manual.

Section 3.1 REGULATIONS

A variety of government branches and international agencies have formulated regulations governing the procurement, use, storage, transportation, and disposal of radioactive materials and sources. The National Council on Radiation Protection and Measurements (NCRP) and the International Commission on Radiological Protection (ICRP), whose members are professionals in health physics or related fields of research, provide recommendations that serve as the basis for most Army and other government agency requirements. Knowledge of and compliance with all applicable regulations are essential factors in the administration of every radiation protection program. Agencies that may have jurisdiction over specific radiological situations are discussed briefly below, and the applicability of their regulations is summarized in Table 3.1.

3.1.1 Department of the Army

All Army installations that produce, procure, receive, store, use, ship, or dispose of radioactive materials or sources are required to have a radiation protection program. Specific requirements for ionizing radiation protection programs can be found in AR 385-11, AR 40-14, DARCOM-R 385-25, and AR 700-64.

TABLE 3.1. Regulations Applicable to Army Activities

Activity	Applicable Regulations
Day-to-day operations	10 CFR 20, 10 CFR 19 AR 40-14, AR 700-64, AR 385-11 DARCOM-R 385-25
Use of radiation-producing machines (such as x-ray machines)	21 CFR 1000-1050
Transport of radioactive materials	49 CFR
Shipment through mails	39 CFR
International shipments	Inter-Governmental Maritime Consultative Organization and International Air Transport Association

3.1.2 Federal

The U.S. Nuclear Regulatory Commission (NRC) regulates the production, distribution, use, and disposal of source, byproduct, and special nuclear materials. The use of radioactive materials and radiation sources within the work environment not governed by the NRC is regulated by the U.S. Occupational Safety and Health Administration (OSHA). The requirements of NRC are described in Title 10 of the U.S. Code of Federal Regulations, Parts 19 and 20 (10 CFR 19 and 20). Army regulations require that civilian and military personnel within the United States and overseas be provided radiation protection that is at least equal to that required by 10 CFR 19 and 20.

The U.S. Department of Health and Human Services (HHS) conducts a radiation control program for electronic products. The program includes the development of performance standards to protect the public health from ionizing and nonionizing radiation in electronic products. This department also regulates and sets standards for the use of radioactive materials and radiation sources in foods, drugs, cosmetics, and medical devices, as set forth in 21 CFR.

The U.S. Department of Transportation (DOT) regulates the packaging and transportation of radioactive materials shipped in interstate commerce by air, rail, highway, and water. The U.S. Postal Service regulates shipment via the

U.S. mail. The regulations of their agencies are presented in Titles 49 and 39 of the Code of Federal Regulations, respectively.

The U.S. Environmental Protection Agency (EPA) provides federal guidance on radiation protection. The EPA also develops standards governing the release of radioactive materials and radiation sources to the environment (40 CFR).

3.1.3 International

An agency of the United Nations, the International Atomic Energy Agency (IAEA), provides overall safety guidance for the international shipment of radioactive materials. The Inter-Governmental Maritime Consultative Organization (IMCO) and the International Air Transport Association (IATA) provide regulations for the international shipment of radioactive materials. The specific application and enforcement of the regulations is the responsibility of each nation through which material is transported. Normally, a shipment that complies with the regulations of the nation of origin complies by agreement with the regulations of the nations through which the shipment is routed.

Section 3.2 RADIATION PROTECTION STANDARDS

Dose-equivalent limits for controlling occupational and nonoccupational exposure to ionizing radiation and radioactive materials have been established by DA (AR 40-14). These limits are based on the recommendations of NCRP and ICRP. Both organizations emphasize that dose-equivalent limits are upper limits for planned exposures and that every effort must be made to keep exposures below these limits and to avoid unnecessary radiation exposure. This principle is strongly emphasized in federal regulations as the As Low As is Reasonably Achievable (ALARA) philosophy.

3.2.1 Radiation Exposure Standards

Standards established by the Army fall into several categories: occupational exposures, occupational exposures to women, occasional exposures, exposure of minors, emergency exposures, nonoccupational exposures, and alternate exposure standards. These categories are described below.

A. Occupational Exposure. Occupational radiation exposure standards are presented in Table 3.2. Occupational exposure to ionizing radiation is that resulting from military or civilian duties that directly support the use of radioactive materials or equipment capable of producing ionizing radiation. Occupational exposure does not include exposure to naturally occurring ionizing radiation or exposure received as a result of medical or dental diagnosis or treatment. An occupationally exposed individual, or radiation worker, is one whose work is performed in a radiation area or a controlled area (see Chapter 8) and who might be exposed to more than 5% of the limits given in Table 3.2.

B. Occupational Exposure to Women. Special radiation exposure controls are established for the protection of unborn children. The NCRP recommends that during the entire gestation period, the maximum dose equivalent to the

TABLE 3.2. Radiation Protection Standards[a]

Organ	Occupational Dose-Equivalent Limit, rem	
	Calendar Quarter	Calendar Year
a. Whole body, head and trunk, active blood-forming organs, gonads, lens of the eye	1.25	5
b. Skin of the whole body (other than hands, wrists, feet, or ankles) forearms, cornea of the eye, bone	7.50	30
c. Hands and wrists, or feet and ankles	18.75	75
d. Forearms	10	30
e. Thyroid, other organs, tissues, and organ system	5	15
Individuals under the age 18, and occasionally exposed individuals	10% of the values listed above	
Individuals between ages 18 and 19 (whole-body limit)	1.25	

(a) AR 40-14.

embryo-fetus from the occupational exposure of the expectant mother should not exceed 0.5 rem (NCRP Report Nos. 39 (1971) and 53 (1977)). A woman staff member is responsible for advising her employer that she is pregnant. Special consideration, such as a change in work assignment, may be necessary to ensure that her occupational exposure does not exceed recommended limits and is kept as low as is reasonably achievable. The installation commander and the Radiation Protection Officer (RPO) should determine appropriate actions and policies.

C. Occasional Exposure. An occasionally exposed individual is one whose duties do not normally involve exposure to ionizing radiation or radioactive material, but who may have a reason to enter a restricted area on a nonroutine basis. Examples are repair personnel and messengers. When such individuals enter a restricted area, they shall not be exposed to a whole-body dose equivalent of more than 1) 2 mrem in any 1 hour, 2) 100 mrem in any 7 consecutive days, 3) 500 mrem in any 1 calendar year, or 4) 5% of the values for other areas of the body detailed in Table 3.2.

D. Exposure of Minors. A minor is any person under 18 years of age. For a minor, the accumulated dose equivalent of radiation shall not exceed 10% of any of the values listed in Table 3.2. Persons over the age of 18, but who have not reached their 19th birthday, may be occupationally exposed to ionizing radiation if they do not receive a dose equivalent of more than 1.25 rem to the whole body in any calendar quarter.

E. Emergency Exposure. Radiation exposure standards in emergency situations vary according to the severity of the emergency. When entry into a hazardous area is necessary to search for and remove seriously injured persons, or to prevent conditions that may injure a number of people, the accumulated whole-body dose of each individual entering the area should not exceed 100 rad, and the accumulated dose to the hands and forearms should not exceed 300 rad. In a less severe situation, when it is desirable to enter a hazardous area to protect property, minimize the release of effluent, or control fires, the accumulated whole-body dose of each individual entering the area should not exceed 25 rad, and the dose to the hands and forearms should not exceed 100 rad. Individuals who incur such radiation exposures during an emergency

should not be allowed to do so more than once in a lifetime. The record of such exposure becomes part of the person's health record or civilian employee medical file.

F. Nonoccupational Exposure. Sources of ionizing radiation must be used in such a way that 1) the accumulated dose equivalent to the whole body for an individual person in the general public does not exceed 0.5 rem in any 1 calendar year, and 2) the average accumulated dose equivalent for a suitable sample of the exposed population or for the whole exposed population does not exceed 0.170 rem/year from all sources of radiation (excluding medical and natural background radiation).

G. Alternate Exposure Standards. Radiation exposures standards that are less restrictive than those described above may be used in special circumstances, but only when approved by the Surgeon General of the United States or the director of the Defense Logistics Agency, as appropriate. Proposals for alternate radiation exposure standards must contain a complete justification and must specify the procedures by which the standards will be implemented. Less restrictive standards will not be considered for 1) persons under 19 years of age, 2) women known to be pregnant, 3) occasionally exposed persons, and 4) nonoccupational exposure of the general public.

3.2.2 Administrative Limits and Action Levels

Administrative limits and action levels are frequently set to help maintain occupational exposures within established limits. Administrative limits are radiation exposure limits established by the administrator of a radiation protection program, for example, 80% or less of the occupational exposure standard. An administrative limit is basically a control point: as an individual's exposure approaches this level, the individual is carefully monitored so that the exposure does not exceed the limit unless specific management approval is obtained. Thus, individual exposures are kept lower, and the possibility of exceeding permissible exposure limits is reduced.

Action levels are dose-equivalent limits that, when reached or exceeded by an individual, require formal investigation into the cause of exposure. The RPO should establish investigative procedures. An investigation should lead to

the identification of portions of the radiation protection program that need to be improved. Action levels, also called investigative levels, are established by radiation protection management.

3.2.3 The ALARA Philosophy

Even though current occupational exposure limits keep the risk of injury to personnel very low, it is prudent to avoid unneccessary exposure to radiation. The operating philosophy of every radiation protection program should be to reduce occupational exposures as far below specified limits as is reasonably achievable. This philosophy, emphasized in federal regulations and referred to as ALARA (As Low As is Reasonably Achievable), means that each work procedure that will result in a radiation dose should be subject to scrutiny and that methods to reduce the dose should be identified. The methods that involve the least cost and result in the greatest reduction of dose should be considered and implemented wherever possible. References in the bibliography discuss ALARA and ALARA programs in greater detail than is possible here.

It is not desirable to maintain the dose equivalent of a radiation worker at a small fraction of the applicable limit if this practice requires that a larger number of people be exposed. Therefore, in addition to maintaining occupational exposure to individuals as far below limits as is reasonably achievable, the goal of ALARA is to keep the sum of the doses received by all exposed individuals (radiation workers, other personnel, and the general public) at the lowest practicable level. The sum of the dose equivalents received by all exposed individuals is called the collective dose equivalent.

Section 3.3 ELEMENTS OF A RADIATION PROTECTION PROGRAM

An effective radiation protection program includes licensing, an ALARA program, surveillance and monitoring programs, proper design of facilities in which radiation sources are used, control of radioactive materials and waste disposal, emergency planning, adequate training of personnel, the maintaining of reliable and complete records, and a quality assurance program.

3.3.1 Licenses, Authorizations, and Permits

Whenever radioactive materials or radiation sources are produced, procured, used, stored, transported, or disposed of at DA facilities, an NRC license and/or DA approval is required. Procedures for obtaining the necessary documents are contained in AR 385-11. Non-Army agencies, including civilian contractors, are required to obtain a DA radiation permit to possess, use, store, or dispose of radiation sources on an Army installation.

3.3.2 ALARA Program

The establishment and management of all radiation protection programs within Army facilities should be guided by the ALARA philosophy. Each radiation protection program should therefore include a formal ALARA program. An effective ALARA program requires management commitment and the assignment of ALARA responsibility to an individual or committee, as discussed below. Procedures for maintaining exposures ALARA are described throughout this manual. Particular attention should be directed to Chapters 5 and 6, which described the control of internal and external exposure.

A. Management Commitment. Management commitment to the safe and correct use of radiation and radioactive materials is probably the single most important characteristic of a good radiation protection program. Upper management, specifically the base commander, sets the tone for the safety program. The commander must indicate by word and action that safety is important. Simply displaying safety slogans and posters, holding safety contests, and establishing safety committees have little effect unless individual staff members believe that safety is important to their supervisors.

The commitment made by management to minimize exposures should result in clearly defined responsibilities for radiation protection and an environment in which the radiation protection staff can do its job properly. This commitment should be made evident in the following areas:

(1) Personnel Awareness of Management Commitment. The ALARA principle should appear in policy statements, instructions to personnel, and similar documents. Staff members should be familiar enough with this commitment to explain what management policy is, what is meant by keeping exposure to

radiation "as low as is reasonably achievable," why it is recommended, and how they have been advised to implement it on their jobs. They must understand the importance of the philosophy.

(2) Radiation Protection Personnel. Management should ensure that there is a well-supervised radiation protection staff with well-defined responsibilities. The RPO should be qualified to handle any potential problems at the installation.

(3) Training. Management should ensure that personnel receive sufficient training. Section 19.12 of 10 CFR 19 requires that personnel be instructed in radiation protection. They should understand how radiation protection relates to their jobs and should be tested on this understanding at least once each year. Radiation workers should have opportunities to discuss radiation safety with the radiation protection staff whenever the need arises. The training program in radiation protection should be reviewed by management at least once every two years.

(4) Facility Modifications. Modifications in operating and maintenance procedures and in plant equipment and facilities should be made if they will substantially reduce exposures at a reasonable cost. Management should encourage the staff to suggest improvements and modifications and should implement them where practicable.

(5) Audit Programs. A formal audit should be conducted periodically to determine how exposures might be reduced. The audit should include reviews of operating procedures and exposure records, inspections, and consultations with the radiation protection staff.

B. Assignment of ALARA Responsibility and Authority. The base commander should formally assign ALARA responsibility to an individual such as the RPO or to a group of individuals such as the Ionizing Radiation Control Committee (IRCC). The RPO should have sufficient authority to prevent unsafe practices and to communicate promptly with an appropriate level of management about halting unsafe operations. This authority should be specified in written policy statements. The members of the IRCC are chosen for their knowledge of radiation safety principles, engineering, and design, knowledge that is useful in evaluating the safety of projects involving radioactive materials.

Operating procedures related to radiation safety should be reviewed and approved by radiation protection personnel. The RPO and/or the IRCC should be responsible for conducting surveillance programs and investigations to ensure that occupational exposures are as far below the specified limits as is reasonably achievable. All of these individuals should constantly be seeking new and better ways to perform all radiation jobs with less exposure. There are several aspects of this responsibility.

(1) Monitoring of Exposures. The RPO and the radiation protection staff should know the origins of radiation exposures by location, operation, and job category and should be aware of trends in exposures. They should be able to describe which locations, operations, and jobs are associated with the highest exposures and why exposures are increasing or decreasing. Where standing operating procedures are used, exposures received should be recorded on the written procedures.

(2) Investigation of Unusual Exposures. When unusual exposures have occurred, the radiation protection staff should direct and participate in an investigation of the circumstances to determine the causes and take steps to reduce the likelihood of similar future occurrences. For each such occurrence, the RPO should be able to demonstrate that an investigation was carried out, that conclusions were reached as a result of the investigation, and that appropriate corrective actions were taken.

(3) Review of Operating Procedures. The RPO and the radiation protection staff should periodically review operating procedures that may affect radiation safety. They should survey plant operations to identify situations in which exposures can be reduced, and should implement any changes that are needed. The RPO should repeatedly emphasize that work performance that results in personnel meeting dose-equivalent limits is not acceptable when it is practical to reduce the dose to a lower level. Procedures should be established for receiving and evaluating staff members' suggestions relating to radiation protection and dose reduction, and the staff shquld be aware of these procedures.

(4) Provision of Equipment and Supplies. The RPO should be responsible for ensuring that equipment and supplies appropriate for radiation protection

work are available, are maintained in good working order, and are used properly. Written procedures for the use of the equipment should be available and followed.

3.3.3 Surveillance and Monitoring Programs

Another component of a radiation protection program is surveillance and monitoring, which help keep radiation exposures to personnel and the public ALARA and within applicable dose-equivalent limits. Routine survey programs, used to assess the radiological status of a facility, are discussed in Chapter 4 of this manual. Procedures for monitoring personnel are described in Chapters 5 and 6.

3.3.4 Radiological Design

The terms facility design, radiological design, and radiological engineering are often used interchangeably, although their meanings are different. Facility design refers to a plan for a building or installation as a whole, and thus includes nonradiological as well as radiological design features. Radiological design refers to the specific set of features required in a facility because of the planned presence of radioactive source or radiation-generating machines. Radiological engineering refers to the actual construction of a facility in which radioactive materials will be stored or used. (The term can also be used in a broader context to include design.) Design implies the development of an idea as opposed to the actual construction and operation of a facility.

Proper facility design is an effective approach to reducing occupational exposures. Well-designed facilities provide a greater degree of safety than can be obtained by dependence on administrative rules and procedures alone. Although design can never eliminate the possibility of accidental radiation exposure or contamination, it can reduce the probability and magnitude of such accidents. A qualified expert should therefore participate in the planning and design of new facilities and of modifications to existing facilities. Topics that should be considered in radiological design are discussed in Chapter 8.

3.3.5 Radioactive-Material Control and Waste Management

Proper control of radioactive materials is necessary to ensure that personnel and the general public are protected from unnecessary exposure to radiation. Such control extends to all aspects of radioactive-materials handling, including procurement, use, storage, shipment, and waste disposal.

The RPO should review all procurement and transfer requests for radiation-producing sources and devices and should monitor and inventory radioactive materials when they are received to ensure that they have not been damaged in transit or caused contamination of personnel and facilities. Radiation sources may then be transferred to authorized users in the organization or stored in specially designated facilities until needed. Later transfer of radioactive materials may require special procedures to assure proper controls, and care should be taken to ensure that the person or organization receiving the materials is licensed and authorized to received and use them.

An inventory should be maintained to ensure that the RPO can at any time determine the identity, quantity, and location of all radioactive materials. The location, safe condition, and use of radioactive materials should be confirmed by a periodic audit and by routine surveys performed by the RPO.

The RPO should review the disposal of all radioactive materials. They should be disposed of by transfer in suitably prepared containers to authorized locations for radioactive waste disposal. Transportation is discussed more fully in Chapter 9, radioactive-waste disposal in Chapter 10, and inventory record systems in Chapter 13.

3.3.6 Emergency Planning

Every facility in which radioactive material, radiation-generating devices, or radiation sources are produced, used, or stored should have an emergency plan. The emergency plan may be simple or complex, depending upon the facility. In all cases, however, it should be documented, reviewed periodically, and tested at least yearly.

An emergency plan is created through evaluation of the accident potential of a facility. The emergency actions necessary to reduce the consequences of potential accidents, and the individuals responsible for those actions, are

then determined. Coordination with outside emergency forces (public information officials, hospitals, and police, fire, and health departments) is also planned. When an emergency plan has been established, realistic exercises in which key staff members participate should be held to test the adequacy of emergency preparedness. These exercises should include tests of evacuation procedures, the use of emergency equipment, and those rescue and first aid techniques in which staff members may play a role. Periodic testing of emergency equipment and instrumentation is also necessary. Procedures for developing a plan are described in Chapter 11.

3.3.7 Personnel Selection, Qualification, and Training

Adequate training is fundamental to a radiation protection program. Appropriate training should be extended to the radiation protection staff, installation management, and radiation workers. Training programs are discussed in Chapter 12.

3.3.8 Recordkeeping

Documentation is needed as evidence to support the reliability and effectiveness of a radiation protection program. Records should be complete and should reveal the patterns of radiation exposure at the facility. Data on all operating and working conditions should also be available. The records that should be considered for retention are described in Chapter 13.

3.3.9 Quality Assurance Program

A quality assurance program is a means of verifying that each part of a radiation protection program is being carried out adequately and that the total program meets its purpose. A quality assurance program should be developed for any facilities or locations where the following take place:

1. radioactive material is received, used, stored, or prepared for disposal
2. radiation-generating machines are operated
3. personnel dosimeters are evaluated
4. radiation detection or measuring equipment is procured, received, repaired, calibrated, or used

5. facilities or equipment that will be used for these activities are designed, constructed, or modified.

Quality assurance is discussed in Chapter 14.

Section 3.4 ADMINISTRATION OF THE RADIATION PROTECTION PROGRAM

The success of a radiation protection program is dependent on firm management commitment to the program and on the availability of individuals who have a thorough understanding of radiation protection principles. Within the DA, the overall responsibility for the radiation protection program rests with the commander, director, or chief of the installation or activity. The management and administration of the radiation protection program is delegated to designated personnel such as the RPO or the IRCC. The IRCC is an advisory body that assists the commander in establishing local rules and procedures for the procurement, storage, and safe use of radiation sources. The committee consists of the commander, the RPO, the safety officer, and the medical officer (if available)--or representatives of these individuals--together with a representative of employee groups, and others knowledgeable in radiation protection. The RPO is generally responsible for the implementation of the radiation protection program. This individual must be technically qualified through education, training, and professional experience.

The assignment of responsibility must be accompanied by accountability and authority. Authority granted to the radiation protection staff should be broad and fully supported by upper management. Specific authorities should include the following:

1. approve plans for the construction or modification of facilities in which radioactive materials will be used or stored, or in which radiation-generating machines will be located
2. issue and approve standing operating procedures or job safety analyses (this implies review and approval of operating plans and procedures before their implementation)

3. determine operational protective measures to ensure that exposures are kept ALARA

4. train and assess the qualification of radiation workers

5. plan for and establish equipment and procedures for monitoring and control of personnel exposures.

Authorities should be delineated between the IRCC and the RPO. One way this can be done is outlined below.

3.4.1 Ionizing Radiation Control Committee

The duties of the IRCC can include the following:

1. Review proposals for the use of ionizing radiation sources and recommend protective measures to the commander (AR 40-14).

2. Prescribe any special conditions and requirements that may be needed (such as physical examinations, additional training, designation of limited areas or locations of use, disposal methods, etc.).

3. Prepare and disseminate information on radiation safety for use by and guidance of personnel.

4. Pass judgment on the adequacy of safety measures and health protection for safeguarding personnel.

5. Keep a record of actions taken in approving the use of radioisotopes, and of other transactions, communications, and reports involved in the work of the committee.

6. Provide policy direction to the RPO, based upon state and federal regulations and licenses, for the use of ionizing radiation at the installation.

7. Approve or disapprove all applications from prospective users of radioactive materials and from prospective operators of sources of ionizing radiation.

8. Approve or disapprove all applications for laboratories in which radioactive materials would be used or in which sources of ionizing radiation would be operated.

9. Review plans for all new buildings or for modifications to existing buildings in which radioactive materials or other sources of ionizing radiation would be used.

10. Suspend any operation that, in the opinion of the IRCC, represents a serious radiation hazard or violates applicable regulations.

3.4.2 Radiation Protection Officer

The RPO's responsibilities can include the following:

1. Ensure compliance with current directives for radiation protection.

2. Provide consultation on the hazards associated with radiation and the effectiveness of measures to control these hazards.

3. Supervise the radiation protection program and advise on the control of hazards to health and safety.

4. Coordinate the day-to-day administration and development of the radiation protection program.

5. Disseminate information on radiation safety and health physics.

6. Review all proposals for radiation usage and recommend to the IRCC approval or disapproval of all applications from prospective users of radioactive materials and from prospective operators of sources of ionizing radiation. Detailed information on such reviews is given in Appendix A.

7. Inspect facilities and equipment on behalf of the IRCC.

8. Review plans for all new radioisotope and radiation facilities.

9. Obtain all necessary licenses and registrations pertaining to radioactive materials and sources of ionizing radiation for the installation or activity.

10. Develop procedures for the purchase and transfer of radioactive materials.

11. Develop procedures for the disposal of solid and liquid radioactive wastes.

12. Maintain required records, including the following: personnel dosimetry, radioactive waste disposal, radioisotope inventory, instrument calibration, and leak tests on sealed sources.

13. Provide radiation surveys and monitoring of all radioisotope and radiation facilities.

14. Offer brief courses on radiation safety for users and prospective users of radioactive materials and ionizing radiation.

15. Suspend any operation that, in the opinion of the RPO, represents a serious radiation hazard or violates applicable regulations. The operation suspended will be reviewed by the IRCC.

REFERENCES

National Council on Radiation Protection and Measurements (NCRP). 1971. Basic Radiation Protection Criteria. NCRP 39, Washington, D.C.

National Council on Radiation Protection and Measurements (NCRP). 1977. Review of NCRP Radiation Dose Limit for Embryo and Fetus in Occupationally Exposed Women. NCRP 53, Washington, D.C.

U.S. Code of Federal Regulations. 1982. Title 10, Part 19, "Notices, Instructions and Reports to Workers; Inspections." U.S. Government Printing Office, Washington, D.C.

U.S. Code of Federal Regulations. 1982. Title 10, Part 20, "Standards for Protection Against Radiation." U.S. Government Printing Office, Washington, D.C.

U.S. Code of Federal Regulations. 1982. Title 10, Part 40, "Domestic Licensing of Source Material." U.S. Government Printing Office, Washington, D.C.

U.S. Code of Federal Regulations. 1982. Title 21, "Food and Drugs." U.S. Government Printing Office, Washington, D.C.

U.S. Code of Federal Regulations. 1982. Title 39, "Postal Service." U.S. Government Printing Office, Washington, D.C.

U.S. Code of Federal Regulations. 1982. Title 40, "Protection of Environment." U.S. Government Printing Office, Washington, D.C.

U.S. Code of Federal Regulations. 1982. Title 49, "Transportation." U.S. Government Printing Office, Washington, D.C.

U.S. Department of Defense, Defense Supply Agency. Radioactive Commodities in the DOD Supply Systems. DSAM 4145.8, AR 700-64, Washington, D.C.

U.S. Department of the Army, Headquarters. Safety - Ionizing Radiation Protection (Licensing, Control, Transportation, Disposal, and Radiation Safety). AR 385-11, Washington, D.C.

U.S. Department of the Army, Headquarters, Army Materiel Command. Safety - Radiation Protection. DARCOM-R 385-25, Washington, D.C.

U.S. Department of the Army and Defense Logistics Agency. Medical Services - Control and Recording Procedures for Exposure to Ionizing Radiation and Radioactive Materials. AR 40-14, DLAR 1000.28, Washington, D.C.

APPENDIX A

REVIEW OF PROPOSALS FOR RADIATION USE

The RPO is responsible for reviewing project plans, personnel, and facilities before work with radioactive material or radiation-producing devices is begun. Standing operating procedures are then prepared by the RPO and the IRCC, and records are maintained as the work proceeds.

A.1 PROJECT EVALUATION

The project should be evaluated based on the following criteria:

A. License. The RPO should check the site or facility license to ensure that the radioactive material proposed for use can be brought onsite and that the proposed chemical and physical form and the proposed uses of the material are allowed by the license. If the license does not show the proposed uses, an amendment to the license must be requested. For assistance in preparing an amendment to the license, or in interpreting the license to determine whether an amendment is necessary, contact DARCOM headquarters.

Six months or more may elapse before a requested license amendment is authorized. Project leaders should be made aware of the possibility of delay; they can then inform the RPO of the needs of the project early enough in the planning process so that the license amendment will be approved at about the same time as the project is scheduled to begin.

B. Radionuclide. The RPO should assess the radionuclide to be used, considering whether an alternate, less hazardous radionuclide could be used (for example, ^{33}P rather than ^{32}P) and whether a radionuclide is necessary at all or whether other methods of achieving the same purpose are available.

C. Quantity. The amount of radioactive material used for the project should be the minimum possible. If possible, the stock quantity of radioactive material should be divided into small aliquots.

The quantity of radionuclide proposed for use should be compared with the amount for which the site or facility is licensed. This comparison should take into account both the quantity to be used during the project and the total onsite inventory for that radionuclide. The inventory of concern includes both quantities in laboratories and waste quantities that are stored and waiting for shipment.

D. Chemical and Physical Form. If the material proposed for use is volatile, the need for a volatile form should be assessed. Chemical methods for reducing the volatility of the chemical compound may be available; for example, raising the pH of an iodine solution reduces the amount of iodine released into the atmosphere. Concentrated solutions of alpha-emitting radionuclides, such as ^{244}Cm, may present difficulties. Dilute solutions are less likely to cause volatilization.

E. Work Procedures. The RPO should consider whether there are standard procedures for doing the proposed work; whether the proposed work follows the established procedures; whether the procedures can be improved, for example, by reducing the work time; and what types of protective apparel should be worn.

A.2 PERSONNEL CONSIDERATIONS

Personnel considerations in the assessment of a project include:

A. Pregnant or Potentially Pregnant Women. The DA recommends in AR 40-14 that, during the entire gestation period, the maximum dose equivalent to an embryo-fetus from occupational exposure of the expectant mother should not exceed 0.5 rem. Because pregnancy may not be confirmed for two or more months after conception, women staff members should be made aware of this recommendation and should be encouraged to tell the RPO when they are contemplating pregnancy or as soon as pregnancy is suspected.

B. Minors. Individuals under 18 years of age shall not be exposed to more than 10% of the occupational dose limits.

C. Education and Training. Personnel assigned to work on projects involving the use of radioactive materials or radiation-generating sources should be educated as to the hazards associated with radiation and trained in

the specific skills required for their job. Their attendance at education and training sessions should be documented by attendance rolls, and the RPO should administer tests that cover the material following the training sessions. The tests should show whether the material was understood and indicate areas of training that require increased emphasis.

D. Personnel Monitoring. The RPO should ensure that personnel who will work with radioactive materials are provided with appropriate monitoring devices. Monitoring devices such as film badges shall be worn by all personnel who receive, or may be expected to receive, a radiation dose higher than 5% of the applicable standard to the whole body or skin. In practice, whole body badges are usually issued to all individuals who work with x- or gamma-ray sources or with beta emitters that have a maximum energy of 1.0 MeV. Film badges should also be worn by individuals who work around particle accelerators and neutron sources.

Extremity monitors should be worn by individuals who may receive an extremity dose higher than 5% of the applicable standard.

A.3 EVALUATION OF FACILITIES

The facility or work area in which the project will be carried out should be evaluated to ensure that radioactive materials can be used safely. The U.S. Environmental Hygiene Agency and DARCOM headquarters should be contacted for assistance. The information to be considered includes:

A. Shielding. The amount of shielding required depends on the radionuclide to be used (or the operating energy of the radiation-producing machine), the quantity of radioactive material to be present (or the operating time of the machine), and the proposed use of adjacent areas. If shielding already exists, the RPO should assess whether it will be sufficient, how much additional shielding will be required, and whether the building can support the required shielding.

B. Equipment. The working area should have appropriate equipment, which may include hoods, glove boxes, and air filter systems.

A.4 STANDING OPERATING PROCEDURES

After the project has been analyzed, a standing operating procedure (SOP) is prepared by the IRCC and the RPO. The SOP is a summary of the safety findings and a listing of the procedures that must be followed during the course of the project. The SOP should include the following items:

1. type of protective apparel required, if any
2. posting requirements
3. radiation-monitoring devices required
4. personnel dosimeters required
5. bioassay types and frequency
6. recordkeeping requirements
7. reiteration of applicable administrative guidelines
8. any special procedures that may be required.

A.5 RECORDKEEPING

The purpose of recordkeeping is to help the RPO 1) document the radiation doses received by personnel and 2) assess trends in the rate at which doses are being received over time. Recordkeeping also allows the RPO to compare the doses received by staff members who are working on similar projects and in this way to learn which techniques result in the lowest doses to workers. It can also make possible intercomparisons of doses received during similar projects at different facilities.

CHAPTER 4. RADIATION SURVEY PROGRAMS

4.1 SURVEY REQUIREMENTS 4.6

4.1.1 Facilities That Require a Survey Program 4.6

4.1.2 Areas Within a Facility That Require a Survey Program . 4.6

A. Radiation Areas 4.6

B. Controlled Areas 4.7

C. Uncontrolled Areas 4.7

4.1.3 Frequency of Surveys 4.7

4.2 ROUTINE SURVEY PROCEDURES 4.8

4.2.1 Preparation 4.8

A. Gathering Information 4.8

B. Diagramming the Facility 4.10

C. Preparing an Inspection List 4.10

D. Obtaining Equipment and Material 4.12

4.2.2 Inspection and Measurement 4.12

A. Inspection 4.12

B. Measurements 4.13

4.2.3 Evaluation and Recommendations 4.13

4.2.4 Survey Records and Reports 4.13

4.3 SPECIFIC MONITORING PROCEDURES 4.14

4.3.1 Measurements of Radiation Fields 4.15

4.3.2 Measurements of Contamination 4.15

A. Direct Measurements 4.15

B. Indirect Measurements 4.16

C. Action Levels and Reporting 4.17
4.3.3 Leak Testing Sealed Sources 4.17
A. Direct Leak Testing 4.18
B. Indirect Leak Testing (Container Interior) . . . 4.18
C. Indirect Leak Testing (Container Exterior) . . . 4.19
4.3.4 Personnel Monitoring 4.19
A. Contamination 4.20
B. Internal Exposure 4.20
C. External Exposure 4.21
4.3.5 Air Monitoring 4.21
4.3.6 Tritium Monitoring 4.21
A. Water 4.22
B. Urine 4.22
C. Surfaces 4.23
D. Air 4.23
4.4 NONMEDICAL X-RAY INSTALLATIONS 4.23
4.4.1 Classification of Nonmedical X-Ray Installations . . 4.24
A. Protective Installation 4.24
B. Enclosed Installation 4.24
C. Unattended Installation 4.24
D. Open Installation 4.25
4.4.2 Engineered Safeguards 4.25
A. Protective Installation 4.25
B. Enclosed Installation 4.26
C. Unattended Installation 4.26
D. Open Installation 4.27

4.4.3 Administrative Controls 4.27

A. Training 4.27

B. Standing Operating Procedures 4.27

C. Operation and Maintenance Logs 4.28

D. Radiation Area Requirements 4.28

4.4.4 Survey of Nonmedical X-Ray Installations 4.28

A. Frequency 4.28

B. Procedure 4.29

C. Radiation Survey Report 4.29

4.5 ENVIRONMENTAL SURVEY PROGRAMS 4.30

REFERENCES 4.31

APPENDIX A - MAXIMUM PERMISSIBLE CONTAMINATION LEVELS FOR INANIMATE OBJECTS 4.33

CHAPTER 4. RADIATION SURVEY PROGRAMS

Routine survey programs are used to evaluate actual or potential radiation hazards at facilities where radiation sources are used. Surveying and monitoring are ways of maintaining radiation exposure to personnel and the environment at a level that is as low as is reasonably achievable (ALARA) within applicable dose-equivalent limits.

The terms "radiation survey" and "radiation monitoring," although frequently used interchangeably, are not synonymous. A radiation survey is an evaluation, under specific conditions, of the radiation hazard associated with the production, use, or storage of radioactive materials or other sources of radiation. Radiation surveys are conducted both in the working environment and in the environment surrounding a facility. Radiation monitoring, an activity frequently performed during a survey, is the measurement of radiation fields or radioactive contamination using fixed or portable instruments. Radioactive contamination can be defined as any radioactive material that has escaped from its intended location or container, or as the deposition of radioactive material in any place where it is not desired, and particularly in any place where its presence might be harmful. Radioactive contamination can be any combination of alpha-, beta-, gamma-, or neutron-emitting radionuclides. Radiation surveys and radiation monitoring are usually performed by the Radiation Protection Officer (RPO) or a member of the radiation protection staff.

Survey requirements and procedures for facilities where radiation sources or radioactive materials are produced, used, or stored are discussed in this chapter. Specific radiation monitoring procedures are also described, as are special requirements for facilities that house nonmedical x-ray units. The objectives and development of environmental survey programs are discussed briefly at the end of the chapter.

Section 4.1 SURVEY REQUIREMENTS

Radiation surveys are recommended or required for certain types of facilities and for specific areas within those facilities. The frequency of surveys varies depending on the facility, area, and other factors.

4.1.1 Facilities That Require a Survey Program

A routine survey program should be considered for any facility where the radiation level may be higher than the natural background level. A survey program is required for facilities that contain the following specific sources:

1. radioactive solids that exceed 1 μCi in activity, that have a specific radioactivity exceeding 0.002 μCi/g, or that emit radiation at a dose rate of 0.1 mrad/hr or more at contact
2. materials controlled by the Nuclear Regulatory Commission (NRC), in quantities that exceed those listed in Title 10 of the U.S. Code of Federal Regulations, Section 30.71, Schedule B (10 CFR 30.71)
3. machines that produce radiation, for example, x-ray devices, accelerators, and electron microscopes
4. radioactive gases or liquids in concentrations that exceed the values listed in 10 CFR 20, Appendix B, Table II
5. items activated in nuclear reactors, by accelerators, or by nuclear weapons.

4.1.2 Areas Within a Facility That Require a Survey Program

Facilities are generally divided into a series of sequential areas according to the radiation hazard in each area. The designations of these areas helps control personnel exposure to radiation. The areas used are: 1) radiation areas, 2) controlled areas, and 3) uncontrolled areas. Each of these areas should be surveyed by a member of the radiation protection staff. The areas are described briefly below and more fully in Chapter 8, "Selection of Radiation Facilities."

A. Radiation Areas. Radiation areas include three subclassifications: radiation areas, high-radiation areas, and airborne-radioactivity areas.

A radiation area is defined in 10 CFR 20 as any area accessible to personnel in which radiation levels could result in a major portion of the body receiving a dose in excess of 5 mrem in any 1 hour or 100 mrem in any 5 consecutive days. Practically, this would be any area in which the dose-equivalent rate is greater than 2 mrem/hr but less than 100 mrem/hr. A high-radiation area is any area accessible to personnel in which radiation levels could result in a major portion of the body receiving a dose in excess of 100 mrem in any 1 hour. An airborne-radioactivity area is any area, enclosure, or operating area in which airborne radioactivity exceeds the concentrations specified in 10 CFR 20, Appendix B, Table 1, Column 1 or in which the concentration of airborne radionuclides, averaged over the number of hours an individual works, will exceed 25% of the amounts specified in 10 CFR 20, Appendix B, Table 1, Column 1.

B. Controlled Areas. Controlled areas are areas controlled for the purpose of protecting personnel from exposure to radiation. Normally, they are areas adjacent to radiation areas. They are usually free of contamination, but they could become contaminated because of accidental spreads or releases from the radiation area or because radionuclides and contaminated equipment may be transported through them.

C. Uncontrolled Areas. Uncontrolled areas are areas where direct radiation exposure is not necessary or anticipated in the performance of a job. These areas include "cold" laboratories (those containing no activity), offices, lunchrooms, conference rooms, and reception areas. Access to these areas does not need to be restricted for radiological reasons.

4.1.3 Frequency of Surveys

Radiation areas, high-radiation areas, and airborne-radioactivity areas should be surveyed at least once each month. Permanent storage areas may be exempted from monthly surveys at the discretion of the Ionizing Radiation Control Committee (IRCC). However, the time between surveys of storage areas may not exceed 12 months. Controlled areas should be surveyed on a routine basis.

The frequency of surveys should increase if changes in conditions or procedures could increase the possibility of personnel exposure. Daily surveys

or continuous monitoring may be required if conditions are highly variable or unpredictable, if unsealed radioactive materials are being handled directly, or if a radiation accident has occurred.

Surveys should be conducted before an operation involving radiation sources is begun and before changes in an existing operation are approved. A survey is also required at the termination of a project involving the use of radiation, to verify that no contamination exists and that radiation sources and radioactive materials have been properly stored or disposed of.

All sealed sources in quantities larger than the quantities listed in 10 CFR 30.71, Schedule B, must be leak tested at least every 6 months, unless specifically exempted by a DA authorization or an NRC license. Alpha sources in quantities larger than those listed must be tested every 3 months, unless otherwise exempted.

Section 4.2 ROUTINE SURVEY PROCEDURES

An effective routine survey program includes the following steps: 1) preparation, 2) inspection and measurement, 3) evaluation and recommendations, and 4) completion of records and reports. These steps are described in detail below. Special considerations for the survey of facilities containing nonmedical x-ray devices are considered in Section 4.4.4.

4.2.1 Preparation

It is essential that adequate preparation be made before any routine survey is conducted. The member of the radiation protection staff who is conducting the survey must be thoroughly familiar with the sources of radiation and the nature and purpose of the work performed in the facility. The steps for complete preparation are: 1) gathering information, 2) diagramming the installation, 3) preparing an inspection list, and 4) obtaining necessary equipment and material.

A. Gathering Information. Preparation for a survey should begin with the gathering of information about the radiation sources present, their intended use, and the physical safeguards and written procedural controls used to

minimize personnel exposure to radiation. This information can be obtained by talking to personnel and by examining plans, drawings, records, and written procedures. A file containing all information pertinent to a particular facility or work area should be maintained. Examples of the types of information to be obtained and filed are:

1. the types and numbers of sources used (e.g., sealed sources, unsealed sources, or radiation-generating devices)
2. the types and energies of radiation produced by the sources, together with any information about absorbers or moderators used to alter the initial energy spectra
3. the geometry, size, and position of radiation fields
4. the direction of beams produced by radiation-generating devices
5. the chemical composition and physical form of radioactive materials
6. the expected type(s) of radiation and/or contamination (e.g., alpha, beta, gamma, neutron)
7. the potential for release or dispersion of radioactive material
8. the procedures and the nature of the facilities used for the storage, handling, transportation, and disposal of radiation sources and radioactive material
9. the design and construction of devices for containing unsealed radioactive materials and sources (e.g., hoods or glove boxes)
10. the design of ventilation and exhaust systems
11. the design of interlock, alarm, and emergency shutdown systems
12. the nature of fixed monitoring equipment used in the facility
13. the locations inside and outside the facility that are occupied by personnel, and whether persons potentially exposed there are classified as occupationally or nonoccupationally exposed
14. protective barriers used for exposure control
15. standing operating procedures (SOPs)
16. previous survey records

17. emergency plans

18. the training and experience of personnel working with the radiation sources.

B. Diagramming the Facility. The second step in preparing for a survey is to make a diagram of the facility showing the location of radiation areas, controlled areas, and uncontrolled areas. The relative position of sources, work areas, waste storage areas, and disposal areas within radiation areas should also be shown. Such a diagram can be useful in identifying locations where radiation measurements should be made. The location of the following items should be included on the diagram when appropriate:

1. radiation sources, radiation-generating devices, and radioactive materials

2. the direction of beams produced by radiation-generating devices

3. radiation areas, controlled areas, and uncontrolled areas

4. protective barriers (e.g., ropes, shielding)

5. interlocks, alarms, emergency shutdown systems, and warning signs

6. equipment, such as hoods and glove boxes, used to contain unsealed radioactive sources and materials

7. waste storage and disposal areas

8. ventilation and exhaust systems

9. monitoring equipment.

C. Preparing an Inspection List. After reviewing all the information related to the facility, the radiation protection staff member conducting the survey should list all the items to be inspected during the survey. The inspection should include a review of the adequacy of procedural controls and physical safeguards used to control personnel exposure, and verification that all radiation protection procedures are being complied with. A review of the lists above can be useful in preparing the inspection list. Examples of items that could be included are:

1. the presence, location, use, and physical integrity of each radiation source

2. the means of identifying each radiation source (e.g., serial number, type, activity, size, room location)
3. the presence and adequacy of required protective barriers (e.g., ropes, shielding)
4. the possibility of inadvertent movement or removal of shields
5. the possibility of change in the orientation of beams produced by radiation-generating devices, or of any change in the position of sources
6. the availability, condition, and use of safety and special-handling equipment (e.g., portable shields, remote-control devices, hoods, protective clothing, showers)
7. the possibility of the introduction of radioactive materials into the facility's effluent stream because of improper air flow or water drainage
8. the adequacy of facilities and procedures for retaining and/or disposing of radioactive waste
9. the facility's design, including traffic flow, any restriction of access or exits, ventilation, the type of surface finish, the location and type of water outlets, and the accessibility of shutoff valves or switches for air conditioning, electricity, water, gas, etc.
10. the presence, correct functioning, and use of protective devices (e.g., interlocks, warnings devices, evacuation alarms, ventilation failure alarms, emergency shutoff switches)
11. the possibility of bypassing protective devices without adequate warning
12. the posting of radiation areas
13. the correct labeling of radioactive materials and radiation sources
14. the adequacy of and compliance with procedures for controlling personnel radiation exposure and for controlling the spread of contamination during the handling, storage, transportation, and disposal of radioactive sources

15. the availability, adequacy, and correct functioning, calibration, and use of survey and monitoring equipment

16. the adequacy of and compliance with routine survey and monitoring procedures

17. the existence, adequacy, and display of emergency plans and the familiarity of personnel with these plans

18. the status of personnel radiation protection training.

D. Obtaining Equipment and Material. After evaluating what type of radiation and/or contamination (alpha, beta, gamma, neutron) can be expected, the surveyor should decide what radiation detection and measurement equipment is needed. The information in Chapter 2 of this manual, "Radiation Instrumentation," is useful for this determination. Other miscellaneous equipment and materials may be needed, for example, clipboards, survey report forms, smears, protective clothing, shoe covers, and disposable plastic gloves.

4.2.2 Inspection and Measurement

When adequate preparation has been made, the inspection can be started and measurements made. The radiation protection staff member who is responsible for conducting the inspection and making radiation measurements should be aware of the controls needed to ensure that his/her own radiation exposure is kept ALARA. Personnel dosimeters, protective clothing, and respiratory equipment should be used when appropriate, and the surveyor should ensure that radiation generators, source-shielding mechanisms, or source-handling equipment cannot be operated except under his/her control during the survey.

A. Inspection. The inspection of a facility is conducted to: 1) provide firsthand knowledge of the installation, personnel, surroundings, radiation sources, and equipment; 2) assess where radiation measurements should be made; and 3) assess the presence and effectiveness of each physical safeguard and the extent of compliance with procedural controls used for radiation protection. The checklist prepared prior to the start of the survey should be useful in identifying the items to be inspected. The surveyor should be alert for any deviation from written plans and procedures.

B. Measurements. The places identified for measurements during the facility inspection should be monitored for contamination, and measurements of the radiation field produced by sources should then be made. Specific monitoring procedures are described later in this chapter.

4.2.3 Evaluation and Recommendations

When all inspections and measurements have been made, the results should be evaluated to determine the overall radiological status of the facility. The evaluation should include a determination of any significant levels of contamination and any significant dose rates produced by sources, and the identification of any deficiencies in the radiation protection program. Recommendations for corrective action should be made so that dose equivalents are kept ALARA. Such recommendations may include changes in:

1. operational factors (e.g., time spent by personnel in radiation areas, equipment use time, or methods of operation)
2. shielding (e.g., size, thickness, type of material, or location)
3. manipulative equipment, particularly relating to the equipment's speed of operation and the distance of personnel from sources
4. procedural controls, particularly those that eliminate unnecessary personnel exposure or contamination
5. personnel protection or warning devices
6. survey and monitoring procedures
7. personnel monitoring and survey equipment
8. plans of action for accidents or emergencies
9. personnel training.

A resurvey may be needed after corrective action is taken, to ensure that the changes made are effective.

4.2.4 Survey Records and Reports

Records of radiation surveys are needed for assessing the effectiveness of the radiation protection program. They may also be useful in interpreting the

results of personnel monitoring. Survey reports should contain the following information:

1. date and time of the survey
2. general location of the survey (building and room)
3. specific locations and objects where radiation measurements were made
4. purpose of the survey (e.g., leak test of sealed source; routine survey for contamination on floors and other surfaces; or survey to establish dose rates to personnel)
5. identification (type and serial number) of the radiation detection instruments used to perform the survey
6. measurement results and conditions observed (e.g., dose rates and contamination levels)
7. conclusions and recommendations
8. identification of the individual performing the survey.

A facility diagram may be attached directly to the report and used to note the dose rates and contamination levels observed during the survey.

More information on records of surveying and monitoring activities can be found in Chapter 13, "Recordkeeping." The degree of detail included in survey records must be sufficient to make them meaningful after the passage of several years. Records should be kept for at least 5 years.

Section 4.3 SPECIFIC MONITORING PROCEDURES

Procedures for measuring radiation fields and contamination, for leak testing sealed sources, and for personnel monitoring, air monitoring, and tritium monitoring are described below. Information on the instrumentation for these procedures is given in Chapter 2, "Radiation Instrumentation."

4.3.1 Measurements of Radiation Fields

Measurements of radiation fields--the areas around sources that receive radiation from the sources--are made to provide a basis for estimating personnel exposure and for determining the effectiveness of procedures used for radiation protection. The number of measurements to be made depends on how much people move about within a given field and how much the field varies in space and time. If the radiation field is fixed, as in many x-ray installations, few measurements are required. However, if the radiation pattern is variable, such as during the removal of a source from a shielded container, more measurements are required. In the extreme case, it may be necessary to continuously monitor work in progress. The intensity of the radiation should be measured using dose rate instruments in locations occupied by personnel. The measurements should be recorded on a data sheet or on a floor plan corresponding to the area monitored and should be compared with specified limits.

Procedures for calculating external exposure are discussed in Chapter 6. It may be useful, when planning the control of an individual's occupational exposure, to compare short-term measurements in a radiation field with estimates of the dose equivalent that would be received by an individual who worked in that field for extended periods of time. For example, if the maximum dose-equivalent rate for a particular radiation field is 10 mrem/hr, and if an individual worked in that field for 5 hours each week, the expected dose-equivalent rate would be: 10 mrem/hr x 5 hr/wk = 50 mrem/wk. The results of this type of conversion can be compared directly with applicable administrative or regulatory limits.

4.3.2 Measurements of Contamination

Familiarity with the work performed in a radiation area is essential for determining what type of surface contamination is most likely to be present, where it is likely to be, and whether it is likely to be fixed or removable. Fixed, or nonremovable, contamination contributes to external exposure. Removable contamination can enter the body and contribute to internal exposure.

Because removable contamination can be spread and presents an internal hazard, the member of the radiation protection staff who is measuring the contamination must be careful to avoid both exposure to himself and the spread

of contamination. The surveyor should wear adequate protective clothing during the survey, taking care to avoid contamination of hands, clothing, and radiation detection instruments. When only gamma radiation is present, the detection instrument can be entirely covered by a thin plastic material for contamination control. The sensitive areas of the detector must not be covered when alpha radiation is present. Shoe covers, gloves, instruments, and other equipment used during an extensive survey should be monitored periodically during the survey. As soon as the entire survey has been completed, protective clothing should be removed and surveyed for contamination, together with the instruments and equipment used.

Direct measurements using portable instruments can be used to determine the total amount of fixed and removable contamination present. An indirect measurement technique is used to detect removable contamination. These two techniques are described below.

A. Direct Measurements. Any area within a facility where there may be contamination should be systematically monitored with a sensitive detection instrument. During the measurement, the probe should be held close to (within 0.6 cm of) the surface. To prevent instrument contamination and damage, the probe must not contact the surface. The probe should be moved slowly over the surface to allow the instrument time to respond. Instrument readings should be recorded on a data sheet or on a floor plan of the area being monitored.

B. Indirect Measurements. A smear taken from a surface that may be contaminated can be used to monitor for removable contamination. A smear test is considered an indirect measurement of contamination.

To perform a smear test, a floor plan of the facility to be monitored is needed, as well as small pieces of paper, such as filter paper discs, to be used as smears. A smear is taken by wiping a 100-cm^2 portion of the surface to be monitored. The items or areas from which smears are taken are identified on the floor plan. The smear should be removed from the facility being monitored and counted according to specified laboratory procedures.

Care should be taken to avoid touching either the surface being monitored or the contaminated side of the smear, and to keep the probe from touching the smear. Cross-contamination of the smears can be avoided by placing each smear

in an individual envelope immediately after the smear is taken. Smears should be treated as radiation sources and handled according to radiological safety procedures.

C. Action Levels and Reporting. The results of monitoring for both fixed and removable contamination should be compared with the contamination limits given in Appendix A. The actions to be taken if the levels found exceed the limits are also identified in the table.

4.3.3 Leak Testing Sealed Sources

The instruments and supplies needed for leak testing sealed sources are 1) a remote-handling tool, 2) sheets of paper with impermeable backing (or sheets of ordinary paper and sheets of polyethylene film), 3) discs of filter paper that have a high wet strength (for making smears), 4) envelopes, 5) rods of wood, plexiglass, aluminum, or some other material, 6) adhesive tape, and 7) a radiation detection instrument.

Before a leak test is begun, a data sheet should be started that includes a description of the source, the type of leak test to be performed, the date of the leak test, and the name of the person performing the test. Space should be left on the data sheet so that the results of the leak test in μCi and any action taken as a result of the test can be recorded later.

Leak testing should be planned so that the surveyor's exposure is kept to a mimimum. The dose rates at given distances from the source should be calculated so that shielding needs, the length of the remote-handling tool needed, and the time allowable near the source can be determined. A rule of thumb is to plan an operation so that the person performing a test or a series of tests does not receive a whole-body dose in excess of 5 mrem. "Dry runs" can be performed if desired.

It is always a safe procedure to assume that a source is leaking and to assess the physical provisions and operations that would be needed to deal with a contamination incident. Knowing the construction of the source is important so that leak testing does not damage the source. Protective rubber gloves should be worn during the test.

A. Direct Leak Testing. This method is applicable to sealed sources that are not in a container, or that are in a container but are not fastened in it, and that can be handled safely with available equipment and facilities. The total whole-body dose received during the test should not exceed 5 mrem. This procedure must be performed in a hood or glove box rather than on an open bench top to prevent possible contamination of the work area.

A sheet of impermeable paper (or paper backed with a polyethylene sheet) should be placed on the working surface and taped down if necessary, to prevent contamination of the working surface if the source is leaking. A clean filter paper disc should be marked to indicate the particular source being leak tested. If the source contains water-soluble radioactive material, the filter paper smear should be dampened with distilled water.

When a contained source has been removed from its shielded container, using the appropriate remote-handling tool and observing applicable radiological safety procedures, all of its surfaces should be carefully wiped. The source should then immediately be replaced in its container. Dry smears (or wet smears that have been allowed to dry) should be checked with an instrument that monitors low levels of alpha or beta-gamma radiation, as appropriate. Readings should be taken with the open window of the probe near the smear but not touching it. If contamination is detected, the source is likely to be leaking, and precautionary measures should be taken to avoid unnecessary exposure of personnel until the situation has been fully evaluated. The smear should be counted according to specified laboratory procedures in order to obtain quantitative results.

B. Indirect Leak Testing (Container Interior). This method is applicable to sealed sources that are not in a container, or that are in a container but are not fastened in it, and that have activity levels that prevent safe direct leak testing with existing equipment and facilities. The test or series of tests should be planned so that the radiation protection staff member performing it does not receive a whole-body dose in excess of 5 mrem.

For this test, a contained source is removed from its normal shielded container and transferred to an alternate shielded container or temporary shielding set up specifically for this purpose. An appropriate monitoring

instrument should be used to ensure that the source in the temporary housing is adequately shielded. In addition, instruments for monitoring low-range beta-gamma or alpha radiation should be used to monitor accessible surfaces of the empty container. Any positive readings should be recorded, and if contamination is detected, further precautionary measures should be taken before the leak test is continued.

For this test, smears of the inside surfaces of the empty source container are taken, particularly of areas normally in direct contact with the source. The smearing device should consist of a rod (of wood, plexiglass, aluminum, or other material) long enough to reach the area to be wiped, with a filter paper smear attached to one end. If the source contains water-soluble radioactive material, the filter paper should be moistened with distilled water. The wet or dry smear should be rubbed on the inside surfaces of the empty container, especially on the surfaces that most closely contact the source. Dry smears, or dried wet smears, should be checked with a low-range beta-gamma or alpha-monitoring instrument, the readings taken with the open window of the probe near the smear. If contamination is detected, steps should be taken to prevent unnecessary exposure of personnel until the situation has been fully evaluated. The smear should be counted according to specified laboratory techniques in order to obtain quantitative measurements.

C. Indirect Leak Testing (Container Exterior). This method is applicable to sealed sources that are fastened in a container. It is also applicable to other sealed sources that cannot be leak tested safely with existing facilities and equipment.

The portions of the shielded container or device where contamination would be expected to appear if the sealed source were leaking should be smeared using the rod-and-smear device described above. All applicable radiological safety procedures should be observed, and the smear should be counted in the same manner as used for the interior indirect leak test.

4.3.4 Personnel Monitoring

Personnel are monitored to determine whether contamination is present on them and to measure internal and external exposure. Personnel monitoring

serves two purposes: 1) to assure that all exposures are maintained ALARA, and 2) to identify any unsuspected source of exposure so that prompt corrective action can be taken.

A. Contamination. Personnel must be monitored for contamination before leaving any area in which radioactive materials or sources are used or stored. If an individual is contaminated, follow-up surveys must be made to determine the source of contamination and to detect any contamination that may have been spread by the individual. Prompt corrective action must be taken to eliminate the source of contamination.

A sensitive detection instrument should be used to monitor personnel. Skin and clothing should be carefully monitored, with an emphasis on the head, hands, and feet. Any point that shows visible signs of contact, such as dirt, grease, or liquid stains, should be monitored. In addition, any surface known to have come in contact with equipment or contaminated surfaces should be monitored.

The probe of the instrument should be held close to the individual's skin or clothing but must not be allowed to contact it. The probe should be moved slowly to allow time for the instrument to respond.

B. Internal Exposure. The principal objective of internal personnel monitoring is to determine whether radionuclides have entered the body. The routine determination of internal contamination is necessary only in facilities where unsealed radioactive materials may become airborne. Internal personnel monitoring should also be considered whenever a routine survey indicates significant levels of contamination.

Internal dose is determined using two indirect methods: 1) radiochemical analysis, which is the measurement of radioactivity in urine, feces, blood, secretions, and body tissues; and 2) in-vivo (or whole-body) counting, which is the measurement of radiation emitted from the body, using an external detector. These procedures are highly specialized. More information on their use and on the control of internal exposures is provided in Chapter 5, "Internal Exposure."

C. External Exposure. The external whole-body dose to an individual is estimated using personnel dosimeters. A personnel dosimeter should be worn by each individual who is occupationally exposed to sources of ionizing radiation. Dosimeters must be worn in radiation areas and should be worn by anyone who periodically enters a controlled area and is likely to receive more than 5% of the quarterly dose-equivalent limit listed in Table 3.2 (Chapter 3). An individual under the age of 18 who enters a controlled area and is likely to receive more than 5% of the quarterly dose-equivalent limit for minors should also use a personnel dosimeter. The dosimeters designated by the DA and other methods of controlling external exposures are described in Chapter 6, "External Exposure."

4.3.5 Air Monitoring

The purpose of air monitoring is to determine the cleanliness of the air in the work area. The need for stringent controls on airborne radioactivity should be stressed in SOPs. High concentrations of airborne radioactive contamination can lead to contamination of surfaces in a facility or the environment, and can result in internal exposure to personnel.

Inhalation is the principal means by which radioactive materials can enter the body. The amount of material deposited in the body depends largely upon the concentration in the air inhaled, the particle size of the contaminant, and the length of time the individual is exposed. Control levels for various isotopes are given in 10 CFR 20, Appendix B, Table I. To determine whether control levels are being met, routine air samples are collected and evaluated.

Criteria for the development of an air monitoring program are given in Chapter 5. Several useful references are included in the bibliography. Equipment used to monitor air is discussed in Chapter 2, "Radiation Instrumentation."

4.3.6 Tritium Monitoring

Tritium is a radioisotope of hydrogen that decays to helium by the emission of a beta particle with a maximum energy of 18 keV and an average energy of 5.7 keV. The weak beta particle has a maximum range of 6 μm in water or

0.5 cm in air. When released to the environment, tritium can enter biological materials by several routes. It can be taken into the body in water, in foods, or as tritium or tritium oxide in inhaled air. In both gaseous and liquid forms, tritium can readily penetrate directly through human skin surfaces. Tritium's ability to be readily incorporated into biological systems makes it of concern from the standpoint of internal exposure.

The low energy of the beta particle emitted by tritium creates a special monitoring problem. Portable detection instruments cannot be used because the distance between the tritium source and the detector is usually greater than the particle's range, and even in detectors with a window, the window may be too thick to be penetrated by the beta particle. Windowless gas-flow proportional counters and liquid scintillation counters are therefore used to assay, or test, for tritium. In the special case of tritium gas, ionization chambers may be used. These instruments are described in Chapter 2, and their application for monitoring tritium levels in water, in urine, on surfaces, and in air is reviewed briefly below. Additional references specific to tritium measurements are provided in the bibliography at the end of the manual.

A. Water. The maximum permissible concentration (MPC) of tritium in drinking water is 3×10^{-9} µCi/ml (10 CFR 20, Appendix B). This MPC corresponds to 110 disintegrations per second in each ml of water (dps/ml). Liquid scintillation counting is the method of choice for measuring tritium in water.

B. Urine. A radioassay for tritium in urine should be performed every 2 weeks for all personnel who routinely work with tritium, and immediately following any unusual occurrence involving the spread of tritium contamination. If tritium is found in urine, additional urine samples should be obtained daily to determine the biological half-life of the tritium deposited in the body. Biological half-lives between 7 and 12 days are commonly observed.

Several hours are needed before tritiated water becomes equally distributed throughout the body. Consequently, urine samples should not be taken immediately after a potential tritium inhalation. Generally, 2 to 4 hours should elapse between the time of the exposure and the time of sample collection. When a urine sample is collected, personnel should remove all protective

clothing and wash their hands to avoid contaminating the sample. The urine sample should be placed in an air-tight container and refrigerated. Liquid scintillation counting is used for the radioassay of tritium in urine.

C. Surfaces. Because the energy of the beta particle emitted by tritium is too low to allow the particle to enter portable detectors, a smear test should be used to monitor for surface contamination. The procedure is similar to that described in Section 4.3.2 except that the smear should be lightly coated with glycerin or moistened with water to increase its efficiency in collecting contamination. Smears should be placed into vials immediately after each sample is taken. The sample can be counted using liquid scintillation.

D. Air. In air, tritium occurs primarily as water vapor or hydrogen gas. Flow-through ionization chambers and proportional counters can be used to monitor air for tritium. Ionization chambers cannot distinguish tritium from some other types of radioactive particles and are sensitive to interference from cigarette smoke, aerosols, and external gamma fields. Gas-flow proportional counters can partially discriminate against other radionuclides and are less sensitive to aerosols. The sensitivity of ion chambers is similar to that of gas-flow proportional counters (in the pCi/cm^3 range). To detect tritium levels much below about 1 pCi/cm^3 in air, it is necessary to remove tritiated water vapor from the air using silica gels and bubblers. Information on this procedure is given in Report No. 47 of the National Council on Radiation Protection and Measurements (NCRP 1976). Liquid scintillation counting can be used to assay the water vapor samples.

Section 4.4 NONMEDICAL X-RAY INSTALLATIONS[a]

X-ray equipment poses a potential hazard, both for those who operate it and for those who may be in the vicinity, because of the extremely high dose rates generated by the devices at the flip of a switch. Extensive engineered safeguards and administrative controls are used to minimize normal operating

(a) For this section of the manual, an installation is defined as the space occupied by a radiation-generating source with its associated equipment.

exposures and prevent accidental exposures. Radiation protection is accomplished through the combined efforts of the manufacturers of the devices, the designers and builders of the installations where the devices are used, the operators of the equipment, and radiation protection personnel.

Requirements for the design and operation of x-ray installations are discussed in two reports of the American National Standards Institute, ANSI N543-1974 and ANSI N537-1976. Installations, including necessary shielding, should be designed by a qualified expert and should meet applicable regulations of federal, state, and local agencies.

This section describes the classification of nonmedical x-ray installations, the engineerec and administrative safeguards used in them to minimize exposures, and procedures for surveying them. A discussion of surveys for medical x-ray installations is beyond the scope of this manual; information on this topic can be found in NCRP Report No. 33 (1968).

4.4.1 Classification of Nonmedical X-Ray Installations

Installations are divided into four classes, which are described briefly below and in greater detail in ANSI 543-1974. A separate classification for x-ray diffraction and fluorescence analysis equipment is described in ANSI N43.2-1977.

A. Protective Installation. An x-ray unit within a permanent, shielded enclosure is considered a protective installation if the exposure rate at any accessible surface of the enclosure is less than 0.5 mR/hr during operation of the device. Personnel may not remain inside the enclosure during irradiation.

B. Enclosed Installation. An enclosed installation is similar to a protective installation in that the x-ray unit is within a permanent, shielded enclosure. However, a higher exposure level is allowed for this class of installation. The exposure rate at any accessible, occupied area 30 cm from the outside surface of the enclosure must not exceed 10 mR/hr and the exposure rate at any accessible but normally unoccupied area may not exceed 100 mR/hr. During operation of the device, personnel may not remain inside the enclosure.

C. Unattended Installation. An x-ray unit in a shielded enclosure that is small enough to prohibit personnel occupancy is considered an unattended

installation if the exposure rate 30 cm from the outside surface of the device does not exceed 2 mR/hr during operation of the unit. The shielded enclosure may not be used for any purpose other than to enclose the x-ray unit.

D. Open Installation. An x-ray unit that is not in a shielded enclosure and that is located in an area that may potentially be occupied by personnel during operation of the device is considered an open installation.

4.4.2 Engineered Safeguards

Engineered safeguards are safety systems such as warning devices, shields, and interlocks that are built into either the x-ray installation or the x-ray device itself. They should be designed by a qualified expert in accordance with the requirements of the installation class. The fail-safe principle is used whenever possible in the design and construction of safety systems. A fail-safe system is a system in which any malfunction, including malfunction of the safety system, causes the device to stop functioning or to fail in a manner that does not expose personnel to radiation.

Examples of the engineered safeguards required for each installation class are described below. Greater detail can be found in ANSI N543-1974. Engineered safeguards for x-ray diffraction and fluorescence analysis equipment are described in ANSI N43.2-1977.

A. Protective Installation.

1. Each machine must be totally enclosed within physical barriers that have sufficient shielding to reduce exposure rates during operation to less than 0.5 mR/hr at all points accessible to personnel.
2. All entrances to the installation must have a fail-safe interlock system that prevents inadvertent entry during machine operation.
3. The enclosure must be equipped for emergency exit when the doors are locked from the outside. A least one clearly marked scram button (emergency power-cutoff switch) must be located conspicuously in the exposure room. Enough switches must be installed to allow a person to reach a switch within 5 sec after a warning alarm is activated. The purpose of the scram button must be clearly marked.

4. Fail-safe visible and audible warning signals within the enclosure must be actuated at least 20 sec before irradiation begins. The visible signal must stay on during the entire operation of the equipment. Specifications for audible signals are provided in ANSI N2.3-1967.

5. A steady red light activated by the control circuit must be located outside the entrance to each enclosure. A warning sign showing the radiation symbol and the words "Caution: Entering Radiation Exposure Room" must also be posted.

B. Enclosed Installation. The engineered safeguards for protective installations also apply to enclosed installations with the exception of item 1 pertaining to exposure rates. For enclosed installations, each machine must be totally enclosed within physical barriers that have sufficient shielding to reduce operational exposure rates at all accessible and occupied points to less than 10 mR/hr and at all accessible but normally unoccupied points to less than 100 mR/hr. The following additional safeguards are also necessary:

1. All accessible areas in which the exposure rate exceeds 5 mR/hr must be posted with a sign showing the radiation symbol and the words "Caution: Radiation Area."

2. All entrances to the installation must have a sign posted showing the radiation symbol and the words "Caution: Entering Radiation Area."

C. Unattended Installation.

1. The exposure rate at any accessible area 30 cm from the outside surface of the shielded device may not exceed 2 mR/hr during operation. Service doors to areas with exposure levels higher than 2 mR/hr must be locked.

2. The device must be posted with a sign showing the radiation symbol and the words "Caution: X-Rays."

3. A steady red light that is activated by the control circuit must be installed near the head and beam port(s) of each device.

4. All beam ports that are not in use must be secured in a closed position in a manner that prevents their casual opening.

5. The shielding must be secured in a manner that prevents its casual removal or the exposure of personnel.

D. Open Installation.

1. A steady red light that is activated by the control circuit must be mounted on or near the source of radiation.

2. Steady or flashing red lights activated when the device is operating must be located at the radiation area boundary in sufficient numbers to ensure that at least one is visible from each avenue of approach.

3. The perimeter of any area where the radiation level exceeds 5 mR/hr must be posted with a sign displaying the radiation symbol and the words "Caution: Radiation Area."

4. The radiation source and all exposed objects must be within a conspicuously posted perimeter that limits access to areas where the exposure rate is greater than 100 mR/hr. A sign displaying the radiation symbol and the words "Danger: High-Radiation Area" must be posted at the perimeter of this area. During periods of unattended irradiation, this area must be locked to prevent access.

4.4.3 Administrative Controls

Administrative controls are procedures used to minimize the radiation exposure of operating personnel. These procedures require the cooperation of radiation protection and operations personnel. Enclosed, unattended, and open installations require more extensive administrative controls than protective installations because of their higher potential exposure rate.

A. Training. All individuals who use x-ray equipment must be trained to operate it safely. Information on the content of a training program can be found in NCRP Report No. 61 (1978).

B. Standing Operating Procedures. An SOP should be prepared for each x-ray device. The SOP should be posted where it is easy to see, on or next to the console for the device, and should contain the following information:

1. the class of the installation
2. survey and monitoring requirements
3. a list of all required administrative and engineered safeguards
4. operating procedures
5. emergency procedures
6. a list of trained operators
7. the name of the individual responsible for the device.

C. Operation and Maintenance Logs. The individual responsible for an x-ray device should keep two log books: an operations log and a maintenance log. The operations log should contain a complete description of all work performed with the device. The maintenance log should contain a description of all maintenance work. All log entries should be signed and dated.

D. Radiation Area Requirements. X-ray units must be operated only within a radiation area. When a qualified operator is not present, the area must be locked or else the device must be locked prevent its unauthorized operation. Before using the device, the operator must make sure that only required personnel are present within the area and that any exposure of personnel within the area will be minimal.

4.4.4 Surveys of Nonmedical X-Ray Installations

Surveys of nonmedical x-ray installations should include both physical inspection of the facility and measurement of radiation levels. Each installation should be inspected to verify the current and expected occupancy of all areas surrounding the installation. Devices that affect radiation protection (e.g., audible and visible warning signals, shielding, interlocks, and devices that restrict the positioning of radiation sources) should be inspected to determine whether they are operating properly. Administrative controls for each class of installation should be reviewed.

A. Frequency. All new installations must be surveyed before routine operation is begun. Existing facilities should be surveyed every 6 months or whenever changes in the installation could affect radiation protection procedures.

B. Procedure. The RPO should maintain a list of all engineered and administrative safeguards necessary for the safe operation of each nonmedical x-ray installation. Before beginning a survey of an installation, the RPO or a member of the radiation protection staff should review this list and the general procedures outlined in Section 4.2. The following items should be included on the check list for the inspection:

1. Check for a posted, up-to-date SOP. All operators' names must be listed on the SOP.
2. Check for modifications to the device that may affect any safety system (e.g., shielding, interlocks).
3. With the device operating at full power, check for measurable beams of radiation at all appropriate locations. Measurements should be taken at all points accessible to personnel and in other normally occupied spaces, such as offices not related to machine operation. A strong effort must be made to maintain exposure rates ALARA even if they fall within stated guidelines. Thus, it is important to determine and document any exposure rate that could be reduced by administrative or engineered safeguards.
4. Test all engineered safeguards listed on the SOP, including interlocks, warning lights, alarms, and scram buttons.
5. Verify that the device is operated within a radiation area that is adequately posted.
6. Determine that all operators are trained.

C. Radiation Survey Report. A report of a radiation survey of an installation should include:

1. who conducted the survey and the date of the survey
2. the device and installation being surveyed, identified by suitable means (e.g., serial number, room number, and building number or name)
3. the survey instrument used and the date of its last calibration
4. the potential and current at which an x-ray tube was operated during the survey, and any measured x-ray beams

5. the classification of the installation
6. the location of the x-ray source and the orientation of the x-ray beam in relation to each exposure measurement (a diagram may be useful)
7. a description of all engineered and administrative safeguards along with a verification that they were tested or inspected
8. all deficiencies found during the survey and the corrective action to be taken.

Section 4.5 ENVIRONMENTAL SURVEY PROGRAMS

An environmental survey is a systematic investigation and measurement of radiation levels and radioactive contamination levels in the environment surrounding a facility. The objectives of an environmental survey program include:

1. assessment of the natural radiation and radioactivity levels in the environment before operations begin
2. assessment of the actual or potential exposure of man from the additional radioactive materials or radiation contributed to the environment by the facility, or estimation of the probable upper limits of such exposure
3. determination of the fate of contaminants released to the environment
4. detection of sudden changes and evaluation of long-term trends, which can indicate failure or lack of adequate control in the operation of the facility
5. demonstration of compliance with applicable regulations and legal requirements concerning releases to the environment.

The extent of an environmental survey program depends on several factors, including the nature of the facility, the type and quantity of radionuclides handled, and the potential for the release of radioactivity to the environment.

Environmental surveys should be conducted prior to the initiation of radiological operations at a facility and at least once a year thereafter. More frequent surveys may be needed depending on the scope and nature of the facility's activities. The results of an environmental survey should be used to determine any need to modify controls or operations.

The development of a survey program should include the following general steps:

1. Evaluate the facility as a source of direct radiation and radionuclides, especially the composition, concentrations, release rates, points of release, and physical and chemical forms of the nuclides.
2. Identify the pathways leading to exposure to man, using analytical models, the experience gained at other sites, and preoperational data on local meteorology, hydrology, and population distribution and diet.
3. Select the pathways (e.g., water, food, air) that may be most critical in terms of their contributions to exposure, and determine the critical population groups.
4. Determine the measurements required to provide data for dose assessment for normal and abnormal conditions.
5. Allow for flexibility in the program design. As operational experience is accumulated, other types of measurements or measurement frequencies may be desirable.

Details on establishing and carrying out environmental survey programs can be found in the bibliography.

REFERENCES

American National Standards Institute (ANSI). 1967. Immediate Evacuation Signal for Use in Industrial Installations Where Radiation Exposure May Occur. ANSI N2.3, New York.

American National Standards Institute (ANSI). 1974. General Safety Standard for Installations Using Non-Medical X-Ray and Sealed Gamma-Ray Sources, Energies up to 10 MeV. ANSI N543, New York. Also published in 1975 as National Bureau of Standards Handbook No. 114, Washington, D.C.

American National Standards Institute (ANSI). 1976. Radiological Safety Standards for the Design of Radiographic and Fluoroscopic Industrial X-Ray Equipment. ANSI N537, New York.

American National Standards Institute (ANSI). 1977. Radiation Safety for X-Ray Diffraction and Fluorescence Analysis Equipment. ANSI N43.2, New York. Also published as National Bureau of Standards Handbook No. 111, Washington, D.C.

American National Standards Institute (ANSI). 1978. Control of Radioactive Surface Contamination on Materials, Equipment, and Facilities to be Released for Uncontrolled Use. ANSI 13.12 (Draft), New York.

National Council on Radiation Protection and Measurements (NCRP). 1968. Medical X-Ray and Gamma-Ray Protection for Energies up to 10 MeV - Equipment Design and Use. NCRP 33, Washington D.C.

National Council on Radiation Protection and Measurements (NCRP). 1976. Tritium Measurement Techniques. NCRP 47, Washington, D.C.

National Council on Radiation Protection and Measurements (NCRP). 1978. Radiation Safety Training Criteria for Industrial Radiography. NCRP 61, Washington, D.C.

U.S. Code of Federal Regulations. 1982. Title 10, Part 20, "Standards for Protection Against Radiation." U.S. Government Printing Office, Washington, D.C.

U.S. Code of Federal Regulations. 1982. Title 10, Part 30, "Rules of General Applicability to Licensing of Byproduct Material." U.S. Government Printing Office, Washington, D.C.

U.S. Department of the Army, Headquarters, Army Materiel Command. Safety - Radiation Protection. DARCOM-R 385-25, Washington, D.C.

U.S. Department of the Army, Headquarters. Safety - Ionizing Radiation Protection (Licensing, Control, Transportation, Disposal, and Radiation Safety). AR 385-11, Washington, D.C.

APPENDIX A

MAXIMUM PERMISSIBLE CONTAMINATION LEVELS FOR INANIMATE OBJECTS[a]

Contaminated Item	Corrective Action	Maximum Alpha		Maximum Beta	
		Fixed[b] (dpm/100 cm^2)	Removable[c] (dpm/100 cm^2)	Fixed[b] (mrad/hr at 2.5 cm)	Removable[c] (dpm/100 cm^2)
1) Personal clothing, including shoes	Replace, decontaminate, or store until radioactive contamination has decayed if above:	200	None	0.05	None
2) Protective clothing					
a. General	Replace, decontaminate, or store until radioactive contamination has decayed if above:	1000	200	0.02	1000
b. Respirators	Replace, decontaminate, or store until radioactive contamination has decayed if above:	200	None	0.6	None
c. Laundry	Release only to licensed launderer if contaminated	-	-	-	-
3) Work areas and equipment[d]					
a. Uncontrolled	Control and post, then decontaminate if above:	200	30	0.05	100
b. Controlled	Decontaminate (or if decontamination is impossible, fix and then check fixation periodically) if above:				
(1) Areas		1000	200	0.2	400
(2) Hoods		1000	200	2.0	2000
(3) Glove boxes		5000	1000	2.5	5000
(4) Workbench surfaces		1000	200	0.5	400
(5) Other equipment		1000	200	2.0	2000
4) Tools, equipment, containers	Prior to nonradioactive use, decontaminate if above:	200	50	0.25	100
5) Vehicles					
a. Used in controlled areas	Decontaminate (or if decontamination is impossible, fix and then check fixation periodically) if above:	1000	300	0.4	500
b. Used in uncontrolled areas	Decontaminate if above:	500	30	0.25	100

(a) Reference: AMC 385-25 and AR 385-11. (Note: These limits may be changed to reflect those found in ANSI 13.12.)
(b) Measured with a calibrated radiation measurement instrument.
(c) Determined using smears analyzed with a calibrated counting system.
(d) For natural and depleted uranium and for ^{238}U, levels for alpha contamination should be increased by a factor of 5, in accordance with NRC guidelines. If ^{226}Ra is a contaminant, levels for alpha contamination should be reduced by a factor of 2.

CHAPTER 5. INTERNAL EXPOSURE

5.1 CONTROL OF INTERNAL EXPOSURE 5.4

5.1.1 Contamination Control Through Design Features . . . 5.4

5.1.2 Contamination Surveys During the Course of Work . . . 5.5

5.1.3 Decontamination of Contaminated Objects and Individuals . 5.5

5.1.4 Air-Sampling and Air-Monitoring Programs 5.6

5.1.5 The Use of Protective Apparel 5.7

A. Protective Clothing 5.7

B. Respirators 5.10

5.1.6 Administrative Guidelines 5.14

5.2 MONITORING INTERNAL EXPOSURE 5.17

5.2.1 Bioassay Programs 5.17

A. Preparatory Evaluation 5.17

B. Exposure Control 5.17

C. Diagnostic Evaluation 5.18

D. Removal of Work Restrictions 5.18

E. Termination of Employment 5.18

5.2.2 Action To Be Taken Upon Detection of an Intake . . . 5.18

5.3 INTERNAL DOSIMETRY CALCULATIONS 5.19

5.3.1 Calculation of Acceptable Intake 5.19

A. Determining the Critical Organ 5.20

B. Calculating the Maximum Permissible Body Burden . . 5.21

C. Calculating the Maximum Permissible Concentrations in Air and Water 5.21

5.3.2 Estimation of Internal Dose 5.21

A. Calculating the Initial Dose-Equivalent Rate to an Organ 5.22

B. Calculating the One-Year Dose Commitment Based on a Single In-Vivo Measurement 5.22

C. Calculating the Fifty-Year Dose Commitment . . . 5.23

REFERENCES 5.25

APPENDIX A - ICRP 30 RECOMMENDATIONS FOR LIMITING RADIONUCLIDE INTAKES 5.27

TABLES

5.1 Parameters for Internal Dosimetry 5.24

5.2 Weighting Factors Recommended in ICRP 30 . . . . . 5.30

CHAPTER 5. INTERNAL EXPOSURE

Internal radiation exposure is the exposure of the body to radioactive materials deposited in the body. Radioactive materials can enter the body through the inhalation of radioactive dusts, mists, and fumes, the ingestion of contaminated food or water, injection via puncture wounds, or occasionally absorption through the skin or via a wound.

Several methods can be used to control exposure of the body to external radiation (see Chapter 6). However, once radioactive material has entered the body, there is usually no practicable method of reducing the internal radiation exposure or the resultant dose. Moreover, if the radioactive material has a sufficiently long half-life, it may continue to irradiate the individual for the rest of his or her life. Because of these difficulties, the intake of radioactive materials into the body must be limited and programs for monitoring the internal exposure of radiation workers should be followed.

When an intake of radioactive material is detected, estimating the resulting internal radiation dose is difficult for several reasons. First, in most cases the quantity of radioactive material taken into the body is not known. Some procedures for assessing this quantity partially solve this problem. Second, radionuclides tend to accumulate, or concentrate, in specific organs of the body, which then receive a larger radiation dose than do other organs. For example, plutonium, strontium, and radium concentrate in the bone; uranium concentrates in the kidneys or lungs (depending upon its solubility); and iodine concentrates in the thyroid. Third, a fraction of the energy emitted by a radionuclide in an organ is absorbed within that organ, while the remainder of the energy escapes to other tissues of the body or leaves the body. The fraction of energy emitted that results in a dose to any single organ depends on several factors, including the type of radiation emitted, the size and shape of the organ and body of the individual, and the distribution of the radioactive material within the organ or body.

In this chapter, procedures for controlling and monitoring internal exposure and for estimating internal dose are discussed.

Section 5.1 CONTROL OF INTERNAL EXPOSURE

Considerable effort should be expended to prevent any intake of radioactive material through the accidental ingestion of removable surface contamination or the inhalation of airborne contamination. Removable surface contamination is radioactive material that is easily moved from a surface by wiping or dissolution using common solvents. Removable contamination presents an external hazard and, more important, an internal hazard if it is ingested. (Fixed surface contamination, which is bound to an object, presents only an external hazard.) Airborne contamination is radioactive material that has become airborne as a result of normal work procedures, suspension or resuspension of surface contamination, breach of containment, sputtering of heated fluids, or vaporization of volatile compounds. Once airborne, the material may be inhaled by personnel, resulting in an internal radiation dose. Airborne contamination can present an additional external and internal hazard if it settles out of the air onto surfaces as removable contamination.

Because of the internal radiation hazard posed by removable and airborne contamination, every means of preventing the spread of contamination should be used. The following approaches are discussed in this section:

1. the use of design features to limit the movement of airborne contamination and the spreading or resuspension of removable surface contamination
2. routine surveys for surface contamination
3. decontamination of contaminated objects and individuals
4. air-sampling and air-monitoring programs
5. the use of protective apparel
6. administrative guidelines.

5.1.1 Contamination Control Through Design Features

Design features are a key element in contamination control. Of particular importance is the design of a facility's ventilation system. Other design features, such as the elimination of surfaces from which material can be

resuspended (e.g., scaffolding, open rafters, and cable runs), are also important in preventing contamination. Contamination-producing substances should be used only in hoods or glove boxes. Such substances would include heated solutions; volatile substances, such as iodine and mercury; and high-specific-activity solutions of alpha-emitting nuclides, such as ^{244}Cm and ^{90}Sr. See Chapter 8 for a complete discussion of facility design.

5.1.2 Contamination Surveys During the Course of Work

Surveys for surface contamination should be conducted routinely, with the frequency dependent upon the radiotoxicity of the material handled, the quantity used, and the relative ease of spreading the contamination. In areas containing radioactive materials that include more than one level of radiotoxicity (see Chapter 1, Table 1.10), all removable contamination should be assumed to be due to the most highly radiotoxic agent until proven otherwise. Personnel surveys should be conducted periodically during the course of work in a radiation area and must be conducted as each person leaves the area. All surveys should be made using the procedures discussed in Chapter 4.

Detection equipment appropriate for the type of contamination involved should be available. For most nuclides that emit beta-gamma radiation, a Geiger-Mueller (GM) survey meter is suitable. If the area contains low-energy-beta emitters (e.g., ^{14}C, ^{35}C), special survey instrumentation such as a thin-window GM should be used. Alpha-emitting nuclides are best counted with windowless proportional counters or with ZnS crystal scintillation detectors. For additional information on instrumentation, see Chapter 2.

5.1.3 Decontamination of Contaminated Objects and Individuals

All contamination should be cleaned up at the earliest possible time. Contaminated objects should be decontaminated to levels below the maximum permissible levels shown in Appendix A of Chapter 4. When an individual is contaminated, the person responsible for decontamination should be given as much information as possible, including the radionuclide(s) involved and the chemical form(s) of each radionuclide. Often, all that is known is that the contaminant is a beta-gamma emitter or an alpha emitter. In many instances, the exposure may be to mixed radionuclides that emit predominantly beta-gamma or alpha radiations.

Instrumentation used to assess the extent of contamination must be able to detect the radiations in question. Use of the wrong type of instrument can lead to underestimation of hazards or failure to detect any contaminants, and to release of the object or individual without proper decontamination. Decontamination procedures for both personnel and objects are discussed in detail in Chapter 7.

5.1.4 Air-Sampling and Air-Monitoring Programs

Air-sampling and air-monitoring programs have two major purposes: 1) to detect the presence of radioactive dusts, mists, and fumes in the air; and 2) to quantify the amount of radioactive material in the air. Sampling devices are designed simply to collect dusts, mists, or fumes; the radioactivity of the sampled material is quantified at a later time. These devices are useful in identifying the amount and type of airborne radiation to which an individual has been exposed. Monitoring devices, on the other hand, detect radioactive material and usually sound an alarm when a specified limit is exceeded. Monitors are generally not as accurate as samplers; however, they do provide an immediate indication of airborne radiation in the work area.

Continuous monitoring or sampling for airborne particulate radioactivity should be conducted whenever personnel have a significant potential for airborne exposure because of radiological conditions in the work area. Continuous air monitors should have both a visual and an audible alarm. Areas where the potential for personnel exposure exceeds the limits of 10 CFR 20, Appendix B, Table I, shall be provided with an air monitor that is sensitive enough to alarm at $\leq$30 maximum permissible concentration-hours (MPC-hr). (An MPC-hr is a unit that expresses the total MPCs an individual has been exposed to. It is the product of the number of MPCs the individual was exposed to and the number of hours the individual was exposed. For an individual exposed to 2 MPCs for 2 hours, for example, the product would be 4 MPC-hr.)

When a continuous air monitor alarms, the following actions should be taken:

1. Personnel who are not wearing respiratory equipment shall immediately leave the area. However, these individuals shall remain in the general

vicinity and shall be surveyed for contamination by a member of the radiation protection staff.

2. The Radiation Protection Officer (RPO) shall be notified immediately.

3. Personnel who are wearing respiratory equipment may remain in the area to stop operations that might be the source of airborne radioactivity. Other personnel may enter the area only if they are wearing appropriate respiratory equipment and only for the purposes of evaluating the source of airborne radioactivity or stabilizing it. When the source of the immediate problem has been identified and controlled, all personnel shall leave the area.

Air samples shall be taken in all potentially contaminated work locations that are not continuously monitored. These samples shall be analyzed to ensure that personnel are not exposed to levels of airborne radioactivity higher than the levels given in 10 CFR 20, Appendix B, Table I. Sampling devices should be located where they will ensure detection of abnormal concentrations of airborne radioactivity. Examples of good sampling locations include on hood faces and above laboratory benches.

5.1.5 The Use of Protective Apparel

The purpose of protective apparel is to place a barrier between radioactive material and the individual. This barrier has negligible shielding characteristics; that is, it does not effectively attenuate, or reduce the intensity of, the radiation reaching the wearer. Its main purpose is to prevent contamination of the skin of personnel and inhalation of airborne radioactive materials. The two classes of protective apparel discussed in this section are protective clothing, which minimizes the contamination of an individual's skin, and respirators, which minimize the inhalation of airborne radioactive material.

A. Protective Clothing. Protective clothing includes gloves, laboratory coats, coveralls, and shoe covers. All protective clothing for use in radiation areas should be clearly marked and easily identified so that it can be kept separate from other clothing.

Because protective clothing often becomes contaminated, it must be removed carefully so that contamination is not transferred to the wearer's skin or street clothing. In all cases, if protective clothing is ripped or torn while an individual is working with radioactive material, the individual should leave the area immediately. The following discussion includes a brief description of the proper methods for removing the clothing.

(1) Gloves. Gloves should always be worn in radiation areas, particularly for handling sealed and unsealed sources or potentially contaminated objects. The best gloves are both strong enough not to tear and tight enough not to continually slip off or catch on experimental apparatus. Disposable surgical gloves are frequently used. "One size fits all" gloves tend to be large and to slip off the hands, and may promote the spread of contamination because of the unconscious movements used to keep them on. In some instances, for example during work with radioactive elemental iodine or alpha-emitting radionuclides, two pairs of gloves should be worn.

Glove removal can cause contamination if not performed properly. During the removal process, avoid quick movements that may cause dust to become airborne. Touch the outside of gloves only with gloved hands, and touch uncontaminated skin only with ungloved hands. Grasp the upper, inside wrist cuff of one glove with the opposite gloved hand and pull down on the glove so that, as it is being removed, it is also being turned inside out. When the first glove is off, it should be held, inside out, in the gloved hand. To remove the second glove, slide the fingers of the ungloved hand down the inside of the gloved wrist until the fingers can grasp the inside cuff of the glove. Grasp the inside cuff with the bare fingers and pull down on the cuff while withdrawing the hand from the glove; this should cause the glove to be turned inside out. Pull the second glove over the previously removed glove. The result should be two inside-out gloves, one inside the other, which are disposed of as radioactive waste. The wearer's hands should be surveyed after the gloves are removed.

(2) Laboratory Coats. Laboratory coats are required for work with radioactive materials. The coats should be correctly sized for the individuals wearing them and should be worn buttoned up. They should be worn only in

radiation areas and controlled areas, where contamination might exist, and should never be worn in uncontrolled areas, where food or beverages will be consumed.

(3) Coveralls. In areas with a high likelihood of contamination or where loose laboratory coats would be inconvenient and might cause excessive resuspension of radioactive materials, coveralls should be used. Coveralls have the relative advantage of protecting all the street clothing of an individual. They can be made of ordinary cloth, special fabrics, or chemically treated papers. Velcro® fasteners make it easier to remove coveralls.

Coveralls are removed as follows. First, remove gloves if they are being worn. Then insert the index finger and the middle finger of each hand inside the front of the collar and loosen the Velcro fasteners by pulling the hands apart. Slide the fingers down the front opening until the coveralls are open below the waist. Place the fingers inside the coveralls at about the height of the collarbone and pull the coveralls off the shoulders and down until the arms are free. Roll the coveralls, inside out, down the body to the ankles, then step out.

(4) Shoe Covers. Shoe covers are required wherever floors may become contaminated. They can be made of any durable material such as plastic, fiber-embedded paper or cloth, or rubber. Shoe covers should be tight enough so that they do not tend to fall off the worker's shoes, but not so tight that they are difficult to remove. A step-off area or pad for removing shoe covers should be located at the exit from the contaminated area. To remove shoe covers, approach but do not stand on the step-off area. Lift one foot so that it crosses in front of the opposite leg, grasp the outside of the cover at the heel with a gloved hand, and pull it off the street shoe, being careful to maintain balance. Do not remove the street shoe with the shoe cover. Place the contaminated shoe cover in a receptacle, then step onto the step-off pad with the street shoe. Do not step on the pad with the remaining contaminated shoe cover. Remove the remaining shoe cover as described above.

® A trademark of Velcro U.S.A. Incorporated.

If the protective gloves have already been removed, shoe covers can be removed by placing the index finger and middle finger of the left hand between the right street shoe and its shoe cover at the inside of the heel, pushing down until the heel of the street shoe is out of the shoe cover, and then sliding the rest of the street shoe out of the shoe cover and placing the right street shoe on the step-off pad. Reverse the procedure for the left foot.

(5) Care of Contaminated Clothing. Contaminated clothing should be placed in receptacles specifically designed for contaminated apparel, and should be sent only to laundries that are equipped to handle contaminated clothing. If protective clothing is worn many times before laundering, it should be stored so that any contamination on it could not be transferred to other items of apparel. Protective clothing contaminated with more than 50 mrad/hr of beta-gamma radiation or more than 40,000 dpm of alpha radiation shall be considered contaminated waste and shall be removed from service.

B. Respirators. Respirators are devices designed to keep the wearer from inhaling airborne radioactive material. Some devices also protect against oxygen-deficient atmospheres. They are not a substitute for either good ALARA (as low as is reasonably achievable) or good engineering practices. Respirators are considered an acceptable method of protecting the health of personnel only under the following circumstances:

1. when the Ionizing Radiation Control Committee (IRCC) has determined that no feasible engineering or work practice controls can be used to control the airborne radioactive material
2. during intermittent, nonroutine operations (1 hour/day for 1 day/week)
3. during interim periods when engineering controls are being designed and/or installed
4. during emergencies.

Respiratory protection programs, the selection of respirators, and the types of respirators available are discussed below.

(1) Respiratory Protection Program. An effective respiratory protection program requires the cooperation of the commander, the RPO, supervisors, and

medical personnel. An adequate program includes, at a minimum, the requirements detailed below. Radiation Protection Officers who are responsible for respiratory protection programs should obtain a copy of the Nuclear Regulatory Commission's NUREG-0041 (NRC 1976) for further detail concerning these requirements.

1. Air sampling and other surveys must be sufficient to identify the radiation hazard, to evaluate individual exposures, and to permit proper selection of respirators.

2. Written standing operating procedures (SOPs) must be followed to ensure proper selection, supervision, and training of personnel using respirators.

3. Written SOPs must be followed to ensure adequate individual fitting of respirators, as well as procedures for testing respirators for operability immediately prior to each use. Individuals who issue respirators shall be provided with training in these procedures.

4. Respirators should be assigned to individuals for their exclusive use, where practicable.

5. Written SOPs must be followed for respirator maintenance (including cleaning and disinfection), decontamination, inspection, repair, and storage. Respirators issued for the exclusive use of one indivudal should be cleaned after each day's use. Respirators used by more than one individual shall be thoroughly cleaned and disinfected after each use.

6. Respirators shall be stored in a convenient and sanitary location. They must be stored where the potential for contamination by airborne or surface radioactive material is minimal.

7. Before initial use, each respirator shall be properly fitted, leakage tests performed, and the facepiece-to-face seal tested in a realistic test situation.

8. Before each use, both positive and negative pressure tests shall be conducted (see Standard Z88.2 of the American National Standards Institute (ANSI 1980)). Respirators shall not be worn when a beard or sideburns, a skull cap that projects under the respirator, temple pieces on corrective

glasses, the absence of one or both dentures, or other conditions prevent a good facepiece-to-face seal.

9. Respirators shall be inspected during cleaning. Experienced personnel shall replace worn or deteriorated parts with parts designed for the respirator. No attempt shall be made to replace components or to make adjustments or repairs beyond the manufacturer's recommendations. Reducing-admission valves or regulators shall be returned to the manufacturer or to trained technician for adjustment or repair. The manufacturer's parts replacement schedule should be followed.

10. Respirators for emergency use, such as self-contained breathing devices, shall be thoroughly inspected at least once a month and after each use, and a written record kept of inspection dates and findings.

11. Supervisors and personnel shall be instructed and trained in the selection, use, care, and maintenance of respirators. Training shall provide, for each user, an opportunity to handle the respirator, to have it fitted properly, to test its facepiece-to-face seal, to wear it in normal air for a familiarization period, and to wear it in a realistic test atmosphere.

12. Personnel should not be assigned to tasks that require the use of respirators unless the installation's medical authorities have determined that they are physically and psychologically able to perform their work while wearing the prescribed respirator. The medical status of the respirator user should be reviewed periodically, with the frequency of review depending upon the results of appropriate medical examinations, the type of respirator used, and the age of the individual.

13. Bioassays and other surveys should be conducted as appropriate to evaluate individual exposures and to assess the protection actually provided.

(2) Selection of a Respirator. The selection of a respirator depends on a number of health and safety factors, such as the nature of the radiation hazard, the limitations and the intended use of the respirator, how much the respirator limits movement and work rate, the time needed to escape in case of emergency, and training requirements. Because the effectiveness of a respiratory protection program can be determined largely by the degree to which

personnel accept the program, the human factor must also be considered. Personnel acceptance of respirators is influenced by comfort, ability to breathe without undue interference, confidence in facepiece fit, and convincing evidence that a respirator is necessary and that action is being taken where possible to eliminate the need for respirators.

The degree of protection afforded by a given respirator is defined in terms of its protection factor (PF), which is the ratio of the concentration of the contaminant in the ambient atmosphere to that inside the equipment (usually inside the facepiece) under conditions of use. Protection factors are based on laboratory leakage studies and field experience with the device.

Respirators should be selected to provide a PF greater than the multiple by which peak concentrations of radioactive materials are expected to exceed the values specified in Table I, Column I, of 10 CFR 20, Appendix B. For example, if the airborne concentration of a radionuclide in a work area is expected to be five times as high as the permissible concentration listed in the table, then the respirator selected for use in that area should have a PF of 6 or more. The equipment selected should be used so that the average concentration of radioactive material in the air inhaled by the wearer, during any period of uninterrupted use in the area, does not exceed the values specified in the table. For the purpose of this manual, the concentration of radioactive material inhaled when respirators are worn may be estimated initially by dividing the concentration in the air of the work area by the PF. Additional measurements, however, must be taken to evaluate worker exposure.

The protection factors for respirators may not be appropriate where chemical or other respiratory hazards exist in addition to radiation hazards. The selection and use of respirators for such circumstances should take into account recommendations and requirements of the National Institute for Occupational Safety and Health (NIOSH) and the Occupational Safety and Health Administration (OSHA).

The installation's medical authority, or personnel under the guidance of the medical authority, shall determine the type of respirator best suited to each task. The RPO should assist the responsible individual by providing

environmental evaluations and any other appropriate information. Only equipment that is certified by the National Institute for Occupational Safety and Health/Mine Safety and Health Administration (NIOSH/MSHA) should be used.

(3) Description of Respirators. There are basically two forms of respirators: air purifying and air supplying. An air-purifying respirator removes contaminants from the air of the work area by either filtering out particulate contaminants or removing contaminated gases and vapors by chemical means. An air-supplying (or atmosphere-supplying) respirator furnishes respirable air or oxygen to the wearer from an uncontaminated supply.

Respirators are designed to be used with an enclosure such as a facepiece, hood, helmet, or suit. The enclosure excludes contaminated air and ensures that clean, respirable air is supplied to the nostrils and mouth of the wearer.

A facepiece is a tight-fitting enclosure over all or a portion of the face. Only full-facepiece devices should be used to protect against airborne radioactive material. (Facepieces that enclose only a portion of the face are not acceptable for use in radiation areas; they are to be used only for industrial safety applications for protection from nonradioactive particulates, gases, and vapors.) A full-facepiece mask is generally constructed from flexible rubber or plastic and has one or two transparent lenses for viewing. The device completely encloses the wearer's eyes, nose, mouth, and chin. A head harness is attached to the facepiece at five or six points to provide support.

A hood is a loose-fitting, flexible enclosure over the head, neck, and shoulders that is gathered around the neck or shoulders to provide a snug fit. A helmet has a more rigid construction than a hood and protects parts of the head against impacts. Air is supplied to the hood or helmet from a compressed-air supply. Suits are one-piece garments to which a continuous supply of respirable air is provided.

5.1.6 Administrative Guidelines

Some administrative guidelines that will help personnel reduce any intake of radioactive materials are listed below. The list may not be all-inclusive and should not be substituted for common sense in the laboratory.

1. Smoking, eating, and drinking shall not be allowed in radiation areas or controlled areas. The danger of transmitting radionuclides internally is too great.

2. Food containers such as returnable bottles and coffee cups shall not be taken into radiation areas or controlled areas. If they are inadvertently taken in, they should be destroyed.

3. Refrigerators shall not be used to store both food and radioactive materials. Ice cubes from refrigerators used for storing radioactive materials shall not be used for human consumption.

4. Frequently while working with radioactive materials, or upon the completion of work, each individual shall survey hands, shoes, and other areas of the body or clothing that may be contaminated. Contamination should be removed when found and shall be removed before the individual leaves the laboratory. If significant levels of personnel contamination are found, or if the contamination cannot be readily removed, the individual shall contact the RPO.

5. Frequent radiation surveys shall be performed around radiation and/or controlled areas to determine whether there is any deviation from normal background levels of radiation (see Chapter 4).

6. All containers used for radioactive materials shall be labeled in accordance with Army regulations (AR 385-11). Radioactive warning labels, tape, signs, etc., shall not be used for purposes other than those for which they are intended.

7. Radioactive materials shall be stored so that unauthorized individuals are not likely to accidentally handle or otherwise come in contact with them.

8. Each person shall wash hands and arms thoroughly after handling any radioactive source (sealed or unsealed), and in particular before touching any object that goes in the mouth, nose, or eyes.

9. Equipment or apparatus that has come in contact with radioactive materials shall not be used for other purposes until it is demonstrated to be free of contamination.

10. Mechanical devices shall be used for pipetting. NEVER PIPETTE RADIOACTIVE SOLUTIONS BY MOUTH. In addition, to preclude accidental ingestion of radioactive materials through cross-contamination, mislabeling, etc., never pipette any substance by mouth in laboratories where radioactive materials are used.

11. Radioactive materials in liquid form shall be stored and transported in containers that, if dropped, will not release the materials, for example, in plastic bottles or in glass bottles with styrofoam containers (see Chapter 9).

12. All transfers and dilutions should be performed in functioning exhaust hoods or glove boxes, unless procedures have been approved for working in the open (see Chapter 8).

13. Work should be planned ahead; whenever possible, a dry run to test the procedure should be done first.

14. All items of equipment intended to provide features of safety shall be evaluated periodically to ensure that they are providing the safety feature intended (see Chapter 8). For example, a fume hood in which radioactive materials are handled should provide a uniform air flow through the opening of the hood. This air flow should be checked periodically to ensure that the hood is operating properly.

15. Laboratories shall be kept neat and clean. Equipment or material not being used should be stored away from the work area.

16. Absorbent paper should be placed on work surfaces on which radioactive materials are used. If liquid radioactive materials are used, a container large enough to hold the entire volume of liquid should be positioned to catch any spill.

17. Fingernails should be kept short and clean.

18. If there is a break in the skin below the wrist, gloves of rubber, plastic, or some other substance impervious to the material being worked with shall be worn to cover the break.

Section 5.2 MONITORING INTERNAL EXPOSURE

Inhalation is the pathway by which radioactive material is most likely to enter the body of an occupationally exposed individual. After being inhaled, the radioactive material may be gradually or immediately transferred to the blood, depending upon the solubility of the material, and then excreted from or retained by the body, depending upon other characteristics of the material.

Two methods are used to estimate the amount of radioactive material taken into the body and the consequent radiation dose: radioanalysis and in-vivo counting. Radioanalysis is the measurement of radioactivity in urine, feces, secretions, and other body samples, such as blood and other tissues. In-vivo counting is the measurement of the radiation emitted from the body, using an external detector. Radioanalysis and in-vivo counting are bioassay procedures. Because they are highly specialized techniques, assistance in carrying them out should be sought from the Army Environmental Hygiene Agency.

5.2.1 Bioassay Programs

Bioassay programs should be established whenever there is a potential for internal contamination. Bioassays are appropriate for five purposes: 1) preparatory evaluation, 2) exposure control, 3) diagnostic evaluation, 4) removal of work restrictions, and 5) termination evaluation (ANSI N343-1978).

A. Preparatory Evaluation. Bioassays should be performed before an individual begins work that could result in an internal exposure. These evaluations are performed to determine the nature and extent of any prior exposure that could affect an individual's availability for job assignments. Knowledge of prior exposures is also helpful in distinguishing, in later bioassays, which exposures are not attributable to the present working environment.

B. Exposure Control. Bioassays should be performed periodically to ensure the adequacy of physical containment and contamination control measures. Personnel should be evaluated often enough so that unfavorable exposure trends can be identified. Bioassays may be required more frequently whenever new processes, procedures, controls, or equipment are put into use, to verify that protective measures are adequate. An increased frequency is also required whenever surface or air contamination is detected.

C. Diagnostic Evaluation. Bioassays are used after a known intake of radioactive material to determine the location and amount of the deposition; to provide data necessary for estimating internal dose rates, the fraction of the deposition retained in the body, and dose commitments; and to determine the necessity of work restrictions or referrals for therapy.

D. Removal of Work Restrictions. If an individual's internal dose rate has approached or exceeded applicable limits and the individual's work in radiation areas has been restricted, bioassays should be performed to determine whether the dose rate has decreased enough so that the work restrictions can be lifted.

E. Termination of Employment. Bioassays should be performed as a regular part of the formal termination sequence in order to determine the level of internal exposure attributable to the individual's job function.

5.2.2 Actions To Be Taken Upon Detection of an Intake

If a routine bioassay performed to assess control indicates an abnormal (i.e., unexpected) presence of a radionuclide in the body or excreta, further evaluations should be made to confirm that an intake has actually occurred. (False indication of an intake may result from contaminated skin in the case of in-vivo counting, or from contaminated samples in the case of radioanalysis of excreta.) The individual should be surveyed for external contamination, procedures for external decontamination should be used (see Chapter 7), and then another in-vivo measurement should be made. If the measured activity decreases, the contamination is probably external. Continue decontamination procedures until two consecutive measurements result in no significant change. If the measured activity remains constant and an intake cannot be ruled out, then radioanalysis of excreta should follow.

The interpretation of in-vivo counting data is influenced by a number of variables. Examples of equations that can be used to calculate internal dose are provided in Section 5.3. However, the interpretation of bioassay data requires trained personnel. The RPO should contact the Army Environmental Hygiene Agency for assistance. The radioanalysis of excreta and other body samples is also performed by the Army Environmental Hygiene Agency. If activity is found in excreta samples, the agency can provide assistance in

interpreting the data in light of Publications 10 and 10A (1968, 1971) of the International Commission on Radiological Protection (ICRP).

The cause of a confirmed intake should be investigated, especially if the contamination occurs in several persons or recurs from time to time in one person. The dose reduction methods discussed in Report No. 65 of the National Council on Radiation Protection and Measurements (NCRP 1980) should be considered for use under the supervision of medical personnel.

Section 5.3 INTERNAL DOSIMETRY CALCULATIONS

Dosimetry is the measurement of the radiation absorbed by an object. Calculations of internal dosimetry, or the radiation absorbed by the body's organs and tissues, serve two purposes: 1) to determine the amount of radioactive material that can be inhaled in air or ingested in water by an individual without a radiation dose limit being exceeded; and 2) to estimate the radiation dose an individual will receive from radioactive material that has already entered the body. In the first case, the calculations are used for preventive purposes, to limit the dose that might be received by setting limits for the uptake of radioactive material; in the second case, the calculations are used for diagnostic purposes, to determine the dose that will actually be received. The two uses of internal dosimetry calculations will be discussed separately.

5.3.1 Calculation of Acceptable Intake

Most federal regulations concerning safe concentrations of radionuclides in air or water are based on the recommendations of the ICRP in its Publication 2 (1979), Report of Committee II on Permissible Dose for Internal Radiation. However, ICRP has recently issued revised recommendations in ICRP Publication 30, and these recommendations are being considered for incorporation into the Environmental Protection Agency's "Federal Radiation Protection Guidance for Occupational Exposures" (Federal Register, January 23, 1981).

The major difference between the two ICRP publications lies in the sophistication of the dose calculations used. In ICRP 30, mathematical descriptions

of organ shapes are used, whereas in ICRP 2, organs of a rather nebulous shape are assumed. The limits in ICRP 30 also account for tne radiation dose to an organ from radioactive material situated in an unrelated organ, and ICRP 30 uses a more complex model of radionuclide distribution kinetics (that is, the rate of radiation's absorption into the body, distribution within the body, and eventual excretion from the body) than does ICRP 2.

Because current regulations are based on the earlier ICRP publication, the material in the text of this section relates to ICRP 2. The terms used in ICRP 30 and the equations developed there for calculating the radiation dose to various body organs are discussed in Appendix A.

The ICRP 2 methodology for calculating acceptable intakes of radionuclides in air or water involves three steps:

1. determining the critical organ; that is, determining which organ or tissue of the body would be most damaged by a given radionuclide entering the body
2. calculating the maximum permissible body burden; that is, calculating the maximum amount of the radionuclide that can enter the body without the maximum acceptable dose limit for the critical organ being exceeded
3. calculating maximum permissible concentrations; that is, calculating how much of the radionuclide can be in air that is breathed or water that is drunk without the maximum permissible body burden being exceeded.

These steps are explained below.

A. Determining the Critical Organ. The critical organ or critical tissue is the organ or tissue that, if damaged by radioactive material taken into the body, would cause the greatest physiological damage to the body. In concept, the critical organ or tissue for a given radionuclide is determined by considering: 1) which organ accumulates the greatest concentration of the radionuclide; 2) the importance of each organ to the well-being of the entire body; 3) which organs are most affected by the route of entry of the radionuclide into the body (e.g., the lungs are most affected by the inhalation of a radionuclide); and 4) the radiosensitivity of each organ, that is, which organ is damaged by the lowest dose. In practice, the first criterion (the organ that

has the greatest concentration of a given radionuclide) is used in ICRP 2 to determine the critical organ because of the difficulty of evaluating the other criteria. If the radionuclide is not concentrated in any single organ, then the whole body is considered to be the critical organ.

B. Calculating the Maximum Permissible Body Burden. The maximum permissible body burden (MPBB) is the amount of a radionuclide, accumulated throughout the body of an individual over 50 years of occupational exposure, that will result in a maximum permissible dose-equivalent rate to the critical organ for that radionuclide. (See Chapter 3, Table 3.2, for maximum permissible dose-equivalent rates.)

C. Calculating the Maximum Permissible Concentrations in Air and Water. The MPBB must be considered in order to estimate the acceptable concentrations of a radionuclide in air or water. In ICRP 2, a maximum permissible concentration for air, $(MPC)_a$, and a maximum permissible concentration for water, $(MPC)_w$, are given. The $(MPC)_a$ and $(MPC)_w$ are calculated based on a constant intake of a radionuclide into the body and an exponential elimination of the radionuclide from the body by radioactive decay and biological excretion. The calculations account for the breathing rate of the individual in the case of $(MPC)_a$ and for the amount of water the individual might consume during the day in the case of $(MPC)_w$. The fraction of the material actually retained in the body is also considered. The ICRP 2 recommendations for $(MPC)_a$ and $(MPC)_w$ limits have been incorporated into the permissible concentrations of radionuclides in air and water that are listed in 10 CFR 20, Appendix B. The MPC is given in μCi/ml.

5.3.2 Estimation of Internal Dose

Following the ingestion or inhalation of radioactive material, three dose computations can be made: 1) the initial dose-equivalent rate, which is important because it serves as the basis for calculating the total dose received; 2) the dose equivalent the critical organ or the total body will receive over 1 year; and 3) the total dose equivalent the critical organ or the total body will receive as a result of the ingestion. The total dose equivalent can be calculated either for an infinite time following the ingestion or for 50 years following the ingestion. A calculation based on the 50-year period results in

what is called the 50-year dose commitment. The methods of dose calculation described in this section are for an individual of standard size and average metabolism (which affects the rate of excretion of the radioactive material). If the calculations are to be modified to fit a particular individual, the Army Environmental Hygiene Agency should be contacted for assistance.

Equations provided in ANSI Standard N343-1978 can be used for calculating the initial dose-equivalent rate and the 1-year and 50-year dose equivalents resulting from an intake of radioactive material. In all cases, it is necessary to know the amount of radioactive material in the body or in the organ for which the dose is being calculated. The calculations would be based on a single in-vivo measurement (i.e., a measurement of the radiation emitted from the body, made using an external detector soon after the intake).

A. Calculating the Initial Dose-Equivalent Rate to an Organ.

$$\dot{H} = \frac{51.2 \times q(t) \times f_2 \times \varepsilon}{m} \qquad (5.1)$$

where $\dot{H}$ = the dose-equivalent rate to the organ (rem/day)

$q(t)$ = the activity in the whole body at the time of measurement (μCi)[(a)]

f_2 = the fraction of the total-body radioactivity in the organ of reference, from ICRP 2[(a)]

ε = the effective absorbed energy per disintegration (MeV/dis)

m = the mass of the organ of reference (g)

51.2 = constant ([rem·g·dis]/[μCi·MeV·day]).

B. Calculating the One-Year Dose Commitment Based on a Single In-Vivo Measurement. Equation (5.1) allows the calculation of the dose-equivalent rate to an organ containing radioactive material. One may be more interested in the total dose an individual will receive for a year and/or a lifetime following a deposition. Equation (5.2) allows for the calculation of the 1-year dose equivalent to an organ containing radioactive material.

(a) If the amount of radioactive material actually in the organ of interest is known, then that activity, in units of microcuries, may be used in the equation rather than the product f_2 $q(t)$.

$$H_y = \frac{51.2 \times q(t) \times f_2 \times \varepsilon \times e^{\lambda t} \times [1 - e^{-365\lambda}]}{m \times \lambda} \qquad (5.2)$$

where H_y = the 1-year dose equivalent based on a single in-vivo measurement (rem)

$q(t)$ = the activity in the whole body at the time of measurement (μCi)

f_2 = the fraction of the total-body radioactivity in the organ of reference

ε = the effective absorbed energy per disintegration (MeV/dis)

e = the base of the natural logarithms ($e = 2.71828$)

λ = the effective removal constant ($\lambda = 0.693/t_{eff}$) ($days^{-1}$)

t = the time between the intake and the in-vivo measurement (days)

m = the mass of the organ (g)

51.2 = constant ([rem·g·dis]/[μCi·MeV·day]).

C. Calculating the Fifty-Year Dose Commitment. The 50-year dose equivalent can be calculated by modifying the exponent (-365λ) in the above equation to (-18250λ), which corresponds to a 50-year time interval.

Values of f_2, λ, and ε for a few selected radionuclides are given in Table 5.1. The parameters f_2 and λ listed in this table are based on a "standard man," defined in the Radiological Health Handbook (1970) as having a body weight of 70 kg. The use of these values in an equation will provide an estimate of the radiation dose to an individual who is the same size as the standard man. If possible, bioassay procedures should be used to obtain estimates of f_2 and λ that more closely match the individual.

Another source of reference for calculating the 50-year dose commitment is NUREG-0172 (NRC 1977). This report lists 50-year committed radiation doses to selected organs following the chronic intake of several radionuclides over a 1-year period. The radiation doses are calculated in terms of mrem per 50 years per pCi (10^{-12} Ci) of radioactive material. The dose calculations are for populations rather than occupationally exposed individuals and include 1) radiation doses from liquid effluents, 2) radiation doses from gaseous

TABLE 5.1. Parameters for Internal Dosimetry[a]

Organ Mass (grams) for Standard Man			
Total Body	70,000	Liver	1,700
Lung	1,000	Spleen	150
Thyroid	20	Bone	7,000

Nuclide	Organ	f_2	λ[b]	ϵ[c]	[1-exp(-365λ)]
^{3}H	Total Body	1.0	3.2 (-4)	0.01	0.11
^{54}Mn	Lung	(d)	8.1 (-3)	0.23	0.95
	Liver	1.0	3.0 (-2)	0.23	1.0
^{59}Fe	Lung	(d)	2.1 (-2)	0.42	1.0
	Spleen	0.02	1.7 (-2)	0.34	1.0
^{58}Co	Lung	(d)	1.5 (-2)	0.29	1.0
	Total Body	1.0	8.3 (-2)	0.61	1.0
^{60}Co	Lung	(d)	6.1 (-3)	0.72	0.89
	Total Body	1.0	7.3 (-2)	1.5	1.0
^{95}Zr-Nb	Lung	(d)	1.7 (-2)	0.52	1.0
	Total Body	1.0	1.2 (-2)	1.1	0.99
^{95}Nb	Lung	(d)	2.6 (-2)	0.26	1.0
	Total Body	1.0	2.1 (-2)	0.51	1.0
^{106}Ru-Rh	Lung	(d)	7.7 (-3)	1.4	
	Kidney	0.07	2.8 (-1)	1.3	1.0
	Total Body	1.0	9.6 (-2)	1.4	1.0
^{131}I	Thyroid	0.2	9.6 (-2)	0.23	1.0
^{133}I	Thyroid	0.2	8.0 (-1)	0.54	1.0
^{134}Cs	Lung	(d)	9.5 (-3)	0.57	0.97
	Total Body	1.0	1.1 (-2)	1.1	0.98
^{137}Cs-^{137m}Ba	Lung	(d)	5.8 (-3)	0.41	0.88
	Total Body	1.0	9.9 (-3)	0.59	0.97
^{140}Ba-La	Lung	(d)	6.0 (-2)	1.4	1.0
	Bone	0.7	6.5 (-2)	4.2	1.0
	Total Body	1.0	6.5 (-2)	2.3	1.0
^{144}Ce-Pr	Lung	(d)	8.2 (-3)	1.3	0.95
	Bone	0.38	2.9 (-3)	6.3	0.65
	Liver	0.19	4.7 (-3)	1.3	0.82
	Total Body	1.0	3.6 (-3)	1.3	0.73

(a) American National Standards Institute 1978.
(b) Units of day^{-1}.
(c) Units of (MeV/disintegration) x (rem/rad).
(d) Estimates of lung dose should be based on a measured lung burden. However, a total-body in-vivo measurement can be used to estimate an upper limit of the lung dose commitment by setting f_2 = 1.0 for the lung.

effluents, and 3) radiation doses from contaminated surfaces or volumes (i.e., external radiation).

The intake of the same amount of radioactivity can result in different radiation doses for people of different ages; consequently, four sets of dose factors are presented in NUREG-0172. The age groups considered are infant, child, teen, and adult. The 50-year dose commitment is calculated by reading the dose factor from the approriate table and multiplying this value by the number of picocuries taken into the body. The tables of NUREG-0172 are not reproduced in this manual.

REFERENCES

American National Standards Institute (ANSI). 1978. Internal Dosimetry for Mixed Fission and Activation Products. ANSI N343-1978. Washington, D.C.

American National Standards Institute (ANSI). 1980. Practices for Respiratory Protection. ANSI Z88.2, New York.

International Commission on Radiological Protection (ICRP). 1959. Report of Committee II on Permissible Dose for Internal Radiation. ICRP 2, Pergamon Press, Oxford.

International Commission on Radiological Protection (ICRP). 1968. Evaluation of Radiation Doses to Body Tissues From Internal Contamination Due to Occupational Exposure. ICRP 10, Pergamon Press, Oxford.

International Commission on Radiological Protection (ICRP). 1971. The Assessment of Internal Contamination Resulting from Recurrent or Prolonged Uptakes. ICRP 10A, Pergamon Press, Oxford.

International Commission on Radiological Protection (ICRP). 1978. Limits for Intakes of Radionuclides by Workers. ICRP 30, Part 1 and Supplement to Part 1, Pergamon Press, Oxford.

International Commission on Radiological Protection (ICRP). 1980. Limits for Intakes of Radionuclides by Workers. ICRP 30, Part 2, Pergamon Press, Oxford.

National Council on Radiation Protection and Measurements (NCRP). 1980. Management of Persons Accidentally Contaminated with Radionuclides. NCRP 65, Washington, D.C.

Radiological Health Handbook. 1970. U.S. Department of Health, Education, and Welfare, Washington, D.C.

U.S. Code of Federal Regulations. 1982. Title 10, Part 20, "Standards for Protection Against Radiation." U.S. Government Printing Office, Washington, D.C.

U.S. Department of the Army, Headquarters. Safety - Ionizing Radiation Protection (Licensing, Control, Transportation, Disposal, and Radiation Safety). AR 385-11, Washington, D.C.

U.S. Environmental Protection Agency (EPA). "Federal Radiation Protection Guidance for Occupational Exposures." Federal Register, January 23, 1981.

U.S. Nuclear Regulatory Commission (NRC). 1976. Manual of Respiratory Protection Against Airborne Radioactive Materials. NUREG-0041, Washington, D.C.

U.S. Nuclear Regulatory Commission (NRC). 1977. Age-Specific Radiation Dose Commitment Factors for a One Year Chronic Intake. NUREG-0172, Washington, D.C.

APPENDIX A

ICRP 30 RECOMMENDATIONS FOR LIMITING RADIONUCLIDE INTAKES

The most recent recommendations of the ICRP for safe limits of radioactive material in air and water are found in Publication 30, Limits for Intakes of Radionuclides by Workers. To date, ICRP 30 consists of two parts published in 1978 and 1980, each with a supplement. A third part and supplement are expected to be published. Because ICRP 30 is so recent, its recommendations have not been incorporated into current government regulations; however, they may be incorporated into future regulations.

A.1 EXPLANATION OF TERMS USED IN ICRP 30

The sequence of steps used in ICRP 30 to determine acceptable concentrations of radionuclides in air or water is identical to that used in ICRP 2 and discussed in Section 5.3. The terminology used in ICRP 30 is different from that used in ICRP 2, however, and is explained below.

A. Committed Dose Equivalent. In ICRP 30, the Commission is attempting to limit two types of radiation effects in the body: 1) stochastic effects are those that are increasingly likely to occur as the radiation dose increases (for example, genetic effects and malignant diseases such as cancer); 2) non-stochastic effects are those that are increasingly severe as the radiation dose increases and that are unlikely to occur at all below a certain threshold dose (for example, loss of hair, skin damage, and cataracts).

The incidence of stochastic effects is limited if the risk of such effects resulting from the radiation dose to any single organ or combination of organs in 1 year does not exceed the risk associated with a whole-body dose equivalent of 5 rem in any 1 year. The risk of stochastic effects is quantified by a weighting factor for each organ; the weighting factor is an attempt to scale both the relative importance of the organ to the well-being of the body, and the organ's relative radiosensitivity. The weighting factors can be used to obtain a dose equivalent, H_L, to a tissue that yields the same risk as 5 rem

to the whole body. The committed dose equivalent ($H_{T,50}$) in a tissue is the total radiation dose equivalent received by an organ or tissue during the 50 years following an intake. The maximum intake of a radionuclide is limited in ICRP 30 by the requirement that the sum of the ratios of $H_{T,50}/H_L$ in all irradiated tissues not exceed 1.0. It is not possible to directly compare the doses to the critical organs given in ICRP 2 with the annual doses to the critical organs given in ICRP 30 (see Table 5.2 below). This is because ICRP 30 restricts the sum of the doses received by all the tissues of the body, whereas ICRP 2 restricts the dose to the critical organ only.

TABLE 5.2. Weighting Factors Recommended in ICRP 30

Organ or Tissue	Weighting Factor	H_L (a) (rem)
Gonads	0.25	20
Breasts	0.15	33
Red bone marrow, lung	0.12	42
Thyroid, bone surfaces	0.03	167
Five other tissues receiving the greatest dose in the remainder of the body	0.30	83

(a) Dose equivalent to a tissue giving the same risk as 5 rem to the whole body.

In order to prevent nonstochastic effects, ICRP 30 limits the radiation dose equivalent to any organ over the 50 years following an intake (the committed dose equivalent) to 50 rem.

B. Annual Limit of Intake. In ICRP 30, the MPBB of ICRP 2 has been replaced by the annual limit of intake (ALI). The ALI is the amount of a radionuclide that can be ingested or inhaled such that the sum of the ratios $H_{T,50}/H_L$ in all the tissues irradiated is equal to 1. In addition, the committed dose equivalent to any organ cannot exceed 50 rem in 1 year.

The ALI is calculated based on a constant inhalation or ingestion over the year. Also considered is the rate at which radioactive material is eliminated from the body by both radioactive decay and excretion. The intake rate can be exceeded at times as long as the total yearly intake does not exceed the specified ALI.

C. Derived Air Concentration. The MPCs given in ICRP 2 have been replaced in ICRP 30 by a derived air concentration (DAC), which is the acceptable concentration of a radionuclide in air. The ICRP 30 recommendations are listed in units of Bq/m^3, which can be converted to μCi/ml by multiplying by the conversion factor 2.7×10^{-11} $(\mu Ci \cdot m^3)/(ml \cdot Bq)$. No derived water concentration is defined in ICRP 30, nor is any value given that would be equivalent to the MPCs. The only mention made of a maximum concentration allowable in air and water is that the total intake should be less than the ALI.

A.2 DEVELOPMENT OF EQUATIONS USED IN ICRP 30

A major change in ICRP 30 as compared to ICRP 2 is that the radiation dose to an organ is determined taking into account the radioactive material in other organs as well as in the organ of concern. This change is especially important for intakes of radionuclides that emit gamma rays, x rays, or neutrons by spontaneous fission.

The committed dose equivalent to an organ ($H_{T,50}$) is a product of the committed absorbed dose ($D_{T,50}$), the quality factor of the radiation (Q), and other modifying factors (N). For the time being, ICRP has stated that N is equal to 1. In the following paragraphs, the equations used in ICRP 30 for calculating the internal dose are developed.

A. Radiation Energy, E. The dose equivalent to an organ is related to, or proportional to (symbolized $\propto$), the energy of the radiation. In the case of alpha particles and gamma rays, E is the energy of the radiation listed on periodic tables and in reference books. In the case of beta particles, an average energy of the radiation must be calculated because beta particles are emitted from the nucleus with a spectrum of energies. As a general rule, the

average beta energy is about one-third of the listed or maximum energy. A more exact equation is:

$$E = 0.33 \times \left(1 - \frac{\sqrt{Z}}{50}\right) \times \left(1 + \frac{\sqrt{E_{max}}}{4}\right) \times E_{max} \qquad (5.3)$$

where E = average beta energy (MeV)
Z = atomic number of the emitting nucleus
E_{max} = maximum beta energy (MeV)
0.33 = constant.

For positrons, the equation is:

$$E = 0.33 \times \left(1 + \frac{\sqrt{E_{max}}}{4}\right) \times E_{max} \qquad (5.4)$$

where E = average positron energy (MeV)
E_{max} = maximum positron energy (MeV)
0.33 = constant.

The relation of the committed dose equivalent to the radiation energy is:

$$H_{T,50} \propto E \qquad (5.5)$$

where $H_{T,50}$ = committed dose equivalent to a target organ
E = energy of the radiation (MeV).

B. Type of Radiation Emitted. Each type of radiation has a characteristic rate of energy deposition, or linear energy transfer (LET), as described in Chapter 1. The quality factor, Q, is a function of the radiation's LET and is included in the calculation of the dose equivalent.

The relation can now be written as follows:

$$H_{T,50} \propto E \times Q \qquad (5.6)$$

where $H_{T,50}$ = committed dose equivalent to a target organ
E = energy of the radiation (MeV)
Q = quality factor of the radiation.

C. Mass of the Organ, m_T. The radiation dose received by an organ is inversely proportional to the mass of the organ. Because the absorbed dose is defined in terms of energy absorbed per unit mass, if the amount of energy deposited remains constant, then the absorbed dose necessarily decreases as the mass of the organ increases.

The relation for the committed dose equivalent is therefore:

$$H_{T,50} \propto \frac{E \times Q}{m_T} \tag{5.7}$$

where $H_{T,50}$ = committed dose equivalent to a target organ
E = energy of the radiation (MeV)
Q = quality factor of the radiation
m_T = mass of the target organ (g).

D. Absorbed Fraction of the Emitted Energy, AF(T←S). A fraction of the energy emitted by radioactive material is absorbed in the organ containing the material, and the remainder escapes. The energy that escapes from the organ may penentrate through the body and produce a radiation dose in another organ, or it may escape from the body. The fraction of the emitted energy absorbed in a given organ is symbolized by AF(T←S); T represents the target organ (the organ receiving the dose), and S represents the source organ (the organ containing the radioactive material). The target organ and the source organ may be the same organ, or they may be different organs of the body. As a result, it is now possible to calculate the radiation dose to an organ resulting from radioactive material in a different organ.

For the calculation of the absorbed fraction, radiations can be placed into two categories: nonpenetrating radiation and penetrating radiation.

Nonpenetrating radiation is radiation that loses all of its energy after traveling a short distance in tissue. Examples of nonpenetrating radiation are alpha particles, beta particles, and protons. If the organ containing the radioactive material is large compared to this distance, all the energy emitted is deposited in the organ containing the radioactive material. That is:

$$AF(T\leftarrow S) = \begin{cases} 0, \text{ if T is not S} \\ \\ 1, \text{ if T is S} \end{cases} \qquad (5.8)$$

Penetrating radiation is radiation that penetrates through the body, depositing energy both in the organ that contains the radioactive material and in other organs. Examples of penetrating radiation include x rays, gamma rays, and neutrons. The calculation of AF(T←S) for penetrating radiation is quite complex and virtually impossible without the aid of a computer. The computer is first programmed with a mathematical description of a man of average size, termed the reference man or standard man. This mathematical description is called a phantom and describes the shape, density, and relative locations of the various bones and organs of the body. The absorbed fraction is then calculated using a "Monte Carlo" computer calculation. A description of the basic principles behind these calculations follows. The "Monte Carlo" calculations, although equivalent to this description, are different in detail to save computer time.

The radioactive nuclei are assumed to be distributed uniformly throughout the source organ. A point within the source organ is picked. The computer model emits a photon of energy E in some direction picked at random from all possible directions. The photon is followed along its path; after it has traversed a very short distance, the probability of its interacting is calculated. The computer then "flips a coin" with this probability. If a "head" results from the coin flip, the photon is considered to interact at that point. If the interaction is Compton scattering (see Chapter 1), the angle is picked at random with a relative probability determined by the energy of the photon and by the interacting medium. The energy of a recoil electron for scattering at that angle is calculated and deposited at the interaction site. Similar procedures are followed for the photoelectric effect and pair production. The scattered photon is then followed in the same way. If a "tail" occurs on the first coin flip, the photon is allowed to travel another small distance and the probability of interaction is again calculated. This procedure is repeated until all the energy has been absorbed or the radiation leaves the

body. The entire procedure is repeated many times for each organ, until one has a map of the radiation deposited in all organs by gamma rays (or other penetrating radiation) leaving the specified point in the source organ. The result of these calculations is the AF(T←S) for penetrating radiation. These values are tabulated in ICRP 30 and its supplements.

The relation for the committed dose equivalent is now written as:

$$H_{T,50} \propto \frac{E \times Q \times [AF(T \leftarrow S)]}{m_T} \qquad (5.9)$$

where $H_{T,50}$ = committed dose equivalent to an organ
E = energy of the radiation (MeV)
$AF(T \leftarrow S)$ = absorbed fraction of the emitted energy
m_T = mass of the target organ (g)
Q = quality factor of the radiation.

E. Radiation Yield, Y. A radionuclide can undergo decay by different pathways. In the case of a beta-emitting nuclide, all pathways are similar in that they entail the emission of a beta particle followed by a gamma ray, but they differ from each other in the distribution of energy between the beta particle and the gamma ray. The radiation yield, Y, is the fraction of disintegrations that yield a certain radiation type and energy.

The committed dose-equivalent relation can now be written as:

$$H_{T,50} \propto \frac{Y \times E \times Q \times [AF(T \leftarrow S)]}{m_T} \qquad (5.10)$$

where $H_{T,50}$ = committed dose equivalent to an organ
Y = radiation yield (no units)
E = energy of the radiation (MeV)
$AF(T \leftarrow S)$ = absorbed fraction of the emitted energy
m_T = mass of the target organ (g)
Q = quality factor of the radiation.

The expression on the right side of Equation (5.10) is collectively referred to as the specific effective energy [SEE(T-S)]. This indicates the energy, in units of MeV, deposited per gram of the target organ for each

disintegration. Because the radioactive material may emit more than one type of radiation, it is necessary to sum the contributions from all radiations emitted; that is:

$$SEE(T \leftarrow S)_{total} = \sum_{i=1}^{n} [SEE(T \leftarrow S)]_i \qquad (5.11)$$

where

$SEE(T \leftarrow S)_{total}$ = specific effective energy of the nuclide (MeV/[g·Bq]), which is unique for any given combination of nuclide, source organ, and target organ

$$\sum_{i=1}^{n} [SEE(T \leftarrow S)]_i = [SEE(T \leftarrow S)]_{radiation\ 1} + [SEE(T \leftarrow S)]_{radiation\ 2} + \ldots + [SEE(T \leftarrow S)]_{radiation\ n}$$

Thus, we can write the relation for the committed dose equivalent as

$$H_{T,50} \propto SEE(T \leftarrow S) \qquad (5.12)$$

where $H_{T,50}$ = committed dose equivalent to an organ

$SEE(T \leftarrow S)$ = specific effective energy of the radioactive nuclide per disintegration (MeV/g·dis).

F. Total Number of Disintegrations in the Source Organ, U_S. The total number of disintegrations in an organ over the 50 years following a single uptake of radioactive material is a complicated function of the physical decay of the radionuclide and the metabolic characteristics of the chemical compound that contains the radionuclide. For example, radioactive material may be biologically eliminated from one organ, perhaps the lung, only to be absorbed by a second organ, such as the liver. The equations describing the time-dependent distribution of the radioactive material can be found in ICRP 30 and are not discussed here.

If the 50-year cumulated activity in the source organ, U_S, is given in disintegrations, then the relation for the committed dose equivalent may be written as:

$$H_{T,50} \propto U_S \times [SEE(T \leftarrow S)] \qquad (5.13)$$

where $H_{T,50}$ = committed dose equivalent to an organ
U_S = number of transformations in the source organ S over 50 years following the intake of a radionuclide.

G. Conversion Factors. Finally, the calculation of appropriate conversion factors allows the replacement of the proportionality symbol by an equal sign. The conversion factors convert the energy deposition to rem for the traditional system, or to sievert if the SI system is to be used. In units of rem, the appropriate equation is:

$$H_{T,50} = (1.6 \times 10^{-8}) \times U_S \times [SEE(T \leftarrow S)] \qquad (5.14)$$

where $H_{T,50}$ = committed dose equivalent to a target organ (rem)
U_S = number of transformations in the source organ S over 50 years following the intake of a radionuclide
$SEE(T \leftarrow S)$ = specific effective energy of the radionuclide (MeV/g).

In units of sievert, the equation is:

$$H_{T,50} = (1.6 \times 10^{-10}) \times U_S \times [SEE(T \leftarrow S)] \qquad (5.15)$$

where $H_{T,50}$ = committed dose equivalent to a target organ (Sv)
U_S = number of transformations in the source organ S over 50 years following the intake of a radionuclide
$SEE(T \leftarrow S)$ = specific effective energy of the radionuclide (MeV/g).

CHAPTER 6. EXTERNAL EXPOSURE

6.1 CONTROL AND REDUCTION OF EXTERNAL RADIATION DOSE 6.3
6.1.1 Exposure Time 6.4
A. Basic Principle 6.4
B. Control of Time 6.4
C. Reduction of Time 6.5
6.1.2 Distance from the Source 6.6
A. Basic Principle 6.6
B. Control of Distance 6.7
6.1.3 Shielding 6.9
6.1.4 Other Methods of Controlling External Exposure . . . 6.11
A. Inventory Limitations 6.11
B. Good Practices 6.11
6.2 MONITORING OF EXTERNAL RADIATION DOSE 6.12
6.2.1 Dosimetry Service 6.12
6.2.2 Review of Radiation Doses 6.13
6.3 ESTIMATION OF EXTERNAL RADIATION DOSE 6.14
6.3.1 External Dose from Alpha Particles 6.14
6.3.2 External Dose from Beta Particles 6.14
6.3.3 External Dose from Gamma Radiation 6.15
A. Exposure Rate from Any Gamma Point Source . . . 6.17
B. Other Methods of Calculating Gamma Exposure . . . 6.19
REFERENCES 6.19
APPENDIX A - ESTIMATION OF EXTERNAL GAMMA DOSE 6.21

FIGURES

6.1 The Inverse-Square Relationship 6.7

6.2 Line Source 6.24

6.3 Plane Disk Source 6.25

TABLES

6.1 Half-Value and Tenth-Value Layers 6.10

6.2 Specific Ionization for Electrons 6.15

6.3 Conversion Factors for Computing Dose Equivalent from Exposure . 6.16

6.4 Gamma Radiation Levels for One Curie of Some Radionuclides . . 6.18

6.5 Gamma-Ray Energy Absorption in Tissue 6.26

CHAPTER 6. EXTERNAL EXPOSURE

External radiation exposure is the exposure of the body to radiation originating outside of the body. For example, an external radiation exposure may be received from radioactive material in a package, from fixed contamination on a bench top, or from an x-ray machine. The hazard presented by external radiation and the methods used to control external exposure are dependent upon the penetrating ability of the radiation and the dose rate encountered. Penetrating radiations such as photons and neutrons, which can pass into the body and irradiate the internal organs, are considered more hazardous than the relatively nonpenetrating charged particles, such as alpha and beta particles.

If a radioactive source material is shielded so that the radiation is emitted as a beam, then only those parts of the body that traverse the beam will be irradiated. This causes a partial-body irradiation. Common sources of severe partial-body irradiation are radiation-producing machines such as x-ray machines and accelerators, which are capable of producing intense beams of radiation. If the beam is large enough, or if the radioactive source material is not shielded, then the entire body may receive a dose of radiation; this is called a whole-body dose.

Exposure to external radiation can be controlled or reduced by a number of methods, primarily the judicious use of time, distance, and shielding. In this chapter, these and other methods are discussed, the monitoring of external doses is described briefly, and procedures for estimating external dose are given.

Section 6.1 CONTROL AND REDUCTION OF EXTERNAL RADIATION DOSE

The primary methods of reducing external radiation dose are the use of time, distance, and shielding. Other methods are also available. Each task involving radioactive material should be carefully evaluated to determine which control procedures are appropriate. The ALARA (as low as is reasonably achievable) philsophy should always be considered in the development of control procedures.

6.1.1 Exposure Time

The longer the time spent working in a radiation field, the higher the dose received. An individual's working time can be reduced if work is planned and if dry runs, complete in every detail except for the use of radioactivity, are performed before any work with radioactive materials or radiation-producing machines is begun.

A. Basic Principle. The total dose received at a given distance from a particular source is a linear function of the exposure time; that is, doubling the exposure time doubles the total dose, and halving the time halves the total dose. This relationship can be expressed by Equation (6.1):

$$D = \dot{D} \times t \qquad (6.1)$$

where D = radiation dose

$\dot{D}$ = radiation dose rate, or dose per unit time

t = time of exposure to radiation.

This equation assumes that the dose rate is constant during the exposure time.

Minimizing an individual's exposure time is one of the simplest ways of reducing the individual's total dose. For example, if the dose rate from an unshielded source is 2 rad/hr and the time of exposure is 30 minutes, then the radiation dose received is:

$$D = 2 \text{ rad/hr} \times 0.5 \text{ hr} = 1 \text{ rad}$$

However, if the time of exposure to the source can be reduced to 15 minutes, then the radiation dose received is:

$$D = 2 \text{ rad/hr} \times 0.25 \text{ hr} = 0.5 \text{ rad}$$

B. Control of Time. Time spent in a radiation area can be controlled by the use of timekeepers. This practice requires that the dose rate in a given work area be known. The maximum allowable residence time in the area can then be calculated using Equation (6.2):

$$t = \frac{D}{\dot{D}} \qquad (6.2)$$

where t = maximum allowable residence time in the radiation area

D = maximum dose to be received by the individual

$\dot{D}$ = dose rate of the source.

In instances of very high dose rates or where rigid control of exposure is needed, a timekeeper should be available for each individual. The timekeeper stands away from the radiation source but within sight of the individual. When the specified time has elapsed, the timekeeper notifies the individual, who then leaves the area. Personnel should be instructed to leave the area immediately and without question upon notification by the timekeeper.

C. Reduction of Time. Time spent working in a radiation area can be reduced by a number of methods; examples include training, the use of power equipment, easy access to equipment, and modification of the task to be performed.

The amount of time an individual spends in a radiation area can depend on how quickly and efficiently he or she can perform a task. Training can improve work efficiency and thus reduce exposure in day-to-day use of radioactive material.

Training programs should include actual performance of a procedure, complete in every detail (including the use of protective clothing, survey instruments, etc.) with the sole exception that radioactivity is absent. In some instances, this may mean that full-scale mockups constructed. Personnel can then practice the procedures, becoming more proficient and confident. At the same time, the procedures should be observed and analyzed by the Radiation Protection Officer (RPO) in an attempt to reduce the working time. Training is discussed in greater detail in Chapter 12.

The use of power equipment can reduce the time spent on a job. Examples of time-saving equipment include motorized carts for transporting materials in warehouses; impact wrenches; and power screwdrivers, saws, and drills. Most power tools can be used on the job without modification, although tools for specialized applications may require modifications. Equipment used in a radiation area should always be monitored for contamination before being removed from the area.

Efficient access to components, systems, or equipment can significantly reduce the time required for their operation, maintenance, repair, or replacement. The ease of access to equipment and components should be assessed wnen equipment or work areas are being designed and should be evaluated frequently in existing situations. For example, the fabrication of work platforms or the removal of obstructions may improve access to equipment and reduce the time spent in a radiation area.

Task modifications that result in decreased exposure time also reduce the radiation dose received. A conscientious review of all repetitious tasks is the best metnod of maintaining radiation exposure ALARA. After each task is completed, all participants should discuss the task and methods to improve performance. Task modifications may also be identified in training sessions. All standing operating procedures (SOPs) should be continually upgraded and improved.

6.1.2 Distance from the Source

Often, the time spent near a radiation source cannot be reduced. Personnel should then either work farther away from the radiation source or place shielding between themselves and the source.

A. Basic Principle. If time and shielding remain constant, then the radiation dose decreases as the square of the distance from the source of radiation. Consequently, the relationship between distance and dose rate is commonly called the inverse-square law. This relationship is illustrated in Figure 6.1.

The equation for the inverse-square law is:

$$\dot{D}_2 = \dot{D}_1 \times \frac{(s_1)^2}{(s_2)^2} \qquad (6.3)$$

where $\dot{D}_1$ = the dose rate at distance 1
$\dot{D}_2$ = the dose rate at distance 2
s_1 = distance 1
s_2 = distance 2.

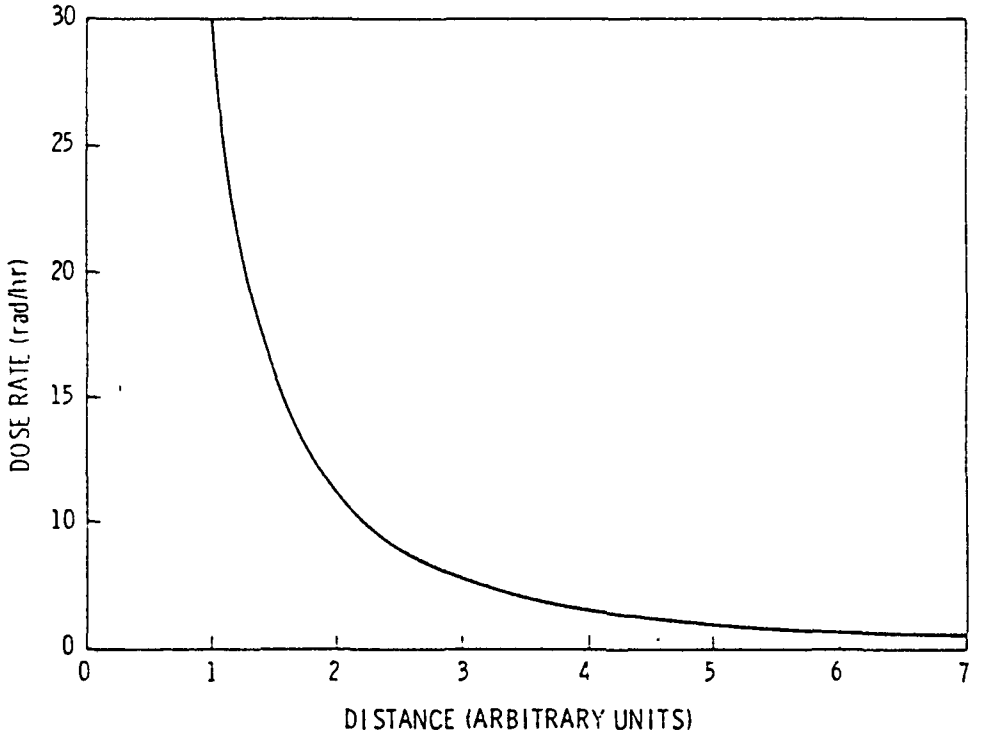


FIGURE 6.1. The Inverse-Square Relationship

The inverse-square law assumes that the radiation source is very small (a point source). If the distance between a nonpoint source and the irradiated object is at least five times the largest dimension of the source, then the inverse-square law can still be used. The inverse-square law also holds only in a vacuum. Attenuation of gamma rays and neutrons by air is usually negligible and does not influence the dose rate to an appreciable extent. However, alpha and beta particles are greatly attenuated by air, and as a result, inverse-square calculations overestimate the actual radiation dose for three types of radiation.

B. Control of Distance. Distance, as a method of reducing radiation exposure, can include remote operation, moving work away from radiation sources, and moving extraneous radiation sources away from the work area. Each task should be carefully evaluated to determine whether these procedures or others can be used to increase the distance between personnel and radiation sources.

(1) Remote Operation. Remote operation generally requires the use of a manipulating device, or remote-handling tool, to place distance between the operator and the radioactive source. For example, small radioactive sources are commonly equipped with a detachable handle or tool; most sealed sources come with a handling device; and forceps can be used to manipulate swipes for leak testing sources. Remote operations can also be performed using specially designed manipulators operated from behind barriers. Manipulators range in complexity from simple devices used in conjunction with temporary shielding to complex devices built into specially constructed hot cells.

Some manipulations are difficult to perform using remote-handling tools and can be performed faster and with a lower resultant dose using the fingers. However, direct handling of radioactive sources should be minimized and should be performed, when absolutely necessary, as quickly as possible to minimize the high dose rates that can result from direct handling. A 2-cm-diameter, 1-Ci source of ^{137}Cs, for example, gives a dose-equivalent rate of about 1.5×10^3 rem/hr to the hand when held in the hand. At this rate, the maximum allowable dose equivalent to the hand for one calendar quarter (18.75 rem) would be received in about 45 seconds. When sources must be handled directly, a finger dosimeter should be worn.

(2) Moving Away from Sources. A simple, often-overlooked technique for reducing exposure through the use of distance is for individuals to move away from the radiation source whenever possible. For example, if personnel need to discuss a procedure, they should move away from the source. If a defective part of a machine needs to be serviced, it should be removed and serviced elsewhere. Tradeoffs might be required if the object to be worked on is bolted onto or close to the radiation source and removal time exceeds servicing time. The ease of removing components should be considered during the design of equipment and of the building in which it is to be housed. Ideally, components that can be removed from the radiation area quickly and safely should be used.

Another example of moving away from the source is found in the use of gauging devices, such as those used to determine the surface density of road beds and the moisture content of roofs. During the operation of these devices,

the radiation source is moved from a well-shielded configuration to a less well shielded configuration. The operator should step back from the device while the timer is operating and the measurement is being taken.

(3) Removing Other Sources. Moving other sources away from the work area is the third method of using distance to reduce exposure. For example, piping can be backflushed to dislodge and remove radioactive debris. Other extraneous sources that should not be overlooked are contaminated stock bottles and accumulations of radioactive waste.

6.1.3 Shielding

Shielding is the use of barriers or absorbers placed between a source and an individual to stop some of the radiation reaching the individual. Alpha particles can be totally absorbed by a few centimeters of air or a few sheets of paper. Beta particles can be stopped by a few meters of air or a few millimeters of lead or plexiglass. Gamma radiation can penetrate even dense materials such as lead; however, the intensity of gamma radiation can be reduced to negligible levels by the use of shielding.

The attenuation of gamma radiation by an absorbing material can be described by the equation:

$$I = I_0 \times e^{-\mu s} \qquad (6.4)$$

where

I = radiation intensity after traversing a thickness, s, of material

I_0 = original radiation intensity, i.e., the radiation intensity that would be observed had the attenuating material not been present

e = base of the natural logarithms (e = 2.71828)

μ = linear attenuation coefficient (cm^{-1})

s = thickness of the attenuating material (cm).

The linear attenuation coefficient, μ, is related to both the attenuating material and the energy of the photon. In many instances, the mass attenuation coefficient is available in references, rather than the linear attenuation coefficient.

The mass attenuation coefficient is the linear attenuation coefficient divided by the density of the medium. That is:

$$\mu_m = \mu/\rho \tag{6.5}$$

where μ_m = mass attenuation coefficient (cm^2/g)

μ = linear attenuation coefficient (cm^{-1})

ρ = density of the attenuating material (g/cm^3).

Thus

$$\mu = \mu_m \times \rho \tag{6.6}$$

Mass attenuation coefficients as a function of photon energies are listed for many materials in the Radiological Health Handbook (1970). The densities of common materials can also be found in the Radiological Health Handbook.

The half-value layer concept is useful in determining the necessary shielding for gamma radiation. A half-value layer (HVL) is the thickness of material required to reduce the radiation intensity by a factor of 2. This concept is similar to the half-life of radioactive decay. A related term, the tenth-value layer (TVL), is the thickness of an attenuating medium necessary to reduce the radiation intensity by a factor of 10. Both HVLs and TVLs for selected gamma sources and absorbing materials are given in Table 6.1.

TABLE 6.1. Half-Value and Tenth-Value Layers

Radionuclide	Half-Life	Gamma Energy (MeV)	Half-Value Layer (cm)			Tenth-Value Layer (cm)		
			Concrete	Steel	Lead	Concrete	Steel	Lead
^{60}Co	5.24 yr	1.17, 1.33	6.6	2.1	1.20	20.8	6.9	4.0
^{137}Cs	27 yr	0.66	4.8	1.6	0.65	15.7	5.3	2.1
^{192}Ir	74 d	0.13 to 1.06	4.3	1.3	0.60	14.7	4.3	2.0
^{198}Au	2.7 d	0.41	4.1	--	0.33	13.5	--	1.1
^{226}Ra	1622 yr	0.047 to 2.4	6.9	2.2	1.66	23.4	7.4	5.5

6.1.4 Other Methods of Controlling External Exposure

Inventory limitations, access restrictions, and a variety of other approaches can be used to help control exposure to external radiation.

A. Inventory Limitations. The hazard presented by radioactive material is a direct function of the quantity of material present. Inventories of radioactive material in laboratories can be reduced by the frequent collection of radioactive waste. An inventory of a radioactive chemical reagent can also be reduced by separating aliquots of the material into individual vials and storing the material that will not be used immediately away from the work area. The material can be separated by the user after receiving it, or it can be ordered in multiple containers from most suppliers, for a nominal fee. Two advantages result from this separation: 1) the radiation hazard resulting from spills or other accidents is reduced, and 2) inventory recordkeeping is simplified. The use of a centralized storage room for radioactive material not in use or used only occasionally is often convenient, relatively inexpensive, and secure. Such a facility is also helpful in keeping exposures ALARA, since less radioactive material is stored in laboratories or other areas occupied by personnel.

B. Good Practices. Other methods of reducing radiation exposures, which are discussed in more detail in other chapters of this manual, include the following:

1. Restrict access to areas that present a radiation hazard, through the use of locked doors, intrusion alarms, or guards. The means of restriction selected depends upon the radiation dose rates that are anticipated, the presence of interlocks, security restrictions, and budget.
2. Minimize the number of authorized radiation workers present by limiting the number of persons in an area at a given time.
3. Post signs in radiation areas. The work area should be surveyed every few months to ensure that the signs adequately describe the hazard associated with the area. The posting should indicate the actual hazard involved; do not "overpost." Habitual overstatement of radiation hazards may cause personnel to ignore the warning signs.

4. Keep copies of SOPs readily available to all radiation workers.

5. Maintain operating logs for all radiation-producing machines and radioactive sources. These logs should contain information such as date, time in, time out, and the names of the individuals working with the machines or sources. In some cases, it may be desirable to include the readings of a pencil dosimeter as each individual enters and leaves the area.

6. Use a "buddy system" so that an individual never works alone in a radiation area, particularly in one that is locked.

7. Establish areas that require an estimation of the dose rate before a person can enter.

Section 6.2 MONITORING OF EXTERNAL RADIATION DOSE

The primary DA dosimeter is the film badge (see Chapter 2). Pocket dosimeters and thermoluminescence dosimeters (TLDs) can be used to supplement the film badge. Supplementary dosimeters should be used when an individual is likely to receive more than 5 mrem in 1 hour and must be used when an individual enters a high-radiation area where the dose rate may be greater than 100 mrem/hr.

The dosimetry service for Army personnel and the responsibilities of the RPO in reviewing radiation doses to personnel are discussed in the following sections.

6.2.1 Dosimetry Service

Dosimeters for all personnel (army, civilian, and contractor) working with DA, ARNG, and USAR are provided by DARCOM. The dosimetry service is coordinated through the Lexington-BlueGrass Army Depot (Attn: AMXLX-ME-1), and an informational packet that describes the procedures for obtaining dosimetry services is available upon request. Because these procedures are updated periodically, they will not be detailed here. Actual requisitions for dosimetry service should be sent to the appropriate Army depot designated in the informational packet obtained from Lexington-BlueGrass.

When dosimetry service is requested for an individual, the RPO should be prepared to provide the following information about that person:

1. name of individual
2. date of birth
3. social security number
4. work classification
5. type of dosimeter required (i.e., whole-body or extremity)--If extremity, include the body part it is to be worn on (i.e., wrist, finger). If whole-body, include the radiation of interest (i.e., beta, gamma, x ray, or neutron). If a neutron badge is required, a beta-gamma badge should also be requested because neutron radiation is almost always accompanied by gamma radiation.

6.2.2 Review of Radiation Doses

The RPO is responsible for reviewing the radiation dose received by personnel (10 CFR 20, AR 40-14). These evaluations provide the basis for showing compliance with existing regulations and can be used to spot trends in doses received by personnel.

Dosimetry services that process dosimeters report personnel doses in terms of rem; no further calculations need to be performed by the RPO. The dose and the date the information is received are transferred onto each individual's record. The RPO should review the individual records at least once each calendar quarter to check for administrative overexposures and to spot any unusual trends in both individual and collective dose equivalents. If any trends are noted, especially increases in dose equivalents, an investigation should be conducted to determine the cause and correct any situations contributing to the increases. Criteria for judging whether an individual overexposure has occurred and for reporting any overexposures are discussed in Chapter 11, Section 11.3. Briefly, any monthly whole-body dose equivalent exceeding 500 mrem is categorized as an overexposure.

Section 6.3. ESTIMATION OF EXTERNAL RADIATION DOSE

Factors that affect the external radiation dose a person may receive from a radiation source include time, distance, shielding, and the activity of the source. The first three factors have already been discussed. The activity of the source material, often referred to as the source strength, has a direct linear relationship to the dose rate. That is, if the source activity is doubled, then the dose rate is doubled. Source activity is expressed as the activity of the parent radionuclide and is given in units of curies. Terms such as intense source, large source, or small source are relative terms and should be avoided.

Many methods can be used to estimate radiation doses from radioactive sources outside the body. The more sophisticated methods are computer-based calculations that must be performed by experienced individuals. However, for evaluating a facility's safety requirements, rapid estimates of radiation doses that are relatively accurate are often sufficient.

6.3.1 External Dose from Alpha Particles

An alpha particle must have an energy of at least 7.5 MeV to penetrate the 0.07-mm-thick protective layer of the skin. The vast majority of alpha-emitting radionuclides have alpha energies less than 7.5 MeV. For this reason, alpha particles do not present an appreciable external radiation hazard, and dose calculations are generally not required.

6.3.2 External Dose from Beta Particles

The dose rate 10 cm from a source of beta particles is given by Equation (6.7), which is valid over a wide range of beta energies.

$$\dot{D} = 2700 \times A \qquad (6.7)$$

where $\dot{D}$ = the dose rate (rad/hr)

A = the activity of the source (Ci).

In order to calculate the dose rate at distances other than 10 cm, the inverse-square relationship can be used. Equation (6.7) neglects the ability of air,

and even of the source material itself, to reduce or attenuate the dose rate. The attenuation of beta particles by air can be appreciable, and large errors in the calculated dose rate occur at distances beyond about 1 meter from the source.

The dose rate, in air, at the surface of a beta source is given by Equation (6.8):

$$\dot{D} = \frac{A}{S} \times P_i \qquad (6.8)$$

where $\dot{D}$ = dose rate (rad/hr)

A = source activity (mCi)

S = surface area of the source (cm^2)

P_i = specific ionization of the radiation, or the average number of ion pairs produced per centimeter of the radiation's path in air (taken from Table 6.2).

TABLE 6.2. Specific Ionization for Electrons[a]

Radiation Energy (MeV)	P_i (Ion Pairs/cm)	Range in Air (cm)
0.05	250	3.02
0.10	175	10.80
0.20	96	32.50
0.30	76	59.60
0.50	60	122.00
1.00	53	310.00
1.50	47	526.00

(a) Brodsky and Beard 1960.

6.3.3 External Dose from Gamma Radiation

Most equations for calculating the gamma-ray dose result in the exposure (the measure of the ionization of air by gamma radiation, measured in roentgen (R)), rather than the absorbed dose (rad) or dose equivalent (rem). The factors

for converting from exposure in units of roentgen to dose equivalent in units of rem are nearly equal to 1 for photons with energies greater than about 600 keV. Photons with energies less than about 600 keV are greatly scattered, resulting in a dose-equivalent rate in rem that is higher than the exposure rate in roentgen. Therefore, for photons with energies above 662 keV, the conversion factor 1.03 should be used, and for photons with energies below 662 keV, the conversion factors listed in Table 6.3 should be used. The three depths included in the table are for dose equivalents to 1) the whole body (1.0-cm depth, or deep dose equivalent); 2) the lens of the eye (0.3-cm depth); and 3) the skin (0.007-cm depth, or shallow dose equivalent).

TABLE 6.3. Conversion Factors for Computing Dose Equivalent from Exposure[a]

Photon Energy (keV)	Conversion Factor at a Depth of		
	1.0 cm ("deep")	0.3 cm	0.007 cm ("shallow")
15	0.28	0.67	0.90
20	0.58	0.79	0.94
30	1.00	1.07	1.11
40	1.28	1.29	1.34
50	1.46	1.46	1.50
60	1.47	1.47	1.52
70	1.45	1.45	1.50
80	1.43	1.43	1.48
90	1.41	1.41	1.45
100	1.39	1.39	1.43
110	1.37	1.37	1.40
120	1.35	1.35	1.36
130	1.33	1.33	1.34
140	1.32	1.32	1.32
150	1.30	1.30	1.30
662	1.03	1.03	1.03

(a) American National Standards Institute (ANSI) Standard N13.11-1978.

A. Exposure Rate from Any Gamma Point Source. A point source is a small source of radiation. The commonly used equations for calculating the exposure rate to an individual from a point source assume that the distance between the source and the individual is at least five times the diameter of the source or the diameter of the individual, whichever is larger. The simplest equation used to calculate the exposure rate from a gamma-emitting radionuclide is based on the specific gamma-ray constant (Γ) of the radionuclide, as given in Table 6.4.

$$\dot{X} = \frac{A\,\Gamma}{s^2} \tag{6.9}$$

where $\dot{X}$ = exposure rate (R/hr)

A = source activity (mCi)

Γ = specific gamma-ray constant ($[R \cdot cm^2]/[hr \cdot mCi]$)

s = distance from the source (cm).

If the specific gamma-ray constant for a gamma-emitting radionuclide is not listed in Table 6.4, then the following two equations can be used. For a distance from a source measured in meters:

$$\dot{X} = \frac{0.54\ A \sum_{i=1}^{k} E_i\, n_i}{s^2} \tag{6.10}$$

where $\dot{X}$ = exposure rate (R/hr)

A = source activity (Ci)

E_i = energy of photon i (MeV)

n_i = number of photons of energy E_i emitted per disintegration

$\sum_{i=1}^{k} E_i\, n_i = E_1\, n_1 + E_2\, n_2 + \ldots\ldots E_k\, n_k$

s = distance from the source (m)

0.54 = constant ($[R \cdot m^2]/[MeV \cdot hr \cdot Ci]$).

TABLE 6.4. Gamma Radiation Levels for One Curie of Some Radionuclides[a]

Nuclide	Γ[b]	Nuclide	Γ[b]	Nuclide	Γ[b]
Actinium-227	∿2.2[c]	Gold-198	2.3	Potassium-43	5.6
Antimony-122	2.4	Gold-199	∿0.9	Radium-226	8.25
Antimony-124	9.8	Hafnium-175	∿2.1	Radium-228	∿5.1
Antimony-125	∿2.7	Hafnium-181	∿3.1	Rhenium-186	∿0.2
Arsenic-72	10.1	Indium-114m	∿0.2	Rubidium-86	0.5
Arsenic-74	4.4	Iodine-124	7.2	Rutherium-106	1.7
Arsenic-76	2.4	Iodine-125	∿0.7	Scandium-46	10.9
Barium-131	∿3.0	Iodine-126	2.5	Scandium-47	0.56
Barium-133	∿2.4	Iodine-130	12.2	Selenium-75	2.0
Barium-140	12.4	Iodine-131	2.2	Silver-110m	14.3
Beryllium-7	∿0.3	Iodine-132	11.8	Silver-111	∿0.2
Bromine-82	14.6	Iridium-192	4.8	Sodium-22	12.0
Cadmium-115m	∿0.2	Iridium-194	1.5	Sodium-24	18.4
Calcium-47[d]	5.7	Iron-59	6.4	Strontium-85	3.0
Carbon-11[d]	5.9	Krypton-85	∿0.04	Tantalum-182[d]	6.8
Cerium-141	0.35	Lanthanum-149	11.3	Tellurium-121	3.3
Cerium-144	∿0.4	Lutecium-177	0.09	Tellurium-132	2.2
Cesium-134	8.7	Magnesium-28	15.7	Thulium-170	0.025
Cesium-137	3.3	Manganese-52	18.6	Tin-113	∿1.7
Chlorine-38[d]	8.8	Manganese-54	4.7	Tungsten-185	∿0.5
Chromium-51	1.16	Manganese-56	8.3	Tungsten-187	3.0
Cobalt-56	17.6	Mercury-197	∿0.4	Uranium-234	∿0.1
Cobalt-57	0.9	Mercury-203	1.3	Vanadium-48	15.6
Cobalt-58	5.5	Molybdenum-99	∿1.8	Xenon-133	0.1
Cobalt-60	13.2	Neodymium-147	0.8	Ytterbium-175	0.4
Copper-64	1.2	Nickel-65	∿3.1	Yttrium-88	14.1
Europium-152	5.8	Niobium-95	4.2	Yttrium-91	0.01
Europium-154	∿6.2	Osmium-191	∿0.6	Zinc-65	2.7
Europium-155	∿0.3	Palladium-109	0.03	Zirconium-95	4.1
Gallium-67	∿1.1	Platinum-197	∿0.5		
Gallium-72	11.6	Potassium-42	1.4		

(a) Radiological Health Handbook 1970.
(b) Γ = specific gamma-ray constant = $R \cdot cm^2/hr \cdot mCi$, or $\Gamma/10 = R \cdot m^2/hr \cdot Ci$.
(c) ∿ = approximately.
(d) A Manual of Radioactivity Procedures 1961, Appendix A, pp. 137-140.

When the distance from the source is measured in feet, an approximation of the exposure rate is given by Equation (6.11).

$$\dot{X} = \frac{6\,A \sum_{i=1}^{k} E_i\, n_i}{s^2} \qquad (6.11)$$

where $\dot{X}$ = exposure rate (R/hr)

A = source activity (Ci)

E_i = energy of photon i (MeV)

n_i = number of photons of energy E_i emitted per disintegration

s = distance from the source (ft)

6 = constant ($[R \cdot ft^2]/[MeV \cdot hr \cdot Ci]$).

B. Other Methods of Calculating Gamma Exposure. In special cases, such as for calculating of gamma dose from line sources or from planar disc sources, more complex equations than those listed above are needed. These equations, presented in Appendix A, are for estimating exposure based on the intensity of the photon radiation.

REFERENCES

American National Standards Institute (ANSI). 1978. Criteria for Testing Personnel Dosimetry Performance. ANSI N13.11, New York.

Brodsky, A., and G. V. Beard. 1960. A Compendium of Information for Use in Controlling Radiation Emergencies. TID-8206 (Rev.), U.S. Atomic Energy Commission, Washington, D.C.

National Council on Radiation Protection and Measurements (NCRP). 1961. A Manual of Radioactivity Procedures. NCRP 28, Washington, D.C. Also published in 1961 as National Bureau of Standards Handbook No. 80, Washington, D.C.

Radiological Health Handbook. 1970. U.S. Department of Health, Education, and Welfare, Washington, D.C.

U.S. Code of Federal Regulations. 1982. Title 10, Part 20, "Standards for Protection Against Radiation." U.S. Government Printing Office, Washington, D.C.

U.S. Department of the Army and Defense Logistics Agency. Medical Services - Control and Recording Procedures for Exposure to Ionizing Radiation and Radioactive Materials. AR 40-14, DLAR 1000.28. Washington, D.C.

APPENDIX A

ESTIMATION OF EXTERNAL GAMMA DOSE

Equations were presented in Section 6.3.3 for estimating the exposure rate from point sources of gamma radiation. A slightly more complicated method of dose estimation involves first calculating the flux, or intensity, of the radiation, which is measured in photons per unit area in unit time (usually in photons/$cm^2 \cdot sec$), and then using the flux to calculate the absorption of the radiation's energy by body tissues.

To calculate the flux from any source, it is necessary to consult a decay scheme to determine the number of photons emitted per disintegration. Cobalt-60, for example, emits two gamma rays per disintegration, and both of these must be taken into account in the calculation of the flux.

A.1 FLUX FROM A POINT SOURCE

For a point source, the photon flux can be calculated from:

$$I = \frac{(3.7 \times 10^{10}) \times A \times n}{4 \times \pi \times s^2} \qquad (6.12)$$

where
- I = photon flux for photons of a given energy (photons/[$cm^2 \cdot sec$])
- A = source activity (Ci)
- n = fraction of disintegrations that yield a gamma ray of a given energy (photons/disintegration)
- s = distance from the source (cm)
- π = pi = 3.1416
- 3.7×10^{10} = constant (disintegrations/[sec·Ci]).

A.2 FLUX FROM A LINE SOURCE

A typical problem might entail calculating the dose rate from a pipe that contains radioactive material. In principle, the problem could be solved by

considering the pipe (or line) to be a series of point sources, calculating the flux from each point, and then adding up the dose rates from all the points. At best, this would be tedious. Therefore, the following equation has been derived to calculate the photon flux from a line source. The equation is valid for any point, p, along the source.

$$I = \frac{(3.7 \times 10^{10}) \times A_s \times n}{4 \times \pi \times s} \times (|\theta_1| + |\theta_2|) \qquad (6.13)$$

where I = photon flux for photons of a given energy (photons/[cm^2·sec])

A_s = source activity per unit length of pipe (Ci/cm)

n = fraction of disintegrations that yield a gamma ray of a given energy (photons/disintegration)

π = 3.1416

s = distance from the pipe (cm)

θ_1, θ_2 = the angles shown in Figure 6.2 (radians)

3.7×10^{10} = constant (disintegrations/[sec·Ci]).

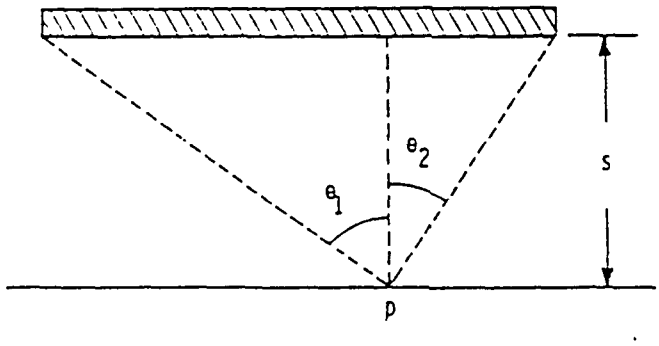


FIGURE 6.2. Line Source

A. FLUX FROM A PLANE DISK SOURCE

The dose rate from a plane disk source can be used to approximate the dose received from radioactive material on the ground. The photon flux at a point, d, from a plane disk source can be estimated from the equation:

$$I = \frac{(3.7 \times 10^{10}) \times A_s \times n}{4} \times \log\left[\frac{R^2}{s^2} + 1\right] \qquad (6.14)$$

where I = photon flux for photons of a given energy (photons/[$cm^2 \cdot sec$])

A_s = source activity per unit area (Ci/cm^2)

n = fraction of disintegrations that yield a photon of a given energy (photons/disintegration)

R = radius of the source (cm)

s = distance from the source (cm), as shown in Figure 6.3

3.7×10^{10} = constant (disintegrations/[$sec \cdot Ci$]).

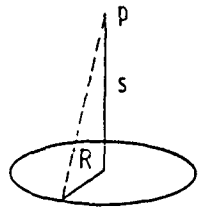


FIGURE 6.3. Plane Disk Source

A.3 ABSORPTION OF ENERGY BY TISSUES

The absorption of energy by body tissues is given by the energy absorption coefficient for the radiation in tissue. The basic equation is:

$$\dot{X} = 5.75 \times 10^{-5} \sum_{i=1}^{k} I_i \, (\mu_{en})_i \, E_i \qquad (6.15)$$

where $\dot{X}$ = exposure rate (R/hr)

I_i = photon flux (photons/[$cm^2 \cdot sec$])

$(\mu_{en})_i$ = mass energy absorption coefficient (cm^2/g)

E_i = the photon energy (MeV)

5.75×10^{-5} = constant ([$R \cdot g \cdot sec$]/[$Mev \cdot hr \cdot photon$])

$\sum_{i=1}^{k} I_i \, (\mu_{en})_i \, E_i = I_1 \, (\mu_{en})_1 \, E_1 + I_2 \, (\mu_{en})_2 \, E_2 + \ldots + I_k \, (\mu_{en})_k \, E_k$

CHAPTER 7. DECONTAMINATION

7.1 GENERAL DECONTAMINATION PROCEDURE 7.3

7.2 PREPARATION FOR DECONTAMINATION 7.4

7.2.1 Area Definition and Access Control 7.5

7.2.2 Personnel Protection During Decontamination . . . 7.5

7.2.3 Evaluation of Decontamination Needs 7.5

7.3 PERSONNEL DECONTAMINATION 7.6

7.3.1 Personnel Decontamination Methods 7.9

7.3.2 Specific Personnel Decontamination Procedures . . . 7.12

7.3.3 Personnel Decontamination Kit 7.13

7.4 EQUIPMENT AND MATERIAL DECONTAMINATION 7.14

7.4.1 Decontamination Methods 7.14

A. Cleaning, Abrasive, Chemical and Electrochemical Methods 7.14

B. Aging and Sealing 7.15

7.4.2 Selection of Decontamination Methods 7.15

7.4.3 Specific Decontamination Techniques 7.16

REFERENCES 7.16

APPENDIX A - PERSONNEL DECONTAMINATION PROCEDURES 7.17

APPENDIX B - EQUIPMENT AND MATERIAL DECONTAMINATION METHODS . . . 7.29

APPENDIX C - EQUIPMENT AND MATERIAL DECONTAMINATION PROCEDURES . . 7.39

FIGURES

7.1 Personnel Contamination Record 7.8

7.2 Decontamination and Evaluation Log 7.10

TABLES

7.1 Personnel Decontamination Methods 7.11

7.2 Contamination Removal Methods 7.31

7.3 Sealing Methods 7.36

7.4 Decontamination Methods for Various Surfaces 7.37

CHAPTER 7. DECONTAMINATION

The presence of contamination, or unwanted radioactivity, can result from normal operations, maintenance activities, and abnormal events such as equipment failure, accidents involving radioactive materials, and improper work practices. Detecting and determining the extent of contamination usually require use of the survey techniques described in Chapter 4 of this manual. When the extent of contamination has been determined and appropriate barriers have been established to limit further spread, the process of cleanup, or decontamination, can begin.

Decontamination has three purposes: 1) to prevent any uptake of radioactive material into the human body; 2) to limit external radiation exposure; and 3) to prevent further spread of contamination. Decontamination may be required for personnel, for equipment of all types and sizes, and for large surface areas such as land, floors, roads, or buildings. The basic method of decontamination is to remove radioactivity by one or more wet or dry processes. Two other approaches that decrease the level of removable contamination are allowing short-lived radionuclides to dissipate through radioactive decay and fixing contamination in place by covering or sealing it. These approaches are not generally recognized as decontamination processes; however, under some circumstances they may be the best possible actions. For that reason they are included in this chapter.

Section 7.1 GENERAL DECONTAMINATION PROCEDURE

The specific decontamination methods and procedures selected for use in particular circumstances depend on the type, extent, and location of the contamination; however, the general approach to decontamination outlined below applies to most situations.

1. Control access to contaminated areas.
2. Provide personnel protection, including appropriate clothing, for workers.

3. Evaluate what is to be decontaminated.

4. Obtain necessary equipment and materials.

5. Survey all items to be released to an unrestricted area.

6. Begin with the mildest decontamination methods and progress to harsher, more abrasive, or caustic methods as required.

7. Work from the outside of the contaminated area to the inside.

8. Isolate all clean areas from contaminated areas. Clean areas adjacent to those being decontaminated should be covered with taped-down paper or plastic to prevent recontamination.

9. Minimize the generation of contaminated liquids and airborne radioactivity during the work, and collect and treat as contaminated waste all liquids generated and materials used during decontamination.

10. Survey between major steps in the decontamination process (i.e., between successive applications of each technique and between different techniques).

11. Continue decontamination until contamination levels are reduced to appropriate levels as given in Chapter 4, Appendix A, of this manual.

12. Document the completion of decontamination, including the name of the individual performing the final survey, the date, and the survey results. (Documentation of intermediate survey results may also be desirable.)

These steps are discussed further in the following sections on preparation for decontamination and on methods for decontaminating personnel, equipment, and materials. Specific procedures for applying these methods are given in the appendixes at the end of this chapter.

Section 7.2. PREPARATION FOR DECONTAMINATION

Preparation for decontamination includes establishing boundaries within which contamination is to be contained and controlling access to the area;

providing radiation protection for personnel involved in the decontamination operation; and evaluating the specific items to be decontaminated.

7.2.1 Area Definition and Access Control

Contaminated areas (e.g., floor or land areas) should be posted and barriers established to limit access to and further spread of contamination. In more complex situations (e.g., pieces of contaminated equipment or several rooms within a building), it may be necessary to segregate and isolate areas of relatively high contamination from those of relatively low contamination. Segregation can be useful in determining what effort will be required to complete decontamination, and it helps in the establishment of priorities, or a sequence for the work.

7.2.2 Personnel Protection During Decontamination

Radiation protection requirements for decontamination operations are the same as those for work in contaminated or high-dose-rate areas. The key concerns are to protect personnel from becoming contaminated and to keep both individual and collective radiation doses at levels that are as low as is reasonably achievable (ALARA).

Personnel can be protected against contamination by the use of protective clothing. For decontamination operations involving tritium, organic solvents, or other wet substances, clothing impervious to the liquids involved should be selected to prevent absorption of contamination through the skin. Respiratory protection should be used in highly contaminated areas, particularly when decontamination methods may generate or stir up loose contamination. Step-off pads should be positioned at exits from the contaminated area.

The radiation dose to personnel during decontamination can be monitored and controlled using standard instruments and techniques (e.g., thermoluminescence dosimeters, pocket dosimeters, dose rate monitoring, and surveys of individuals).

7.2.3 Evaluation of Decontamination Needs

Many materials such as wood, damaged equipment, scrap metal, cables, cords, hoses, and clothing require more time and effort to decontaminate than

they are worth. In general, these items should be disposed of as contaminated waste (see Chapter 10). If proper control procedures are used, some contaminated items can be assigned for use in permanently contaminated areas (e.g., in nuclear reactor facilities or radiochemistry laboratories).

Decontamination is begun at the perimeter of a large contaminated area and progresses toward the center. When appropriate, decontamination is from top to bottom of vertical surfaces. Perimeters should be surveyed and reestablished as the size of the contaminated area is reduced. The environment or topography may impose additional considerations for sequence; on sloping or windy terrain, decontamination should begin with the highest or upwind points, respectively. The presence of drains, sumps, or sewers warrants special consideration. Where they exist specifically for the collection of radioactive liquids, they should be used during decontamination; however, if they could become pathways for the further spread of contamination to the environment, every effort should be made to ensure their isolation.

Where areas with varying degrees of contamination can be identified, adequately segregated, and controlled, the priority for decontamination is less critical. In general, work should begin where the most significant reduction in personnel dose can be achieved through early decontamination. Other factors that may contribute to setting decontamination priorities include the availability of materials, equipment, and personnel, and how immediate the need is for uncontrolled access to or use of the area or equipment to be decontaminated.

Section 7.3. PERSONNEL DECONTAMINATION

Before external decontamination of an individual is begun, the following steps should be taken to help establish priorities for decontamination and for follow-up efforts:

1. Observe any physical effects to the contaminated person, such as bleeding, irregular breathing rate, burns, or shock.
2. Assess the extent of any injuries: medical treatment of injuries takes priority over decontamination.

3. Immediately flush with water any skin contamination involving caustic, corrosive, or organic-solvent solutions.

4. Determine the extent and magnitude of contamination using personnel survey techniques.

5. Document survey results.

6. Remove contaminated clothing, place it in a plastic bag, and hold it for further disposition.

7. Obtain assistance from medical personnel if decontamination of eyes, ears, nose, or mouth is necessary or if harsh chemicals (other than soap and water) will be required.

8. Investigate to determine how the contamination occurred.

For accident situations involving both contamination and personnel injury, medical treatment must take priority over decontamination. The only exceptions to this are 1) when an extremely high level of contamination presents a greater hazard to the victim than does the physical injury, and 2) when decontamination can be performed prior to treatment of minor injuries, and the medical officer concurs. In all cases, decontamination must be performed in a manner that prevents indiscriminate spreading of contamination.

When personnel contamination is suspected or detected, a thorough personal survey should be performed. Contaminated clothing should be removed and bagged for subsequent disposition. During the survey, particular attention should be paid to locating any hot spots of contamination. The results of this survey, including the locations and measured levels of contamination, should be documented. Figure 7.1 is an example of a data sheet for assessing personnel contamination. Refer to AR 385-40 to determine whether an accident/incident report is required.

In the event of a known or suspected internal deposition of radioactivity (by inhalation, injection, consumption, etc.), arrangements must be made for a prompt bioassay (see Chapter 5) and for consultation with the medical staff. The treatment and removal of internally deposited radioactivity is a highly specialized field, and the assistance of qualified medical personnel is essential.

DARCOM-P 385-1

PERSONNEL CONTAMINATION RECORD

Name:_____ Social Security Number:_____

Date of Incident:_____ Time of Occurrence:_____

Location of Incident:_____

_____

Description of How Contamination Occurred:_____

_____

_____

_____

_____

How was contamination discovered?_____

SURVEY RESULTS

Survey Performed by:_____

Survey Instrument Manufacturer and Model:_____

Serial Number:_____ Probe Type:_____

Indicate type, extent, and magnitude of contamination on figure below.

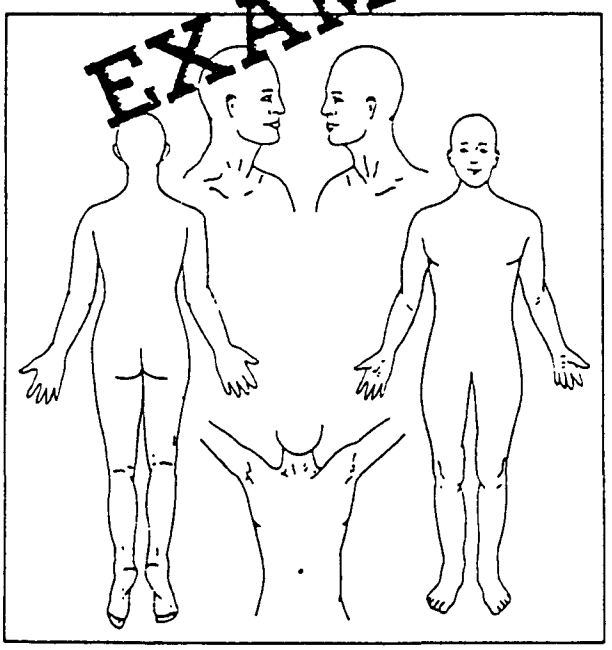


FIGURE 7.1. Personnel Contamination Record

7.3.1 Personnel Decontamination Methods

Personnel should be decontaminated as quickly as possible using the least drastic means necessary. Decontamination efforts should begin with mild methods, which should be continued as long as they are effective, and progress to harsher methods only as required. Medical supervision is required when harsh materials or methods are used. Extreme care should be taken to prevent the spread of contamination to any skin or body opening, and all liquids generated and materials used during decontamination should be collected and treated as contaminated waste. Personnel performing the decontamination should take all necessary precautions to protect themselves.

The progress of decontamination should be closely monitored by surveying between successive washings or techniques. A log of methods used and survey results should be maintained. A typical log sheet for personnel decontamination is shown in Figure 7.2.

Basic methods for personnel decontamination are listed in Table 7.1 in increasing order of harshness, along with their advantages, disadvantages, and decontaminating action, and some commonly available agents for each method. This is not a complete listing; many other agents have also been used effectively.

Simple washing methods (mild soaps, abrasive soaps, and detergents) are straightforward in their use. Generally, mild soap and water is sufficient for localized skin decontamination. A modification of simple washing is to make a paste by applying a powdered household laundry detergent to wet skin and rubbing. This method provides somewhat more effective decontamination, although it is also more irritating to the skin. Cool or lukewarm water should be used for all washing and rinsing. Hot water causes the skin pores to open, driving contamination deeper into the skin. Cold water closes the pores, trapping contamination in the skin.

If extensive washing is required or harsher methods must be used, obtain assistance from medical personnel before proceeding. In these circumstances, particular attention must be given to preventing skin damage. Chapping or cracking of the skin from repeated washing or abrasion can lead to the intake

DECONTAMINATION RECORD

Initial Contamination Level _____

Time Decontamination Begins	Skin Area Concerned	Decontamination Agent Used	Contamination Level After Decontamination	Skin Condition

Decontamination Completed by: _____ Time: _____

BIOASSAY (Check as applicable. Attach results when available.)

☐ in-vivo count ☐ nasal swipe

☐ urine sample ☐ feces sample

☐ none required ☐ other (specify) _____

FOLLOW-UP

Further evaluation needed? Yes____ No____

Type? _____

_____

Similar to previous occurrences? Yes____ No____

Explain _____

_____

Steps taken to prevent recurrence: _____

_____

_____

Comments: (attach if more space required)

_____

_____

_____

Radiation Protection Officer: _____ Date: _____

Reviewed by: _____ Date: _____

EXAMPLE

FIGURE 7.2. Decontamination and Evaluation Log

TABLE 7.1. Personnel Decontamination Methods

Method[a]	Common Agents	Action	Advantages	Disadvantages
Tape	Adhesive tape, masking tape	Removes by adhesion of contamination to tape	Simple, useful for spot contamination	Not useful for area contamination
Flushing	Water	Removes by flushing	Removes contamination if used immediately. May be used (with medical supervision) for eyes, ears, nose, mouth, and wounds	When used for nose and mouth, contaminated person should be warned not to swallow rinses
Mild soap and water	Bar soap, liquid soap	Emulsifies and dissolves contaminant	Readily available; effective for most cases	Continued washing defats skin. May spread contamination to other parts
Abrasive soap and water	Pumice-impregnated bar soap, powdered grit soap	Emulsifies, dissolves, and abrades	Readily available; effective for tough, calloused skin	Continued washing abrades skin
Detergent and water	Household laundry detergents	Same	Slightly more effective than soap	Will defat and abrade skin; use with care
Chemical complexing	10% EDTA solution	Chelates (bonds to contaminant)	Useful for heavy metals	
Oxidizing agents	Household bleach, potassium permanganate and sodium bisulfite	Dissolves contaminant absorbed in the epidermis	Superior for skin decontamination	Removes a layer of skin
Sweating[b]		Removes by sweating	Cleansing is from inside out	Contamination may seep into skin pores if profuse sweating is prolonged

(a) Listed in increasing order of harshness. Begin decontamination using mild methods and progress to harsher methods only as required. Medical supervision is required for all methods harsher than the use of soap and water.
(b) Sweating is a passive, mild decontamination method that should be used when other methods have been discontinued because of skin irritation or decreased effectiveness.

of radioactivity through minor cuts. The use of a hand cream or lotion between washings can help prevent chapping. If contamination still remains after extensive washing, covering the contamination with plastic (e.g., a plastic glove taped over the hand) and allowing the skin to sweat can provide further decontamination.

Chemical complexing agents, which should be used only under medical supervision, remove contamination by chemical interactions such as ion exchange and bonding. A solution of EDTA (ethylene-diamine-tetra-acetic acid) can be prepared by dissolving 10 grams of EDTA salts in 100 ml of water. This solution, which can be prepared in advance and stored, is applied to the skin with cotton swabs or sponges. Following each application of the solution, the area should be rinsed.

Oxidizing agents decontaminate by chemically removing the contaminant and a thin layer of skin. Household bleach is a weak oxidizing agent that can be applied full strength using cotton swabs or sponges. A stronger oxidizing agent is potassium permanganate ($KMnO_4$) followed by sodium bisulfite ($NaHSO_3$). Saturated solutions of each of these chemicals should be made up at the time of need by dissolving crystals of each in a small amount of water. (A saturated solution is one in which no more crystals will dissolve.) The $KMnO_4$ solution is painted thickly onto the skin and allowed to dry. It is then removed by gently scrubbing with the $NaHSO_3$ solution. The skin should be rinsed after each use of oxidizing agents, and their use should be discontinued if the skin becomes tender. Medical supervision is required for the use of this method.

Commercial decontamination agents--soaps, detergents, and complexing agents--are available under various trade names. They should be used with medical assistance and the manufacturer's instructions should be followed.

7.3.2 Specific Personnel Decontamination Procedures.

Specific procedures for personnel decontamination are provided in Appendix A of this chapter. Procedures for decontaminating the skin, hair and scalp, body, face, eyes, ears, mouth, and nose are included.

7.3.3 Personnel Decontamination Kit

A personnel decontamination kit should be assembled for field use, or supplies should be available at designated decontamination stations. Typical materials that should be included are as follows:

Item	Approximate Quantity
Applicators, cotton-tipped	500
Cotton balls	200
Cleansing tissues	4 boxes
Sterile gauze pads (5 cm x 5 cm)	400
Hand brushes	4
Masking tape	1 roll
Plastic cups (4 oz.)	25
Plastic cups (1 oz.)	25
Plastic bags (for waste)	20
Scissors	1 pair
Surgical gloves (talced)	1 box
Flexible tube	1.2 meters
Filter paper (for smears)	1 box
Envelopes (to hold smears)	1 package
Hand cream	1 jar
Soaps: Regular bar soap	2 bars
Abrasive soap	1 bar
Detergent (household laundry type)	1 box
Reagents: Household bleach	1 bottle
Potassium permanganate crystals	1 small jar
Sodium bisulfite crystals	1 small jar
EDTA salts	1 small jar
Basin (for field use)	1
19-liter jug (for field collection of liquids)	1
Pencils or pens	3
Paper	1 pad

Section 7.4. EQUIPMENT AND MATERIAL DECONTAMINATION

Equipment and materials may need to be decontaminated for a number of reasons, including:

1. for release for unrestricted use
2. for the salvage of valuable material
3. to reduce the potential for exposure of personnel to radiation
4. to reduce the volume of contaminated waste.

Decontamination should be performed as soon as possible after contamination occurs. This is particularly true for liquid contaminants, which can penetrate farther into materials as contact time increases.

Materials that cannot be easily or cost-effectively decontaminated should be evaluated for possible limited use in restricted areas, or disposed of. Porous items (such as wood and unsealed concrete), intricately designed equipment, and items of low replacement cost tend to fall in this category.

7.4.1 Decontamination Methods

Many methods and techniques have been developed for decontaminating equipment (TM 3-220). Most are physical or chemical cleaning processes. Two other methods, which are not considered true decontamination, are radioactive decay (aging) and sealing contamination in place.

A. Cleaning, Abrasive, Chemical, and Electrochemical Methods. True decontamination entails removing radioactivity by cleaning, abrasive, chemical, and electrochemical methods. Cleaning methods are nondestructive but may require that equipment be disassembled for maximum effectiveness. Cleaning includes both manual (wiping, mopping, vacuuming) and mechanical (soaking, spraying, vibrating) techniques. Abrasive methods are destructive, involving the progressive removal of the contaminated material. Chemical methods include both nondestructive techniques (e.g., the use of detergents and complexing agents, which remove contamination by emulsifying and ion exchange), and destructive techniques (e.g., the use of caustics and acids, which dissolve and corrode contamination and sometimes the base material).

Electrochemical methods are destructive, electrolytically removing contamination and some of the base material. Table 7.2 in Appendix B summarizes the applicability, advantages, and disadvantages of specific methods in each of these broad classes.

B. Aging and Sealing. Aging involves isolating a contaminated object until radioactive decay has reduced the contamination to an acceptable level. This approach is suitable only when short-lived radionuclides are involved. Aging for 10 half-lives reduces the contamination level to one-thousandth (1/1000) of the original level.

Sealing involves fixing radioactivity in place by covering it with an impermeable material such as earth, asphalt, cement, paint, or plastic. Sealing is most effective for alpha and low-level beta-gamma contamination. Most sealants are adequate for shielding alpha and some beta contamination. However, thick, high-density materials (e.g., concrete or several inches of earth) are needed to sufficiently attenuate gamma rays. Sealing is of most value where the primary concern is preventing the spread of relatively low levels of contamination, and where dose rate is not a serious concern. Table 7.3 in Appendix B provides a brief description of methods used for sealing contamination in place.

7.4.2 Selection of Decontamination Methods

The selection and application of decontamination methods is dependent upon the material or equipment to be decontaminated. For extensive decontamination, outside assistance may be necessary. Methods may be used individually or in combination. When more than one method is to be used, the least harsh or abrasive method should be used first. Table 7.4 in Appendix B lists some types of surfaces, materials, and equipment, and identifies methods suitable for decontaminating each. In the case of contaminated commodities, consult the appropriate technical manual for decontamination procedures.

Where extensive decontamination work is to be performed, several methods or combinations of methods can be tested on different areas of the same surface and the results can be compared using the decontamination factor (DF), the commonly used measure of decontamination effectiveness. The DF is calculated as follows:

$$DF = \frac{\text{surface contamination before decontamination}}{\text{residual surface contamination after decontamination}}$$

or

$$DF = \frac{\text{dpm before decontamination}}{\text{dpm after decontamination}}$$

The higher the DF, the more effective the method. High DFs are generally achieved with the initial application of any method, but subsequent applications may be less effective. Rinsing usually improves the DF of any decontamination procedure.

All other factors being equal, the decontamination method with the highest DF should be used. However, the resources available for decontamination and the destructiveness of each method also affect the choice of decontamination methods. The RPO should maintain records of the DF obtained during each decontamination in order to assist in the selection of procedures for future decontaminations.

7.4.3 Specific Decontamination Techniques

Specific techniques for decontaminating equipment and materials are described in Appendix C. The techniques include the use of tape patches, vacuum cleaning, wiping or mopping, water jets, detergents, complexing agents, organic solvents, acids, and caustic solutions.

REFERENCES

U.S. Department of the Army, Headquarters. Chemical, Biological and Radiological (CBR) Decontamination. TM 3-2300, Washington, D.C.

U.S. Department of the Army, Headquarters. Safety - Accident Reporting and Records. AR 385-40, Washington, D.C.

APPENDIX A

PERSONNEL DECONTAMINATION PROCEDURES

A.1 LOCALIZED SKIN DECONTAMINATION

Prerequisites

1. Survey to identify extent and magnitude of contamination.
2. Obtain medical assistance if harsh decontamination methods will be necessary.
3. Collect materials needed for decontamination.
4. Document steps and survey results in the appropriate log.

Precautions

1. Medical treatment takes priority over decontamination.
2. Do not spread contamination to clean areas.
3. Do not reuse applicators (replace after each time skin is touched).
4. Handle all waste materials as contaminated waste.
5. Stop decontamination procedures if evidence of skin damage appears or if person complains of soreness or stinging; contact medical personnel for assistance.
6. Person performing decontamination should take precautions not to become contaminated (i.e., wear gloves and other protective clothing as required).

Procedure for Spot Decontamination

1. Press masking tape over contaminated area.
2. Slowly remove and discard.
3. Repeat as necessary, avoiding skin irritation.
4. Proceed with area decontamination if tape method is not effective.

Procedures for Area Decontamination (in increasing order of harshness)

1. Soap and water

   Use one or more of the following techniques until no further reduction in contamination occurs:

   (a) Wash with mild bar soap and cool or lukewarm water.

   (b) Wash with abrasive soap and water; this method is particularly applicable to toughened skin areas such as fingertips and the palms of the hands.

   (c) Swab with mild liquid soap using cotton-tipped applicators, then rinse with water.

   (d) Use a soft hand brush in combination with any of the above techniques.

   Consult with medical personnel before proceeding with harsher techniques.

2. Detergent and water

   (a) Wash using a detergent and water.

   (b) Make a paste by first lathering the skin area with mild soap and water, then applying detergent powder to lathered skin and working into a paste; rub skin area and rinse paste off.

3. Mild oxidizing agent

   Apply household bleach full strength using cotton sponges or applicators. Rinse after each application. Continue until no further contamination reduction occurs.

4. EDTA solution

   Prepare a 10% EDTA solution by dissolving 10 grams of EDTA salts (Na_4EDTA) in 100 ml of water. (This solution can be prepared in advance and stored.) Apply the solution to the skin using cotton sponges. Rinse after application. Do not apply more than two times.

5. Strong oxidizing agent

   Prepare a saturated solution of potassium permanganate ($KMnO_4$) by dissolving $KMnO_4$ crystals in 1 ounce of water until no more crystals will dissolve (solution will be a dark red or brown). Prepare a saturated solution of sodium bisulfite ($NaHSO_3$) by dissolving $NaHSO_3$ crystals in 1 ounce of water until no more crystals will dissolve. Paint contaminated skin area with $KMnO_4$ solution using cotton applicators or sponges. Allow to dry, then repeat two more times. Remove brown stain by gently swabbing with $NaHSO_3$ solution using cotton swabs. Then rinse with water. If necessary, repeat the application one time.

6. Further decontamination

   If contamination remains after all these procedures have been tried, a medical expert should be consulted for assistance.

7. Post-decontamination

   Following successful decontamination, apply hand lotion to skin to prevent chapping.

8. Sweating

   If soreness or tenderness develops during decontamination, the procedure being used should be stopped for a time. During this interval, the contaminated area can be covered with plastic and allowed to sweat, thus cleansing the area from the inside out. The area should then be gently washed in lukewarm water. (This method is particularly useful for decontaminating the hands, using surgeons' gloves for covering.)

A.2 HAIR AND SCALP DECONTAMINATION

Prerequisites

1. Survey to identify extent and magnitude of contamination.
2. Collect materials needed for decontamination.
3. Document steps and survey results in the appropriate log.

Precautions

1. Medical treatment takes priority over decontamination.
2. Do not spread contamination to clean areas.
3. Do not reuse applicators (replace after each time skin is touched).
4. Handle all waste materials as contaminated waste.
5. Stop decontamination procedures if evidence of skin damage appears or if person complains of soreness or stinging; contact medical personnel for assistance.
6. Person performing decontamination should take precautions not to become contaminated (i.e., wear gloves and other protective clothing as required).

Procedure

1. Contaminated person should remove outer clothing and put on overalls or a laboratory coat and surgeons' gloves.
2. Wrap a towel around the person's neck.
3. Bend the person over a sink or basin and wash hair using mild soap or shampoo. Massage hair and scalp carefully, preventing lather or water from entering the ears, eyes, nose, or mouth.
4. Rinse hair with water. Change the towel if it becomes saturated.
5. Thoroughly dry the hair with towels (do not use a blow dryer).
6. Resurvey hair, also checking face and neck.
7. Repeat shampoo process as long as it is effective.
8. If shampooing ceases to be effective, contaminated hair can be cut with scissor or clippers and the scalp can be decontaminated using the procedures for localized skin decontamination.

A.3 GENERAL BODY DECONTAMINATION

Prerequisites

1. Survey to identify extent and magnitude of contamination.
2. Collect materials needed for decontamination.
3. Document steps and survey results in the appropriate log.

Precautions

1. Medical treatment takes priority over decontamination.
2. Do not spread contamination to clean areas.
3. Do not reuse applicators (replace after each time skin is touched).
4. Handle all waste materials as contaminated waste.
5. Stop decontamination procedures if evidence of skin damage appears or if person complains of soreness or stinging; contact medical personnel for assistance.
6. Person performing decontamination should take precautions not to become contaminated (i.e., wear gloves and other protective clothing as required).

Procedure

1. Remove clothing.
2. Shower with lukewarm water.
3. Lather, using mild soap and soft brush or scrub pad.
4. Rinse, taking care not to spread contamination to skin or body openings.
5. Survey and repeat as necessary.
6. If only localized contamination remains, follow procedures for localized skin decontamination.

A.4 FACIAL DECONTAMINATION

Prerequisites

1. Survey to identify extent and magnitude of contamination.
2. Collect materials needed for decontamination.
3. Document steps and survey results in the appropriate log.

Precautions

1. Medical treatment takes priority over decontamination.
2. Do not spread contamination to clean areas.
3. Do not reuse applicators (replace after each time skin is touched).
4. Handle all waste materials as contaminated waste.
5. Stop decontamination procedures if evidence of skin damage appears or if person complains of soreness or stinging; contact medical personnel for assistance.
6. Person performing decontamination should take precautions not to become contaminated (i.e., wear gloves and other protective clothing as required).

Procedure

1. Use only mild soap and water to decontaminate the face.
2. Exercise special caution to prevent the spread of contamination to eyes, ears, nose, or mouth.
3. Avoid the use of oxidizing agents because of the sensitivity of facial skin and to prevent harm to the eyes.
4. Take nasal smears to assess the presence of nasal contamination.
5. Contact medical personnel for assistance in treating persons with high levels of facial contamination or a suspected internal deposition of radioactivity.

A.5 EYE, EAR, AND MOUTH DECONTAMINATION

Prerequisites

1. Obtain assistance of medical personnel.
2. Survey to identify extent and magnitude of contamination.
3. Collect materials needed for decontamination.
4. Document steps and survey results in the appropriate log.

Precautions

1. Medical treatment takes priority over decontamination.
2. Do not spread contamination to clean areas.
3. Do not reuse applicators (replace after each time skin is touched).
4. Handle all waste materials as contaminated waste.
5. Stop decontamination procedures if evidence of skin damage appears or if person complains of soreness or stinging; contact medical personnel for assistance.
6. Person performing decontamination should take precautions not to become contaminated (i.e., wear gloves and other protective clothing as required).

Procedure for Eye or Ear Decontamination

1. Flush with water. A fountain can be prepared by attaching a flexible tube to a faucet or water bottle.
2. Survey.
3. Repeat as necessary.
4. If eye becomes irritated or activity cannot be removed, obtain further medical assistance.
5. Fluids or agents other than water should not be used unless approved by medical personnel.

Procedure for Mouth Decontamination

1. Special Cautions:

   (a) Under no circumstances should a person with mouth contamination be allowed to eat, drink, chew, or use tobacco until decontaminated.

   (b) In no cases shall oxidizing agents (bleach, potassium permanganate, or sodium bisulfite) be used in the mouth because they will damage the mucous membranes.

2. For localized mouth contamination (spot on tongue or tooth), swab with an applicator or cotton sponge.

3. For general mouth contamination, flush using tap water and a flexible tube connected to a faucet or water bottle (the fountain method).

4. If contamination cannot be effectively removed by flushing, further medical assistance should be obtained.

5. Bioassay should be initiated for individuals with mouth contamination.

A.6 NASAL DECONTAMINATION

Prerequisites

1. Obtain the assistance of medical personnel.

2. Survey to identify extent and magnitude of contamination.

3. Collect materials needed for decontamination.

4. Document steps and survey results in the appropriate log.

Precautions

1. Medical treatment takes priority over decontamination.

2. Do not spread contamination to clean areas.

3. Do not reuse applicators (replace after each time skin is touched).

4. Handle all waste materials as contaminated waste.

5. Stop decontamination procedures if evidence of skin damage appears or if person complains of soreness or stinging; contact medical personnel for assistance.

6. Person performing decontamination should take precautions not to become contaminated (i.e., wear gloves and other protective clothing as required).

Procedure

1. When nasal contamination is suspected, have the person blow nose into disposable tissue. Survey used tissue and nose.
2. Take smears externally on the nose and upper lip area using filter papers moistened with water.
3. Take smears inside each nostril using cotton-tipped applicators moistened with water.
4. Gently swab nasal passages using wet cotton applicators and periodically have the person blow nose into tissue.
5. If contamination is not removed, obtain further medical assistance in performing nasal irrigation.
6. Bioassay should be initiated for individuals with nasal contamination.

APPENDIX B

EQUIPMENT AND MATERIAL DECONTAMINATION METHODS

Table 7.2. Contamination Removal Methods
Table 7.3. Sealing Methods
Table 7.4. Decontamination Methods for Various Surfaces

TABLE 7.2. Contamination Removal Methods

Method	Applicability	Advantages	Disadvantages
MANUAL CLEANING			
Tape patches	. Dry, localized contamination	. Inexpensive, simple	. Useful only on small areas; can be very time-consuming
Strippable coating	. Dry contamination . Spray on coating, peel off when set	. Similar to tape patches . Better suited for larger surface areas	
Vacuum cleaner (dry)	. Dry surfaces with loose contamination	. Good preparatory step for further decontamination . Effective for dry, porous surfaces	. Vacuum cleaner exhaust must have high-efficiency filter . Contamination concentrated in collection bag can cause dose rate concerns . Not effective for crusted deposits . Airborne radioactivity may be generated
Vacuum cleaner (wet)	. Contaminated liquids . Wet spray or washdown of dry contamination	. Less risk of airborne radioactivity	. Liquid waste generated
Wet wipe or mop	. Dust or accumulated contamination; wipe with water or decon solution . Good follow-up for vacuuming or other methods	. Versatile, simple	. Worker intensive . May involve higher worker dose because of proximity to work
Brushing	. Loose, crusty contamination . Debris	. Preparatory step	. Can generate airborne radioactivity . Not effective for dust or fine particulates

TABLE 7.2. (continued)

Method	Applicability	Advantages	Disadvantages
MECHANICAL CLEANING			
Water jet Steam jet	. Nonporous surfaces (metal, paint, plastic, etc.) . Not suitable for porous surfaces (wood, concrete, etc.)	. May be used in low-pressure hose or high-pressure jet (10,000 psi) applicators . High-pressure jets can be very effective in loosening and dissolving deposits . Can quickly decontaminate large areas	. Can drive alpha contamination into concrete . Drainage must be controlled . Liquid becomes contaminated . Not effective on oiled surfaces . Danger in handling high-pressure nozzles . Airborne contamination probable
Soaking Spraying	. Small and moderate-sized equipment	. Soaking provides good access to surfaces . Many soaking agents available . Spraying combines mechanical action with chemical action	. May require support equipment and systems . Can produce large waste volume
Ultrasonic cleaning	. Small parts	. Combines soaking and mechanical action . Remote operation . Rapid decontamination of irregular shapes and crevices	. Not always useful for strongly adsorbed or absorbed contamination
Vibratory finishing	. Small tools	. Removes rust and gross contamination	. Size limitation . More suitable for exposure reduction than complete decontamination
Freon cleaning	. Cloth, plastic, small tools, respirators	. Remote or manual operation . Small quantity of waste generated	

TABLE 7.2. (continued)

Method	Applicability	Advantages	Disadvantages
ABRASIVE METHODS			
Abrasive blasting	. Irregularly shaped or large surfaces where critical dimensions are not involved	. Rapid, very effective decontamination . Variety of abrasives available . Wet or vacuum blasting can reduce generation of airborne activity and spread of contamination	. Usually generates airborne contamination . May spread surface contamination . Grit size must be finer than surface finish
Grinding	. Small objects or isolated spots on large objects	. Economical, effective	. Leaves residual contamination . Airborne contamination
Chipping Spalling Cutting	. Concrete or structural surfaces	. Effective for removal of porous surfaces . Removes surface in thin layers (0.3 cm per pass)	. Leaves residual contamination . Can generate airborne activity . Usually slow
Scabbling	. Concrete surfaces	. Same as for chipping and spalling . Faster than chipping and spalling . Can be fitted with high-efficiency filter	. Can leave residual contaminants . Can generate airborne activity

TABLE 7.2. (continued)

Method	Applicability	Advantages	Disadvantages
CHEMICAL CLEANING[a]			
Detergents	Nonporous surfaces with contaminated films	. Dissolves contaminated films and oils . May be applied by rag or soaking	. Relatively mild; may not be effective for deep-seated contamination
Complexing agents (oxalates, carbonates, citrates, EDTA)	Nonporous surfaces (unweathered, no rust)	. Contamination retained in solution . Easily stored . Carbonates and citrates are nontoxic, non-corrosive	. Little penetrating power . Not effective for weathered surfaces
Organic solvents	Nonporous surfaces (greased, waxed, painted, plastic-covered)	. Quick dissolving action . Solvent can be recovered by distillation	. Flammable . Ventilation required . Toxic . Not as effective as acid processes
Inorganic acids	Metal surfaces (porous deposits, rust, corrosion)	. Corrosive action on porous deposits	. Personnel hazard . Toxic . Explosive gases generated . Ventilation required

(a) Many chemical solutions can be applied either hot or cold. Hot applications are usually more effective than cold applications.

TABLE 7.2. (continued)

Method	Applicability	Advantages	Disadvantages
CHEMICAL CLEANING (continued)			
Acid mixtures	Nonporous surfaces (porous deposits)	. Highly effective dissolving action	. Weathered surfaces may require long treatment
Caustics	Painted surfaces (horizontal)	. Softens paint with minimum contact . Easy storage	. Personnel hazard . Slow reaction rate . Not efficient for vertical or overhead surfaces . Do not use on aluminum or magnesium
Trisodium phosphate	Painted surfaces (vertical and overhead)	. Softens paint	. Destructive to paint . Do not use on aluminum or magnesium
ELECTROCHEMICAL CLEANING			
Electropolishing	Small tools and parts, tanks, pipes, larger surfaces	. Highly effective . Can be aimed at spots . Fast decontamination . Remote application	. Removes thin layer (2 mils) of base material . Attacks high spots first . Possible material compatibility problems with acid electrolytes

TABLE 7.3. Sealing Methods

Method	Applicability	Advantages	Disadvantages
Earth	. Temporary barrier	. Material readily available . Shovel application small area	. Heavy equipment needed for large areas
Asphalt Concrete	. Roads, surfaces	. Thin layer provides quick temporary seal . Thicker layer (2.5 cm) provides permanent seal . Complete alpha and beta shielding	. Heavy equipment needed
Grout	. Concrete or masonary surfaces	. Can be spread on by hand . Thin layer (0.6 cm) provides effective seal	
Paint Varnish Plastic	. Areas subject to periodic recontamination	. Inexpensive . Can be sprayed or brushed on . Effectively shields alpha and low-energy radiation	. Degrades with time . No gamma attentuation

TABLE 7.4. Decontamination Methods for Various Surfaces

Surface	Description	Decontamination Methods
Terrain	Decontamination of terrain usually involves large areas and requires elaborate machinery or extensive manpower. Fields and vegetation strongly absorb liquids, making wet decontamination procedures impractical. Natural objects, loose dirt, and dust make removal procedures such as brushing or vacuuming difficult.	Earth moving (removal) Sealing in place
Hard, porous surfaces (concrete, asphalt, brick, stone, wood)	Porous surfaces absorb or trap liquids within the pores in the material. Any radionuclides dissolved or suspended in the trapped liquid remain in the pores after the liquid evaporates. Porous materials also mechanically trap dust particles. Complete removal of any contamination is difficult.	Vacuum cleaning Water flush Destructive removal (planing, chipping, scabbling)
Fibrous material (cloth, canvas)	Fibrous materials contain many small pores, allowing free flow of liquids through them. There is little chance for particles to become permanently lodged, absorbed, or adsorbed in the pores.	Brush Tape Patches Laundering Freon
Glass Porcelain Plastic	Glass, metal, plastic, and porcelain surfaces, which are generally smooth and relatively inert to chemicals, are best decontaminated by using water or water and detergent. Dust and liquids have little chance of becoming trapped on these surfaces. Adsorbed materials are readily removed with slight abrasion or brushing. Glass is attacked and etched by strong caustics. Plastics may be attacked by caustics, oxidizing and mineral acids, and organic chemicals.	Water Detergent Complexing agents Inorganic acids Freon
Metal	Surface description similar to glass, porcelain, and plastic. Metal is attacked and dissolved by strong oxidizing agents and acids.	Water Detergent Complexing agents Organic acids Inorganic acids Acid mixtures Oxidizing agents Ultrasonics Electropolishing Vibratory finishing Freon

TABLE 7.4. (continued)

Surface	Description	Decontamination Methods
Paint Varnish	Surfaces that are painted, varnished, or waxed are generally smooth and nonporous. Dust and liquids are readily removed by wiping, brushing, or vacuuming. Adsorbed materials are usually removable by water, detergent, or complexing agents. These surfaces do not stand up to heavy abrasive techniques. If they become contaminated, they may be removed by caustics, acids, and organic chemicals.	Vacuum cleaning Wiping Water Detergent Complexing agents Organic solvents Caustics Abrasion
Floor coverings: Linoleum Tile	Floor coverings such as linoleum and asphalt tile are best decontaminated by wiping, brushing, or vacuuming. The surfaces readily absorb liquids unless protected by a layer of wax, which limits absorption. Because they are smooth, they do not mechanically trap solid particles; however, cracks between tiles can absorb some contamination. Tile and linoleum are attacked by strong acids, caustics, and organic solvents.	Wipe Brush Vacuum Destructive removal Seal
Rubber	Rubber is a porous material that strongly absorbs liquids. It is not easily decontaminated by abrasive techniques. Brushing and vacuuming remove surface contamination, and water and detergents remove some absorbed contamination. Strong acids, alkalies, and organic solvents deteriorate and decompose rubber.	Brush Vacuum Wipe Detergent
Leather (shoes)	Leather is a porous material that can be very difficult to decontaminate. Scraping and tape patches are most effective.	Tape patches Knife and sandpaper Acetone wipe

APPENDIX C

EQUIPMENT AND MATERIAL DECONTAMINATION PROCEDURES

C.1 Tape Patches
C.2 Vacuum Cleaning
C.3 Wiping or Mopping
C.4 Water Jets
C.5 Detergents
C.6 Complexing Agents
C.7 Organic Solvents
C.8 Acids and Acid Mixtures
C.9 Caustics

APPENDIX C

EQUIPMENT AND MATERIAL DECONTAMINATION PROCEDURES

C.1 TAPE PATCHES

Materials

1. Masking, adhesive, friction, or duct tape

Procedure

1. Place tape over contaminated area.
2. Remove tape and discard as radioactive waste.
3. Repeat as long as effective.

C.2 VACUUM CLEANING

Materials

1. Conventional wet or dry vacuum cleaners may be used if modified to include a high-efficiency particulate air (HEPA) filter on the exhaust.

Procedure

1. Use conventional vacuum-cleaning techniques.
2. Periodically monitor build-up of radioactivity or dose rate from bag or canister during operation.
3. Dispose of bag or collection container as radioactive waste.
4. For extensive use, monitor build-up of dose rate from collection container and HEPA filter.

C.3 WIPING OR MOPPING

Materials

1. Mop, cloth, or towel.

Procedure

1. Wipe or wet-mop using a decontaminating agent and hot water.
2. Rinse with clean water, damp-mopping.
3. Repeat as necessary.

C.4 WATER JETS

Materials

1. High-pressure, low-volume jet and/or low-pressure jet or spray.

Procedure

1. Spray from top to bottom at an angle of 30° to 45°.
2. Use high-pressure jets to loosen decontamination.
3. Use low-pressure jets or sprays to wash and flush.
4. Determine cleaning rate experimentally or else use 0.5 to 0.9 m^2/min.

C.5 DETERGENTS

Materials

1. Detergent.

Procedure

1. Apply full strength or per manufacturer's recommendations.
2. Wipe with towel or rag.
3. Powered brush may be used.
4. May be applied by a mist applicator, using caution to prevent spread to other surfaces.

C.6 COMPLEXING AGENTS

Materials

1. Solution containing 3% (by weight) of complexing agent (e.g., EDTA).

Procedure

1. Spray surface with agent.
2. Keep moist for 30 minutes.
3. Flush with water.

   Note: May be applied to vertical and overhead surfaces by adding chemical foam (sodium carbonate or aluminum sulfate).

C.7 ORGANIC SOLVENTS

Materials

1. Kerosene, paint thinner, or acetone.

Procedure

1. Use standard wiping techniques.
2. Immerse in solvent bath.

   Caution: High flammability and toxic fumes. The use of acids and complexing agents is generally preferable.

C.8 ACIDS AND ACID MIXTURES

Materials

1. Single Acids (1 to 2 normality)
   3%-6% sulfuric acid
   9%-18% hydrochloric acid
   5% oxalic acid
2. Acid Mixture
   0.4 liter hydrochloric acid
   90 grams sodium acetate
   4 liters water
3. Other acid mixtures may include acetic acids, citric acids, acetates, citrates.

Procedure

1. Use dip bath for movable items.
2. Leave weathered surfaces in contact with acid solution for 1 hour.
3. Allow pipe circulation systems to soak for 2 to 4 hours.
4. Flush with water.
5. Flush with neutralizing solution.
6. Flush with water.

Caution: Personnel hazard, toxic and explosive fumes generated. Provide good ventilation.

C.9 CAUSTICS

Materials

1. Lye (sodium hydroxide)
2. Calcium hydroxide
3. Potassium hydroxide
4. Typical solution for removing paint:
   38 liters water
   1.8 kg lye
   2.7 kg boiler compound
   0.34 kg cornstarch

Procedure

1. Apply caustic solution to painted surface.
2. Keep solution in contact with paint until paint is soft enough to be washed off with water.
3. Wash off paint and caustic solution with water.
4. Remove remaining paint with scraper.

Caution: Caustics pose personnel burn hazard.

CHAPTER 8. SELECTION AND DESIGN OF RADIATION FACILITIES

8.1 GENERAL PRINCIPLES 8.5

8.2 INITIAL PLANNING PROCESS 8.6

8.2.1 Designs for New Facilities 8.7

A. Commander's Responsibility 8.8

B. Ionizing Radiation Control Committee 8.8

8.2.2 Review of Designs for Modifying Existing Facilities . . 8.9

8.3 SITE SELECTION 8.10

8.3.1 Impact of Surrounding Operations Upon the Proposed Facility 8.10

A. Background Radiation 8.10

B. Effluents From Facility and Nearby Operations . . 8.11

C. Fire and Explosion Hazards 8.11

D. Chemicals Spills 8.11

E. Access Control 8.11

8.3.2 Impact of Proposed Facility Upon Surrounding Area . . 8.12

A. Potential Environmental Releases 8.12

B. Accident Analysis 8.12

C. Future Land Use 8.13

D. Additional Considerations 8.13

8.3.3 Natural Phenomena 8.14

A. Regional Climate 8.14

B. Hydrology 8.14

C. Geologic and Seismic Considerations 8.14

8.4 FACILITY DESIGN 8.15

8.4.1 General Considerations in Facility Design 8.15

8.4.2 Building Areas 8.16

A. Radiation Area 8.16

B. Controlled Area 8.17

C. Uncontrolled Area 8.18

8.4.3 Work Stations 8.18

A. Class A Laboratories 8.18

B. Class B Laboratories 8.19

C. Class C Laboratories 8.20

8.4.4 Building Materials 8.21

A. Ease of Decontamination 8.21

B. Corrosion Resistance 8.22

C. Fire Resistance 8.22

8.4.5 Building Access 8.22

8.5 CONTROL OF EXTERNAL RADIATION 8.23

8.5.1 Shielding Requirements 8.23

A. Integrity 8.23

B. Materials 8.23

C. Entryways 8.25

D. Quality Assurance 8.25

8.5.2 Access Restrictions for Radiation Areas 8.25

A. Interlocks and Warning Systems 8.25

B. Guards 8.26

8.6 CONTROL OF INTERNAL RADIATION 8.27

8.6.1 Containment Devices 8.27

A. Sealed Sources 8.27

B. Hoods 8.27
C. Glove Boxes 8.29
D. Hot Cells 8.29
8.6.2 Ventilation Systems 8.29
A. Ventilation Zones 8.30
B. Air Flow Patterns 8.30
C. Pressure Differentials 8.30
D. Duct Routing 8.30
E. Filtration 8.31
8.6.3 Sampling and Monitoring Equipment 8.32
A. Air Samplers and Monitors 8.32
B. Radiation Area Monitors 8.32
8.7 FACILITY SUPPORT 8.33
8.7.1 Change Room Facilities 8.33
8.7.2 Personnel and Property Decontamination Facilities . . 8.33
8.7.3 Water Supply and Sanitary Sewers 8.33
REFERENCES 8.34

FIGURES

8.1 Facility Layout 8.16
8.2 Class A Laboratory 8.19
8.3 Class B Laboratory 8.20
8.4 Class C Laboratory 8.21

CHAPTER 8. SELECTION AND DESIGN OF RADIATION FACILITIES

Facilities in which radioactive materials are used have specific needs that must be recognized and planned for from the initial design phase through the construction and operation of each facility. The location of the facility must be considered in relation to the work that will be carried on there. The building must be designed to keep radioactive materials in certain areas while still allowing efficient operation. Finally, equipment must be built in or brought in to control external and internal radiation doses to personnel and to keep the amount of radioactive material leaving the facility within permissible limits.

The purposes of this chapter are: 1) to help the Radiation Protection Officer (RPO) and the Ionizing Radiation Control Committee (IRCC) judge whether a facility is adequate for handling radioactive materials, and 2) to delineate what should be considered when a facility is being designed and the rationale behind each item. Because DARCOM and the installation's engineering staff have ultimate responsibility for facility design, this chapter is for information purposes only.

Section 8.1 GENERAL PRINCIPLES

Safety should be achieved as much as possible through engineered safeguards rather than administrative controls or the use of personnel protective equipment. The National Council on Radiation Protection and Measurements (NCRP) recommends in Report No. 59 (1978) that a qualified expert be consulted during the planning and design of new and modified radiation facilities to ensure the incorporation of proper radiation safety procedures. Certification by the American Board of Health Physics or the American Board of Radiology is evidence of a consultant's qualifications.

Items that must be considered when a new facility is being planned or an existing structure is being renovated include:

1. meteorological and hydrological parameters of the site
2. facility layout, which should be compatible with the establishment of contamination areas
3. shielding, especially with respect to floor-loading limits
4. ventilation, which should be capable of controlling the movement of air to prevent or minimize the spread of contamination within the facility
5. types of monitoring equipment needed.

The facility should be arranged to meet the following objectives:

1. keep dose equivalents received by personnel as low as is reasonably achievable (ALARA)
2. confine radioactive materials accidently released within the facility and control releases from the facility to levels below the concentration guides in 10 CFR 20, Appendix B, Table II, averaged over 2 hours
3. achieve a uniform level of safety through physical and engineered safeguards
4. accommodate normal or anticipated changes in mission requirements without compromising radiation protection.

Section 8.2 INITIAL PLANNING PROCESS

The terms "facility design," "radiological design," and "radiological engineering" are often used interchangeably, although they have different meanings. Design is the planning and development of a facility as opposed to its actually construction and operation. Facility design refers to a plan for a building or installation as a whole, and thus includes nonradiological as well as radiological design features. Radiological design refers to the specific set of design features included because of the planned presence of radioactivity or radiation-generating machines. Radiological requirements should be made known to the architect and/or engineer responsible for designing a facility as early as possible, to minimize the cost of incorporating safety features; it is

less expensive to redraw preliminary plans than final blueprints, and less expensive to revise final blueprints than to rebuild or alter the finished facility.

Radiological engineering refers to the implementation of the radiological design (i.e., the actual construction). Radiological engineering requires the use of quality control procedures during construction. For example, precautions should be taken to minimize air pockets in concrete walls used for shielding, to sufficiently overlap lead sheets used for shielding, and to ensure that foundations, footings, and pilings have sufficient loadbearing capacity so that concrete shield walls do not buckle or crack. In essence, good radiological engineering ensures that the design criteria are met (Kathren and Selby 1980).

Review of the radiological hygiene aspects of blueprints, drawings, and other documents relating to the design of facilities and devices for generating radiation should be coordinated through channels with the DARCOM Field Safety Activity and the U.S. Army Environmental Hygiene Agency (USAEHA). Therefore, contact with DARCOM and the agency should be made early in the planning process to avoid the necessity of expensive changes in the structural design.

8.2.1 Designs for New Facilities

When a facility is being designed, all proposed uses and needs of the facility--both current and projected--must be considered, especially if the projected needs will exceed the current needs. If possible, the facility should be designed to meet the maximum needs, because the cost of altering or rebuilding may be greater than the cost of overbuilding initially. The scope of work to be performed in the building should be defined in terms of the purpose of the work, the proposed inventories of radioactive materials, the presence of radiation-generating devices, and the expected lifetime of the building.

Many safety features must be considered early in the design of a facility. With few exceptions, shielding and facility layout are difficult to change, and adequate safety often cannot be ensured in a redesigned or rebuilt facility

without high costs and the loss of usable work space. Thus, future uses of the facility, which may include increased workloads, must be considered so that shielding, containment, confinement, and work spaces can be designed to suit those uses.

A. Commander's Responsibility. The local commander is responsible for providing proper facilities for the use of radioactive materials (AR 385-11). Therefore, the commander shall provide for the review and approval of all blueprints, drawings, and other documents relating to the design of facilities that will contain radioactive materials. Assistance in judging the adequacy of new and renovated facilities may be obtained from USAEHA and the DARCOM Field Safety Activity.

B. Ionizating Radiation Control Committee. The IRCC should have as part of its responsibility helping to design safe facilities. The committee should include construction or general engineering personnel and representatives from maintenance, operations, health, and safety, including the RPO. The committee should be informed of all proposed uses for each building, both immediate and future. The local commander shall establish an approval process that guarantees that all safety-related concerns (both radiological and nonradiological) have been addressed and adequately resolved.

(1) Maintenance and Operations Representatives. Representatives from maintenance and operations should be consulted because they are usually aware of the problems associated with various building designs. They can advise on whether a design will allow ease of maintenance and repair, which can minimize work times in radiation areas.

(2) Health and Safety Representatives. The RPO and the other health and safety representatives should be responsible for the following:

1. reviewing the general layout of the facility, giving particular attention to corridors, traffic patterns, radiation areas, change rooms, radiation-monitoring sites, and personnel decontamination facilities
2. working with the installation's environmental coordinator to prepare or coordinate the preparation of the environmental impact statement (if any)

3. identifying manuals and standards that deal with radiological aspects of the facility design

4. ensuring that the ventilation system will provide the public and site personnel with maximum protection against airborne contamination

5. ensuring that maximum practical control of liquid, solid, and gaseous wastes is provided, to protect the environment

6. verifying that the proposed design and application of hoods, glove boxes, and shielded cells ensures ease of decontamination and remote operation, to reduce occupational exposures

7. ensuring that the thickness of all shielding meets design criteria, and coordinating shielding calculations and design to keep radiation doses ALARA

8. ensuring that needs for sampling and monitoring instrumentation have been identified and that the instrumentation being provided meets the latest occupational and environmental standards, can be installed properly, and is capable of obtaining representative samples

9. ensuring that radiological safeguards and safety systems are adequately protected from fires, floods, and other similar accidents, and are fail-safe

10. assessing the adequacy of facilities for receiving, storing, and packaging any radioactive wastes that may be produced during the operation of the building.

8.2.2 Review of Designs for Modifying Existing Facilities

How extensively a facility is being modified influences the extent of the design review needed. Major modifications, such as extensive renovation of a radioactively contaminated facility or preparation of a facility that has never before housed radioactive materials, may require application of all steps involved in the design of a new facility and may therefore require the same attention from the members of the IRCC. The RPO, or the appropriate health and safety representative, has the following additional responsibilities whenever an existing radiation facility is being upgraded:

1. If the building previously contained radioactive material, evaluate the modification plans to ensure that radiation dose equivalents received by construction workers during the renovation are kept ALARA. (Consider removing radioactive sources and decontaminating the facility.)
2. Evaluate the impact of the modification on existing safety systems, such as air filters and ventilation systems.
3. Review the design of any structures needed to contain radioactive materials (e.g., greenhouses and special waste containers).
4. Approve all modifications.

Section 8.3 SITE SELECTION

The initial step in selecting the site for a radiation facility is to establish the requirements of the facility and the interrelations between the facility and its environment. Proposed sites and the area surrounding each should be reviewed for location and for distances from air, ground, and water traffic, pipelines, and fixed manufacturing, processing, and storage facilities.

8.3.1 Impact of Surrounding Operations Upon the Proposed Facility

The level of background radiation at a proposed site can affect some operations and should be considered during site selection. Other external factors affecting site selection are the location of other facilities, the potential for fires, explosions, and chemical spills, and any need for restricted access.

A. Background Radiation. Background radiation is an important consideration for facilities that will house laboratory counting instruments, which are extremely sensitive to radiation. Fluctuations in the level of background radiation can affect the instrument readings, and high background radiation rates, even if they are constant, increase the lower limit of detection for these instruments.

Background radiation levels can be increased by either natural or man-made sources. One natural source of increased background radiation is certain types of rocks that have a fixed raciation. The evolution of radon gas from rocks and soil also raises the concentration of radioactive material in air and thus results in more surface contamination and higher dose rates. Man-made causes of increased background radiation levels include nuclear power reactors and mining and milling operations. Uranium mining is an obvious cause; however, phosphate mining and even coal mining are also sources of background radiation.

The extent to which radiation background levels fluctuate because of these sources is small and under ordinary circumstances does not present a significant radiation hazard to personnel. However, a radiation hazard may occur in submerged or underground facilities, especially if the air flow rates are low.

B. Effluents From Facility and Nearby Operations. A facility should be designed so that its air intakes are not likely to draw in its own exhaust materials. As a general rule, air intakes should be at the upwind end of the facility and exhaust vents should be at the downwind end, with the prevailing wind direction used as a guide. In addition, air intakes should be at least 155 meters away from the exhaust vent of any other facility that is venting radioactive material or other toxic or hazardous materials.

C. Fire and Explosion Hazards. Operations that might present fire and explosion hazards include petroleum refineries and storage facilities, docking facilities (for example, for oil tankers), and chemical-manufacturing plants. Also, military depots may be sites of storage for explosive compounds. Radiation facilities should be located at a safe distance from such hazards.

D. Chemical Spills. The manufacture, storage, and transportation of chemicals lead to the potential for chemical spills or releases. The release of toxic gas may require that a facility be evacuated promptly. However, in some facilities such as nuclear reactors, operators cannot be evacuated immediately. In such cases, protection must be provided for the workers.

E. Access Control. Access to a facility may be restricted for either radiation safety or national security reasons. Access control for national

security purposes is beyond the scope of this manual. Whenever a high-radiation area is not mechanically secured to prevent unauthorized entry, a guard must be posted (DARCOM-R 385-25). Physical safeguards that are appropriate for the hazard or security classification must be used.

8.3.2 Impact of Proposed Facility Upon Surrounding Area

The use of radioactive materials at a facility may increase the level of background radiation if any materials used outside of sealed containers are released to the environment. The releases may be of two types: routine low-level releases and accidental releases that could be of any magnitude. The possibility of such releases influences the selection of a facility site. The anticipated use of the land around a proposed radiation facility should also be considered in site selection.

A. Potential Environmental Releases. Routine releases usually enter the air from hood vents and enter sanitary sewage systems via floor and sink drains. Radioactive material may also be transported to the environment on the clothing of personnel and can be tracked about extensively if it gets on their shoes. Facilities in which radioactive materials are used should be located downwind from major metropolitan areas and in flat or gently rolling terrain, so that any radioactive material accidentally released into the air is dispersed rapidly and evenly, with minimal impact. In addition, engineered safeguards should be provided to prevent or at least limit the release of radioactive materials to the environment. Such safeguards are discussed later in the chapter.

B. Accident Analysis. The potential for accidents should be analyzed before any accident occurs. The RPO and individuals familiar with ventilating systems should review the proposed levels of radioactivity in each laboratory. Accidents that could result in the release of radioactive materials should then be analyzed. This analysis can be detailed, involving determination of the possible causes, probabilities, and impacts of an accident; or it can be as simple as assuming that the largest amount of material that might be unsealed at any time is available for release (see Chapter 11).

Accident analysis is extremely important for major facilities. It can help ensure that engineered safeguards are provided to prevent or minimize radiation exposures of personnel and the public. If an accident analysis is performed early in the design process, safeguards may be suggested that otherwise would have been omitted.

C. Future Land Use. Sources of information on projected population growth and proposed land uses should be consulted. County engineers can provide information on public roads and traffic volumes; local government councils may have information on population growth, proposed new industries, or future transportation routes; and zoning boards are sources of information on land use controls. The increase in the local population brought about by the construction and use of the proposed facility should also be considered, as it may not have been included in the projections of the state and local agencies just mentioned.

D. Additional Considerations. Before a particular site is selected, the following topics should be considered:

1. personnel traffic routes and their relation to the flow patterns for exhaust air where accidental or routine releases of radioactive material could occur (radioactive material should not be vented to high-traffic areas)
2. the relationship between the exhaust and air supply systems of various facilities (radioactive material should not be vented where it is likely to be drawn into other buildings or back into the building it came from)
3. the impact of additional radioactive waste on waste removal systems (e.g., consider stress on sewer systems that may contain radioactive material, on retention or diversion systems, and on systems that handle liquid waste containing high levels of radioactivity)
4. the availability of emergency systems (fire, ambulance, and radiological-emergency response teams)
5. the ability to simultaneously evacuate all neighboring facilities

6. the need for special transportation capabilities (railroad spurs, rigs for moving heavy material)

7. the impact of future modifications.

8.3.3 Natural Phenomena

Facilities should be designed to withstand the influences of natural phenomena. This requirement can be relaxed for facilities located where the only natural phenomena likely to occur are those that can be accurately forecasted, such as hurricanes and floods. In these cases, adequate warning time for securing materials and evacuating personnel can be provided. Other phenomena, such as earthquakes, volcanic eruptions, and floods caused by dam failure, cannot be adequately forecasted and may occur with little or no warning.

A. Regional Climate. Meterological conditions that may affect a facility include hurricanes, tornadoes, water spouts, thunderstorms, lightning, hail, and high levels of air pollution.

Data on severe weather phenomena should be based on standard meteorological records from a nearby National Weather Service station or from military or other stations that are recognized as standard installations and that have kept records for a long time.

B. Hydrology. The hydrology of a site should be reviewed, especially if a facility will house large quantities of special nuclear materials (plutonium or uranium enriched in isotope 233 or 235, or any material artificially enriched by either isotope). The hydrologic characteristics of streams, lakes, shore regions, and existing or proposed water control structures (e.g., dams and irrigation ditches) should be considered as they relate to potential flooding of the structure. The hydrology of both surface water and ground water should also be considered as it relates to the possible contamination of these waters by activities within the facility.

C. Geologic and Seismic Considerations. Ideally, the site should be in a geologically stable area--one low in seismicity, free of active faults, underlain by competent foundation materials, and free from the adverse effects of other geologic hazards.

Section 8.4 FACILITY DESIGN

A properly designed facility can lead to reduced radiation doses to personnel through the establishment of designated areas for the use of radioactive materials, and of designated types of laboratories within these areas. The materials used in the construction of a facility and the ease of access to areas within the facility also affect radiation safety for personnel.

8.4.1 General Considerations in Facility Design

The layout of rooms, corridors, entrances, exits, ventilation systems, and other utilities in a building should be designed to meet the following objectives:

1. Keep the dose equivalent received by personnel ALARA.
2. Confine radioactive materials accidentally released within the facility and control any releases from the facility so that they remain below the concentration guides in 10 CFR 20, sections 20.106 and 20.303.
3. Accommodate routine programs or anticipated program changes without compromising radiation protection.

The flow of people and materials in a facility is a function of building design. One design, shown in Figure 8.1, has a central service corridor for equipment, piping, and waste handling. Laboratories on both sides open to both the central corridor and the outer corridors, with offices located between the outer corridors and the outside of the building. The advantages of this design are that it allows for two exits from each laboratory, permits easy access to utilities for the laboratories, and allows radioactive materials to be transferred without affecting the clean areas of the facility. An alternate design might have offices located in one part of the building and laboratories in another, so that only laboratory personnel need enter the laboratory areas.

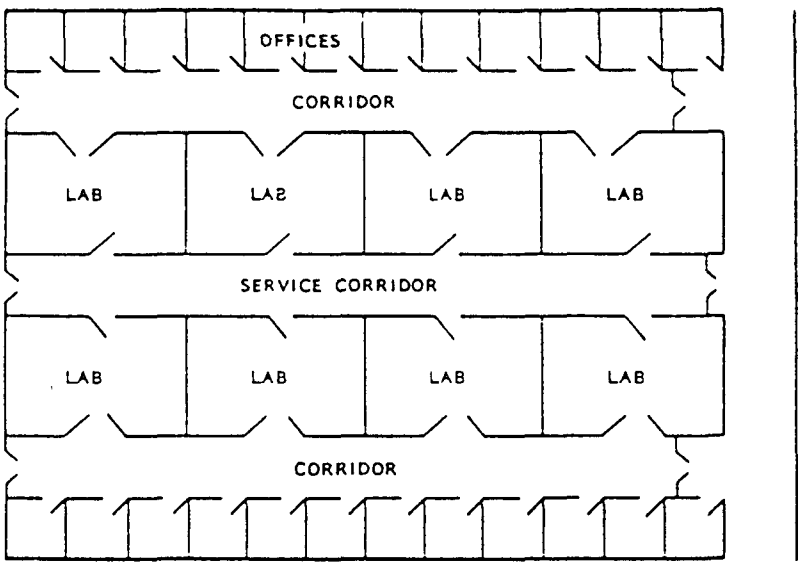


FIGURE 8.1. Facility Layout

8.4.2 Building Areas

Facilities are generally divided into a series of sequential areas that are based upon the presence of radiation or radioactive materials and are designed to control personnel exposure to radiation. The three types of areas--radiation, controlled, and uncontrolled--are described below.

A. Radiation Area. Radiation areas include three subclassifications: radiation areas, high-radiation areas, and airborne-radioactivity areas. A radiation area is defined in 10 CFR 20 as any area accessible to personnel in which radiation levels could result in a major portion of the body receiving a dose-equivalent rate in excess of 5 mrem in any 1 hour or 100 mrem in any 5 consecutive days. For practical purposes, AR 40-14 defines this as any area in which the dose-equivalent rate is greater than 2 mrem/hr but less than 100 mrem/hr. A high-radiation area is any area accessible to personnel in which radiation levels could result in a major portion of the body receiving a dose equivalent in excess of 100 mrem in any 1 hour. All radiation areas must be marked and posted as described in 10 CFR 20.20. An airborne-radioactivity area is any room, enclosure, or operating area where the concentration of airborne radioactivity exceeds the amounts specified in 10 CFR 20, Appendix B, Table I, Column 1 or where the concentration, when averaged over the number of

hours in any week an incividual works in the area, will exceed 25% of the amounts specified in 10 CFR 20, Appendix B, Table I, Column 1.

To ensure that regulatory and administrative limits are not exceeded, consideration should be given during facility design to the establishment of radiation areas at:

1. any location where unsealed (unencapsulated) radioactive materials will be stored, handled, or processed
2. any area containing a radiation-generating device
3. any routinely occupied area where an individual would be expected to receive more than 500 mrem in 1 year
4. any area, regardless of the expected occupancy, there the anticipated dose-equivalent rate exceeds 2 mrem/hr
5. any routinely occupied area where the concentration of airborne radioactive materials may exceed 25% of the values presented in 10 CFR 20, Appendix B, Table I, Column 1
6. any area, regardless of the occupancy, where the concentration of airborne radioactive materials may exceed the values presented in 10 CRF 20, Appendix B, Table I, Column 1.

Radiation areas should be remote from offices, lunchrooms, and conference rooms, to preclude the exposure of support personnel (e.g., secretaries and clerks). Persons entering a radiation area should pass through a controlled area. To keep nonradiation workers out of radiation areas during the normal course of their work, separate corridors should be provided.

B. Controlled Area. A controlled area is any area to which access is controlled and in which occupancy and working conditions are controlled for the purpose of protecting personnel against exposure to radiation. Such areas include:

1. any area normally free of contamination that is adjacent to a radiation area and that may become contaminated through accidental spreads or releases from the radiation area

2. any area that may occasionally contain radioactive material because of the transportation of radionuclides between radiation areas or the maintenance of contaminated process equipment that cannot be entirely placed inside a radiation area

3. any area where the anticipated dose-equivalent rate exceeds 0.2 mrem/hr but is less than 2 mrem/hr

4. any area where the concentration of airborne radioactive materials may exceed 50% of the values presented in 10 CFR 20, Appendix B, Table II, Column 1.

C. Uncontrolled Area. An uncontrolled area is any area where direct radiation exposure is not necessary or anticipated in the performance of a job. These areas include "cold" laboratories (those containing no radioactivity), offices, lunchrooms, conference rooms, and reception areas. The traffic patterns in a building should keep radioactive materials from being brought into uncontrolled areas for any reason (such as by delivery personnel). Further, the building should be designed so that the dose-equivalent rate in uncontrolled areas does not exceed 0.2 mrem/hr.

8.4.3 Work Stations

Work stations are subdivisions of a radiation area. One method of designating work stations is to define three classes of laboratories, A, B, and C, which depend upon the radiotoxicity, dispersibility, and total quantity of unsealed radioactive materials to be used. (See Chapter 1, Section 1.6.2, for definitions of the levels of dispersibility, and Chapter 1, Table 1.10, for groupings of radionuclides by degree of radiotoxicity.)

A. Class A Laboratories. Class A laboratories are specially designed and equipped for the safe handling of 1) large quantities of highly radiotoxic materials (groups VI through VIII in Table 1.10) in any dispersible form and 2) large quantities of moderately radiotoxic materials (Groups III through V) in highly dispersible form.

Each Class A laboratory should be wholly within a radiation area and should be separated from uncontrolled areas by at least two confinement barriers (see Figure 8.2). Within a Class A laboratory, a fume hood should be

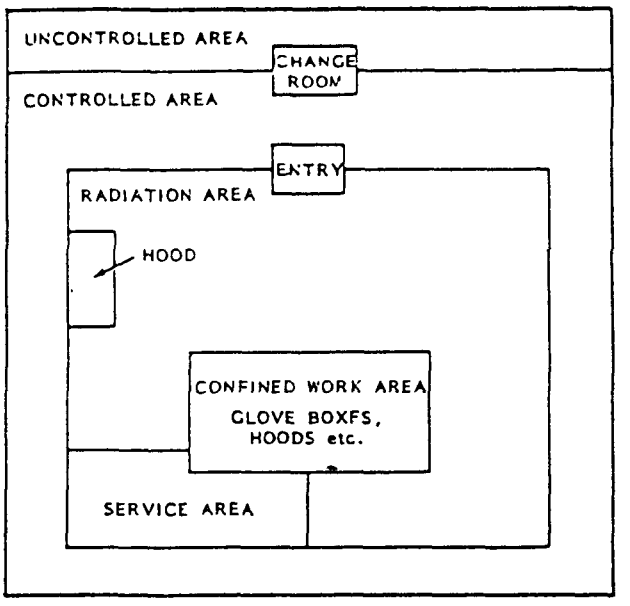


FIGURE 8.2. Class A Laboratory

used for work involving dispersible material, and sealed glove boxes, hot cells, or similar devices should be used for work involving readily or highly dispersible materials. Class A laboratories should have access to a clothing change room through which personnel pass before entering an uncontrolled area.

The air of a Class A laboratory should be exhausted through two stages of high-efficiency particulate air (HEPA) filters that are testable using a dioctylphthalate (DOP) mist. (Because DOP is a suspected carcinogen, it should be used with care.) The air of hoods, glove boxes, or other sealed enclosures where readily and highly dispersible materials are used should be exhausted through three stages of HEPA filters, at least two of which must be DOP-testable. The use of gaseous materials (wet operations) may cause early failure of HEPA filters. Therefore, if these materials are used, HEPA filters may need to be replaced frequently, air flow monitors should be used, and additional filtration devices may be needed.

B. Class B Laboratories. Class B laboratories are designed for the handling of 1) large quantities of minimally radiotoxic materials (Groups I and II in Table 1.10) or 2) moderate quantities of moderately or highly

radiotoxic materials (Groups III through VIII). The materials may range from dispersible to highly dispersible.

Each Class B laboratory should be separated from uncontrolled areas by at least two confinement barriers (see Figure 8.3). A glove box or other enclosure should be used for work with highly radiotoxic or highly dispersible materials. Each laboratory should have at least one fume hood.

The air of a Class B laboratory should be exhausted through at least two DOP-testable HEPA filters that are in series. The exhaust system for hoods, glove boxes, or other enclosures should contain two stages of DOP-testable HEPA filters.

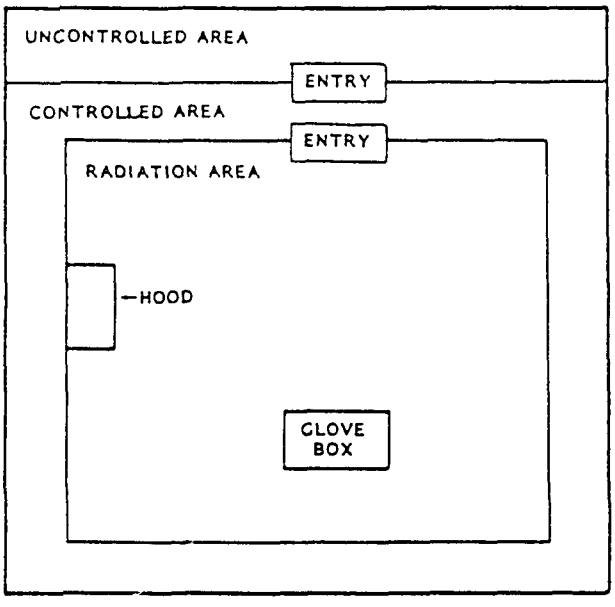


FIGURE 8.3. Class B Laboratory

C. Class C Laboratories. Class C laboratories are designed for work involving simple chemical processes and minimal quantities of radioactive material. Materials of low and moderate radiotoxicity (Groups I through V in Table 1.10) may be present in forms that are dispersible or of limited dispersibility.

Each Class C laboratory should be separated from uncontrolled areas by at least one confinement barrier, which may be the laboratory wall (see Figure 8.4). At least one hood should be provided in each laboratory. The exhaust system should contain at least a single-stage DOP-testable HEPA filter.

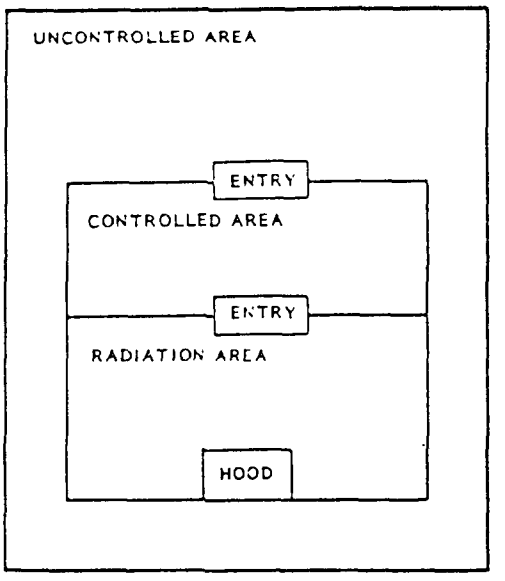


FIGURE 8.4. Class C Laboratory

8.4.4 Building Materials

The building materials used in a radiation facility should be easy to decontaminate, extremely durable, corrosion resistant, and fire resistant. Unfortunately, very few materials combine all of these characteristics.

A. Ease of Decontamination. The building materials chosen should be nonporous and should have few, if any, cracks. They should be readily removable if contaminated, and chemically inert to reduce the likelihood that contamination would become chemically bonded to the materials. (See Chapter 7 for details on the ease of decontaminating various materials.)

(1) Flooring. Flooring materials should be chosen based on price; availability; ease of installation, service, and maintenance; chemical inertness; and any special requirements imposed by the use of radioactive materials. Porous materials such as concrete and wood are not acceptable by themselves; they must be covered by other, removable materials to facilitate decontamination in the event of an accident. Examples of acceptable covering materials include sheet flooring (such as vinyl flooring) or poured vinyl or epoxy floor covering. The floor covering should be sealed and waxed regularly.

(2) Walls and Partitions. Walls and partitions should be protected by coatings that are hard, smooth, and easy to clean. If extensive contamination is possible, then strippable coatings should be used. These form an effective seal over porous wall, ceiling, or floor materials and are easily stripped off or removed when the surface must be decontaminated.

(3) Bench Tops and Laboratory Equipment. Laboratory benches with synthetic or plastic tops are now available. Many of these tops are quite impermeable and durable; consult manufacturers' literature for details. Laboratory equipment can be tested for susceptibility to contamination and ease of decontamination, as described by Fitzgerald (1969). In general, furniture in laboratories where low and intermediate levels of radiation are used should be of high-quality, impermeable materials.

B. Corrosion Resistance. Bench tops, hoods, walls, and floors should be corrosion resistant because the pitted surfaces caused by corrosion are difficult to decontaminate.

C. Fire Resistance. Laboratory facilities should be fire resistant. Where a fire could result in the dispersal of radioactive materials, exits and a means of closing the facility to prevent the spread of radioactive materials should be provided. Fire extinguishers should be located throughout each facility, and showers and fire extinguishers should be provided in laboratories where flammable chemicals are used.

8.4.5 Building Access

Consideration should be given to pathways for moving radioactive materials in and out of buildings and laboratories. Examples of items that should be considered are:

1. doorways - Because radioactive sources are usually integrated with large, heavy shielding, motorized carts, trucks, or fork lifts may be needed to move them. Doorways and hallways leading to exits should be large enough to allow passage of these machines.
2. ramps - Sealed, shielded radioactive sources can weigh tons and may exceed the lifting capacity of freight elevators. Gently sloping ramps should be

provided between floor levels so that such sources can be transported by fork lifts from one building level to another.

3. ceiling openings - Ceilings can be designed so that the roof is easily dismantled, providing an opening large enough for a crane to lift out a shielded source or any large heavy object.

Section 8.5 CONTROL OF EXTERNAL RADIATION

Dose rates to personnel from radioactive materials can be greatly reduced by the placement of attenuating or shielding materials between personnel and the radiation source. The shielding materials can be designed into the building structure or they can be separate from the building. Shielding may be required to protect personnel from radiation emitted from open, unsealed radioactive materials and from radiation-generating devices. External dose rates are also controlled by restricting access to radiation areas through the use of interlocks, warning systems, and guards. (See Chapter 6 for details on the control and reduction of external exposure.)

8.5.1 Shielding Requirements

Shielding is required wherever the anticipated dose-equivalent rate will exceed 2.0 mrem/hr. The shielding should reduce the dose-equivalent rate to 0.2 mrem/hr or less.

A. Integrity. Shielding must be designed so that the degree of protection is constant from all angles of approach. The simplest method of achieving uniform protection is to surround a source with a uniform shield. In practice, however, a shield is usually penetrated by cooling pipes, electrical power and signal cables, rotating shafts, and removable plugs or covers, and special considerations must be made for these penetrations in the shield. Design features such as shadow shields, baffles, and offsets can help ensure adequate protection.

B. Materials. The choice of shielding material depends upon factors such as cost and the desired thickness and mass of the shield. However, all of the following should be considered whenever shielding material is being selected:

1. attenuation characteristics - Different shielding materials have different abilities to attenuate photons, neutrons, and beta particles.
2. structural integrity - The material selected must be structurally stable.
3. nonflammability - The shielding material should be fire resistant or noncombustible and should not release toxic gases or smoke when heated.
4. confinement capability - The shielding material may have to contain gases, solids, and liquids in the shielded enclosure.

Shielding materials commonly used for various types of radiation are described below.

(1) Shielding for Ions and Electrons. Virtually any material can be used as shielding for ion and electron sources as long as the shield is thicker than the range of the particles. Bremsstrahlung radiation may be produced if shielding materials with a high Z number (atomic number), such as lead or iron, are used. The likelihood of bremsstrahlung radiation can be reduced by the use of low-Z shielding materials, such as plastics. If bremsstrahlung radiation is produced, it can be attenuated by lead, iron, or any material that shields against x and gamma rays (see Chapter 1).

(2) Shielding for X- and Gamma-Ray Sources. Common shielding materials for photon sources are lead and iron. Depleted uranium and tungsten are expensive materials for shielding but they can be used if a relatively thin shield is required. Concrete and water can be used if the thickness of the shield is of no consequence.

(3) Shielding for Neutrons. Shielding for thermal (slow, or low-energy) neutrons is provided by thin layers of materials that have a high cross section for capture, for example, boron or cadmium. A disadvantage of cadmium is that, after a neutron is captured, the material emits high-energy gamma rays for which shielding must also be provided.

Fast neutrons are not easily shielded. In addition, sources of fast neutrons are commonly also sources of gamma rays; the shielding material must therefore be able to shield against both the photons and the neutrons. Shielding of fast neutrons is generally a two-step process. First, hydrogen-

containing materials such as plastic, water, or concrete are used to moderate, or reduce, the neutron energies to thermal levels by elastic scatter. If the shielding material contains high-Z elements, such as lead or iron, then the neutrons may lose their energy through inelastic collisions. The thermal neutrons may then be captured, as described above, by boron, cadmium, or (to a lesser extent) the hydrogen in water.

C. Entryways. Wherever possible, entryways should consist of a labyrinth, or passage with turnings, that scatters radiation twice before it hits a door. This scattering reduces the amount of radiation reaching the door, with two positive results: first, the likelihood of radiation streaming around the door is lowered; and second, the shielding requirements for the door are reduced and the weight of the door is thus lowered. Labyrinths can reduce the shielding requirements for a door to negligible levels.

D. Quality Assurance. Following the construction of any shield, the shield must be tested for uniformity. In concrete, for example, voids may occur or the aggregate may settle, making the shielding characteristics uneven and unacceptable. Special scrutiny should be given to all penetrations and to the crevices between concrete blocks, if they are used.

8.5.2 Access Restrictions for Radiation Areas

Access to radiation areas should be restricted whenever the dose-equivalent rate exceeds the levels that define a radiation area (see Section 8.4.2), and shall be restricted whenever the dose-equivalent rate exceeds the level that defines a high-radiation area. Requirements for access restrictions are defined in 10 CFR 20.203. Access may be restricted by interlocks and warning systems or by guards.

A. Interlocks and Warning Systems. An interlock is an electromechanical device such as a switch that causes a radiation-generating device to stop producing radiation if the access barrier to the device is violated. Examples of interlocks include:

1. door interlocks - These interlocks turn off the radiation-generating device if the door to the high-radiation area is opened; they also prevent operation of the device until the door is closed.

2. device-mounted switches - A switch integrated with a timer is mounted on the radiation-generating device. To operate the device, the operator must enter the room, turn on the switch (and timer), leave the room, and close the door before starting the device from outside the room. The purpose of this type of switch is to ensure that the operator enters the room before every procedure is begun and instructs all personnel to leave the room. The timer allows sufficient time for all these steps to be performed without rushing.

3. emergency shutoff or SCRAM switches - These switches are located throughout the room containing the radiation-generating device. Their purpose is to allow personnel inadvertently left in the high-radiation area to shut off the device or prevent it from starting up. These switches must be reset before the device can be operated.

Warning systems may consist of lights or alarms or both, as follows:

1. lights - Rotating red warning lights (the kind used on emergency vehicles) are located near eye level and are bright enough to be seen anywhere in the exposure room even if not viewed directly. The lights should be on for 15 seconds before an irradiation starts and during the entire irradiation.

2. alarms - Warning alarms sound for 15 seconds before an irradiation can start. When irradiation is started after the 15-second delay, lights remain on and audible alarms stop.

All interlocks and alarm systems shall be fail-safe so that a radiation-generating device cannot be operated if the warning systems or interlocks are inoperable. Signs describing the systems and how they are used should be posted near each interlock or warning system.

B. Guards. Security guards can prevent unauthorized personnel from entering radiation areas by checking the credentials of each individual who desires entry. Security guards are necessary when electrical or mechanical devices for restricting access have been inactivated (for repair or testing), the radioactive material is at a temporary location, or national security requires the use of guards.

Section 8.6 CONTROL OF INTERNAL RADIATION

Internal radiation is controlled by the use of 1) containment devices, which prevent radioactive materials from entering work areas where they might be inhaled or ingested by personnel; 2) ventilation systems, which remove radioactive materials from the air of work areas to ensure clean breathing air; and 3) air-sampling and air-monitoring systems, which have alarms to notify personnel if concentrations of radioactive materials exceed permissible limits. (See Chapter 5 for details on the control of internal exposure.)

8.6.1 Containment Devices

The spread of radioactive materials can be kept to a minimum by the use of sealed sources and containment devices such as hoods, glove boxes, and hot cells.

A. Sealed Sources. A sealed (or encapsulated) source is defined as a radioactive source sealed in a container that has a banded cover. The containers are designed not to rupture and thus to prevent dispersion of the radioactive material under normal operating conditions and following minor accidents, such as a container inadvertently being dropped. The integrity of sealed sources should be tested as described in Chapter 4.

B. Hoods. Open-face or fume hoods should be designed and located to provide constant air flow into the hood. The velocity of the air flowing into the hood (the face velocity) must be sufficient to ensure that no contamination enters the room. For conventional hoods, a face velocity of 46 ± 8 linear meters/min meets this criterion. Supplied-air hoods and National Cancer Institute hoods have other criteria; consult the manufacturer's literature for details concerning a specific hood.

Hoods should be illuminated with lights that can be serviced from outside the hood. Outlets for gas, air, and water should be located along the back or sides of the hood and should be controlled through knobs located outside the hood. Electrical outlets should be on the outside of the hood.

Each hood should be strong enough to support all necessary shielding, which should attenuate radiation in all directions. The air from each hood

should be exhausted through HEPA filters of a type appropriate for the laboratory classification (see Section 8.4.3). In all cases, a prefilter should be placed ahead of the HEPA filters. The exhaust ducts should be designed to allow in-place testing of the filter systems. In addition, pressure taps should be provided to allow measurement of the pressure drop across the filters. The filters should be located to allow rapid, clean servicing with little danger of the workplace being contaminated.

The following general rules have been established for the design of hoods for work with radioactive and chemically toxic materials (Industrial Ventilation 1980); they are applicable for glove boxes and hot cells as well.

1. Operations in which radioactive materials are handled should, as often as possible, be performed in enclosed areas to prevent the contamination of large air volumes.
2. High-velocity cross-drafts should be avoided because they may increase contamination and dust loading.
3. The volume of air withdrawn from the hood must be larger than the volume of contaminated gases, fumes, or dusts created in the hood.
4. If possible, operations requiring large amounts of wet digestion, volatilized acid, or solvent treatment should be confined to one group of hoods, and dry material should be handled in others.
5. Whenever possible, radioactive aerosols should be removed by filtration. The filters should be as close to the hood as practical to prevent unnecessary contamination of equipment and ductwork.
6. The value or accountability of the material used in a hood may require that the hood be designed so that even the smallest chips and turnings can be reclaimed.
7. A supply of coolant inside the hood may be needed, depending on the pyrophoric nature of the contaminant (its ability to ignite spontaneously).
8. Hoods and duct systems should be designed to be easily accessible for decontamination, and should be constructed of materials that are easily decontaminated. For this reason, stainless steel is frequently used for the metal parts of hoods.

9. The hood fan should be located close to the release point from the building so that ductwork within the building is under a negative pressure.

C. Glove Boxes. Glove boxes can be designed to function as a primary containment to minimize the potential for release of radioactive materials. The use of glove boxes minimizes contaminated-air volumes and simplifies air treatment problems. Glove boxes should be designed to operate at a negative pressure (1.8 ± 0.64 cm water gauge pressure) with respect to the room in which they are located. They should be equipped with differential gauges to measure the pressure drop and with control devices to prevent excessive vacuum or pressure build-up. Penetrations in the glove box (e.g., conduits, ports, ducts, and windows) should be sealed to prevent the release of radioactive materials.

D. Hot Cells. Hot cells are specialized rooms in which large quantities of radioactive materials are used. The cells are normally fitted with remote manipulators, which allow the manipulation of nuclides that emit gamma rays and high-energy beta particles without personnel receiving excessive radiation doses to the hands, wrists, and forearms. Hot cells are maintained under negative pressure to minimize the spread of radioactivity in the event of a leak. The exhaust should be filtered through two HEPA and charcoal filters.

8.6.2 Ventilation Systems

Ventilation systems are an essential part of a building's safety features. Consequently, they should be designed to complement the building layout and should remain functional or fail-safe during all operations and all credible accidents.

The ventilation system must confine airborne radioactive materials within the appropriate areas of the building. It should be capable of removing from routinely occupied areas any airborne radioactive materials resulting from normal or accident conditions. Further, the ventilation system should be designed to clear all normal or accidentally generated effluents from the air before the air is released to the environment.

A. Ventilation Zones. The ventilation system should include physically separate ventilation zones to prevent cross-contamination of air. Ventilation Zone I should correspond to the confinement portion of the radiation area (i.e., hoods, glove boxes, and hot cells). Ventilation Zone II should correspond to the remainder of the radiation area and to controlled areas. Ventilation Zone III should correspond to uncontrolled areas. Ventilation Zone III is required for buildings containing predominantly Class A laboratories that need office support. (Ordinarily, Class A laboratories should be in separate buildings with minimal office space; in these areas, ventilation Zone III is optional for the uncontrolled areas.)

B. Air Flow Patterns. Air should flow from the ceiling to the floor of a laboratory and should not flow directly across bench tops. In general, laboratories should be designed to provide draft-free conditions to keep the movement of particulate matter by air currents as low as possible.

The air flow for the whole building and for individual laboratories should be from areas of low (or no) radioactivity to areas of progressively higher activity. This direction of flow ensures that material that may become airborne will not contaminate other areas in excess of their permitted limits.

C. Pressure Differentials. Pressure differentials should be used to maintain the desired air flow characteristics. The exhaust system should be used to keep areas with relatively high activity levels at a negative pressure relative to the rest of the building. The building itself should have a negative pressure relative to the outside. In order to maintain the proper pressure differentials and keep the air flowing in the desired direction, the supply fan delivering air to laboratories should be controlled by interlocks that automatically shut off the air supply so that it is impossible to deliver air to the laboratories when the exhaust system is shut down for any reason.

D. Duct Routing. Exhaust ducts in multistory buildings should be routed to common ducts, or plenums, that are easily accessible. In addition, ducts should be labeled as to their point of origin. For single-story buildings, hoods should be vented to the roof using the least possible amount of ducting inside the building.

E. Filtration

(1) Type and Location. Filters or traps for exhaust air are required to ensure that release levels are kept ALARA. Filter systems should be designed for easy access, removal, contamination control, and in-place testing. In general, exhaust filters should be placed close to the hoods, glove boxes, and hot cells in order to avoid contaminating ventilation duct systems.

(2) Backflow Prevention. If the air flow through a filter were reversed, radioactive particulates could be pulled into a laboratory, with serious consequences. For this reason, filters that routinely become burdened with radioactive particulates should be protected by dampers that restrict the reverse flow of air. Inverse-flow dampers can be simple, weighted, shutter-like dampers that open passively with positive air flow. In dampers with more complex designs, electrical mechanisms keep the dampers open, and springs or pressurized air ensures their closure if the electrical supply is disrupted.

(3) Testing. Filters should be designed so that they can be tested in place. A DOP mist is used to test HEPA filters. Charcoal filters can be tested using a gaseous halogenated-hydrocarbon refrigerant, in accordance with Section 12 of the American National Standards Institute's (ANSI) Standard N510-1975, to ensure that bypass leakage through the absorber section is less than 0.05%.

(4) Maintenance Accessibility. Ventilation filters and blowers require periodic removal and replacement. Filter systems are often contaminated at the time of their replacement, and maintenance personnel must be protected against possible inhalation of radioactive dusts, mists, and fumes during filter replacement. External exposure is also a potential problem if the filters are loaded with radionuclides that emit gamma rays or high-energy beta particles. The filter units should be placed so that individual filters can be removed easily without the need for scaffolding. If scaffolding is required, however, enough free floor space should be available for the installation of the scaffolding.

8.6.3 Sampling and Monitoring Equipment

An important aspect of facility design is to provide for sampling and measurement of the concentration of airborne radioactive materials and for monitoring of the radiation levels in the workplace. As discussed in Chapter 5, sampling is the collection of air that is then analyzed for activity levels at a later time and in a different place; monitoring, on the other hand, is the continuous reading of the radiation level in a facility by a radiation detection instrument. Types of sampling and monitoring equipment are discussed in Chapter 2.

All sampling and monitoring instruments should have lights that indicate whether the instrument is turned on, in standby mode, or not operating. These lights, or status indicators, should be readily visible from any work area. All monitors should be provided with both visual and audible alarms. The instruments should be designed so that, if an alarm has been tripped, the instrument must be rest manually; automatic cessation of the alarm function is not acceptable.

A. Air Samplers and Monitors. All Class A and B laboratories should be equipped with fixed systems for sampling and monitoring the air. The sampling heads should be placed where releases could occur, as well as in front of each room's air exhaust.

Areas occupied by personnel where concentrations of airborne radionuclides may exceed the concentrations given in 10 CFR 20, Appendix B, Table 1, should contain a continuous-monitoring device that activates an alarm when the airborne concentration exceeds 25% of the values given in the table.

B. Radiation Area Monitors. Continuously operating area monitors should be provided to measure the ambient dose-equivalent rate wherever that rate may exceed 50 mrem/hr. An alarm on each radiation monitor should notify workers if the device is not operating. Each radiation monitor should actuate audible and visual alarms whenever a preset radiation limit has been exceeded. The instruments should be capable of measuring dose-equivalent rates in the range of 10,000 mrem/hr. Finally, the detector portions of the monitors should be easily replaced and should be located where they can be calibrated in place.

Section 8.7 FACILITY SUPPORT

Other considerations in facility design are the provision of change rooms, decontamination facilities, and separate supply and sewer systems for sanitary and process water.

8.7.1 Change Room Facilities

Rooms in which workers can change clothing should be available and should be designed to prevent cross-contamination. Each worker should have two lockers, one for clean clothing and another for potentially contaminated clothing. Showers should also be provided in the change rooms. Change rooms may be separate from or part of personnel decontamination facilities.

8.7.2 Personnel and Property Decontamination Facilities

Facilities for the decontamination of personnel and property should be available. Decontamination facilities for personnel should have showers. The shower drains should be separate from the sanitary sewer system and should empty into a holding tank if contamination levels are expected to be high.

Facilities for the decontamination of property should be large enough to accommodate the largest piece of equipment. Each facility should include a hood and should have drains that are directed to holding tanks.

8.7.3 Water Supply and Sanitary Sewers

Sanitary water provided in radiation areas shall be used for safety showers and fire protection sprinklers only. Drinking fountains should not be located in radiation areas. Process water supplied to radiation areas shall be isolated from sanitary water systems by the use of either separate systems or back-flow preventors.

Sinks in radiation areas should not be equipped with drains connected to a sanitary sewer. If sinks and drain lines are connected to a sanitary sewer, they shall be so labeled, and the discharge of radioactive wastes to any sanitary sewer shall be prohibited.

REFERENCES

American National Standards Institute (ANSI). 1975. Testing of Nuclear Air-Cleaning Systems. ANSI N510, American Society of Mechanical Engineers, New York.

Fitzgerald, J. J. 1969. Applied Radiation Protection and Control, Volume 1. Gordon and Breach, New York.

Industrial Ventilation - A Manual of Recommended Practice. 1980. American Conference of Governmental Industrial Hygienists. Available from the Committee on Industrial Ventilation, P.O. Box 16153, Lansing, Michigan 48901.

Kathren, R. L., and J. M. Selby. 1980. A Guide to Reducing Radiation Exposure to As Low As Reasonably Achievable (ALARA). DOE/EV/1830-T5, National Technical Information Service, Springfield, Virginia.

National Council on Radiation Protection and Measurements (NCRP). 1978. Operational Radiation Safety Program. NCRP 59, Washington, D.C.

U.S. Code of Federal Regulations. 1982. Title 10, Part 20, "Standards for Protection Against Radiation." U.S. Government Printing Office, Washington, D.C.

U.S. Department of the Army, Headquarters. Safety - Ionizing Radiation Protection (Licensing, Control, Transportation, Disposal, and Radiation Safety). AR 385-11, Washington, D.C.

U.S. Department of the Army, Headquarters, Army Materiel Command. Safety - Radiation Protection. DARCOM-R 385-25, Washington, D.C.

CHAPTER 9. TRANSPORTATION OF RADIOACTIVE MATERIALS

Transportation of radioactive materials is governed in part by Title 49, Code of Federal Regulations; Title 10, Code of Federal Regulations; Army Regulations AR 700-64, AR 385-11, and AR 55-355.

CHAPTER 10. MANAGEMENT OF LOW-LEVEL RADIOACTIVE WASTE

10.1 MINIMIZING THE GENERATION OF WASTE 10.3

10.2 COLLECTION OF WASTE 10.4

10.2.1 Segregation of Radioactive Waste 10.4

A. Half-Life 10.5

B. Biological Waste 10.5

C. Nonbiological Waste 10.6

D. Scintillation Vials 10.7

10.2.2 Containers for Collection and Temporary Storage of Waste 10.8

A. Containers for Biological Waste 10.8

B. Containers for Nonbiological Solid Waste . . . 10.8

C. Containers for Nonbiological Liquid Waste . . . 10.8

10.3 FACILITIES FOR THE STORAGE OF WASTE 10.8

10.3.1 Site Selection 10.9

10.3.2 Control Procedures 10.9

10.4 REDUCTION OF WASTE VOLUMES 10.9

10.4.1 Solidification 10.10

10.4.2 Compaction 10.11

10.4.3 Incineration 10.11

10.5 AUTHORIZED WASTE DISPOSAL PROCEDURES 10.12

10.5.1 Requests for Disposal Instructions 10.12

10.5.2 Shipping Instructions 10.13

10.5.3 Onsite Assistance 10.14

REFERENCES 10.14

CHAPTER 10. MANAGEMENT OF LOW-LEVEL RADIOACTIVE WASTE

Low-level radioactive waste is waste that contains 1) low enough levels of beta-gamma activity so that no special provisions must be made for heat removal, and 2) low enough levels of penetrating radiation so that minimal or no biological shielding or remote handling is necessary for personnel protection. Low-level waste is generally considered to contain less than 100 nCi of transuranic alpha emitters (uranium, thorium, etc.) per gram of waste. The handling, storage, and disposal of low-level radioactive waste must conform to strict requirements imposed by the Department of the Army (DA), the Nuclear Regulatory Commission (NRC), the Department of Transportation (DOT), and the operators of waste burial grounds.

This chapter provides guidance for persons who generate low-level radioactive waste and for those responsible for its handling, storage, and disposal. Topics covered include the generation and collection of waste, facilities for storing it, and procedures for reducing waste volumes and obtaining DA assistance in waste disposal. Further questions about the management of low-level waste should be directed to HQ, ARRCOM, ATTN: DRSAR-SF, Health Physicist, Rock Island, Illinois 61299. Telephone calls can also be placed to (309) 794-3383; FTS 367-3483; or AUTOVON 793-4942.

Section 10.1 MINIMIZING THE GENERATION OF WASTE

The use of radioactive material should be planned so that a minimum amount of radioactive waste is generated. For example, when a procedure requires the use of radioactive material, a dry run using nonradioactive material can eliminate errors that might cause contamination and create considerable waste. The smallest quantity of radioactive material needed to effectively perform a task should always be used.

The volume of radioactive waste can be reduced if nonradioactive and radioactive wastes are separated and not discarded together. Solid dry wastes

that may be contaminated should be surveyed and the nonradioactive portions discarded by conventional methods. When a device is being discarded, any radioactive components should be removed if the device can be disassembled safely and the disassembly is authorized by the NRC license or DA permit. Every effort should be made to decontaminate contaminated property before it is disposed of. However, the volume of waste that would be generated by the decontamination procedure should be considered before low-cost items are decontaminated (see Chapter 7).

Section 10.2 COLLECTION OF WASTE

The total quantity of radioactive material disposed of into sanitary sewage systems, the air, or nearby streams as a result of all activities at an installation must not exceed the quantities for a single licensee given in 10 CFR 20, or the quantity limitations established by applicable regulatory agencies. Individual users of radioactive material must not dispose of waste directly by these methods unless specifically authorized by the Radiation Protection Officer (RPO). Instead, each user should collect any low-level wastes according to the guidelines in this section.

When wastes are being collected at a facility, the radioactive waste should be separated from the nonradioactive waste. Wastes that are taken from a radiation area should be presumed to be radioactive unless shown to be otherwise. This is particularly true in hot laboratories, where paper tissue and even writing paper may become significantly contaminated. Radioactive wastes should be segregated into classes of material so that all constituents of any one batch can be dealt with in the same way. They should be collected in suitable containers for processing and disposal by the RPO or a designated representative.

10.2.1 Segregation of Radioactive Waste

Characterization of low-level radioactive waste is important for proper waste handling and processing for final disposal. Characterization includes identification of the physical form of the waste, the type and half-life of

radionuclides present, the total activity and/or specific activity, and other properties of the waste such as its volatility, explosiveness, and toxicity.

Once characterized, wastes should be collected according to type by each user of radioactive materials. Procedures for segregating and collecting wastes should be developed by the RPC and provided to all individuals who may generate radioactive waste as a result of their work. The procedures should cover the segregation of wastes by half-life and by the characteristics described below. The waste collected under each category can be further separated by whether it is combustible or compactible.

A. Half-Life. Waste containing short-lived radionuclides (those with a half-life ($t_{1/2}$) shorter than 30 days) should be collected separately from waste containing long-lived radionuclides (those with a half-life longer than 30 days). Short-lived material can usually be stored away from work areas for 10 half-lives of the longest-lived radionuclide in the material and then discarded as nonradioactive material. It must be surveyed before disposal by conventional methods. Long-lived material should be processed for disposal as radioactive waste.

B. Biological Waste. Biological waste, which originates primarily from medical and research facilities, normally undergoes decomposition by microorganisms, producing foul-smelling matter. Such material requires freezer storage.

(1) Solid. Solid biological waste includes radioactively contaminated animal carcasses, fecal matter, soiled animal bedding, and plant by-products. Personnel working with animals should be aware of radiation levels and of the excretion routes for various radiochemicals and drugs (National Council on Radiation Protection and Measurements (NCRP) Report No. 48, 1976). Animals that are used in studies of radioactive materials should not be petted or groomed, and their carcasses should not be hand-carried if a radiation overexposure to the hands or body of the person carrying them may result. Remote handling and storage is advised (TM 3-261).

(2) Liquid. Liquid biological waste includes radioactively contaminated blood, urine, and culture media. Because biological waste should be stored frozen, containers should be capable of withstanding temperature extremes

without breaking and should be filled about three-quarters full to allow for expansion of the contents. Polyethylene containers are preferred. Personnel dealing with liquid biological wastes should consider not only the radiological hazards and the need to provide radiation protection, but also the potential chemical and biological hazards that may be associated with the wastes.

C. Nonbiological Waste. Nonbiological waste is any radioactively contaminated waste that, under ordinary circumstances, does not undergo decomposition by microorganisms.

(1) Solid. Solid nonbiological waste makes up the major portion of low-level radioactive waste. It includes radioactively contaminated glassware, protective clothing, gloves, paper, metal scraps, syringes, filters, sealed sources, and equipment or equipment components (compasses, meters, electron tubes, etc.). Depleted uranium, either as an ore or in metal form, also falls into this category. If a device with a solid source is not internally or externally contaminated, it should be handled in a manner that prevents its contamination. For example, it should not be placed in the same collection container as a pair of contaminated gloves.

(2) Liquid. Not all liquids are disposed of in the same way; therefore, liquid nonbiological waste should be segregated into aqueous and nonaqueous waste. Aqueous waste--any waste in which water is the primary solvent--includes water used to decontaminate material or personnel, and solutions of radioactive material used in a laboratory. Nonaqueous waste is any liquid in which water is not the primary solvent.

Any chemically reactive liquids should be further segregated and identified. Organic liquids (those containing carbon compounds) should be segregated from aqueous solutions to prevent the possibility of violent reactions. Nitric acid and alcohol, for example, if disposed of in the same vessel, could react together and cause an extensive spread of contamination. Unless special arrangements are made with the RPO, individuals who generate strongly acidic or basic waste solutions should neutralize or dilute them enough so that they will not cause violent chemical reactions or release strong fumes and vapors. In the case of organic solvents, especially those that are highly volatile, appropriate precautions should be noted on the waste container.

When the methods used to dispose of liquid wastes include absorption of the liquid or ion exchange processes, the potential for chemical interactions that could affect the process should be evaluated. Types of liquid wastes that could cause adverse effects on the processing of the waste include acidic or basic solutions; liquids containing complexing or wetting agents; and liquids containing certain detergents. Precautions must be taken to prevent the accidental processing of incompatible liquid wastes.

D. Scintillation Vials. Small glass or plastic vials containing scintillation fluids and low levels of radioactively labeled compounds may be handled as an entity; the contents of the vials need not be transferred to a waste container. The vials should be packaged (preferably in their original cartons) to avoid breakage, and the box should be properly labeled.

10.2.2 Containers for Collection and Temporary Storage of Waste

Containers used for the collection and temporary storage of radioactive waste should be made of materials that will not rust or corrode from contact with the wastes stored in them. The lids of the containers must be easy to open so that the containers do not tip over when the lids are being removed.

Each container of radioactive waste should be painted bright yellow and marked "Caution - Radioactive Material." It should be labeled with enough information to permit accurate identification of the waste it contains. This information, which should be noted on the label at the time the waste is placed in the container, should include:

1. the name of the waste generator
2. the date
4. the pH of a waste solution
3. the chemical name of the waste material
5. the isotope(s) contained in the waste
6. the activity level
7. any information on the biological or chemical hazards associated with the waste.

Waste containers should be checked periodically to ensure that radiation levels are not excessive, that outside surfaces are free of contamination, and

that corrosion or rust is not weakening the container. If a waste container that is being used for the collection of wastes develops a high external radiation exposure level or becomes externally contaminated, it should not be kept even temporarily at the user's location, but should be moved immediately to the storage site for radioactive wastes. A container that is corroding and losing its integrity should be placed inside a second container before being moved.

Individuals who generate waste should notify the RPO whenever a container is filled and ready for removal. The RPO should remove the waste and place it in a centralized area for temporary storage and consolidation. Containers should not be moved unless they are labeled and the waste is contained in accordance with installation requirements.

A. Containers for Biological Waste. Solid biological waste must be sealed in plastic bags and frozen. Liquid biological waste should be stored in plastic containers that can be frozen without breaking. Glass containers are not acceptable (TM3-261). Biological wastes are packed in lime for shipping.

B. Containers for Nonbiological Solid Waste. Solid waste must be sealed in plastic bags. It can be stored in a metal waste can with a plastic liner and a lid that operates by a step-pedal. When the waste is to be moved, it must be packaged so that pipettes, hypodermic needles, and other sharp objects cannot penetrate through the plastic bag.

C. Containers for Nonbiological Liquid Waste. Glass containers should not be used to store liquid waste. Aqueous waste may be kept in polypropylene carboys or jugs. Nonaqueous waste (organic solvents, acids, and bases) may be kept in metal solvent cans or in plastic containers if the liquid will not dissolve the plastic.

Section 10.3 FACILITIES FOR THE STORAGE OF WASTE

A facility should be designated for the centralized storage of radioactive wastes until they are shipped for processing or burial.

10.3.1 Site Selection

When a storage facility is being selected, whether an existing structure or a new structure, the RPO or the individual responsible should ensure that the following guidelines, in addition to those in Chapter 8, are met:

1. The facility is close to the point of origin of the waste but away from main areas of personnel traffic or areas where routine access is required.
2. The facility is weatherproof and has adequate ventilation.
3. Enough storage space is provided to allow for variations in shipping schedules and, if possible, to store short-lived materials (those with a half-life shorter than 30 days) while they decay.
4. Separate storage compartments are provided for combustible liquids (for fire prevention).
5. Means of handling wastes efficiently are provided, to minimize personnel exposures.
6. The radiation dose limits for the unrestricted area around the facility will not be exceeded.

10.3.2 Control Procedures

To keep personnel exposures to a minimum and to protect the general public, only individuals responsible for storing or shipping waste should have access to the waste storage facility. The wastes should be kept segregated by type, with higher-level waste placed far from the facility entrance to reduce the exposure to personnel who enter the area. As waste is brought into or taken out of storage, the amount and type of the waste moved, the date, and the name of the user or shipper should be entered in a log book. Personnel monitoring should be provided to ensure contamination control.

Section 10.4 VOLUME REDUCTION

Reducing the volume of low-level waste has the following benefits:

1. It increases the stability of the waste form
2. It minimizes the possibility that radionuclides will be released to the environment during interim storage, transportation, and burial.
3. It leads to savings in transportation and burial costs, which are dependent on waste volume.
4. It reduces the exposure of personnel handling the waste.

As discussed earlier, volume reduction should be accomplished primarily by each person minimizing the amount of waste generated. Wastes that have been generated can be reduced in volume by solidification, compaction, and incineration.

Volume reduction processes can be carried out most economically at central waste-consolidation facilities to which many installations or sites ship their radioactive wastes for treatment before final disposal. The use of volume reduction equipment at an Army installation requires an NRC license and a DA authorization or permit.

10.4.1 Solidification

Many burial sites require that the wastes they handle meet certain physical forms. Low-level liquid wastes must be converted to a solid that will not leach. Loose, dry residues from incinerators or dryers must be bound together into a solid waste form.

A variety of methods are used to solidify wastes and reduce their volume. Aqueous solutions are treated by crystallization and dehydration. Crystallization is the removal of water, usually by evaporation, which results in a slurry of precipitated solids mixed with a saturated solution. The slurry is then mixed with a setting agent such as cement. Dehydration is the removal of all the water from liquid wastes, leaving a residue of solids. Aqueous liquids and dry residues from incinerators and dryers can be mixed with a binding agent to form a solid waste. Conventional setting and binding agents are cement, bitumen, glass, and urea-formaldehyde; experimental materials include vinyl esters, polyethylene, epoxy resins, and an inorganic binder.

10.4.2 Compaction

Compaction (the removal of excess air) is the most widely used method of volume reduction for dry, nonbiological wastes that are not combustible. Compaction includes compressing the waste into a final disposal container (such as a 208-liter drum) and baling the compressed waste with bands before packaging it. Items that are currently compacted in the commercial fuel cycle include high-efficiency particulate air (HEPA) filters and old contaminated drums.

Before compaction, the waste should go through some pretreatment. Compactible and noncompactible items should be separated. Hazardous materials (such as explosives) and materials containing free liquid should be removed. Items that would otherwise be too large for the compactor can be shredded using knife cutters or hammermills. For example, equipment and metal can be packaged as is or shredded in a hammermill and compacted.

A typical compactor for low-level waste consists of a hydraulic system with a vertical ram, a contoured support plate, a frame, a safety enclosure, and automatic controls. These drum compactors should be located in protective enclosures, which prevent the escape of airborne particulate matter. A hood or shroud around the drum opening, with a HEPA filter and an exhaust blower, serves to control particulates. Some drum compactors incorporate a metal inner sleeve to protect the drum walls from the pressure of the ram and from rigid metal objects.

10.4.3 Incineration

Incineration is the removal of combustible material in radioactive waste. Water and air are removed at the same time. The types of incinerators available for radioactive-waste processing include controlled-air incinerators, fluidized-bed incinerators, and rotary kilns. These systems differ in operating temperatures, waste residence times, chamber turbulence, and amount of oxygen used. Each incineration system requires specific methods of waste pretreatment, feeding, ash removal, and off-gas treatment.

All incinerators for radioactive waste must have an off-gas system to keep particulate and gaseous effluents within NRC, Environmental Protection

Agency (EPA), and state limits. These off-gas systems result in an additional radioactive waste stream that must be considered.

The main advantage of incineration as a volume reduction process is the uniform end product, ash, which is easy to solidify and thus minimizes the problems associated with the disposal of a wide range of materials. The main disadvantage is the high initial cost; because a relatively large volume of waste material must be generated to make the procedure cost-effective, incineration is not economical for most sites.

Section 10.5 AUTHORIZED DISPOSAL PROCEDURES

The DA program for the disposal of low-level radioactive waste is managed by HQ, ARRCOM, Rock Island, Illinois. The authority for world-wide management of the program is assigned in AR 385-11.

Low-level waste that cannot be disposed of locally because of local restrictions is disposed of by land burial in Barnwell, South Carolina, or Richland, Washington, by commercial radioactive-waste-disposal firms under contract with HQ, ARRCOM. Under certain conditions, waste shipments are sent to a collecting point operated by a waste disposal broker or the Army. At the collecting point, they are consolidated and ultimately disposed of.

10.5.1 Requests for Disposal Instructions

The RPO is responsible for requesting disposal instructions from the Commander, US Army Armament Materiel Readiness Command, ATTN: DRSAR-DSM-D, Rock Island, Illinois 61299. The request can be made by letter or message.

Requests for disposal instructions must contain the following information:

1. nomenclature, national stock number, and serial numbers
2. physical descriptions of the items to be disposed of, including:
   a. whether solid, liquid, or gas
   b. the quantity per stock number and, if gas, the volume under standard pressure and temperature

c. the shipping weight (pounds) and volume (measured to the nearest cubic foot)
d. the number of shipping containers
e. the shipping permit or waiver number
f. the transport group
g. the package specification
h. the labels used

3. chemical and radioisotope description, including:
   a. the hazardous chemicals present
   b. for liquids, the solvent present
   c. the radioisotopes present

4. radioactivity and radiation measurement, including:
   a. the millicuries of activity of each radioisotope; for special nuclear material, give the number of grams; for source material, list the quantity in pounds
   b. maximum radiation dose rates (mrem/hr) at the surface and 1 meter from the surface of the package
   c. the classification, basis for classification, and procedures for declassification
   d. special instructions or requests for unique service, such as return of the containers
   e. the name and telephone number of the responsible person to contact for additional information
   f. remarks, if appropriate.

Requests for technical information or assistance should be submitted to the Commander, ARRCOM, ATIN: DRSAR-SF, Rock Island, Illinois 61299. Telephone requests can be made by calling (309) 794-3383/4728; FTS 367-3383/4728; or AUTOVON 793-3383/4728.

10.5.2 Shipping Instructions

Shipping instructions will be furnished by HQ, ARRCOM, in reply to requests for disposal instructions. Each request will be handled as a separate action, and the instructions will include the following:

1. an ARRCOM-assigned control number, which will serve as the identification for each request
2. the address of the shipping destination as determined by HQ, ARRCOM; the destination may be a land burial site or a collection/consolidation point
3. specific marking, packaging, and transportation instructions.

Because safety concerns and burial criteria change periodically, special instructions will also be furnished.

10.5.3 Onsite Assistance

Radioactive-waste shipments may be audited by HQ, ARRCOM, at the shipper's installation prior to shipment. Some audits require that an ARRCOM audit team be onsite to supervise the packaging and loading of the radioactive material. Requests for onsite assistance should be addressed to Commander, US Army Armament Materiel Readiness Command, ATTN: DRSAR-SF, Rock Island, Illinois 61299.

REFERENCES

National Council on Radiation Protection and Measurements (NCRP). 1976. Radiation Protection for Medical and Allied Health Personnel. NCRP 48, Washington, D.C.

U.S. Code of Federal Regulations. 1982. Title 10, Part 20, "Standards for Protection Against Radiation." U.S. Government Printing Office, Washington, D.C.

U.S. Department of the Army, Headquarters. Handling and Disposal of Unwanted Radioactive Material. TM 3-261, Washington, D.C.

U.S. Department of the Army, Headquarters. Safety - Ionizing Radiation Protection (Licensing, Control, Transportation, Disposal, and Radiation Safety). AR 385-11, Washington, D.C.

CHAPTER 11. RADIATION ACCIDENTS AND EMERGENCY PREPAREDNESS

11.1 THE EMERGENCY PLAN 11.5

11.1.1 Responsibility for Emergency Planning 11.6

11.1.2 System for Classifying Emergencies 11.6

11.1.3 Emergency Response Organization 11.9

11.1.4 Characterization of Installation and Facilities . . 11.13

11.1.5 DA-Authorized and NRC-Licensed Activities 11.13

11.1.6 Emergency Plan Implementation 11.13

A. Procedures 11.13

B. Notification 11.14

11.1.7 Response Actions 11.14

A. Assessment Actions 11.15

B. Corrective Actions 11.16

C. Protective Actions 11.16

11.1.8 Facilities and Equipment 11.17

A. Emergency Control Centers 11.18

B. Medical Treatment Facility 11.19

C. Assembly Areas 11.20

D. Communications Equipment 11.20

E. Monitoring Equipment 11.21

F. Aerial Monitoring 11.22

G. Dosimeters 11.22

H. Transportation Modes 11.22

11.1.9 Offsite Agreements and Support 11.23

11.1.10 Re-Entry and Recovery 11.23

11.2 MAINTAINING A STATE OF EMERGENCY PREPAREDNESS 11.24

11.2.1 Training Staff and Emergency Response Personnel . . 11.24

11.2.2 Training Members of the News Media 11.26

11.2.3 Conducting Emergency Drills 11.26

11.2.4 Maintaining and Inventorying Emergency Equipment . . 11.26

11.2.5 Reviewing and Updating Plans and Procedures . . . 11.27

11.3 NOTIFICATION AND REPORTING REQUIREMENTS 11.27

11.3.1 Notification and Reporting Requipments: Army . . . 11.29

A. Notification 11.30

B. Reports and Investigations 11.31

11.3.2 Notification and Reporting Requirements: NRC . . . 11.32

A. Notification 11.32

B. Reports 11.32

11.3.3 Notification and Reporting Requirements: DOT . . . 11.33

REFERENCES 11.34

APPENDIX A - EXAMPLES OF CHECKLISTS 11.37

APPENDIX B - RESPONSE ACTIONS 11.43

APPENDIX C - EXAMPLE LISTING OF EMERGENCY KIT EQUIPMENT 11.51

APPENDIX D - EXAMPLES OF EMERGENCY ACTIONS 11.57

TABLES

11.1 Significant Quantities of Byproduct Materials 11.7

11.2 Emergency Condition Classification Scheme 11.10

11.3 Minimum Organizational Support for Emergency Preparedness . . 11.12

11.4 Instruments for Emergency Radiological Measurements . . . 11.16

11.5 DA Criteria for Defining Radiation Accidents 11.28

11.6 NRC and DA Notification Requirements for Accidents Involving Licensed Materials 11.28

11.7 DOT and DA Notification Requirements for Accidents Involving Army Motor Vehicles Carrying Licensed Materials 11.29

11.8 DA Criteria for Individual Radiation Overexposures . . . 11.30

11.9 Summary of Response Actions for Individual External Exposure . 11.46

11.10 Actions to be Taken Within Six Hours Following a Whole-Body Exposure 11.47

11.11 Actions to be Taken Following Suspected Internal Contamination 11.48

CHAPTER 11. RADIATION ACCIDENTS AND EMERGENCY PREPAREDNESS

A radiological emergency is any sudden or unforeseen situation in which damage to persons or property, or interruption in operations, has occurred or is imminent unless corrective actions are taken. The severity of both an accident and its effects can be decreased if procedures are followed, engineered controls are used, and corrective and protective actions are taken.

Planning for radiological emergencies can uncover problems that, if corrected, will decrease the likelihood of an accident. Therefore, a plan for responding to abnormal occurrences should be developed and maintained for each individual operation involving radioactive materials. Each plan will vary from others accordings to the specifics of the operation. The magnitude of the emergency planning needed at an installation and the notification, reporting, and investigative procedures required in the event of an accident depend on the potential hazards at each facility and the types of accidents that may occur.

In this chapter, radiological accidents are identified and classified, guidance is provided on how to prepare for potential accidents by developing an emergency preparedness plan and how to maintain a state of emergency preparedness, and accident reporting and investigative procedures are reviewed. Emergency preparedness is a full-time specialty of health physics that requires training and experience. This chapter is intended to introduce the Radiation Protection Officer (RPO) to emergency preparedness. The assistance of a trained specialist should be sought for developig extensive plans and emergency responses.

Section 11.1 THE EMERGENCY PLAN

An emergency plan is a document that details the best response to an emergency situation, with primary cncern for protecting the health and safety of Army and civilian personnel and the general public. A comprehensive plan should contain the following key elements:

1. designation of responsibility for emergency planning
2. assessment of potential accidents
3. system for classifying emergencies
4. description of the emergency response organization
5. characterization of the installation and its facilities
6. description of activities authorized by the Department of the Army (DA) and the Nuclear Regulatory Commission (NRC)
7. procedures for implementing the emergency plan
8. response actions
9. description of facilities and equipment
10. description of offsite agreements and support capabilities
11. re-entry and recovery conditions.

The use of a checklist such as that presented in Appendix A can help ensure that all aspects of an emergency plan have been considered.

11.1.1 Responsibility for Emergency Planning

The commander of each installation is responsible for planning for and providing training for credible emergencies (AR 385-11). This duty may be delegated to an organization within the command that has the operational experience and technical abilities necessary to direct planning efforts. Personnel involved in emergency planning must have the authority to gather site-specific information, write procedures, and enter into discussions with offsite agencies. In many cases, the RPO and the Ionizing Radiation Control Committee (IRCC) are the logical choices for this duty. If the duty is delegated elsewhere, the RPO and the IRCC should be involved in at least the radiological assessment, control, and recovery aspects of emergency planning.

11.1.2 System for Classifying Emergencies

Emergency plans and procedures should be developed for all facilities where radioactive materials are handled, used, stored, or transported, regardless of quantity. However, formal documented emergency plans must be

prepared (DARCOM Disaster Control Plans (DCP), Annex E) if the quantities of radioactive materials exceed:

1. 1 μCi of radium
2. the quantities listed in Schedule B of 10 CFR 30.71
3. 6.8 kg of source material
4. 5 μg of special nuclear material.

Schedule B of 10 CFR 30.71 sets limits for byproduct materials. A portion of Schedule B (the more common byproduct materials) has been reproduced in Table 11.1.

TABLE 11.1. Significant Quantities of Byproduct Materials(a)

Byproduct Material	Microcuries	Byproduct Material	Microcuries
^{3}H (tritium)	1,000	^{115}Cd	100
^{14}C	100	^{115m}Cd	10
^{18}F	1,000	^{124}Sb	10
^{32}P	10	^{125}I	1
^{35}S	100	^{131}I	1
^{36}Cl	10	^{133}Ba	10
^{42}K	10	^{133}Xe	100
^{54}Mn	10	^{135}Xe	100
^{59}Fe	10	^{137}Cs	10
^{60}Co	1	^{144}Ce	1
^{65}Zn	10	^{147}Pm	10
^{85}K	100	^{148}Pm	10
^{90}Sr	0.1	^{197}Hg	100
^{90}Y	10	^{197m}Hg	100
^{99}Mo	100	^{198}Au	100
^{99}Tc	10	^{204}Tl	10
^{99m}Tc	100	^{210}Bi	1
^{109}Cd	10	^{210}Po	0.1
^{115}In	10		

(a) Excerpted from 10 CFR 30.71, Schedule B.

The scope of the emergency plan depends on the potential hazards of the maximum credible accident and other postulated accidents. The maximum credible accident is the accident that would cause the highest radiation exposures to onsite personnel and/or the public. Although the maximum credible accident poses the greatest threat, all potential accidents should be considered in the development of emergency plans. The presence of small quantities of radioactive materials may require only a few procedures and telephone numbers, with minimal supplies and equipment (e.g., ropes, signs, and survey meters). The presence of large quantities may require an extensive plan, many procedures, and facilities and equipment dedicated to an emergency response.

Assistance should be obtained for emergency planning, particularly if the installation does not have the resources to handle the identified credible accidents. Assistance may be available from Army emergency response teams or health physics specialists in emergency preparedness. If local personnel cannot identify such assistance, contact DARCOM or the office of the Surgeon General of the United States.

Four classes of emergency conditions that are frequently used in the nuclear industry to classify potential hazards--unusual event, alert, site emergency, and general emergency--are described in Table 11.2 (pages 11.10-11.11), based on NRC's NUREG 0654 (1980). The classes are defined in terms of onsite and offsite consequences and projected dose commitments and exposure rates at the boundary of the event site, which may be the door of a laboratory or a building, or a restricted-access gate on base. Army operations would typically encompass only the first two emergency classes: unusual event and alert. If a site emergency or general emergency that might cause the release of radioactive materials to offsite locations could occur at an installation, assistance should be sought in designing and developing emergency plans and procedures.

The following topics should be considered in the development of emergency plans:

1. the kinds of radioactive materials potentially released (so that responsive monitoring instrumentation can be identified)

2. the most important exposure pathways for these types of materials (so that the effect on the local population can be determined)
3. a definition of the area for which planning should be carried out (called the emergency planning zone (EPZ))
4. the potential duration of a release and the time available before exposures offsite are significant (so that protective actions can be decided upon).

Specific conditions, both actual and imminent, that require an emergency response are called emergency action levels (EALs) and are the basis for declaring an unusual event, an alert, or a higher classification of accident. When the EALs have been identified and documented, the procedures, facilities, and equipment required for a response can also be identified. Thus, the EALs can provide a framework for developing emergency procedures.

Another useful classification system (Brodsky 1980) groups commonly used radionuclides into eight groups based on the relative magnitudes of their maximum radiotoxicities. This system was presented in Chapter 1 of this manual. It can be useful in determining EALs and specifying subsequent actions.

11.1.3 Emergency Response Organization

The coordinated efforts of several organizations may be required to produce an adequate emergency response. In the emergency plan, one individual must be designated as having overall responsibility and authority for implementing and directing emergency procedures. Each support organization and its responsibilities must be identified, and persons responsible for each group must be identified by title or position, along with any alternates, to assure a 24-hr/day response. All individuals assigned responsibilities must have knowledge of and experience in radiological emergency preparedness.

Table 11.3 is a listing of the organizational support personnel who must be available at any installation and included in any plan, with brief example descriptions of their responsibilities. Site requirements may call for a more complex list or may allow two or more organizational functions to be consolidated. Several duties of key response personnel cannot be delegated. For instance, the emergency director cannot assign subordinates the responsibility

TABLE 11.2. Emergency Condition Classification Scheme (NUREG 0654)

Emergency Class	Description	Projected Dose Commitments and Exposure Rates at Event Site Boundary
Unusual Event	An event that is confined to facilities and personnel onsite but indicates the loss of one level of safety control or control boundary. Emergency response actions are limited to onsite areas. Examples are: laboratory spills, radiation overexposures, and contaminated personnel, rooms, or buildings. The purpose of the unusual event level is to alert plant personnel to unusual radiological conditions, to make management aware that administrative controls have been violated, and to initiate management actions to prevent recurrence.	Whole-Body (WB) dose commitment: <1 mrem Organ dose commitment: <3 mrem WB exposure rate: <0.5 mR/hr
Alert	An event that involves an actual or potential substantial reduction of the level of safety of personnel and the facility. Limited releases of hazardous materials to offsite locations may occur but are not expected to exceed applicable permissible limits. The purpose of an alert level is to ensure that 1) onsite (and possibly offsite) emergency response personnel are properly advised and available for activation if the situation becomes more serious, 2) that confirmatory radiation monitoring is performed, and 3) that response organizations are notified of emergency conditions.	WB dose commitment: 1 to 50 mrem Organ dose commitment: 3 to 150 mrem WB exposure rate: 0.5 to 50 mR/hr

TABLE 11.2. (continued)

Emergency Class	Description	Projected Dose Commitments and Exposure Rates at Event Site Boundary
Site Emergency	An event that involves actual or likely major failure of facility functions that are needed for the protection of onsite personnel, the public health and safety, and the environment. Releases of hazardous materials to offsite locations are likely or are occurring and have the potential to exceed applicable permissible limits. The site emergency may be declared if an emergency has occurred or is imminent. The purpose of the site emergency level is to ensure that 1) emergency control centers are manned, 2) appropriate monitoring teams are dispatched, 3) personnel required for determining onsite protective measures are at duty stations, 4) predetermined protective measures for onsite personnel are initiated, and 5) offsite officials and organizations are informed of the situation.	WB dose commitment: 50 mrem to 1 rem Organ dose commitment: 150 mrem to 3 rem WB exposure rate: 50 to 500 mR/hr
General Emergency	An event that involves actual or imminent substantial reduction of facility safety. Releases of hazardous materials to offsite locations are occurring or are expected to occur and exceed applicable permissible limits. The purpose of the general emergency level is 1) to initiate predetermined protective actions for onsite personnel, the public health and safety, and the environment, and 2) to provide continuous assessment of emergency conditions and exchange of information both onsite and offsite. Declaration of a general emergency will initiate major activation of DA-wide resources required to effectively mitigate the consequences of emergency conditions and ensure the protection of onsite personnel, the public health and safety, and the environment to the greatest extent possible.	WB dose commitment: >1 rem Organ dose commitment: >3 rem WB exposure rate: >500 mR/hr

TABLE 11.3. Minimum Organizational Support for Emergency Preparedness

Emergency Function	Normal Duty	Emergency Responsibility
Emergency Director (ED)	Commander of installation or Officer of the Day	Makes all decisions on how to respond to an accident based on recommendations from emergency support organization and guidance from the emergency plan. Authorizes nonprocedural actions for assessment, protective actions, and recovery. Declares appropriate emergency class.
Assistant Emergency Director	Anyone familiar with plan and designated by ED	Gathers information from various organizations and feeds pertinent information to ED.
Radiological Assessment and Control (RAC)	Radiation Protection Officer	Supervises measurement, assessment, and control of radiological conditions. Performs onsite and offsite dose calculations. Makes protective action recommendations to ED as needed.
Facilities Director	Same as routine operation	Consulted on building designs, utilities, equipment, operations, etc.
Offsite Activity Coordinator	Designated by ED; familiar with offsite agency agreements and capabilities	Keeps offsite agencies informed about situation and coordinates their actions with onsite response.
Public Information	Public relations spokesman	Releases emergency information to public as authorized by ED.
Security	Same as normal operations	Under command of ED, isolates affected areas, controls traffic and crowds. By agreement, assists in offsite control of traffic, crowds, access, etc.
Fire Safety, Search and Rescue	Same as normal operations	Assesses and controls nonradiological hazards; works with RAC on search and rescue; provides first aid medical treatment and fire control.

for declaring emergency classifications or recommending protective actions. Responsibilities that cannot be delegated must be identified in the plan.

11.1.4 Characterization of Installation and Facilities

The emergency plan should include a description of the principal characteristics of the installation. Approximate populations of onsite and offsite structures should be identified. Aerial photographs or site maps should be used to identify the location of facilities or areas relevant to emergency planning. These could include: 1) the location of population centers (office buildings, schools, barracks, stadiums, personnel housing); 2) the location of facilities that could present potential evacuation problems (hospitals, schools); 3) identification of primary routes for bringing in emergency equipment or for evacuating personnel or the public; 4) location of emergency support facilities (fire stations, hospitals with capability for handling patients with radioactive contamination); and 5) other sites of potential emergency significance (hazardous chemicals, gas lines).

Facilities in which radiological activities are conducted should be concisely described. The description should include confinement structures for handling and storing radioactive and other hazardous materials; auxiliary systems such as ventilation; radioactive waste management; and detection and alarm systems.

11.1.5 DA-Authorized and NRC-Licensed Activities

Work that involves radioactive materials and that is authorized by the Army and licensed by NRC should be described in the emergency plan. Included should be the location of the work; the type, form, and quantity of the radioactive materials used; the type of waste produced; and the individuals responsible for the activities.

11.1.6 Emergency Plan Implementation

The emergency plan should include detailed instructions for carrying out emergency response actions and information on required notifications.

A. Procedures. The detailed response procedures should include the following:

1. specific EALs and the actions planned in response to them
2. a statement of the responsibilities assigned to each individual, and which responsibilities may not be delegated
3. references to support documents and procedures that supplement the emergency plan.

The procedures should be developed to ensure that all positions will be manned and all appropriate emergency organizations will be operational in the event of an emergency.

B. Notification. When an emergency class is declared, prompt notification of personnel is vital to response. Methods and procedures for 24-hr/day notification of each organization that has an emergency response assignment are necessary. A site-wide notification system (i.e., public address or pageboy system) is useful in alerting site personnel; however, someone must confirm that response groups have been notified. A call list of key emergency response personnel and their alternates, and of DA and NRC contacts, should be part of the emergency plan, and one person or group should be designated to contact them at the direction of the emergency director. Contacts should be completed within 15 minutes of the declaration of an emergency class.

The methods of communication that will be used to notify onsite and offsite personnel must also be specified in the emergency plan, including a description of all primary and back-up notification equipment. Messages and announcements that are planned and written out in advance are useful and should be incorporated into the procedures to avoid delays and misunderstandings.

11.1.7 Response Actions

Emergency response actions fall into three general categories: assessment actions, corrective actions, and protective actions. Individuals who have emergency response assignments should be experienced in their assigned responsibilities and should have access to procedures that stipulate what actions should be taken. Procedures should be well written, easy to understand, and presented in a "cookbook" format, with space allotted for notes. Appendix A contains a sample checklist of procedures to be followed in the

event of a minor spill. Appendix B provides specific response actions and considerations for accidents involving exposure to individuals and for transportation accidents.

The following sections provide a synopsis of how the three categories of response actions should be treated in the emergency plan.

A. Assessment Actions. Responding to accident situations requires knowing both present and impending radiological conditions, which can be calculated using available information and supplemented with data obtained from radiological surveys. If insufficient information is available for making calculations, survey data alone may be used to determine emergency response actions.

For radiological surveys, instruments and equipment capable of measuring all anticipated conditions must be available and operational. The type and number of instruments needed depend on how extensive the onsite and offsite measurements will be. A program may be greatly simplified if only onsite response is required. An offsite capability requires thorough planning over a large area, special radiological equipment, and vehicles for transporting personnel and equipment.

Instruments must be capable of measuring the full range of anticipated radiation intensities and types. The specifications provided by vendors should be tested, as should each instrument's response to the 50-year environmental extremes recorded in each location.

Onsite parameters that must be measured are dose rate, contamination count rate, and the concentrations of radionuclides in air and effluents. Offsite parameters are the same except that meteorological data are also needed. Examples of instrument types appropriate for making these measurements are found in Table 11.4. (See also Chapter 2, "Radiation Instrumentation.")

For offsite dose assessment, simple equations must be developed that allow accurate calculation of integrated dose within 15 minutes of when data are received. A computer or desk-top calculator can be programmed with complex equations so that the insertion of required parameters is all that is

TABLE 11.4. Instruments for Emergency Radiological Measurements

Parameter	Instrument Types
Dose rate	Medium- to high-range ionization chamber
Surface count rate	Geiger-Mueller detectors Scintillators
Concentrations of radionuclides in air	Air-sampling device (air pump, vacuum pump) Analyzer: gas proportional counter or scintillation counter
Concentrations of radionuclides in effluents	Sampling devices (air, water, soil) Analyzer: gas proportional counter or scintillation counter
Meteorological conditions	Devices to determine wind speed and direction, temperature, and stability class

needed to run the program. Loss of electrical power must not affect the ability to make this calculation. The person responsible for assessment should be guided by the emergency plan on how to apply the assessment data to obtain projected doses.

B. Corrective Actions. Efforts must be made to reduce the likelihood that an accident will recur. In general, a thorough investigation is needed to identify areas that are weak and need strengthening. The results of the investigation should lead to appropriate corrective actions. If several alternative actions are possible, the action taken should be the one that incorporates, to the greatest extent possible, engineered safeguards rather than administrative guidelines.

C. Protective Actions. In an accident, all radiation doses should be kept as low as is reasonably achievable (ALARA) while the situation is brought under control. Limiting doses is best accomplished by limiting the release of materials through either engineered controls or manual actions. Because this is not always possible, protective actions should be developed to control the exposure of personnel and the public.

Examples of onsite actions that should be considered are:

1. providing protective clothing and respirators for use by emergency workers
2. sealing windows and doors and shutting off ventilation systems until conditions improve
3. removing personnel who are not contributing to the emergency response.

If personnel may need to be evacuated to offsite areas, routes and methods of evacuation should be planned and a destination upwind from any release should be identified. Provision must exist for transport vehicles, radiological surveys of personnel and vehicles, and offsite decontamination.

Emergency plans must also include ways of accounting for onsite personnel. Procedures should specify

1. personnel assembly points
2. the individual(s) responsible for accountability at each point
3. the individual to whom accountability status is reported
4. the individual responsible for notifying search-and-rescue teams.

As a general rule, the names of all missing persons should be determined within 30 minutes of the declaration of an emergency. All personnel remaining onsite should be continuously accounted for.

11.1.8 Facilities and Equipment

An emergency plan and the response based on it can be effective only if adequate facilities and equipment are available. For example, an offsite monitoring team would be useless if it did not have monitoring instruments that could measure in the range of emergency conditions or if it did not have communications equipment to report back the information gathered. The design of facilities and the types of equipment required for effective response depend largely upon the maximum credible accident and other postulated accidents. A variety of considerations in the design and selection of facilities and equipment for handling both small- and large-scale accidents is presented below. Judgment should dictate which considerations are appropriate for a given installation.

A. Emergency Control Centers. To facilitate the coordination, direction, and evaluation of the emergency response for site and general emergencies, one facility should be designated as the emergency control center (ECC). Because this area would be the hub of activity in an emergency, its location and design should be considered carefully. The ECC should have a low probability of being affected by an accident. If a postulated accident would result in high radiation levels in the ECC, its location should be changed.

Space is a primary requirement of the ECC. Adequate space must be allotted for each activity or group involved in the emergency response. Consideration must be given not only to the number of persons involved, but also to the space needed for chairs, tables, and monitoring and communications equipment. The assignment of space to groups is also important; groups that work together should not be on opposite sides of the room or across the hall from each other.

The onsite and offsite communications system in the ECC is another primary consideration. The system should be operational within 15 minutes after the activation of the ECC. The director of each emergency response organization must have at least one dedicated communications link between the organization and the ECC. The emergency director should have several open lines available for use.

The facility that is set aside as the ECC should be reserved for emergency use only. The emergency supplies kept there should be periodically inventoried and replenished as needed. Items that should be available in the ECC (depending on the scope of the postulated accidents) include:

1. the documented emergency plans, procedures, and checklists for the site
2. state and local emergency plans and procedures
3. emergency power
4. survey meters
5. air samplers
6. sample-counting equipment (unless adequate provisions are available for counting samples offsite)

7. personnel dosimeters for all the occupants
8. calibration sources
9. site and area maps marked with preselected monitoring points, locations of thermoluminescence dosimeters (TLDs), and environmental air sampling stations (useful maps are the U.S. Geological Survey 7-1/2-minute maps, which cover the plume exposure EPZ and are marked with cardinal polar coordinates and 22-1/2-degree sectors, with the first section splitting true north)
10. a board for posting emergency assignments and team designations
11. a board for posting up-to-date meteorological conditions and estimated doses at given distances from the release
12. as-built facility and building layouts
13. first aid kit and decontamination supplies
14. clock
15. writing materials and note pads
16. protective clothing
17. dose assessment equipment such as calculators
18. basic reference material
19. communications equipment (telephone, radio, etc.).

B. Medical Treatment Facility. Provisions must be made for either the installation's health personnel or a local hospital to care for contaminated individuals who are injured in an emergency. Information may be found in AR 40-13. Briefly, the following needs should be considered when a center for handling contaminated patients is being designed and equipped:

1. easy and immediate access
2. stretchers
3. first aid equipment and supplies
4. communication link
5. medical personnel trained in the handling of contaminated patients

6. operable, calibrated instruments for surveying contaminated patients
7. documented procedures for decontaminating patients
8. source of water and suitable decontaminants
9. provisions for the collection and disposal of solid and liquid waste.

C. Assembly Areas. Assembly areas where personnel gather when an alert is sounded should be able to accommodate the assigned number of persons. Consideration should be given to the adequcy of shielding, ventilation, rest rooms, communications equipment, and portable lighting for these areas.

D. Communications Equipment. Many types of communications equipment can be used during an emergency, including alarms, pageboy call systems, walkie-talkies, telephones, and two-way radios. The operation of each piece of equipment should be checked regularly and personnel should be trained to use the equipment.

Each communications link should have a back-up and an alternate power source. In addition, at least one communications system should provide uninterrupted service during a power failure.

Areas or groups that should be equipped with a communications system include:

1. the ECC, the emergency director, and directors of emergency response organizations
2. assembly areas and medical facilities
3. onsite monitoring teams
4. offsite monitoring teams
5. security personnel
6. the public (if applicable to postulated accidents).

The range of communications equipment used by monitoring teams and security personnel must be known. If the offsite monitoring team uses a two-way radio to communicate with the ECC, the radio must be able to transmit over the required distance.

In a general emergency, a communications system must be available to warn the affected public. Sirens mounted on telephone poles, or the local fire or police station, can serve this purpose. The public must know what action to take when alarms sound.

E. Monitoring Equipment. Onsite and offsite radiation-monitoring equipment must be capable of measuring the types and levels of radiation expected during a postulated accident and must be calibrated in the postulated accident range, using a source traceable to the National Bureau of Standards (see Chapter 2). For this reason, it is suggested that a number of portable instruments be dedicated to emergency response situations. These instruments should be checked routinely for operability and should be calibrated annually.

Many factors affect the choice of fixed and portable instruments for emergency response. The instruments must be capable of responding in extreme environmental conditions, such as high or low temperatures or humidity. Because many instruments do not operate in temperatures below -10°F, the manufacturer's performance specifications (which indicate the range of operability of an instrument) should be checked, and the instruments should be tested in the field during extreme weather conditions.

The accessibility of fixed instrumentation during postulated accidents should be assessed. If valuable data would be lost due to inaccessibility, remote readouts should be considered. A power failure may also render an instrument or its data inaccessible. If a particular instrument's data is necessary for accurately assessing the impact of an accident, provision should be made so that it will continue to function during a power failure.

Fixed air monitors can warn of airborne radiological hazards if they are designed to trip an alarm that will be heard or seen by site personnel. Therefore, these alarms should be placed at manned locations.

Records should be kept for each instrument that will be used in an emergency, documenting the type of radiation the instrument is designed to measure and the maximum and minimum radiation levels it can detect. The dates of and data from operational checks and calibrations should also be documented. A label indicating the date of the latest operational check and calibration and any conversion factors to be used in data interpretation should be placed on

each instrument. The storage location of all portable instruments and supplies for emergency response should be documented in the emergency procedures.

Kits used for onsite measurement and monitoring of radiation should be easily accessible for determining the initial accident conditions. The kits should contain a high-range dose rate meter, a contamination monitor, portable sampling devices, and light protective clothing. Electronic equipment should be tested periodically for operability, and the contents of the kit should be inventoried routinely. A breakable seal should be placed on each kit immediately after inventory so that any intrusion into the kit can be detected. An inventory should be taken promptly upon the discovery of a broken seal. A sample listing of emergency kit equipment is provided in Appendix C.

F. Aerial Monitoring. When an effluent release (the plume pathway) is being tracked, unfavorable meteorological conditions or the passage of the plume over inaccessible areas may hinder an accurate determination of the plume's location. In such cases, aerial surveillance using helicopters or fixed light-wing aircraft can contribute valuable information by providing survey data over a large area. Helicopters are best suited for emergency radiation surveys because of their maneuverability and slower flying speeds. A two-man crew (the pilot and someone to operate the radiation detection equipment) would generally be needed for such aircraft.

G. Dosimeters. Dosimeters that are designated for use only in emergencies should be available for each member of the emergency response team. These dosimeters must be capable of responding to the types and levels of radiation that would be present during postulated accidents. Pocket ionization chambers should be worn and checked frequently, especially by onsite and offsite monitoring teams. Each member of the emergency response organization should be assigned a film badge or TLD or both to record the dose received during the emergency.

H. Transportation Modes. Vehicles must be available to transport injured persons to either an onsite or an offsite medical facility. If an ambulance from a nearby hospital will be used, prior arrangements must be made for immediate service. Monitoring teams need vehicles for their exclusive use that can

carry monitoring equipment and emergency kits and handle any environmental or road conditions that may be encountered.

11.1.9 Offsite Agreements and Support

Offsite support can be invaluable in accident situations. Personnel at an installation cannot always perform all the tasks needed to respond to an emergency. Areas in which offsite support may be needed are fire fighting, health physics, security, and medical aid.

Advance agreements should be made with support organizations for their assistance. The agreements should specify the support to be provided and the conditions under which that support will be used.

11.1.10 Re-Entry and Recovery

During the period between the end of an emergency and restart of operations affected by the accident, imminent danger is not expected but the potential for higher-than-normal exposures may exist. The emergency plan should provide guidance on keeping these exposures to a minimum and ensuring that no recovery actions would place the installation back in an emergency situation.

Evacuated buildings must be re-entered with caution and only after a complete hazard assessment has been made and the emergency director has authorized re-entry. The only exceptions to these conditions may be for firefighting and search-and-rescue teams, whose activities must be supervised by the health physics staff.

The following topics relating to re-entry and recovery should be addressed in the emergency plan:

1. the conditions (e.g., exposure rates, radionuclide concentrations) under which rooms or buildings may be re-entered prior to their return to normal operation
2. the identification of personnel to direct re-entry and recovery
3. the assurance of proper communications to keep site personnel, response organizations, and DA and NRC personnel informed of progress in re-entry and recovery.

Section 11.2 MAINTAINING A STATE OF EMERGENCY PREPAREDNESS

Maintaining a state of emergency preparedness requires the effort of every individual within the installation. Each person needs to understand his or her responsibility and how it helps ensure the safety of the installation and its occupants. Emergency telephone numbers should be posted next to telephones, and diagrams of evacuation routes and lists of emergency signals with their meanings should be posted on bulletin boards or in hallways. Maintaining emergency preparedness includes:

1. training and retraining staff and emergency response personnel
2. conducting emergency drills
3. maintaining and inventorying emergency equipment, instruments, and supplies
4. reviewing and updating plans and procedures.

11.2.1 Training Staff and Emergency Response Personnel

All staff members and emergency response personnel must be familiar with the radiological emergency plan if it is to be effective. They should receive training in:

1. safety and accident control features specific to the facility to which they are assigned
2. the emergency signals (sirens, alarms), their meaning, and the expected response
3. the location of emergency assembly areas
4. the building layout, including emergency exits and evacuation routes
5. notification procedures and immediate actions if they discover or are involved in a radiation accident.

Personnel assigned emergency response duties require additional training in the proper execution of their duties. A representative list of persons or groups requiring this specialized training includes:

1. directors and coordinators of the plant emergency organization (see Table 11.3)
2. personnel responsible for radiological assessment
3. radiation-monitoring and survey teams
4. radiation protection personnel
5. maintenance teams
6. security personnel
7. search-and-rescue teams
8. firefighting squads
9. medical personnel
10. communications personnel
11. staff of state and local agencies and offsite support teams (if applicable).

Formal lesson plans should be drawn up for each training session, and the training program for each group should be documented. Each training program should give personnel an understanding of the emergency response plan and the role that each group plays in its implementation. The specific duties of each group and how these duties are to be performed (e.g., how to use equipment, whom to notify when, and how to treat a contaminated wound) should be included. Special precautions to observe in the performance of radiological emergency duties should also be included in the training program (see Appendix D). Whenever possible, practical hands-on operation of equipment and facilities should be included in the training program.

The quality of training depends to a large extent upon the quality of the instructors. A good instructor is professionally competent and has good communication skills. The instructor must also be thoroughly familiar with the emergency plan and each person's role in it. An effective training program may require the combined efforts of several individuals or organizations.

Retraining is important in maintaining a state of emergency preparedness. Because emergency duties are seldom performed, they are easy to forget. Formal training sessions should be held at least once a year.

Provision must be made for evaluating the ability of individuals to perform their emergency duties. The conditions, tasks, and standards of performance that form the basis for this evaluation should be documented. Attendance records and test scores from training sessions should also be documented.

11.2.2 Training Members of the News Media

When emergency planning includes offsite locations, training should be offered to individuals from the local news media. Newspersons should be trained in basic radiation protection practices and associated terminology. During an accident, one location should be designated as the media center, and all newspersons should be directed to that area upon arrival at the installation. The public relations spokesperson from the installation should be responsible for providing the media with up-to-date information, to help avoid conflicting stories and general confusion among the reporters and to help maintain credibility with the public.

11.2.3 Conducting Emergency Drills

Emergency plans should be tested annually through the use of emergency drills (AR 385-11). Drills jog memories, lead to the application of skills learned in training sessions, and keep interest in emergency response duties high. Drills also allow problem areas to be identified and corrected under controlled rather than accident conditions. In a full-scale drill, all onsite and offsite participants respond to a simulated severe accident. Smaller-scale drills involving specific response organizations should be held every 6 months.

11.2.4 Maintaining and Inventorying Emergency Equipment

To maintain a state of emergency preparedness, a schedule for maintaining equipment and supplies should be developed and followed. The inventory of kits and supplies should be checked periodically for completeness. This check should include operating and calibrating all instruments. The maintenance procedures should specify the corrective actions to be taken promptly when deficiencies are found during these checks.

11.2.5 Reviewing and Updating Plans and Procedures

When conditions change within an installation, emergency plans and procedures may need to be changed to meet the new conditions. The extent of the updating needed may range from changing a name on a call list to reassessing potential accidents if a new radiological function is defined. To ensure the adequacy and effectiveness of emergency preparedness, provisions should be made for a periodic review and update of the radiological emergency plan. A full-scale review should be conducted annually by a committee designated for this purpose in the emergency plan. This committee would ensure that:

1. the emergency plan and procedures are current
2. training sessions and drills have been conducted on schedule, test scores and drill deficiencies have been documented, and corrective actions have been taken
3. the emergency plan addresses the postulated accidents.

An individual or a committee should also be assigned to make necessary changes in call lists or equipment inventories as they occur. The name of the person or persons responsible for such changes should be documented in the emergency plan.

Section 11.3 NOTIFICATION AND REPORTING REQUIREMENTS

The DA criteria for defining radiation accidents are based on individual exposures, effluent releases, damage to property, and loss or theft of radioactive material and are given in Table 11.5. Both Army personnel and civilian licensing agencies must be notified when accidents that meet these criteria occur. Tables 11.6 and 11.7 list how soon notification is required for different accident levels, as set forth by DA (AR 385-40), NRC (10 CFR 20), and the Department of Transportation (DOT) (49 CFR 171). Other requirements for notification and for investigations and reports are given below for the three groups.

TABLE 11.5. DA Criteria for Defining Radiation Accidents (AR 385-40)

Type of Accident	Criteria
Individual Exposure	1. External exposure: Exposure greater than limits in 10 CFR 20 2. Internal exposure: Airborne concentrations in a restricted area, or ^{234}U, ^{235}U, ^{238}U concentrations greater than limits in 10 CFR 20, Appendix B, Table 1, Column 1 3. Fatality, lost-time injury, restricted-duty work
Effluent Releases	Greater than 500 times the limits in 10 CFR 20, Appendix B, Table II (averaged over 24 hours)
Damage to Property	1. Cost is $300.00 or more 2. Loss of facility operation for 1 day or more
Loss or Theft of Radioactive Material	Quantity that may result in substantial hazard to personnel in unrestricted areas

TABLE 11.6. NRC AND DA Notification Requirements for Accidents Involving Licensed Materials[a]

Notification	Individual Exposure	Release	Damage to Property
Immediate	Whole body (head, trunk, active blood-forming organs, lens of eye, gonads) ≥25 rem Skin ≥150 rem Extremities ≥375 rem	>5000 x amount listed in 10 CFR 20, Appendix B, Table II, averaged over 24 hours	>$200,000 Loss of ≥1 week of facility operation
Within 24 hours	Whole body (head, trunk, active blood-forming organs, lens of eye, gonads) ≥5 rem Skin ≥30 rem Extremities ≥75 rem	>500 x amount listed in 10 CFR 20, Appendix B, Table II, averaged over 24 hours	>$2,000 Loss of ≥1 day of facility operation

(a) Excerpted from 10 CFR 20 and AR 385-40.

TABLE 11.7. DOT and DA Notification Requirements for Accidents Involving Army Motor Vehicles Carrying Licensed Materials(a)

Notification	Individual Exposure	Damage to Property
As soon as practicable	Any event that presents a hazard to personnel at the site	>$50,000
	Fatality or lost-time injury	Fire, breakage, slippage, or suspected radioactive contamination

(a) Excerpted from 49 CFR 171 and AR 385-40.

11.3.1 Notification and Reporting Requirements: Army

The criteria indicating what constitutes radiation accidents are further subdivided into four DA classifications based on the degree of damage caused by the accident. These four general classifications are used for all Army accidents except aircraft mishaps.

1. Class A accident
   a. property damage, injury, or occupational illness costing $200,000 or more
   b. fatality as result of Army operations
   c. fatal injury of off-duty Army military personnel.
2. Class B accident
   a. property damage, injury, or occupational illness costing between $50,000 and $200,000.
3. Class C accident
   a. property damage costing between $300 and $50,000
   b. loss of one or more workdays due to injury or occupational illness.
4. Class D accident
   a. property damage less than $300
   b. one or more days of restricted work activity due to injury or occupational illness
   c. nonfatal case without loss of workdays.

Although immediate emergency actions and notification do not depend on these classifications, recording, reporting, and investigation requirements do.

In addition to the accident criteria for individual exposures specified in Table 11.5 and those described by Classes A, B, C, and D above, AR 40-14 defines three types of radiation overexposures to individuals. These classes are summarized in Table 11.8, and the reporting requirements are specified in Section B below.

A. Notification. The following Army personnel must be notified by telephone or electrical means immediately or within 24 hours of an accident (see Table 11.6) (this notification applies to Type III individual overexposures in Table 11.8):

1. the affected major Army commander or his representative
2. the licensee

TABLE 11.8. DA Criteria for Individual Radiation Overexposures (AR 40-14)

Body Part	Type I Overexposure	Type II Overexposure	Type III Overexposure
Whole body, head and trunk, active blood-forming organs, gonads, lens of eye	>400 mrem/mo[a] but <1.25 mrem/qtr	(b)	>5 rem/yr or >1.25 rem/qtr
Skin of whole body, forearms, cornea of eye	>3 rem/mo but <7.5 rem/qtr	(b)	>30 rem/yr or >7.5 rem/qtr
Hands and wrists, feet and ankles	>6 rem/mo but <18.75 rem/qtr	(b)	>75 rem/yr or >18.75 rem/qtr
Other organs (bone, thyroid, tissue, organ systems)	>1 rem/mo but <5 rem/qtr	(b)	>15 rem/yr or >5 rem/qtr

(a) mo = calendar month; qtr = calendar quarter; yr = calendar year.
(b) Dose rate exceeds the quarterly rate for a Type I overexposure but is less than the annual rate for a Type III overexposure.

3. HDQA (DAPE-HRS), AUTOVON 225-7291; DASG-PSP, AUTOVON 227-2796

4. HQ DARCOM (DRCSF-P), AUTOVON 284-9340

5. the Chief of Engineers (DAEN-FEZ-N), AUTOVON 354-5501, if the accident occurs at a reactor facility.

B. Reports and Investigations. The initial report must contain the following information:

"This is a Radiological Accident Report, RCS:DD-SD(AR)1168."

1. the date of the event

2. the radiation-producing device or source involved, including its national stock number, nomenclature, and radiation characteristics and parameters

3. a description of the event, including the cause, the name and social security number of each person exposed, estimated exposures and dose rates, contamination levels, facilities affected, and actions taken

4. any action taken to prevent a recurrence

5. recommendations on how to avoid similar accidents at other installations possessing similar material

6. a specific contact (name, address, telephone number)

7. a statement of when appropriate DA, NRC, and DOT offices were notified.

Class A, B, and C accidents must be documented and a report (DA Form 285) must be submitted to the U.S. Army Safety Center in Fort Rucker, Alabama, within 30 days of the accident. All Class A accidents require a formal board of investigation. This board is appointed by the commander to whom the radioactive materials license has been issued. Class B and C accidents are investigated by the local commander. Reports of these investigations should be forwarded through channels to HQDA (DAPE-HRS, DASG-PSP), Washington, DC 20310 and to Commander, DARCOM (DRCSF-P), 5001 Eisenhower Avenue, Alexandria, VA 22333, within 90 days of the accident. The requirements of the Privacy Act of 1974 must be taken into account whenever an individual is identified.

An informal investigation of Type I individual overexposures (see Table 11.8) is conducted by the immediate commander. The commander must

conduct a formal investigation of Type II and Type III overexposures and forward a report of the investigation and of the corrective actions through command channels to HQDA (DASG-PSP), Washington, DC 20310.

The investigation of a radiation accident can establish its cause and identify corrective and protective actions that will prevent the recurrence of the accident. The investigating individual or group should:

1. collect and preserve evidence
2. interview witnesses
3. prepare diagrams of the accident scene
4. re-enact the accident if appropriate.

When trying to establish the cause of an accident, the investigator(s) should consider possible defects in a component's basic design or construction. If a component is faulty, it should be identified in the investigative report by name, model number, manufacturer, and name-plate data. Other possible causes of an accident that should be considered are human error or misjudgment, incomplete or incorrect procedures, or the absence of procedures.

11.3.2 Notification and Reporting Requirements: NRC

Either NRC or an agreement state[(a)] licenses Army installations to use radioactive materials.

A. Notification. If the license is from NRC, the director of the appropriate NRC Inspection and Enforcement Regional Office (see 10 CFR 20, Appendix D) must be notified of an accident. If the license is from an agreement state, the director of the branch of state government issuing the license must be notified. Notification time shall be as described in Table 11.6.

B. Reports. A formal written report must be sent within 30 days of any accident to the appropriate NRC regional office listed in 10 CFR 20, Appendix B. A copy of this report should be submitted to the Director of Inspection and Enforcement, USNRC, Washington, DC 10555.

(a) An agreement state is any state with which NRC has entered into an effective agreement under Section 274 b. of the Atomic Energy Act of 1954, as amended (73 Stat. 689).

Reports of theft or loss of licensed material or of individual overexposures (Type III) should include the following:

1. a description of the licensed material involved, including the kind, quantity, and chemical and physical form
2. a description of the circumstances under which the loss, theft, or overexposure occurred
3. a statement of the disposition or probable disposition of the licensed material involved
4. quantitative radiation exposures to individuals and the extent of possible hazard to persons in unrestricted areas
5. actions that have been or will be taken to recover lost or stolen material
6. procedures or measures that have been or will be adopted to prevent a recurrence of the loss, theft, or overexposure.

After filing the written report, the licensee shall also report any substantive additional information on the accident within 30 days after the licensee learns of such information.

In reports filed with NRC, the names of individuals who may have been exposed to radiation shall be stated in a separate part of the report, including for each individual exposed the person's name, social security number, and date of birth, and an estimate of the individual's exposure. The requirements of the Privacy Act must be taken into account whenever an individual is identified.

11.3.3 Notification and Reporting Requirements: DOT

Each carrier must notify DOT at the earliest practicable moment after a transportation accident specified in Table 11.7. Notification should be given by telephone ((800)442-8802) and should include the following information:

1. the name and phone number of the individual reporting the accident
2. the name and address of the carrier represented by the individual reporting the accident

3. the date, time, location, and nature of the accident

4 the classification, name, and quantity of radioactive materials involved

5. the extent of injuries, if any, and whether a continuing danger to life exists at the accident scene.

A written report must be submitted to DOT in duplicate within 15 days of the accident.

REFERENCES

Brodsky, A. 1980. "Determining Industrial Hygiene Requirements for Installations Using Radioactive Materials." Health Phys. 38:1155-1171.

International Commission on Radiological Protection (ICRP). 1978. The Principles and General Procedures for Handling Emergency and Accidental Exposures of Workers. ICRP 28, Pergamon Press, Oxford.

Privacy Act, 1974. U.S. Code, Title 5, Section 552a.

U.S. Code of Federal Regulations. 1982. Title 10, Part 20, "Standards for Protection Against Radiation." U.S. Government Printing Office, Washington, D.C.

U.S. Code of Federal Regulations. 1982. Title 10, Part 30, "Rules of General Applicability to Domestic Licensing of Byproduct Material." U.S. Government Printing Office, Washington, D.C.

U.S. Code of Federal Regulations. 1980. Title 49, Part 171, "Hazardous Materials Regulations - General Information, Regulations and Definitions." U.S. Government Printing Office, Washington, D.C.

U.S. Department of the Army, Headquarters. Medical Support - Nuclear/Chemical Accidents and Incidents. AR 40-13, Washington, D.C.

U.S. Department of the Army, Headquarters. Safety - Accident Reporting and Records. AR 385-40, Washington, D.C.

U. S. Department of the Army, Headquarters. Safety - Ionizing Radiation Protection (Licensing, Control, Transportation, Disposal, and Radiation Safety). AR 385-11, Washington, D.C.

U.S. Department of the Army, Headquarters, Army Materiel Command. DARCOM Disaster Control Plans, Annex E, "Radiological Accident/Incident Control."

U.S. Department of the Army and Defense Logistics Agency. Medical Services - Control and Recording Procedures for Exposure to Ionizing Radiation and Radioactive Materials. AR 40-14, DLAR 1000.28, Washington, D.C.

U.S. Nuclear Regulatory Commission and Federal Emergency Management Agency. 1980. Criteria for Preparation and Evaluation of Radiological Emergency Response Plans. NUREG-0654, FEMA-REP-1, U.S. Government Printing Office, Washington, D.C.

APPENDIX A

EXAMPLES OF CHECKLISTS

A.1 EMERGENCY PLAN CHECKLIST

Emergency Planning

___ Has one person or organization been assigned the responsibility for emergency planning?

___ Does this person or organization possess the authority to accomplish the task?

___ Have the maximum credible accident and several of the most probable accidents been determined?

Emergency Classification

___ Is the emergency classification system consistent with potential hazards at the installation?

___ Have the existing or imminent conditions for each class been defined?

___ Are definitions of radiation range continuous but distinct for each class (no gaps or overlap in definitions)?

Emergency Organizations

___ Have all emergency response organizations been identified?

___ Has each organization been assigned its emergency responsibilities?

___ Has each key person within the organizations been assigned a responsibility?

___ Have enough people been assigned responsibilities so that the emergency plan can be carried out completely and efficiently?

___ Do all individuals have sufficient training to carry out their responsibilities?

Emergency Facility and Equipment Identification

___ Are all emergency response facilities identified and fully described?

___ Have all emergency response resources and equipment been identified?

___ Have all onsite and nearsite impediments to the response been identified, along with realistic suggestions on ways to minimize their effects?

Emergency Plan Implementation

___ Do procedures exist for implementing the emergency plan?

___ Are personnel assignments and methods of implementation clear?

___ Do implementing procedures ensure that all organizations are manned at the "alert" stage?

___ Do procedures ensure that all support organizations will be notified promptly of emergency situations?

___ Are emergency action levels defined?

Emergency Response

___ Are all response procedures functional and easy to understand?

___ Is the installation capable of assessing all possible radiological conditions that may exist onsite and offsite as a result of its operations?

___ Have corrective actions to mitigate an accident been identified?

___ Are recommendations for protective action established?

___ Are they consistent with the recommendations of offsite agencies?

Emergency Facilities and Equipment

___ Have all emergency response facilities and areas been described in the plan?

___ Is the ECC expected to be habitable through most accident situations?

___ Have all tools, assessment equipment, protective equipment, and other support equipment used in emergency response been described in the plan or in a procedure referenced in the plan?

Agreements with Offsite Support Groups

___ Have all necessary agreements been made for offsite support and cooperation?

___ Are the agreements specific and the agencies reliable?

Re-entry and Recovery

___ Is re-entry of evacuated buildings controlled?

___ Have radiological conditions been established under which buildings may be re-entered for return to unrestricted use?

___ Are key positions in the recovery organization identified and have the responsibilities associated with those positions been assigned?

___ Is a communications system in place?

A.2 MINOR SPILL CHECKLIST

In the event of a minor spill of radioactive materials, the following checklist should be used.

Immediate Actions

___ Alert everyone in the immediate vicinity of the spill.

___ Have everyone leave the room and assemble in a nearby area such as a hallway. Allow no one to leave the area without a radiation survey. If the spilled material is highly toxic, evacuate the building to an assembly area. No re-entry should be attempted without health physics supervision.

___ Call for health physics assistance.

___ If the material does not present a hazard through toxicity or high dose rates, attempt to stop the leak and contain the contaminant with absorbent pads or other barriers. Try to minimize personnel contamination and exposure.

___ If large quantities of gaseous or highly volatile materials have been released, promptly shut down all heating, ventilation, and air conditioning operations to prevent the material from spreading.

___ Seal off the area with signs, rope, or locked doors until health physics assistance arrives.

Recovery of the Spill Area

___ Have health physics personnel supervise all recovery and re-entry activities.

___ Ensure that all persons involved in the accident or in recovery procedures are surveyed and decontaminated, if necessary, before release.

___ Try to determine the types and quantities of radioisotopes involved so that appropriate protection is used upon re-entry.

___ Establish a step-off pad at the entrance to the affected rooms.

___ Enter the room with appropriate protective clothing and devices, including dosimeters. Ensure that release of the material is halted and that cleanup can be performed without personnel receiving unacceptable doses (evaluate the radiological hazards).

___ Decontaminate the area, being careful not to spread contamination over an area larger than necessary.

___ Collect contaminated waste in plastic bags as it is generated, for later disposal.

___ Make a final survey of the room before it is released for use.

___ Have dosimeters processed promptly.

APPENDIX B

RESPONSE ACTIONS

B.1 EXPOSURES TO INDIVIDUALS

The magnitude of abnormal radiation exposures is not always apparent immediately following an accident. Radiation protection, medical, and administrative decisions will be based on a combination of all available data. However, the immediate care of an injured individual is of prime importance. Initially, any severe physical injuries (e.g., burns, cuts, or trauma) are likely to be more important than possible radiation injuries. Therefore, the extent of the injuries and the mobility of the patient should be assessed immediately, and first aid and lifesaving actions should be performed. Specific actions to be taken if contamination of a wound or the skin accompanies the physical injury are discussed below. (See also Chapt 7.)

In order to identify the response actions appropriate for individual radiation exposures, it is useful to define three categories: external exposure, internal contamination, and external contamination.

External Exposure

The level of action needed to respond to an external exposure depends on the magnitude of the dose received. The individual should be removed from the work environment and an accurate assessment of exposure should be made. Action and investigation levels are defined in AR 40-14. A summary of response actions to various doses received by an individual is outlined in Table 11.9, based on Publication 28 of the International Commission on Radiological Protection (1978).

An accurate dose estimation becomes more important as the dose gets higher and can be accomplished through a combination of clinical, biological, biochemical, and physical assessments of the exposed individual. The information provided by personal dosimeters, reconstruction of the event, and identification of radiation fields can be used to assess the dose. In the case of exposure to neutrons, activation products in or on the body (e.g., in the

TABLE 11.9 Summary of Response Actions for Individual External Exposure

Dose	Response Actions
5-10 rem	Administrative actions, investigation
	Physical dose measurements
10-25 rem	More detailed administrative investigation
	Assessment of possible biological consequences
	Physician brought in to assess the need for and the extent and nature of clinical, biological, or biochemical examinations
>25 rem	Same as above, plus an examination by the physician

blood, on the hair, or on metal objects such as coins or watch bands) can also aid in this assessment. Observable clinical symptoms such as nausea and vomiting would appear in approximately 10% of individuals exposed to 75 to 125 rem.

Priorities for treatment, and response actions for individuals subjected to whole-body exposures, are given in Table 11.10.

Internal Contamination

If an intake is suspected, first aid should be given immediately, the nature and degree of contamination should be determined, and therapy procedures should be started under the direction of a physician.

The initial indications for therapy include the first dose assessment and the results of nose blows and of monitoring for skin contamination, contaminated wounds, and, if appropriate, air and surface contamination. Examples of types of therapy to consider are: 1) isotopic dilution of an ingested radioactive substance by the administration of a stable isotope (e.g., administration of stable iodine, as sodium iodide or potassium iodide, to reduce the deposition of radioiodine in the thyroid gland); 2) acceleration of excretion through the administration of a laxative to minimize gastrointestional absorption; and 3) administration of irritants or expectorants to minimize respiratory absorption. Actions to be taken following a suspected internal contamination are presented in Table 11.11.

TABLE 11.10. Actions to be Taken Within Six Hours Following a Whole-Body Exposure

Medical Management

Administer lifesaving treatment
Check for external contamination
Remove clothing and wash contaminated areas
Give mild sedative for nausea and vomiting

Clinical Observation

Collect dosimetric data
Interrogate patient about accident and relay information to dosimetry team
Make tentative prognosis based on above findings

Biological Investigations

Take and keep urine samples
Take blood samples for immediate cell counts, biochemical analysis, lymphocyte culture, and chromosomal analysis

Dosimetric Studies

Process all personal dosimeters from exposed individual and bystanders
Check installed recording equipment in vicinity of accident
If neutron exposure is suspected, measure induced activity using coins the exposed person was carrying
Make first assessment of likely type, quantity, and distribution of radiation, and inform physician
Interrogate bystanders

Administrative Actions

Perform detailed inquiry into the circumstances of the accident

---

(a) Excerpted from ICRP 28.

TABLE 11.11. Actions to be Taken Following Suspected Internal Contamination

Medical Management

Preliminary therapy (under the direction of a physician)
- isotopic dilution
- expectorants
- laxatives
- chelating agents

Biological Investigations

Take swabs from the nose or mouth
Perform whole-body count
Collect urine and fecal samples
Take blood sample

Dosimetric Studies

Confirm intake
Check installed air monitors
Make direct measurements using an external or wound probe and an organ scanner
Perform radiochemical assay of urine, fecal, and blood samples

Administrative Actions

Perform detailed inquiry into the circumstances of the accident

External Contamination

External contamination can involve both an external dose and internal contamination. First aid (including decontamination procedures) should be given immediately, and the dose received and the extent of contamination should be assessed promptly.

The individual should be decontaminated as effectively as possible before being taken to the hospital. Chapter 7 describes personnel decontamination procedures in detail. A few simple procedures are mentioned here. Skin areas are decontaminated by washing them with soap and large amounts of water. The contaminated individual can often do this. Measurements of residual contamination should be taken after each washing. However, this treatment should cease before skin abrasions appear. The eyes, nose, and mouth can be decontaminated by flushing them with large quantities of water. Contaminated wounds should immediately be washed with large quantities of water, and bleeding should be encouraged. The use of a chelating agent is recommended. All of the procedures except for the washing of skin areas require the supervision of medical personnel (see Chap. 7).

B.2 TRANSPORTATION ACCIDENTS

Accidents that occur during the shipping of radioactive materials may require the involvement of state and local authorities, and/or the DOT. Appropriate responses to the accident include the following actions:

1. Administer first aid to seriously injured persons and summon a rescue squad.
2. Confine contamination to the local area; an exclusion area may be established.
3. Locate people along the shipping route who may have been exposed or contaminated.

Federal interagency radiological assistance can be obtained by calling the Joint Nuclear Accident Coordinating Center at Kirtland Air Force Base (Commercial (505)264-8279 or AUTOVON 964-8279).

The nearest Army facility may also be called upon for assistance. Table 4-1 of AR 385-11 lists Army addresses and emergency telephone numbers.

APPENDIX C

EXAMPLE LISTING OF EMERGENCY KIT EQUIPMENT

Date checked _____

Checked by _____

Items	Quantity	Box 1	Box 2
Protective clothing			
Coveralls			
Neoprene gloves			
Disposable gloves			
Head covers			
Shoe covers			
Goggles			
Respirators			
Respirator cartridges			
Chemical			
Particulate			
Masking tape			
Posting equipment			
Radiation rope			
Radiation signs			
Radiation labels			
Radiation tape			
Masking tape			
Twine			

EXAMPLE

Items	Quantity	Box 1	Box 2
Tools			
Scissors			
Tongs (46 cm)			
Extension cord			
Channel-lock pliers			
Screwdriver			
Radar light			
Knife			
Surveying and sampling supplies			
Cotton swabs			
Disposable bottles			
Large plastic bottles			
Scintillation vials			
Air-sampling filters			
Air-sampling cartridges			
Smears and smear holders			
Tweezers			
Plastic bags			
Large			
Small			
Decontamination aids			
Detergent			
Cleanser			
Gauze pads			

EXAMPLE

Items	Quantity	Box 1	Box 2
Miscellaneous			
Adhesive tape			
Pencils			
Notepads			
Butcher paper			
Stopwatch			
Extra batteries			
Readily Available Equipment			
Survey meters			
Ionization chamber			
Geiger-Mueller counter			
Air samplers			
Alpha detector			
Fast- and slow-neutron meters			
High-range pocket dosimeters			
Spare film badges			
Small fire extinguisher			
Portable power source			
First aid kit			

EXAMPLE

APPENDIX D

EXAMPLES OF EMERGENCY ACTIONS

D.1 AMBULANCE OR RESCUE SQUAD PERSONNEL

Guidelines for handling patients contaminated with radioactive materials:

1. Give lifesaving emergency assistance if needed.(a)
2. If a health physicist is immediately available, have him or her ride with the patient in the transport vehicle.
3. Cover the stretcher and pillow with an open blanket; wrap the patient in the blanket to limit the spread of contamination.
4. Call the appropriate hospital by radio or telephone and provide available information.
5. Save all materials suspected of being radioactively contaminated in plastic bags or containers labelled with patient's name, date, and time.
6. Ensure that rescue squad personnel and equipment are monitored upon arrival at the hospital.

D.2 HOSPITAL EMERGENCY ROOM PERSONNEL

Upon notification of the imminent arrival of a contaminated patient, the following actions should be taken:

1. Notify responsible staff physician, hospital administrator, and health physicist.

(a) Note Medical treatment takes precedence over personnel decontamination and/or contamination control.

2. Take precautions to prevent the spread of contamination:
   a. Prepare a separate space, using an isolation room or cubicle if available.
   b. Cover the floor with absorbent paper.
   c. Mark and close off the area.
   d. Prepare to shut off air circulation system, if dust is involved.
3. Obtain appropriate survey meter.
4. Put on protective clothing.

Upon arrival of the patient:

1. If patient is seriously injured, give emergency lifesaving assistance immediately.
2. Have health physicist check patient for contamination using survey meter. Record patient's name, date, time, location and extent of contamination, and radiation measurements.
3. If external contamination is involved, save all clothing and bedding from ambulance, all metal objects (jewelry, belt buckles), and all blood, urine, stool, and vomitus, and label with patient's name, date, and time. Store in plastic bags or containers marked "Radioactive - Do Not Discard."
4. Begin decontamination procedures (if patient's medical status permits) by cleansing and scrubbing the area of highest contamination first, using soap and warm water; showering may be necessary. Resurvey and record measurement after each washing or showering. If a wound is involved, use self-adhering disposable surgical drape to cover it, then cleanse neighboring skin surfaces and seal with surgical drape. Remove the wound covering and irrigate the wound with sterile water, catching the water in a basin marked "Radioactive - Do Not Discard."
5. Save physicians', nurses', and attendants' scrub or protective clothing. Follow monitoring and decontamination procedures.

D.3 FIREMEN

Special precautions must be taken in fignting a fire involving radioactive materials:

1. Identify and isolate the hazard.
2. Contact a health physicist for guidance and assistance.
3. Stay upwind from the fire.
4. Wear self-contained breathing apparatus and full protective clothing.
5. Limit time spent in hazard area to shortest possible time.
6. Avoid contact with leaking or damaged packages.
7. Fight fire from as far away as possible.
8. Move undamaged packages out of the fire zone if this can be done with no risk.

Additional information may be obtained from the National Fire Protection Association (NFPA 801-Recommended Fire Protection Practice for Facilities Handling Radioactive Materials).

CHAPTER 12. TRAINING

12.1 TRAINING FOR RADIATION WORKERS 12.3

12.1.1 Frequency of Training 12.4

12.1.2 Course Content 12.4

A. Radiation Biology and the Risk from Occupational Exposure 12.4

B. Radiation and Radioactive Material 12.4

C. Measurement and Control of Radiation Exposure and Radioactive Material 12.6

D. Radiation Protection Program 12.6

E. Emergency Preparedness 12.6

12.1.3 Use of Mockup Facilities 12.7

12.1.4 Evaluation of Trainee Performance 12.7

12.1.5 Documentation of Training 12.8

12.2 INSTRUCTION TO WOMEN OF REPRODUCTIVE CAPACITY 12.8

12.2.1 Recommended Prenatal Occupational Exposure Limit . . 12.9

12.2.2 Requirements 12.9

12.2.3 Rationale for Limit 12.10

12.3 INSTRUCTION IN THE USE OF RESPIRATORS 12.11

12.3.1 Extent of Training 12.11

12.3.2 Contents of Training Program 12.12

12.3.3 Drills 12.13

12.4 TRAINING FOR MANAGERS 12.13

12.4.1 Frequency of Training 12.13

12.4.2 Contents of Training Program 12.13

12.5 TRAINING FOR THE RADIATION PROTECTION STAFF 12.14

REFERENCES 12.14

TABLES

12.1 Appropriate Subjects for a Radiation Protection Training Program 12.5

CHAPTER 12. TRAINING

The Radiation Protection Officer (RPO) is responsible for conveying to all staff members policies and procedures relating to radiation safety. The extent and breadth of the training needed varies significantly with job requirements and responsibilities. For a clerk, a brief description of the working environment, an explanation of protective measures to be taken in case of an emergency, and an assurance of personal safety may be sufficient. For a handler of radioactive waste, extensive formal training is required.

Information on the radiation safety policy should be presented during the new staff member's orientation. At that time, a general introduction to the radiation hazards associated with the work should be given. Radiation hazards and related safety programs should be presented not as unique or special entities, but rather as part of the overall program for occupational health. Written material on these topics can be an invaluable resource for distribution to new employees.

This chapter describes the training that should be presented to radiation workers, women of reproductive capacity, users of respirators, managers, and radiation protection personnel.

Section 12.1 TRAINING FOR RADIATION WORKERS

The term "radiation worker" is synonymous with the term "occupationally exposed individual." A radiation worker is an individual whose work is performed in a radiation area or a controlled area and who might be exposed to more than 5% of the basic radiation protection standard listed in Chapter 3, Table 3.2, of this manual (see also AR 40-14) as a result of duties in these areas. Radiation worker training should be extended to all individuals who work in radiation areas or controlled areas even if they do not work directly with radioactive material. For example, fire fighters, security forces, emergency response personnel, janitors, and night guards who may need to enter a radiation or controlled area during the course of their work should receive

radiation training, as should those assigned to work full time in these areas. Required instruction for workers is detailed in 10 CFR 19.12.

12.1.1 Frequency of Training

Individuals should receive training before entering or beginning work in a radiation or controlled area. They should be retrained annually or whenever policies or procedures are changed.

12.1.2 Course Content

The training program should include the subjects listed in Table 12.1 and discussed below. The topics emphasized will vary with the needs of each individual or group being trained. Each individual's work assignment and the standing operating procedures (SOPs) covering the assignment should be carefully reviewed to determine the scope of training needed. Appropriate reference documents covering essential facts, requirements, regulations, procedures, and plant organization should be given to each individual.

A. Radiation Biology and the Risk from Occupational Exposure. Persons who work in or near radiation and controlled areas or make decisions about work in those areas should be taught enough about radiation effects to appreciate the importance of keeping exposures as low as is reasonably achievable (ALARA). These individuals should be informed of the level of radiation dose anticipated in their work area and the risk associated with such a dose level. Appropriate topics could include dose-effect relationships for internal and external radiation and the collective-dose concept of risk (individual and group) as it applies to the ALARA philosophy.

B. Radiation and Radioactive Material. Types of radiation and their characteristics should be discussed to the extent necessary to explain the nature of the material people work with. Types and forms of radioactive material should be detailed so that staff members understand proper control procedures. Sources and origins of radioactive material and radiation onsite should be identified, as should the signs and labels used to mark this material.

TABLE 12.1. Appropriate Subjects for a Radiation Protection Training Program

1. Radiation Biology and the Risk from Occupational Exposure
   a. Dose-effect relationship
      (1) External radiation
      (2) Internal radiation
   b. Collective-dose concept
      (1) Group total man-rem risk
      (2) Individual dose risk

2. Radiation and Radioactive Material
   a. Types of radiation and their characteristics
   b. Types and forms of radioactive materials
   c. Sources (origins) of radioactive materials and radiations onsite
   d. Source identification

3. Measurement and Control of Radiation Exposure and Radioactive Material
   a. Dosimetry
   b. Maximization of distance between people and radiation sources
   c. Shielding
   d. Detection and control of contamination, and decontamination
   e. Radiation measurement and survey instruments
   f. Area and air monitoring
   g. Personnel monitoring
      (1) Internal
      (2) External

4. Radiation Protection Program
   a. Radiation protection standards, guides, and limits
   b. ALARA program
   c. Responsibilities of individuals
   d. Radiation areas at the site
   e. Signs and labels
   f. Control of radiation areas
   g. Investigation and reporting of abnormal exposures
   h. Radiation surveys--purpose and methods
   i. Protective apparel
   j. Respirators and their use
   k. Rules and procedures, including standing operating procedures
   l. Professional guidance and assistance
   m. Control and removal of contamination and contaminated equipment

5. Emergency Preparedness
   a. Plant safety and accident control features
   b. Signals and alarms
   c. Evacuation routes and procedures
   d. Assembly points
   e. Communications
   f. Emergency equipment
   g. First aid and treatment of contaminated wounds

C. Measurement and Control of Radiation Exposure and Radioactive Material. Each radiation worker should be informed that radiation and radioactive materials can be measured at levels significantly below radiation protection standards and controlled by means of suitable design and procedural techniques. Radiation workers should understand the elements of radiation measurement and control well enough to participate in an effective radiation protection program consistent with the ALARA philosophy. Emphasis should be on 1) the sources of radiation, 2) contamination control, 3) the use of time, distance, and shielding to reduce doses, 4) SOPs, and 5) the proper use of dosimeters. The importance of administrative and engineered controls and the performance of work in accordance with carefully planned procedures should be stressed.

D. Radiation Protection Program. Personnel should understand the nature and scope of the radiation protection program, including pertinent portions of regulations, site rules for radiation protection, and safe operating procedures. Emphasis should be placed on the ALARA philosophy, its objectives, and its implementation within the framework of the tasks to be performed. The responsibility of the radiation protection staff in implementing ALARA goals, and the responsibilities of the individual staff member within the ALARA program, should be understood.

At the completion of the training program, radiation workers should understand that personnel outside radiation and controlled areas should not be significantly affected by activities in these areas that involve radioactive materials or radiation. The meaning and importance of posted instructions, including radiation warning signs and tags, and the importance of following instructions should also be understood.

E. Emergency Preparedness. Staff members should know the appropriate response to alarms and signals. They should be familiar with the details of emergency procedures and preparations so they will know what is expected of them and from whom they can expect guidance in an emergency. They should know the locations of emergency facilities and equipment as well as emergency escape routes and safe assembly points. Preparations for possible emergencies should be emphasized; such emergencies should include accidents involving

severe personal contamination, contaminated wounds, and localized fires in radiation and controlled areas.

12.1.3 Use of Mockup Facilities

The use of equipment or facility mockups allows individuals to practice procedures in a realistic setting before they perform the procedures using radioactive materials or enter areas where a potential for exposure to radioactive contamination exists. This type of training is especially valuable for repair and maintenance tasks that could result in high doses to personnel in relatively short periods of time. Another valuable application is in research laboratories where radioisotopes are used.

12.1.4 Evaluation of Trainee Performance

Each radiation worker's knowledge, competency, and understanding of the radiation safety aspects of specific jobs should be evaluated. The evaluation may consist of only a written or oral test, but should, in most cases, include a written test, an oral test, and a "practical" or on-the-job performance test. The questions asked and the responses given in all examinations should be documented. Requalification testing should be conducted in conjunction with refresher training.

High test grades (i.e., 80% or higher) should be required because each person's training covers radiation protection information relevant to the person's needs and safety in the work environment. Radiation workers should be reinstructed and retested in any areas in which their knowledge is shown to be deficient.

Tests should cover all the information presented during training but should emphasize the day-to-day radiation protection practices relevant to each person's job. As experience is gained, test questions should reflect the radiation protection problems actually experienced onsite.

Practical or on-the-job tests should stress knowledge and proper job performance. A person may know what to do but be unable to do it promptly when faced with a situation demanding immediate and effective action. In preparing a test, consideration should be given to individual job responsibilities, training received, and radiation protection experience.

Tests should be designed to:

1. measure the person's ability to recognize and cope with radiation hazards that may be encountered on the job
2. stress preparedness for work in radiation and controlled areas
3. assess the individual's knowledge of and attitude toward his or her rights and obligations regarding radiation protection
4. assess the individual's understanding of control procedures.

12.1.5 Documentation of Training

Records that describe the content of training courses, such as course outlines, syllabuses, brochures, video tapes, texts, and tests, should be maintained. These records serve as a basis for determining the depth and scope of training given in each subject area. Trainee-specific training records, which provide a complete history of each person's training experiences, should also be maintained. A complete description of information to be included in the training records is given in Chapter 13, "Recordkeeping."

A staff member who has been trained at one site and is later to be employed at a different site should receive a statement of training received. This statement will allow the person responsible for training at the second site to take the staff member's previous training into account and thereby avoid needless repetition of training. The statement should clearly and explicitly describe all training received and should identify non-plant-specific training segments that may be applicable to work in the new position.

Section 12.2 INSTRUCTION TO WOMEN OF REPRODUCTIVE CAPACITY

A special situation arises when an occupationally exposed woman is pregnant. Exposure of the woman's abdomen to penetrating radiation from either external or internal sources would also expose the embryo or fetus. A number of studies have indicated that the embryo or fetus is more radiosensitive than

an adult, particularly during the first 3 months after conception, when a woman may be unaware of her pregnancy.

12.2.1 Recommended Prenatal Occupational Exposure Limit

The National Council on Radiation Protection and Measurements (NCRP) recommends in its Publication 53 (1977) that, because the unborn are more sensitive to radiation than adults, their radiation dose from occupational exposure of the mother should not exceed 0.5 rem. The International Commission on Radiological Protection (ICRP) recommends in its Publication 9 (1965) that the occupational radiation exposure of all women of reproductive capacity be received gradually, in small increments, so that an unborn baby would be unlikely to receive more than 0.5 rem in the first 2 months after conception, when a woman may not be aware that she is pregnant.

12.2.2 Requirements

All individuals who work in a restricted area must be instructed as to the risks associated with radiation exposure (Nuclear Regulatory Commission (NRC) Regulatory Guide 8.13 (1975)). This instruction should include information on the risks to the unborn. Women should be encouraged to inform the RPO of a pregnancy. Every effort should be made to limit the dose to an embryo-fetus to 0.5 rem during the entire gestation period. The mother's exposure should be as uniformly distributed over time as is practicable.

The establishment of differential occupational exposure limits for men and women can raise a number of social and legal questions. All alternatives should be considered before the situation arises. Options include the following:

1. The dose to the unborn child can and should be reduced by a) decreasing the time the woman spends in radiation areas, and/or b) increasing the distance between the woman and the source of radiation, and/or c) shielding the abdominal area (the use of lead aprons could be considered).
2. The woman can be reassigned to an area or job involving less radiation exposure.
3. The woman can be reassigned to a nonradiation position.

All available options should be discussed with the expectant mother. It is important that a decision be reached quickly, as the unborn child is most radiosensitive during the first 3 months of pregnancy.

12.2.3 Rationale for Limit

The radiosensitivity of cells (their susceptibility to damage by radiation) is directly related to their degree of differentiation, that is, to the extent to which they have developed distinct and identifiable functions. Kidney cells, for example, have a function different from that of cells of the eye. Because most cell differentiation takes place in newly forming and growing beings, embryos are more radiosensitive than fetuses, fetuses more radiosensitive than children, and children more radiosensitive than adults. This principle has long been a factor in the development of radiation protection standards, as exemplified by the difference in the exposure limits for minors and adults: the occupational radiation exposure of anyone under the age of 18 cannot exceed 10% of the limits for adult workers.

The development of a baby is usually divided into three stages: ovum, embryo, and fetus. An ovum becomes an embryo about 7 days after fertilization; the embryo stage lasts approximately 8 weeks; and the fetal stage is the time remaining until birth. The particular effect of radiation, and its severity, depend on the stage of development at which exposure occurs. An unborn child is more sensitive to radiation during the embryonic stage than in the earlier or later stages of development. During this period, the organs are being formed and the cellular organization of the embryo is changing rapidly. Cells become specialized and start processes leading to the development, in a fixed sequence, of specific tissues. Consequently, the effect of radiation varies from day to day, and different degrees and kinds of organ malformations are produced depending on exactly when the exposure occurs.

During the earlier or ovum stage, relatively few cells are present, and the most common effect of exposure to radiation is chromosomal injury leading to cell death. During the later or fetal period, most organs have already been formed, and malformations from radiation exposure are less common and

less severe. The major radiation effect during this period is reduced growth, which may persist throughout life.

The genetic and cancer risks per unit of radiation dose from in-utero exposure also exceed those from adult exposure. The undeveloped ovum cells in the female fetus are actively dividing and are nearly as sensitive as the male fetus's immature sperm cells. The most sensitive period for genetic damage in both sexes is probably the last 6 months before birth.

The leukemia risk from in-utero exposure has been estimated as being 10 times greater than that for adults who get the same dose. The follow-up period for solid tumors, which have a longer latency period than leukemia, has probably not been long enough to allow a good estimate of the total risk for other cancers caused by in-utero exposures. The absolute risk of getting fatal cancer, other than leukemia, in the first 10 years of life from in-utero exposure, however, has been estimated as five times the risk that an adult has of getting cancer within 10 years of receiving the same exposure. For all of these reasons, the occupational radiation exposure of pregnant women should be limited.

Section 12.3 INSTRUCTION IN THE USE OF RESPIRATORS

Training in the use of respirators should be given by a qualified and experienced instructor, such as a health physicist, industrial hygienist, or safety engineer. The instructor must have a thorough knowledge of the application and use of respirators and of the hazards associated with radioactive airborne contaminants. He or she also must have had considerable experience in the practical selection and use of respirators for protection against radioactive airborne contaminants.

12.3.1 Extent of Training

The instructor should develop an adequate training program based on the hazards that may be encountered and the types of respirators to be worn. Training must be given not only to the persons who will perform work using the respirators but also to those who will direct the work. Especially where

respirators are used only occasionally, staff members should be retrained often enough so that a high degree of proficiency is retained when respiratory equipment is actually used.

12.3.2 Contents of Training Program

Training in the use of any respirator must cover at least the following topics:

1. the nature of the airborne contaminants against which the wearer is to be protected, including their physical properties, maximum permissible concentrations, physiological action, toxicity, and means of detection
2. the construction, operating principles, and limitations of the respirator and why the respirator is the proper type for the particular purpose
3. the reasons for using the respirator and why more positive control of airborne contamination is not immediately feasible, including recognition that every reasonable effort is being made to reduce or eliminate the need for respirators
4. procedures for ensuring that the respirator is in proper working condition
5. how to fit the respirator properly and how to check the adequacy of the fit
6. the proper use and maintenance of the respirator
7. application of available cartridges and canisters for air-purifying respirators
8. what emergency action to take if the respirator malfunctions
9. radiation and contamination hazards, and other protective equipment that may be used with respirators
10. classroom and field training in recognizing and coping with emergency situations
11. other special training as needed for special purposes.

12.3.3 Drills

Training should include actual use of respirators under simulated conditions of exposure so that the wearers develop a sense of confidence in their ability to use the devices properly. A qualified observer should review with the trainees their performance in these drills.

Section 12.4 TRAINING FOR MANAGERS

Managers need to be knowledgeable in all radiation safety policies and procedures and to understand the ALARA philosophy. They should know who the members of the radiation protection staff are and how to contact them.

12.4.1 Frequency of Training

Managers should be offered training when they move into a position which requires that they oversee work with radioactive materials. This training can often be done on a one-to-one basis. Retraining should be provided whenever a change in policy is made. A presentation at a regularly scheduled staff meeting is a convenient way to provide retraining.

12.4.2 Contents of Training Program

Training for managers should include the following topics:

1. basic radiation safety and radiation biology; sufficient detail should be provided to allow an understanding of the ALARA program
2. site-specific radiation program
3. responsibility of the manager
4. responsibility of staff members
5. emergency preparedness.

Section 12.5 TRAINING FOR THE RADIATION PROTECTION STAFF

The responsibilities of the RPO and the radiation protection staff were detailed in Chapter 3. Members of the radiation protection staff need training that will prepare them to meet those responsibilities and to maintain proficiency in their duties. Contact DARCOM Headquarters for assistance in identifying appropriate short courses.

REFERENCES

International Commission on Radiological Protection (ICRP). 1965. Recommendations of the International Commission on Radiological Protection. ICRP 9, Pergamon Press, Oxford.

National Council on Radiation Protection and Measurements (NCRP). 1977. Radiation Dose Limit for Embryo and Fetus in Occupationally Exposed Women. NCRP 53, Washington, D.C.

U.S. Code of Federal Regulations. 1982. Title 10, Part 19, "Notices, Instructions and Reports to Workers; Inspections." U.S. Government Printing Office, Washington, D.C.

U.S. Department of the Army and Defense Logistics Agency. Medical Services - Control and Recording Procedures for Exposure to Ionizing Radiation and Radioactive Materials. AR 40-14, Washington, D.C.

U.S. Nuclear Regulatory Commission (NRC). 1975. "Instruction Concerning Prenatal Radiation Exposure." Regulatory Guide 8.13, Washington, D.C.

CHAPTER 13. RECORDKEEPING

13.1 RADIATION RECORDS FILES 13.6

13.1.1 Personnel File 13.7

A. Identification of the Individual 13.7

B. Training Records 13.7

C. Project/Task Listing 13.7

D. External-Exposure Records 13.8

E. Internal-Exposure Records 13.9

F. Radiation Exposure Received During Prior Employment . 13.11

G. Exposure Received by Individuals at Other Installations During Current Employment . . . 13.11

H. Simultaneous Employment at Another Facility . . 13.12

I. Exposure Evaluation 13.12

J. Unusual Exposures 13.12

K. Transfer of Records 13.13

13.1.2 Radiation Protection Program File 13.13

A. Licenses and Authorizations 13.13

B. Radiation Protection Policies and Standards . . 13.13

C. Documents of the Ionizing Radiation Control Committee 13.14

D. Procedures for Obtaining and Evaluating Data on Individual Exposures 13.14

E. Inspections and Appraisals 13.14

F. Changes in Procedures and Methods 13.15

13.1.3 Project File 13.15

A. General Records 13.15

B. Standing Operating Procedures 13.15

13.1.4 Radiation Work Area File 13.16

A. General Records 13.16

B. Radiation and Contamination Surveys 13.16

C. Area Monitoring Records 13.17

D. Airborne-Radioactivity Monitoring Records . . . 13.18

13.1.5 Instrumentation and Dosimeters File 13.18

A. Capabilities of Dosimeters and Instruments . . 13.18

B. Calibration and Maintenance 13.19

C. Inventory Records 13.19

13.1.6 Radioactive-Material Inventory File 13.20

A. Sealed and Unsealed Sources and Radioactive Commodities 13.20

B. Environmental Samples 13.21

13.1.7 Waste Management File 13.22

13.1.8 Transportation File 13.22

13.1.9 Accidents/Incidents File 13.23

13.1.10 Training File 13.23

13.1.11 Quality Assurance File 13.24

13.2 RECORDS FILING SYSTEM 13.24

13.3 RECORDS RETENTION AND STORAGE 13.25

13.3.1 Types of Records Retention 13.25

A. Hard Copy 13.25

B. Computer Records 13.26

C. Microform 13.25

D. Combinations 13.26

13.3.2 Retention Period 13.26

13.3.3 Storage Precautions 13.27

REFERENCES 13.27

APPENDIX A - SAMPLE RECORDS FORMS 13.29

APPENDIX B - OCCUPATIONAL RADIATION EXPOSURE FORMS 13.37

APPENDIX C - CROSS-REFERENCE SYSTEM FOR FILES, AND FLOW CHARTS FOR PROBLEM SOLVING 13.43

TABLES

13.1 Cross-Reference System 13.45

CHAPTER 13. RECORDKEEPING

Good recordkeeping is essential in the radiation work environment. Accurate records and a filing system that incorporates extensive cross-referencing can help the Radiation Protection Officer (RPO) and the installation commander achieve the following:

1. plan an individual's occupational exposure, keeping in mind the ALARA philosophy (maintaining radiation exposures as low as is reasonably achievable)
2. demonstrate good management practices in the handling of radioactive sources
3. demonstrate compliance with government regulations and the site's Nuclear Regulatory Commission (NRC) license
4. evaluate the effectiveness of the radiation protection and quality assurance programs
5. trace the cause of a trend of elevated doses
6. document, for both legal and medical purposes, the exact conditions under which an individual received a particular radiation dose (i.e., what the radiation source was, its activity or probable concentration, and when and how the individual was exposed).

This chapter describes the content and form of the radiation work records that must be maintained in accordance with the requirements of the Department of the Army (DA) and the following parts of the U.S. Code of Federal Regulations: Title 10, Parts 19 and 20, and Title 29, Parts 570.57 and 1910.96. A method of organizing these records into a filing system that would provide easy access to all records pertaining to an individual, a specific project, a radioactive source, a radiation work area, or a particular radiation-measuring instrument is also described. The chapter closes with a section on retention and storage of records.

Section 13.1 RADIATION RECORDS FILES

A well-managed radiation protection program requires a substantial number of records. Many of these records have been described in previous chapters. In this section, a summary of the required records will be provided. For the purpose of this manual, the records have been organized into the following series of files:

1. personnel file
2. radiation protection program file
3. project file
4. radiation work area file
5. instrumentation and dosimeters file
6. radioactive-material inventory file
7. waste management file
8. transportation file
9. accidents/incidents file
10. training file
11. quality assurance file.

A system for cross-referencing these files is provided in the next section. A records filing system for radiation safety files is also given in AR 340-18-6. Each RPO should evaluate records requirements to determine what kind of filing system is most appropriate.

Reference will be made throughout this chapter to "suspense" files. These are files used for procedures that are repeated regularly (e.g., weekly, monthly, quarterly, or yearly). Data sheets for the particular procedure are filed under the week, month, quarter, or year in which the procedure must be performed next. Suspense files can take the form of card catalogs, spiral notebooks, or file folders, and are appropriate for scheduling routine procedures such as leak tests of sealed sources, contamination surveys of radiation areas, instrument calibration tests, training and retraining sessions, and bioassays.

13.1.1 Personnel File

Complete and up-to-date personnel files provide a means of 1) assessing a radiation worker's training needs for specific projects or job changes, and 2) tracking the history of the individual's exposures and of any doses received. Occupational exposure records must be kept as part of each individual's health record or civilian employee medical file. Each personnel file must include a signed Privacy Act statement (AR 40-14).

A. Identification of the Individual. An individual's social security number should be used for identification on all records. If another number is used to identify the individual, this number should be cross-referenced to the social security number. If an individual who may work with radiation does not have a social security number, he or she should be instructed to get one. The birth date and sex of the individual should also appear on all personnel records as another means of identification. In this chapter, "identification of the individual" will mean the person's name, social security number, birth date, and sex.

B. Training Records. Participation by a radiation worker in formal and on-the-job training sessions should be documented to indicate the individual's qualification to perform radiation-related tasks. The training records should include:

1. identification of the individual
2. title and date of the training program
3. identification of the instructor and training location
4. a performance rating for each segment of training or each training program satisfactorily completed: a numerical or letter grade and/or a written evaluation.

A suggested format for training records is shown in Appendix A.

C. Project/Task Listing. To facilitate tracing an individual's exposure history at a given installation, a listing of all the projects or tasks on which the individual has worked should be included in his or her personnel file. A useful concept is the assignment of a key word descriptor to each project. Key word descriptors are one- or two-word descriptions of the focus of a

project, for example, weapons testing, gaseous effluents, radioimmunoassay. They can be used to locate all other projects of the same type for either onsite or intersite comparisons. A record sheet for listing projects and tasks would include--

1. identification of the individual
2. title and number of the project or task
3. key word descriptor for the project or task
4. the dates on which the individual began and ended participation in the project or task
5. standing operating procedures (SOPs) for the project or task.

A sample record sheet is shown in appendix A.

D. Exrernal-Exposure Records. Two Department of Defense (DD) forms are used to record an individual's occupational radiation exposure history--DD Form 1952 (Dosimeter Application and Record of Occupational Radiation Exposure) and DD Form 1141 (Record of Occupational Exposure to Ionizing Radiation). (Both forms are reproduced in app B. See AR 40-14 for details on the information summarized here.) DD Form 1952 identifies the individual's employment status, gives dosimetry information for the individual's current job (e.g., the type of exposure involved and the dosimeters and bioassays required in connection with the work), and lists the names and addresses of previous employers for whom the individual worked with radiation, with the dates of employment. A new DD Form 1952 is initiated each time the individual is reassigned, and the previous exposure history is transferred to the new form.

DD Form 1141 includes the individual's identity, a summary of exposures from previous jobs, and a month-by-month record of the individual's dose from the current assignment and accumulated lifetime dose from exposures to the whole body or skin of the whole body. The installation or location at which each exposure occurred is also noted on the form.(a) A separate DD Form 1141

(a The inclusion of the title and number of the project on which the individual received each monthly exposure would facilitate cross-referencing of this information with that in other files.

is kept to record exposures to parts of the body other than the whole body or skin of the whole body (e.g., the thyroid, head and neck, or fingers). An alternative to the use of DD Form 1141 is the use of the automated dosimetry records prepared by the Army's Central Dosimetry Record Repository. Whichever record is used, it should include exposures received by the individual from outside (non-Army) work and from medical sources.

Department of Defense Form 1952 is kept in the individual's health record or (for civilian employees) medical file. Department of Defense Form 1141 (or the automated dosimetry records) can be kept either in the individual's personnel file or in his or her health record or medical file. If DD Form 1141 is kept in the personnel file, a chargeout record noting the location of the form must be placed in the health record or medical file.

E. Internal-Exposure Records. Internal-exposure records can include bioassay data, the interpretation of bioassay data, whole-body-counter records, and airborne-radioactivity measurements. All internal-exposure records can be maintained either in the individual's personnel file or in the health record or medical file. If they are kept in the personnel file, a chargeout record noting their location must be placed in the health record or medical file.

(1) Records of Bioassay Data. An individual's internal radiation exposure is determined from bioassay studies. Records of these studies should include the following information (American National Standards Institute (ANSI) Standard N13.6-1972):

1. identification of the individual
2. purpose of the sample and, if applicable, date of suspected intake, work area, and project number and title
3. collection period for the sample and date submitted
4. type of sample and size of aliquot
5. type of radioactivity (e.g., alpha, beta)
6. gross and net activity observed and counting time
7. identity of radionuclide, when required

8. cross-reference to calibration and control data and confidence limits (in the instrumentation and dosimeters file)

9. cross-reference to identity and efficiency of analysis equipment and radiochemical analysis procedure (in the instrumentation and dosimeters file)

10. identification of the laboratory technician(s) performing the analysis.

(2) Records of Bioassay Interpretation. In addition to items 1 through 10 above, records relating to interpretation of the data from a bioassay study should be kept and should include:

1. a listing of the bioassay data used in the interpretation, and the identity of the radionuclide

2. reference to the method of interpretation

3. assumptions used in arriving at the conclusion, including the known or assumed date of exposure

4. conclusion as to the magnitude and location of the body burden, expressed in microcuries of the specific radionuclide

5. identification of the individual making the conclusion.

(3) Whole-Body-Counter Data. Whole-body-counter data provide an assessment of internally deposited radionuclides. Records of an individual's whole-body count should include:

1. identification of the individual

2. date, time, and purpose of the count and, if applicable, date and time of suspected intake

3. quantitative data (e.g., length and type of count, counts per channel, keV per channel, energy range over which counts were made)

4. cross-reference to procedure, calibration factors, periodic background and resolution checks, and confidence levels (in the instrumentation and dosimeters file)

5. description of or reference to calculational procedure

6. identity and location of the radionuclide and magnitude of the body burden

7. identification of the individual making the conclusion.

A sample record sheet is shown in Appendix A.

(4) Airborne-Radioactivity Measurements. If airborne-radioactivity measurements and exposure times indicate that an individual has received an internal exposure via inhalation, the following information should be recorded:

1. identification of the individual

2. period(s) covered by the measurements

3. basis for exposure estimate

4. concentration of airborne radioactive material, length of exposure, and estimated breathing rate

5. reference to any documentation of the factors in item 4

6. estimated internal exposure

7. identification of the investigator.

F. Radiation Exposure Received During Prior Employment. To ensure that the information on DD Forms 1952 and 1141 is complete, the RPO should have each new staff member complete and sign a questionnaire indicating whether any previous employment (civilian or military) may have involved internal or external exposure to radiation, with the names and addresses of former employers where any exposure may have occurred. Previous employers who are contacted for information should be requested to use the individual's social security number when providing information, to ensure the correct identity of the individual.

The following information on each previous exposure should be obtained and kept in the personnel file:

1. the period(s) of employment and the identification of the employer

2. the nature and magnitude of the exposure, both internal and external, and the period of exposure.

G. Exposure Received by Individuals at Other Installations During Current Employment. The radiation exposure received by an individual at another installation during an official visit or special assignment should be maintained in the personnel file. A special film dosimeter may need to be assigned for the visit.

H. Simultaneous Employment at Another Facility. Individuals should report when radiation exposure is being incurred at two facilities as a result of simultaneous employment by two firms or government agencies.

I. Exposure Evaluation. The RPO should review and evaluate DD Form 1141 (or the Automated Dosimetry Records) and the results of any bioassays on a quarterly basis and note the date of the review on DD Form 1141. If action is necessary to limit an individual's exposure, the RPO must notify the individual, the individual's commander and supervisor, and the responsible medical officer.

J. Unusual Exposures. Any accident/incident that involves a radiation worker (such as an exposure in excess of permissible limits, the use of special exposure limits, or an exposure that results in the withdrawal of the individual from a work position--see Chapter 11) must be described and recorded. The extent of the information recorded will depend upon the type of accident/incident but should include:

1. identification of the individual
2. time, date, and location of the accident/incident
3. description of the accident/incident
4. results of the event (e.g., the exposure received by the individual involved, the extent and nature of skin contamination, and any confiscation of personal property)
5. probable cause of the accident/incident
6. action taken at the time of the event
7. reference to or summaries of subsequent action taken to prevent recurrence of the accident/incident

8. reference to or summaries of supporting data used to determine the above items, such as radiation surveys, film dosimeter studies, air sample assays, and photographs

9. identification of the investigator(s).

A sample form is shown in Appendix A.

K. Transfer of Records. When a radiation worker transfers to another assignment or organization, all chargeout records for DD Form 1141 (or the automated dosimetry records) and for bioassay records must be removed from the individual's health record or medical file and replaced with the original forms and records. The health record or medical file, containing complete and accurate originals of DD Form 1952, DD Form 1141 or the automated dosimetry records, and bioassay records, is sent to the gaining organization to which the individual has been assigned. A copy of each document should be retained at the original installation, with the address of the gaining organization noted on the copy of DD Form 1141 to ensure that any additional dosimetry information received after the transfer is forwarded to the gaining organization.

13.1.2 Radiation Protection Program File

A record of the installation's radiation protection policy and procedures should be maintained to allow the RPO and his or her supervisor to continually evaluate and update the program. In addition, records should be readily available to demonstrate to auditors and inspectors the adequacy of the program.

A. Licenses and Authorizations. All documents related to licenses and authorizations to procure and use radioactive materials should be maintained. These documents may include DA permits and authorizations; NRC license applications, licenses, and amendments; and authorizations to store, transfer, ship, or dispose of radioactive materials.

B. Radiation Protection Policies and Standards. Policies and standards established for the overall conduct of radiation work at the installation should be documented. These records should include:

1. scope and organization of the radiation protection program

2. training and experience of the individuals on the radiation protection staff

3. orientation and training requirements for individuals who will perform radiation work

4. specifications for the frequency and techniques to be used in measuring the radiation exposure received by individuals

5. control procedures for radiation work, such as permissible levels of radiation and contamination in work areas, as well as posting and labeling requirements

6. plans and procedures for radiation emergencies, including the type and frequency of training drills

7. criteria for the investigation of unusual radiation occurrences

8. reporting and records requirements

9. regulations, standards, procedures, and higher-headquarters instructions, along with effective dates for each.

C. Documents of the Ionizing Radiation Control Committee. Documents relating to the meetings and decisions of the Ionizing Radiation Control Committee (IRCC) should be kept. This information should include reports on IRCC reviews of applications for approval to use sources of ionizing radiation. The records should note whether each application was approved or disapproved, the conditions under which each source was approved for use, and the qualifications of the users.

D. Procedures for Obtaining and Evaluating Data on Individual Exposures. The procedures used to obtain, process, and evaluate data for individuals' external and internal exposure records should be recorded. Records of the methods used to obtain an individual's exposure should refer to pertinent published documents or reports and should show the period of applicability of the methods used.

E. Inspections and Appraisals. Documents related to compliance inspections performed by DA and civilian licensing agencies should be maintained. These records should include notifications of inspection, inspection reports, and documents related to follow-up corrective actions.

A health physics appraisal provides an evaluation of the overall adequacy and effectiveness of the radiation protection program. Appraisals may be performed by a team of outside experts and/or the installation RPO (see Chapter 15). All of the documents related to the appraisal of the radiation protection program should be maintained and should include appraisal notifications, findings, and corrective actions.

F. Changes in Procedures and Methods. Substantial revisions of procedures, methods of evaluation, or policies should be recorded. When pertinent, the reasons for such changes should also be recorded.

13.1.3 Project File

Each project or task should be fully documented. A title and an identification number should be assigned to a project before it is begun, and project records should be filed by the project identification number.

A. General Records. All documents relating to a project should include the project's title and identification number, key word descriptor(s) relevant to the project, and the name of the principal investigator. A list of key word descriptors available for assignment to a program should also be kept in the project files. The records for each project should include:

1. a complete description of the project with its start and completion dates
2. a complete listing of all radioactive materials used for the project, including for each source its activity, the date the activity was determined, and its half-life
3. a complete listing of all instrumentation used in the project, including for each instrument its identification number (serial or inventory number), company, model number, and storage location
4. the principal investigator, and a list identifying all project workers and the dates on which each individual began and ended work on the project.

Sample project forms are shown in Appendix A.

B. Standing Operating Procedures. Specific procedures performed in connection with a project are described in SOPs. The SOP is a locally developed form completed by the area supervisor and countersigned by the RPO prior to the start of work. The SOP should include:

1. the title and number of the project
2. effective date of the procedure
3. identity of personnel and/or the organization authorized to perform the work
4. location of the work
5. potential radiation hazards and specific procedures, instructions, and precautions to be observed
6. equipment and dosimetry requirements
7. protective-clothing and equipment requirements
8. descriptions of conditions that would terminate or suspend work in progress
9. identity of the individual approving the procedure.

A copy of each SOP initiated for a project should be included in the records for the project and kept in the project file.

13.1.4 Radiation Work Area File

Documentation of work area conditions is necessary to ensure that good housekeeping procedures are followed and that, in the event of an accident/incident, the radiation source could be quickly characterized and doses to personnel in the area estimated with reasonable accuracy.

A. General Records. Any investigation of a radiation accident/incident requires that substantial supportive data be available. The radiation work area file should therefore include for each laboratory or work area:

1. its location and a map showing the layout of the area
2. a description of the uses of the laboratory or area and its facilities (e.g., hoods, glove boxes, permanently installed equipment)
3. the titles and numbers of projects carried out in the area, with the identity of the principal investigator for each.

B. Radiation and Contamination Surveys. Surveys are conducted to assess the condition of a particular work area. Survey records should include:

1. date and time of the survey
2. location of the survey, that is, building and room (sketches may be included)
3. specific location or object surveyed (sketches may be included)
4. purpose of the survey (e.g., leak test of sealed source, routine survey for contamination on floors and other surfaces, or survey to establish dose rates to personnel)
5. identification (type and serial number) of the particular radiation detection instruments used to perform the survey
6. measurement results (e.g., dose rates and contamination levels), and housekeeping conditions observed
7. conclusions and recommendations
8. identification of the individual performing the survey.

C. Area Monitoring Records. Chart recordings of radiation area monitors should identify:

1. period covered by the chart (beginning and ending dates and times)
2. location of the detector and the area monitored
3. a clear relationship between chart divisions and the exposure or exposure rate units
4. identity of the scale or range of operation
5. notations of source checks and calibrations performed
6. identification of the individuals operating the equipment.

Additional information for continuous air monitors should include:

1. type of instrument (e.g., fixed filter or moving tape)
2. tape and chart speed
3. specific relationship between the chart divisions and the concentration of the airborne radioactive material, which depends on the tape speed and flow rate of a moving filter unit, or on the flow rate of a fixed filter unit.

D. Airborne-Radioactivity Monitoring Records. If airborne radioactive material is monitored, the following information should be recorded:

1. date and time of sampling
2. general location of the air-sampling station (building and room)
3. specific location at which the air sample was collected
4. purpose of sample collected (e.g., routine air sampling or air sample for special evaluation)
5. type of sample collection equipment used (e.g, filter, impact, or evacuated ionization chamber)
6. collection efficiency of sampling system
7. flow rate, duration of sampling, and total volume of air sampled
8. identification of sample analysis equipment used
9. counting data: time count was taken, background, source count, gross count, net count, duration of count
10. reference to calculated correction factors such as backscatter, self-absorption, and efficiency of analytical equipment
11. calculated concentration of airborne radioactive material
12. identity of the air contaminant, if determined
13. identification of the individual performing the analysis.

13.1.5 Instrumentation and Dosimeters File

If the limitations of an instrument have not been determined and the instrument has not been calibrated, the information that it provides about radiation levels in work areas is useless. Therefore, records documenting the availability, limitations, and calibration of all radiation-measuring instruments and dosimeters should be kept in an instrumentation and dosimeters file.

A. Capabilities of Dosimeters and Instruments. The following information on the capability of equipment should be recorded:

1. identification, description, and functional specifications of the individually worn dosimeters and the other radiation measurement instruments used in the radiation protection program
2. date and results of any acceptance or performance tests that show the sensitivity, range, and energy dependence of the instruments
3. special studies documenting bases for use, efficiency, correction factors, and interpretation of data.

B. Calibration and Maintenance. Procedures, criteria, and schedules for calibration and maintenance of radiation measurement instruments and dosimeters are of value in demonstrating the instruments' dependability and reliability. Routine survey instruments should be calibrated every 90 days unless subject to extreme environmental conditions, hard usage, or corrosive environments. In these cases, more frequent calibration is required (ANSI N323-1978). Contingency instruments should be calibrated every 240 days. A suspense file can be used for this purpose. The records system should include:

1. procedures used for the calibration of the individually worn dosimeters and other radiation measurement instruments
2. descriptions of the calibration sources and any data showing intercomparisons with sources from other laboratories
3. data on the frequency of calibrations
4. date and results of the calibration tests, including the identification of the individual performing the test
5. maintenance history of individual radiation measurement instruments.

C. Inventory Records. In addition, the following information should be documented for each radiation-measuring instrument and dosimeter:

1. identification: type, company, inventory number
2. manufacturer's specifications
3. titles and numbers of projects for which the instrument has been used
4. person to whom the dosimeter is assigned, and documents used to record issuance and retrieval of dosimeters.

13.1.6 Radioactive-Material Inventory File

The identity, form, activity, and location of each radioactive source must be documented to ensure good housekeeping procedures and provide a quick indication of a lost source. Information on the form and activity of a source can also be used to indicate radiation doses to personnel in the area (in adcition to personnel-monitoring devices), particularly for cases where radioactive material was inhaled or ingested.

A. Sealed and Unsealed Sources and Radioactive Commodities. As soon as a radioactive source or commodity is received, a file containing items 1 through 4 below should be set up. Subsequent information that should be kept in this file includes items 5 through 8 below. Items 9 through 11 should be included for radioactive commodities:

1. name of shipper, and DA authorization and NRC license of shipper
2. packing papers that identify the source, the amount and activity of the source, and the date received
3. designated storage location (a subsequent change in storage location, or transfer or disposal of the source, should also be indicated, with the date of the change)
4. department the source is assigned to, and the responsible individual
5. locations and dates of use, identity of involved personnel and (for unsealed sources) quantity used and quantity remaining
6. titles and numbers of projects in which the source or commodity was used
7. leak test records: date, identity of person performing the test, technique used, counting instrument used (with its inventory or serial number), and test results (in dpm, which may be converted to the appropriate curie unit)
8. disposal details - how, when, and where the sources or commodities were disposed of
9. research, development, and test summary

10. associated technical bulletins

11. system safety sources.

A suspense file may be established to schedule leak testing of sealed sources. A sealed-source inventory should list all sealed sources available at the facility, their activity as specified on the packing papers, with the date of receipt, and their storage location. This list should be kept in the inventory file and updated whenever these conditions change, for example, when the storage location is changed, or the source is transferred to another department or disposed of.

Because unsealed sources present both external-contamination hazards and the possibility of internal exposure through inhalation, ingestion, or entry through a wound, it is essential to know how much material is available at any time in a particular location. An unsealed-source inventory should therefore include a list of all unsealed sources available at the site, the quantity and activity of each on the date of its receipt, the storage location of each, and the quantity and activity remaining on the date of any change in a source's location. The total depletion of an unsealed source should be indicated on the inventory.

B. Environmental Samples. Environmental samples (e.g., air, water, soil, vegetation, and game) are often used to characterize the impact of a particular operation on the environment. The samples themselves should be labeled (a numbering system is frequently used) and the records of these samples should include:

1. label identification number
2. type of sample (water, vegetation, etc.)
3. where the sample was obtained
4. counting results
5. instrument used for counting
6. any actions taken as a result of a high reading
7. disposal details - how, when, and where the sample was disposed of.

13.1.7 Waste Management File

Radioactive waste may include sealed or unsealed radioactive sources; contaminated equipment, clothing, and supply items; and biological organs. Chapter 10 provides guidance for the handling, storage, and disposal of low-level radioactive waste. In general, the following items should be documented for radiaoctive waste:

1. assigned identification number(s)
2. physical description of the waste: solid, liquid, or gas, quantity, shipping weight and volume, number of containers, shipping permit number, transport group, package specification and labels used
3. chemical and radioisotope description: hazardous chemicals, solvent present (liquid), radioisotopes present
4. radioactivity and radiation measurements: activity, maximum dose rates at surface and 1 meter, classification
5. identification of previous responsible department or individual and storage location
6. disposal details - how, when, and where the material will be disposed of
7. identification of responsible individual(s).

13.1.8 Transportation File

Any movement of radioactive material onsite or offsite requires careful planning by the shipper and the receiver. Specific documents must accompany the material, and records of all movements must be kept. Shipping procedures, records, and packaging requirements are discussed in Chapter 9. The shipping documents and records described there include:

1. consignee license
2. bill of lading
3. description of material on shipping papers
4. shipper's certification
5. specific instructions for exclusive-use shipments
6. survey records
7. records showing compliance with package design-and-performance standards.

13.1.9 Accidents/Incidents File

Complete records of radiation accidents/incidents are necessary for after-the-fact documentation of the event. The following information about each accident/incident should be recorded:

1. date, time, and location
2. description
3. results of the event (e.g., the exposure received by the individual(s) involved, the extent and nature of skin contamination, and any confiscation of personal property)
4. probable cause
5. action taken at the time of the event
6. reference to or summaries of subsequent action taken to prevent recurrence
7. reference to or summaries of supporting data used to determine the above items, such as radiation surveys, film dosimeter studies, air sample analyses, and photographs
8. identification of the investigator(s).

13.1.10 Training File

The RPO or the training supervisor should maintain a file that includes the following information for each course that is given:

1. date and location of course
2. identity of instructor(s)
3 description of course content, including course outline, syllabus, and other descriptive information
4 identification of individuals in attendance (name, social security number, birth date, sex)
5. results of examinations.

A suspense file can be set up to schedule training or retraining sessions.

13.1.11 Quality Assurance File

Quality assurance programs are described in Chapter 14. Records of each program element should be maintained, including documents related to:

1. facility design
2. procurement
3. organization of the program
4. control of purchased material, equipment, services, and special processes
5. inspections and tests
6. control of measurement and test equipment
7. handling, storage, and shipping procedures for material and equipment
8. nonconformance and corrective actions.

Section 13.2 RECORDS FILING SYSTEM

A recordkeeping system that incorporates the capacity for extensive cross-referencing among files can be invaluable in answering questions and solving problems related to an individual's radiation dose. The 11 files in which the records just described should be kept--personnel file, radiation protection program file, project file, radiation work area file, instrumentation and dosimeters file, radioactive-material inventory file, waste management file, transportation file, accidents/incidents file, training file, and quality assurance file--contain some overlapping information that would permit an individual's work and exposure history to be traced and the conditions under which the individual received any dose to be reconstructed quickly and accurately.

Through a cross-reference system such as that shown in Appendix C, persons who were involved in a project, whether as principal investigator, calibrator of instruments, or radiation surveyor, can be identified and could be called on to assist in the evaluation of exposure trends or the investigation of occurrences. The two flow charts in Appendix C illustrate how this system could be used to solve specific problems. The repetition of some data in more than one

file permits the investigator to track down information by moving from one file to several others, as necessary.

Section 13.3 RECORDS RETENTION AND STORAGE

13.3.1 Types of Records Retention

Records can be kept as hard copy (paper), on a computer disc or tape, or or microfilm or microfiche.(a) The main considerations in choosing which method of retention to use are:

1. the storage space needed for the number of records generated
2. the ease of accessibility to the stored information that each type of record provides
3. the admissibility of each type of record as evidence in a court of law.

The initial expenses of establishing each type of system should also be considered in relation to the long-term gains of the system, but an extensive cost-effectiveness study is beyond the scope of this manual. Each form of record is discussed below in relation to storage needs, accessibility, and legal status.

A. Hard Copy. The American National Standards Institute recommends in its publication ANSI N13.6-1972 that dose records for every individual occupationally exposed to radiation be kept until 10 years after the individual's death (if the date of death is known) or until the individual would have reached the age of 75 (if the date of death is not known). Records should be kept this long for both scientific purposes (to permit studies of the long-term effects of radiation) and legal reasons. An extensive records system for a large program, if kept in hard-copy form, could involve considerable paper and space. Easy access to such a system would require an excellent centralized

(a) Microfilm is a fine-grained, high-resolution photographic film containing an image greatly reduced in size from the original. Microfiche is a sheet of microfilm containing multiple microimages in a grid pattern. The term microform is used to refer to any storage form that uses microimages.

filing system. For a small installation with relatively few records, hard-copy files would be practicable. Moreover, in terms of legal applications, hard copy is often the preferred method of records presentation; in a court of law, evidence on original hard copy is difficult to dispute.

B. Computer Records. If computer storage is used, space must be allotted for the computer itself, for a terminal, and for storage of the discs or tapes.

There is a great deal of controversy over the admissibility of a computer printout as evidence in a court of law. It is difficult to guarantee that a program or number has not been tampered with, and the data records cannot be signed as a way of verifying a record or a change in a record. To stand up as legal evidence, computer entries would have to be verified upon entry, and access to the computer would have to be strictly controlled.

C. Microform. Microfilm and microfiche do not take up much space, and a good filing system would allow easy access to records in these forms. Microfilm has the legal status of an original document if it has been made in compliance with the law.(a)

D. Combinations. The use of a combination of record retention systems would provide flexibility and make use of the advantages of each system. A computer system could be used to provide day-to-day access to all types of records, and hard copy or microform could be kept for legal evidence.

The filing system described in this chapter assumes the use of hard copy; however, the concepts discussed could be easily incorporated into a computer or microform file.

13.3.2 Retention Period

The minimum retention period for all the records described in this chapter is 5 years (ANSI 13.6-1972; AR 385-11). However, because records relating to personnel exposure have both scientific and legal implications, the following records for each individual should be kept until the individual would have

(a) See the following U.S. Code sections: 44 U.S.C. 3312, 44 U.S.C. 2112.

reached the age of 75 (if the date of death is not known) or until 10 years after his known death (ANSI N13.6-1972):

1. records of internal and external exposures
2. calibration data associated with evaluation of the individual's exposure
3. records of procedures and methods used to interpret and evaluate the individual's exposure
4. records describing unusual occurrences in which the individual was involved.

13.3.3 Storage Precautions

The effort involved in keeping good records would be wasted if they were lost because of fire or theft. To prevent such a loss, the following suggestions are presented:

1. Keep duplicate copies of all vital records in an area remote from the original documents.
2. Use a standard records vault to minimize the possibility of a fire starting in the vault or entering it from outside (National Fire Protection Association 1980).
3. Consider microfilm for records storage after consulting applicable state laws concerning the legal admissibility of microfilm.

REFERENCES

American National Standards Institute (ANSI). 1972. Practice for Occupational Radiation Exposure Records Systems. ANSI N13.6-1966 (R 1972), New York.

American National Standards Institute (ANSI). 1978. Radiation Protection Instrumentation Test and Calibration. ANSI N323, New York.

National Fire Protection Association. 1980. Standard for the Protection of Records. Publication 232, Boston.

U.S. Code. Title 44, Section 2112, "Legal Status of Reproductions; Official Seal."

U.S. Code. Title 44, Section 3312, "Photographs or Micro Photographs Considered as Originals: Certified Reproductions Admissible as Evidence."

U.S. Code of Federal Regulations. 1982. Title 10, Part 19, "Notices, Instruction and Reports to Workers; Inspections." U.S. Government Printing Office, Washington, D.C.

U.S. Code of Federal Regulations. 1982. Title 10, Part 20, "Standards for Protection Against Radiation." U.S. Government Printing Office, Washington, D.C.

U.S. Code of Federal Regulations. 1982. Title 29, Part 570, "Child Labor Regulations, Orders, and Statements of Interpretation." U.S. Government Printing Office, Washington, D.C.

U.S. Code of Federal Regulations. 1982. Title 29, Part 1910, "Occupational Safety and Health Standards." U.S. Government Printing Office, Washington, D.C.

U.S Department of the Army, Headquarters. "Maintenance and Disposition of General Personnel Management and Safety Functional Files." In Army Functional File System. AR 340-18-6, Washington, D.C.

U.S. Department of the Army, Headquarters. Safety - Ionizing Radiation Protection (Licensing, Control, Transportation, Disposal, and Radiation Safety). AR 385-11, Washington, D.C.

U.S. Department of the Army and Defense Logistics Agency. Medical Services - Control and Recording Procedures for Exposure to Ionizing Radiation and Radioactive Materials. AR 40-14, DLAR 1000.28, Washington, D.C.

APPENDIX A

SAMPLE RECORDS FORMS

Personnel File:
- Project Sheet
- Training Record
- Whole-Body-Counter Record
- Radiation Occurrence Record

Project File:
- Project Characterization
- Project Personnel List
- Key Word Descriptors

DARCOM-P 385-1

PROJECT SHEET FOR PERSONNEL FILE

PROJECT SHEET

Name_____ SS#_____ Birth date_____ Sex_____

	Project No.	Project Title	Key Word Descriptor	Date Start	Date End
1.					
2.					
3.					
4.					

SAMPLE

TRAINING RECORD FOR PERSONNEL FILE

TRAINING RECORD

Name_____ SS#_____ Birth date_____ Sex_____

	Course Title	Date	Instructor/Location	Test Score
1.				
2.				
3.				
4.				

DARCOM-P 385-1

WHOLE-BODY-COUNTER RECORD FOR PERSONNEL FILE

WHOLE-BODY-COUNTER RESULTS

Name_____ SS#_____ Birth date_____ Sex_____

Date of Measurement_____

Purpose
_____ routine
_____ suspected intake: see below*

Type of Measurement (check):
_____ whole body
_____ lung
_____ thyroid

Radionuclide (check)	Count Rate (cpm)	Activity (dpm or μCi)	Body Burden (dpm or μCi)
_____ ^{241}Am			
_____ ^{226}Ra			
_____ ^{222}Rn			
_____ ^{235}U			
_____ ^{234}Th			

SAMPLE

Instrument used (name, company, model number, identification number): _____

Calculational Method: cpm to dpm or μCi

* Date of suspected intake: _____

Location of suspected intake: _____

Project number, title, principal investigator:_____

DARCOM-P 385-1

RADIATION OCCURRENCE RECORD FOR PERSONNEL FILE

RADIATION OCCURRENCE REPORT

Name_____ SS#_____ Birth date_____ Sex____

Occurrence Time and Date _____ Building and Location _____

Occurrence Reported by _____

Air Sample ID Number _____ Dosimeter ID Number _____ Survey ID Number _____

Other supporting data (description and location)

Occurrence Description:

Probable Cause:

Initial Actions:

Subsequent Actions to Prevent Recurrence:

SAMPLE

Radiation Exposure Data
(check) _____ α _____ β _____ γ _____ n Dose _____(rem)

(check) _____ Skin contamination _____ Internal deposition _____ First aid
_____Hospitalization
Describe:

Investigated by_____

Date_____

PROJECT CHARACTERIZATION FOR PROJECT FILE

PROJECT CHARACTERIZATION

Project No._____ Key Word Descriptor _____

Title _____ Principal Investigator _____

Start Date_____ Ending Date_____

Location of Work:

Description:

Instrumentation (I.D. Number, company, model number, storage location)

Radioactive Materials

SAMPLE

Identity	ID No.	Sealed or Unsealed	Location	Radiation(s)	Activity and Date	Half-life

---

HP Support

Dosimetry required_____

Monitoring required_____

Protective equipment required_____

Special instructions_____

DARCOM-P 385-1

PROJECT PERSONNEL LIST FOR PROJECT FILE

PROJECT PERSONNEL RECORD

Project No._____ Key word descriptor_____

Title_____ Principal investigator_____

Name of Radiation Worker	Social Security Number	Date (Start)	Date (End)

KEY WORD DESCRIPTORS FOR PROJECT FILE

SAMPLE

KEY WORD DESCRIPTOR LIST

Key Word Descriptor	Project Number and Title

APPENDIX B

OCCUPATIONAL RADIATION EXPOSURE FORMS

Department of Defense Form 1952
Department of Defense Form 1141

DARCOM-P 385-1

DOSIMETER APPLICATION AND RECORD OF OCCUPATIONAL RADIATION EXPOSURE

Print legibly or type all information requested. See Privacy Act Statement on reverse

1. FULL NAME (Last, First, Middle)	2. DATE OF BIRTH (YYMMDD)	3. SOCIAL SECURITY NO
JARVIS, Whitney N.	42-04-15	777-07-3000

4. DUTY SECTION (Dept., Bldg., Unit, etc.)	5. JOB TITLE	6. DUTY PHONE
Research Laboratory	Chemist	283-1814

7. PAY GRADE		8. HAVE YOU WORN A DOSIMETER ISSUED BY THIS COMMAND IN THE PAST	9. DATE OF RADIATION PHYSICAL (YYMMDD)
CIVILIAN	MILITARY		
GS-12		☐ YES ☒ NO	81-05-01

10. DUTY STATUS	IF TRANSIENT SHOW MAILING ADDRESS (street address, city, state, zip code) OF LOCATION OF HEALTH RECORDS
☒ PERMANENT ☐ TRANSIENT 8 WEEKS OR LESS	

EXPOSURE INFORMATION *(ITEMS 11 THROUGH 30 FOR HEALTH PHYSICS USE ONLY)*

11. CLASSIFICATION OF EXPOSURE: ☒ EXTERNAL ☐ NEUTRON ☐ INTERNAL

12. BADGES REQUIRED			13. TLD REQUIRED		
☐ WRIST	☒ WHOLE-BODY	☐ NEUTRON	☐ WRIST	☐ WHOLE-BODY	☐ FINGER

14. BIOASSAYS REQUIRED

WHOLE-BODY COUNT	THYROID UPTAKE	URINALYSIS	FREQUENCY
☐ YES ☐ NO	☐ YES ☐ NO	☐ α ☐ β ☐ β-γ	☐ MONTHLY ☐ QUARTERLY ☐ ANNUALLY

GIVE DATES FOR ITEMS 15 THROUGH 20 (YYMMDD)

15. DOSIMETER(S) ISSUED	16. DD FORM(S) 1141 INITIATED	17. DOSIMETER(S) DISCONTINUED
81-05-03	81-05-03	

18. LAST DOSIMETER(S) RETURNED	19. LOCATOR CARD TO HEALTH RECORD	20. DD FORM(S) 1141 TO MEDICAL RECORDS
	81-05-03	

OCCUPATIONAL EXPOSURE HISTORY

NOTE: This section only applies to the individual who has worked with radiation-producing devices or radioisotopes in a permanent status. List only those employers for whom you worked with radiation.

NAME OF EMPLOYER	ADDRESS (street address, city, state, zip code)	FROM YR	FROM MO	TO YR	TO MO	Do not write in this space
Nuclear Services, Inc	Shickshinny, PA	78	08	80	04	
Rosewater University	Portland, OR	80	04	81	04	
	TOTAL EXPOSURE DATA					

SAMPLE

REMARKS

DD FORM 1 NOV 1952 EDITION OF 1 SEP 74 IS OBSOLETE. (see reverse)

PRIVACY ACT STATEMENT
DATA REQUIRED BY THE PRIVACY ACT OF 1974
(5 USC 552a)

1. TITLE OF FORM: Dosimeter Application and Record of Occupational Radiation Exposure.

2. PRESCRIBING DIRECTIVE: AR 40-14 and DLAR 4145.24.

3. AUTHORITY: 5 USC 301-Departmental Regulation, 10 USC 1071, Medical and Dental Care, Purposes; 42 USC 2073, 2093, 2095, 2111, 2133, 2134, 2201(b), and 2201(o). The authority for soliciting the social security number is 10 CFR 20, 44 USC 3101-Record Management by Agency Heads, General Duties

4. PRINCIPAL PURPOSE(S): To establish qualification of personnel monitoring and document previous exposure history. The information is used in the evaluation of risk of exposure to ionizing radiation or radioactive materials. The data permits meaningful comparison of both current (short-term) and long-term exposure to ionizing radiation or radioactive material. Data on your exposure to ionizing radiation or radioactive materials is available to you upon request.

5. ROUTINE USES: The information may be used to provide data to other Federal agencies, academic institutions, and non-governmental agencies, such as the National Council on Radiation Protection and Measurement and the National Research Council, involved in monitoring/evaluating exposures of individuals to ionizing radiation or radioactive materials who are employed as radiation workers on a permanent or temporary basis and exposure received by monitored visitors. The information may also be disclosed to appropriate authorities in the event the information indicates a violation or potential violation of law and in the course of an administrative or judicial proceeding.

6. MANDATORY OR VOLUNTARY DISCLOSURE AND EFFECT ON INDIVIDUAL NOT PROVIDING INFORMATION: It is voluntary that you furnish the requested information, including social security number; however, the installation or activity must maintain a completed DD Form 1141 on each individual occupationally exposed to ionizing radiation or radioactive material as required by 10 CFR 20, 29 CFR 1910.96 and AR 40-14/DLAR 4145.24. If information is not furnished, individual may not become a radiation worker. The social security number is used to assure that the Army/Agency has accurate identifier not subject to the coincidence of similar names or birthdates among the large number of persons on whom exposure data is maintained.

STATEMENT

Under the provisions of 10 CFR 19.13, 29 CFR 1910.96 and the Privacy Act of 1974, I hereby authorize the release of, and request that all of my radiation exposure records be furnished appropriate authorities in accordance with the "Routine Uses" portion of the above Privacy Act Statement. As a radiation worker, I have been provided instructions in radiation protection as required by 10 CFR 19.12 and 29 CFR 1910.96. As a female radiation worker, I have been informed of the biological affects and the risks from ionizing radiation on the embro-fetus and received a copy of NRC (Nuclear Regulatory Commission) Guide 8.13. I will contact my supervisor or the radiation protection officer if I have any questions. I hereby certify that the exposure history listed on the obverse is correct and complete, to the best of my knowledge and belief. I have read and understand the above Privacy Act Statement.

81-04-25
Date (YYMMDD)

Signature of Applicant

DARCOM-P 385-1

RECORD OF OCCUPATIONAL EXPOSURE TO IONIZING RADIATION

FOR INSTRUCTIONS SEE REVERSE OF SHEET

1. IDENTIFICATION NUMBER	2. NAME (Last, First, Middle Initial)	3. SOC SEC SECURITY NUMBER	4. RANK, RATE, TITLE OF POSITION	5. DATE OF BIRTH (Day, Month, Year)
074	JARVIS, WHITNEY N.	777-07-3000	TDR	15 Apr 42

6. PLACE WHERE EXPOSURE OCCURRED: WHOLE BODY	7. PERIOD OF EXPOSURE FROM (Day-Mo-Yr)	8. PERIOD OF EXPOSURE TO (Day-Mo-Yr)	9. DOSE THIS PERIOD (rem) SKIN DOSE (Sol)[1]	10. GAMMA AND X-RAY	11. NEUTRON	12. TOTAL THIS PERIOD	13. ACCUMULATED DOSE (rem) TOTAL LIFETIME	14. PERMISSIBLE LIFETIME 5(N-18)	15. INITIAL PERSON MAKING ENTRY
Previous Exposure[1]	Aug66	Apr68	NR	00.107	NU	00.107	00.107	-	CED
Admin Dose[3]	Apr68	Apr69	-	-	-	05.000	05.107	45.000	CED
APG-EA, MD	3May69	4Jun69	NR	00.000	NU	00.000	05.107	45.000	CED
do	6Jun69	6Jun69	Quarterly Review by RPO				-	-	JER
do	5Jun69	4Jul69	00.003	00.010	NU	00.010	05.117	45.000	CED
do	5Jul69	7Aug69	NR	00.078	NU	00.078	05.195	45.000	CED
do	8Aug69	6Sep69	Film Badge Lost[3]		NU	00.416	05.611	45.000	CED
do	8Sep69	8Sep69	Quarterly Review by RPO				-	-	JER
do	7Sep69	4Oct69	NR	00.064	NU	00.064	05.675	45.000	CED
do	5Oct69	4Nov69	NR	00.075	NU	00.075	05.750	45.000	WLW
do	5Nov69	6Dec69	00.016	00.070	NU	00.070	05.820	45.000	WLW
do	Film Badge Service Discontinued 6 Dec 69						-	-	WLW
do	6Dec69	6Dec69	Quarterly Review by RPO				-	-	JER
Fort Plunkett	2Jan70	3Feb70	NR	00.000	00.000	00.000	05.820	45.000	RKO
do	4Feb70	3Mar70	NR	00.178	00.062	00.240	06.060	45.000	RKO
do	4Mar70	2Apr70	00.052	02.504	00.126	02.630	08.690	45.000	RKO
do	22Mar70	22Mar70	Quarterly Review by RPO				-	-	MJM
do	3Apr70	4May70	Relieved From Duties[4]				08.690	50.000	RKO
do	5May70	3Jun70	Involving Exposure to RAD[5]				08.690	50.000	RKO
do	4Jun70	2Jul70	00.017	00.100	00.043	00.143	08.833	50.000	RKO
Fort Smith, CA	Aug70	Jul71	No Film Badge Worn or Exposure Received				08.833	55.000	GML
			S A M P L E						

16. REMARKS (Continue on additional sheet if necessary)

1. Nuclear Services, Inc., Shickshinny, PA
2. Rosewater University, Portland, OR
   No film badge records (AR 40-14).

NR - none reported; NU - not used
Has wrist badge No. 086.

3. Admin Dose = $\frac{5 \text{ rem}}{12 \text{ months}}$ = 00.416 rem
4. Alleged overexposure.
5. Pending investigation IAW AR 40-5.

TO BE RETAINED PERMANENTLY IN INDIVIDUAL'S MEDICAL RECORD

DD FORM 1 MAY 68 1141 PREVIOUS EDITIONS ARE OBSOLETE

RECORD OF OCCUPATIONAL EXPOSURE TO IONIZING RADIATION

FOR INSTRUCTIONS SEE REVERSE OF SHEET

(IDENTIFICATION) NAME (Last, First, Middle Initial) NUMBER	SOC SEC NUMBER	GRADE RATE TITLE OF POSITION	DATE OF BIRTH (Day-Mo-Yr)
086 JARVIS, WHITNEY N.	777-07-3000	TDR	18 Apr 42

PLACE WHERE EXPOSURE OCCURRED	PERIOD OF EXPOSURE		DOSE THIS PERIOD (rem) 1. Method of monitoring is presumed to be film badge reading unless otherwise specified under Item 11, "REMARKS"				ACCUMULATED DOSE (rem)		INITIAL
ACTIVITY	FROM (Day-Mo-Yr)	TO (Day-Mo-Yr)	SKIN DOSE (Sol)	GAMMA AND X-RAY	NEUTRON	TOTAL THIS PERIOD	TOTAL LIFETIME	PERMISSIBLE LIFETIME (5(N-18))	PERSON MAKING ENTRY
6	7	8	9	10	11	12	13	14	15
Previous Exposure[1]	Aug66	Apr68	-	-	-	00.204	00.204	NA	CED
Admin Dose[3]	Apr68	Apr69	-	-	-	75.000	75.204	NA	CED
APG-EA, MD	3May69	4Jun69	NR	00.009	NU	00.009	75.213	NA	CED
do	6Jun69	6Jun69	Quarterly Review by RPO				-	NA	JER
do	5Jun69	4Jul69	00.007	00.018	NU	00.018	75.231	NA	CED
do	5Jul69	7Aug69	NR	00.159	NU	00.159	75.390	NA	CED
do	8Aug69	6Sep69	Film Badge Lost[4]		NU	06.250	81.640	NA	CED
do	8Sep69	8Sep69	Quarterly Review by RPO				-	NA	JER
do	7Sep69	4Oct69	NR	00.143	NU	00.143	81.783	NA	CED
do	5Oct69	4Nov69	NR	00.162	NU	00.162	81.945	NA	WLW
do	5Nov69	6Dec69	00.032	00.150	NU	00.150	82.095	NA	WLW
do	Film Badge Service Discontinued 6 Dec69						-	NA	WLW
do	6Dec69	6Dec69	Quarterly Review by RPO				-	NA	JER
Fort Plunkett	2Jan70	3Feb70	NR	00.015	NU	00.015	82.110	NA[2]	RKO
do	4Feb70	3Mar70	NR	00.420	NU	00.420	82.530	NA	RKO
do	4Mar70	2Apr70	00.140	16.125[5]	NU	16.125	100.655	NA	RKO
do	22Mar70	22Mar70	Quarterly Review by RPO				-	NA	MJM
do	3Apr70	4May70	Relieved From Duties[6]				100.655	NA	RKO
do	5May70	3Jun70	Involving Exposure to RAD				100.655	NA	RKO
do	4Jun70	2Jul70	00.025	00.200	NU	00.200	100.855	NA	RKO
Fort Smith, CA	Aug70	Jul71	No Film Badge Worn or Exposure Received				100.855	NA	GML
			S A M P L E						

11. REMARKS (Continue on additional sheet if necessary)

1. Wrist Record (WB Record 074)
2. Nuclear Services, Inc., Shickshinny, PA
3. Rosewater University, Portland, OR
   No film badge records (AR 40-14)
   NR - none reported; NU - not used.
4. Admin Dose = $\frac{75 \text{ rem}}{12 \text{ months}}$ = 06.250
5. Accidental Exposure. Case documented IAW AR 40-5.
6. Necessary to avoid exceeding quarterly limit

TO BE RETAINED PERMANENTLY IN INDIVIDUAL'S MEDICAL RECORD

DD FORM 1 MAY 67 1141 PREVIOUS EDITIONS ARE OBSOLETE

APPENDIX C

CROSS-REFERENCE SYSTEM FOR FILES, AND FLOW CHARTS FOR PROBLEM SOLVING

TABLE 13.1. Cross-Reference System

Records	Cross-Reference
Personnel File	
Identification of the Radiation Worker	
Radiation Exposure Received During Prior Employment	
Exposure Received by Individuals at Other Installations During Current Employment	
Simultaneous Employment at Another Facility	
Training Records	Training File
Project/Task Listing	Project File
External-Exposure Records	Instrumentation and Dosimeters File
Internal-Exposure Records	Instrumentation and Dosimeters File
Exposure Evaluation	Radiation Protection Program File
Unusual Exposures	Accident/Incident File
Radiation Protection Program File	
Licenses and Authorizations	
Radiation Protection Policies and Standards	
Procedures and Methods for Interpretation and Evaluation of Individual Exposure Data	
Inspections and Appraisals	
Changes in Procedures and Methods	

TABLE 13.1. (continued)

Records	Cross-Reference
Project File	
General Records	
- project descripton--dates, location	Radiation Work Area File
- radioactive materials list	Radioactive-Material Inventory File
- instrumentation list	Instrumentation and Dosimeters File
- principal investigator/project workers	Personnel File
Standing Operating Procedures	
Radiation Work Area File	
General Records	
- location/map	
- work area uses/equipment and instruments	Instrumentation and Dosimeters File
- projects in the area	Project File
- project principal investigator	Personnel File
Radiation and Contamination Surveys	
- date, time, location, purpose	
- instrument identification	Instrumentation and Dosimeters File
- measurement results	Radiation Protection Program File
- individual(s) performing survey	Personnel File
Area Monitoring Records	
- date, location	
- instrument type, calibration	Instrumentation and Dosimeters File
- source check records	Radioactive Material Inventory File
- individual(s) operating equipment	Personnel File
Airborne-Radiation Monitoring Records	
- date, time, location, purpose	
- identity of sampling equipment	Instrumentation and Dosimeters File
- collection efficiency	Instrumentation and Dosimeters File
- counting data	
- calculated correction factors, concentrations, and efficiency of equipment	Radiation Protection Program File

TABLE 13.1. (continued)

Records	Cross-Reference
Radiation Work Area File (continued)	
- identity of air contaminant	
- individual performing analysis	Personnel File
Instrumentation and Dosimeters File	
Capabilities of Dosimeters and Instruments	
Calibration and Maintenance	Personnel File Radioactive-Material Inventory File
Inventory Records	Project File
Radioactive-Material Inventory File	
Sealed Sources	
- packing papers	
- storage and use locations	Radiation Work Area File
- responsible department/individual	Personnel File
- projects	Project File
- project personnel	Personnel File
- leak test records:	
- instrument	Instrumentation and Dosimeters File
- individual	Personnel File
- results	Radiation Protection Program File
- disposal history	Waste Management File
- inventory	
Unsealed Sources	
- packing papers	
- storage and use locations	Radiation Work Area File
- responsible department/individual	Personnel File
- dates of use, quantity	
- projects	Project File
- project personnel	Personnel File
- disposal history	Waste Management File
- inventory	
Environmental Samples	
- identification number, sample type	
- location	
- counting results	Radiation Protection Program File

TABLE 13.1. (continued)

Records	Cross-Reference
Radioactive Material Inventory File (continued)	
- counting instrument	Instrumentation and Dosimeters File
- disposal history	Waste Management File
Waste Management File	
General Records	
- assigned identification number	Radioactive-Material Inventory File
- physical description	
- chemical and radioisotope description	
- radioactivity and radiation measurements	
- previously responsible department/individual(s)	Personnel File
- storage location	Radiation Work Area File
- disposal details:	
- how, when, where	
- responsible individual	Personnel File
Transportation File	
Radioactive-Material Shipments	Radioactive-Material Inventory File
Accidents/Incidents File	
General Records	
- date and time	
- location	Radiation Work Area File
- description, cause	
- involved individual(s)	Personnel File
- corrective/protective actions	
- supporting data:	
- survey, sample results	Radiation Work Area File
- instruments, dosimeters	Instrumentation and Dosimeters File
- investigator(s)	Personnel File
Training File	
General Records	
- date	
- instructor/attendees	Personnel File
- description	

FLOW CHART 1. Occupational Exposure History

Problem: Recreate staff member's working conditions and verify exposure from July through December 1980.

PERSONNEL FILE

1. Worker ID
2. Projects worked on → **PROJECT FILE**
3. DD Form 1141
4. Exposure records between July and December 1980

PROJECT FILE

1. Project title and number
2. Principal investigator
3. Participants and dates of involvement
4. Location of work → **RADIATION WORK AREA FILE**
5. Radioactive materials used ↓ **RADIOACTIVE-MATERIAL INVENTORY FILE**

RADIATION WORK AREA FILE

1. Laboratory or work area
2. Project title
3. Survey records between July and December 1980
4. Person performing surveys
5. Survey instruments used → **INSTRUMENTATION AND DOSIMETERS FILE**

RADIOACTIVE-MATERIAL INVENTORY FILE

Unsealed Sources

1. Source ID
2. Amount and activity of source between July and December 1980

Sealed Sources

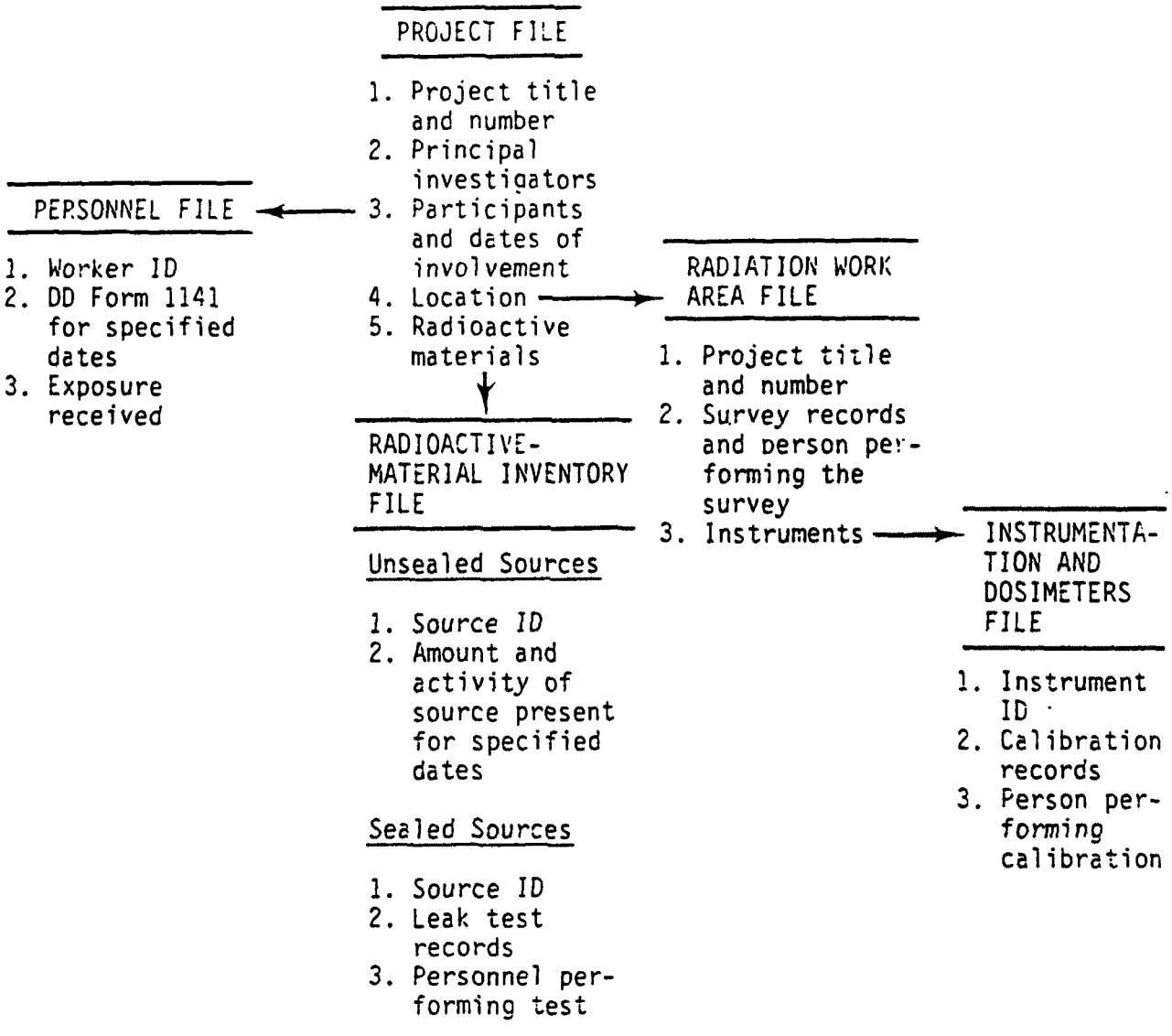
1. Source ID
2. Leak Test
3. Person performing leak test

INSTRUMENTATION AND DOSIMETERS FILE

1. Instrument ID
2. Calibration records
3. Person performing calibration

FLOW CHART 2. Project Characterization

Problem: Confirm or refute allegations of misuse of radioactive materials during a specific project that could have resulted in overexposures.



CHAPTER 14. QUALITY ASSURANCE PROGRAM

14.1 QUALITY ASSURANCE AND QUALITY CONTROL 14.3

14.2 DEFINITIONS 14.4

14.3 IMPLEMENTATION OF QUALITY ASSURANCE 14.5

14.3.1 Who Needs a Quality Assurance Program 14.5

14.3.2 How Extensive a Program Should Be 14.6

14.3.3 Who Determines the Extent of the Program 14.6

14.4 ELEMENTS OF A QUALITY ASSURANCE PROGRAM 14.7

14.4.1 Organization of the Quality Assurance Program . . . 14.7

14.4.2 Preparation and Documentation of the Quality Assurance Program 14.8

14.4.3 Control of Facility Design 14.9

A. Designs for Facilities 14.9

B. Independent Analysis of Designs 14.10

C. Design Verification 14.10

D. Design Changes and Documentation 14.11

14.4.4 Control of Procurement Documents 14.11

14.4.5 Instructions, Procedures, and Drawings 14.11

14.4.6 Document Control 14.12

14.4.7 Control of Purchased Material, Equipment, and Services . 14.12

14.4.8 Material Identification Control 14.12

14.4.9 Control of Special Processes 14.13

14.4.10 Control of Inspections and Tests 14.13

14.4.11 Control of Measuring and Test Equipment 14.13

14.4.12 Handling, Storage, and Shipment 14.14

14.4.13 Inspection, Test, and Operating Status 14.14

14.4.14 Nonconformance and Corrective Action 14.15

14.4.15 Quality Assurance Records 14.15

14.4.16 Audits 14.15

REFERENCES 14.16

CHAPTER 14. QUALITY ASSURANCE PROGRAM

The purpose of a radiation protection program is to provide control in the storage, handling, and use of radioactive material and radiation-generating machines, so as to minimize the hazard to personnel and the general public. Personnel responsible for the radiation protection program must implement established regulations and meet the requirements of the facility license. They are also responsible for ensuring that the radiation protection program accomplishes its purpose. Consequently, a surveillance plan is needed to verify that activities are conducted as desired and that regulations are met. A quality assurance program provides a means of controlling the radiation protection program and verifying that it is meeting the purposes for which it was established. It allows those responsible for a program or a facility to ensure that the quality required for safe and reliable operation is achieved.

This chapter provides a review of the elements of quality assurance and how they are incorporated into a radiation protection program. Special terms are defined near the beginning of the chapter, followed by a discussion of how a quality assurance program is implemented--when a program is needed and how extensive it should be. The elements of a quality assurance program, including the purpose of each element and the activities it involves, are then reviewed.

Section 14.1 QUALITY ASSURANCE AND QUALITY CONTROL

Quality assurance is sometimes confused with quality control. Quality assurance is all of the planned and systematic actions needed to provide adequate confidence that a structure, system, or component will perform satisfactorily in service. In other words, quality assurance is a planned program for verifying that each part of the radiation protection program is being carried out adequately and that the total program meets its purpose. It is the application of systematic management principles, such as planning, documenting, auditing, and verifying. Quality control is the quality assurance actions that relate specifically to the physical measurement of an

item, and it provides a means of controlling the quality of the item to predetermined requirements. Quality control is a part of quality assurance.

While quality performance is the responsibility of each individual, a planned quality assurance program provides a method of 1) ensuring that all the elements necessary for adequate radiation protection have been considered, and 2) verifying their implementation. The installation commander designates who is responsible for the quality assurance program, for example, a Quality Assurance Office, Plans and Programs Office, or Program Evaluation Office.

Section 14.2 DEFINITIONS

Some terms have a specific meaning when used in quality assurance programs. The terms used in this chapter are defined below.

1. Quality assurance - All of the planned and systematic actions needed to provide adequate confidence that a structure, system, or component will perform satisfactorily in service.
2. Quality control - The quality assurance actions that control the physical measurements of an item in accordance with predetermined requirements.
3. Analysis - The examination of a complex problem by separating it into its fundamental elements.
4. Appraisal - The evaluation of the worth, significance, or status of a program or item.
5. Audit - A formal, documented examination of an activity or program to verify compliance with established requirements.
6. Evaluation - The determination of the worth of something by careful appraisal and study.
7. Inspection - Examination or measurement to verify whether an item or activity conforms to specified requirements.
8. Surveillance - Monitoring or observation to verify whether an item or activity conforms to specified requirements.

9. Test - The determination of the capability of an item to meet specified requirements by subjecting the item to a set of physical, chemical, environmental, or operating conditions.

Section 14.3 IMPLEMENTATION OF QUALITY ASSURANCE

Because different operations involve different degrees of risk, not all facilities or operations require the same degree of quality assurance application. The level of control and assurance necessary for a specific facility or operation depends upon the importance and complexity of the operation and its effect on the safety of the facility, its personnel, and the public. For example, the quality assurance program for an instrument calibration facility requires rigorous control and documentation to ensure that instrument measurements are accurate and reproducible; control of radiation sources to ensure that they are traceable to nationally recognized standards; and records to ensure that regulations on the quality of instrument calibration and frequency are met. In contrast, an operation involving the use of a commercial device with an internal, sealed radioactive source may require only a periodic inventory to verify the location of the device, and a routine wipe survey to ensure that the source is intact and not leaking.

14.3.1 Who Needs a Quality Assurance Program

A quality assurance program should be developed for facilities or locations where the following take place:

1. radioactive material is received, stored, handled, or used
2. radiation-generating machines are operated
3. personnel radiation dosimetry is evaluated
4. radiation detection or measurement equipment is procured, received, repaired, calibrated, or used
5. facilities or equipment that will be used for these operations are designed, constructed, or modified.

Each facility or operation should have, as a minimum, a written quality assurance program that defines the extent and content of the program, the records required, and the audit activities needed to verify implementation of the program.

14.3.2 How Extensive a Program Should Be

Not every quality assurance program requires additional staff or a rigorous effort. The extent of the quality assurance program needed for a facility or operation should be determined from a thorough evaluation of the activities to be conducted, their potential effect on the safety of plant personnel and the public, and the requirements of applicable regulations and licenses. The quality assurance program should provide documented, verifiable evidence to support the reliability and effectiveness of the radiation safety program, and compliance with regulatory and license requirements.

Radiation protection actions for which a quality assurance program should be developed include, but are not limited to:

1. dose evaluation for all personnel who work at the facility and for all visitors
2. receipt, inventory, shipping, and disposal of radioactive material
3. radiation and contamination surveys
4. detection, measurement, and evaluation of airborne radioactivity
5. procurement, receipt, maintenance, repair, and calibration of radiation detection and measurement equipment
6. personnel qualification, training, and retraining
7. radioactive-effluent releases and environmental monitoring
8. facility design and modification
9. abnormal occurrences and investigations of them.

14.3.3 Who Determines the Extent of the Program

The extent of a quality assurance program should be determined by the manager responsible for the overall performance and safety of a facility or operation. In most instances, this responsibility is assigned one level above

the person responsible for the facility's radiation protection program. The person responsible should use the general guidelines provided above to develop a quality assurance program as extensive as is needed to assure adequate radiation protection. In some instances, parts of the quality assurance program may be established by regulatory requirements or by the recommendation of the Ionizing Radiation Control Committee.

Section 14.4 ELEMENTS OF A QUALITY ASSURANCE PROGRAM

A quality assurance program is composed of numerous elements. Each one is intended to provide surveillance of a major aspect of the radiation protection program. All elements may not be needed in a particular facility or operation, but each should be considered when the quality assurance program for that facility is being established. How far each element of the quality assurance program is developed depends upon the degree of control required.

14.4.1 Organization of the Quality Assurance Program

A defined organizational structure should be established for the quality assurance program to ensure the effective management of quality assurance activities. The organizational structure, functional responsibilities, levels of authority, and lines of communication for operations affecting the quality of the radiation protection program should be written down. All individuals in the program should know what their jobs are, what authority they have to accomplish their work, and to whom they should report problems so that corrective action will be taken.

The person or organization responsible for developing and implementing the quality assurance program should be specified. This person or organization should have sufficient authority, access to work areas, and organizational freedom to 1) identify quality problems; 2) recommend or provide solutions to quality problems through designated channels; 3) verify that the solutions have been implemented; and 4) ensure that any further processing, delivery, installation, or operation is controlled until the problem has been corrected. The person or organization should have direct access to responsible management at a level where appropriate action can be taken.

The organizational structure should be designed and individual responsibilities should be assigned so that quality is achieved and maintained by those responsible for a job and is verified by persons or organizations not directly responsible for the job. In some instances, it may not be possible or practical to assign a separate organization or person to verify the achievement of quality. In those instances, the quality assurance responsibilities should be written carefully to ensure that they do not conflict with the job responsibilities of the individual assigned to carry out multiple duties. It may be appropriate to have an outside organization provide quality assurance. In all cases, the individual's or organization's responsibility and authority should be clearly defined and documented.

14.4.2 Preparation and Documentation of the Quality Assurance Program

The quality assurance program should be documented as a means of defining the program, providing a basis for review, and ensuring continuity. Adequate planning is needed before the quality assurance document is written to ensure that all necessary elements have been included. The program should:

1. provide control over operations affecting the quality of the radiation protection program, to whatever extent is consistent with the importance of those operations
2. identify the operations, processes, and equipment to which the program applies
3. include consideration of the technical aspects of quality assurance actions
4. be established as early as possible consistent with the schedule for accomplishing the operation
5. provide for any special controls, processes, test equipment, tools, and skills needed to attain the required quality and for necessary verification of quality
6. provide for the training of personnel performing operations that affect quality, to ensure that they can do the job adequately

7. provide for regular management assessment of the adequacy and effective implementation of the quality assurance program.

Not all operations in a facility or program require formal quality assurance consideration. Those operations that are important for adequate radiation protection and/or that must be performed consistently should be included in the quality assurance program plan. The program should specify the qualifications, training, and skills required of quality assurance personnel; the type, frequency, and method of audits, inspections, and tests for the assurance of quality; and the system for reporting, correction, and follow-up on any unsatisfactory condition that may be identified. If an extensive quality assurance program is necessary, additional details on planning the program may be found in the American National Standards Institute's (ANSI's) standards and in the Nuclear Regulatory Commission's (NRC's) regulatory guides. (See the bibliography at the end of this manual.)

14.4.3 Control of Facility Design

It is particularly important that radiation protection requirements be included in the design of new facilities or the modification of existing facilities in which radioactive material will be stored, handled, or processed or in which radiation-generating machines will be operated. Engineered features for controlling radiation and contamination are most cost-effective, and some are only feasible, when included in the original design and construction or in a major modification of a facility. The design for facilities should therefore be defined, controlled, and verified to ensure that radiation protection requirements are met, that the design is approved by appropriate authorities, and that construction meets the design specifications.

A. Designs for Facilities. Appropriate design bases, performance requirements, regulatory requirements, and codes and standards should be identified and documented, and their selection reviewed and approved. For radiation protection purposes, the ventilation criteria, shielding provisions, equipment reliability and maintenance, personnel traffic patterns and occupancy zones, and waste-handling systems must be reviewed specifically for how well they will protect personnel and keep radiation doses as low as is reasonably achievable (ALARA). If designs are changed, the changes and the reason for the

changes should be identified, approved, and documented to ensure that alterations that could affect radiation protection are adequately reviewed. The purpose of quality assurance in this process is to verify that these steps are taken and that reviews and approvals are completed by appropriate personnel.

The organization responsible for the design should document its actions in enough detail so that the design process can be carried out and it is possible to verify that the design meets requirements. The design of the facility, and the materials, equipment, and processes that are essential to radiation protection and exposure control, should be selected and reviewed for suitability of application.

B. Independent Analysis of Designs. It may be advisable to provide for an independent analysis of the design of facilities and equipment, to ensure that all factors have been considered and that the resulting designs are correct. The independent analysis should be performed by individuals who are technically qualified in the subject and independent of the original designers. These persons may vary from electrical experts, who ensure that electrical load-carrying capacities are adequate, to health physicists, who ensure that shielding factors for shielding casks are correct.

The analysis should be documented in enough detail so that a person technically qualified in the subject can review the analysis and verify the findings. Documentation of an analysis should include the purpose of the analysis, pertinent sources of data and supporting information, and review and approval. Here again, the quality assurance function is to verify that analyses, reviews, and approvals required as part of the quality assurance program have been completed.

C. Design Verification. Designs for important facilities should be verified to ensure that the design was performed correctly and that the final product as provided for in the design will perform the function described in the design criteria.

Designs should be verified by competent personnel other than those who drew up the original design. The design verification results should be documented and the verifier identified. The extent of the design verification

required depends on the importance to safety of the item under consideration, and verification methods may include analyses, simple reviews, alternate calculations, and/or qualification testing.

D. Design Changes and Documentation. Once a design has been approved, any changes, including field changes, should be controlled in the same manner as the original design.

The design documentation and records, which provide evidence that the facility was designed and the design was verified as required, should be generated and maintained in accordance with documented procedures.

14.4.4 Control of Procurement Documents

A fourth function of a quality assurance program is to ensure that documents generated for the procurement of items or services include enough information (applicable design bases, technical requirements, specifications, drawings, instructions, etc.) so that the items being procured will be adequate in quality; they must fit, work properly, and do the job required.

The procurement documents should identify the means (tests, inspections, documentation) that the purchaser will use to determine the acceptability of the items. If certain aspects of acceptability cannot be determined at this point, the procurement documents should specify the quality assurance requirements necessary in the supplier's plant.

Procurement documents and changes to them should be reviewed and approved by the purchaser to ensure that they are clear and detailed enough so that the supplier can provide the items or services that meet the specified requirements.

Depending upon the type and use of the item or service being procured, it may be necessary to include in procurement documents the requirement that suppliers also have and implement a documented quality assurance program.

14.4.5 Instructions, Procedures, and Drawings

Operations that affect the quality of the radiation protection program must be reproducible, and complex operations should be performed in accordance with documented instructions, procedures, or drawings as appropriate to the circumstances, to ensure consistent and adequate performance. Such operations include tests, equipment control, calibration of instruments, and surveys.

14.4.6 Document Control

Documents tnat specify quality requirements or prescribe operations affecting quality should be prepared, issued, and changed in a controlled manner to ensure that correct documents are being used. These documents, including changes to them, should be reviewed for adequacy and approved for release by authorized personnel.

The document control system should identify which documents are to be controlled; who is responsible for preparing, reviewing, approving, and issuing them; how their adequacy, completeness, and correctness is to be ensured prior to issuance; and the methods of ensuring that documents in use are current and that outdated or inappropriate documents are removed from use.

14.4.7 Control of Purchased Material, Equipment, and Services

The procurement of material, equipment, and services should be controlled to ensure conformance with the requirements specified in the procurement documents. Procurement operations should be planned and documented and should include the preparation and review of procurement documents and control of changes to them (see item 14.4.4 above); selection of procurement sources; the evaluation of bids and the award of a contract; purchaser control of supplier performance, if warranted by the circumstances; any necessary verification actions, including surveillance, inspection, or audit of the supplier; plans for controlling and disposing of material, equipment, or services that do not meet requirements; methods of correcting problems occurring in the procurement process; acceptance of material, equipment, or services; and the quality assurance records needed. Most purchased material, equipment, and services should be inspected when they are received from the supplier to ensure that they meet the requirements of the procurement documents and the purpose for which they were purchased.

14.4.8 Material Identification Control

Controls should be established to ensure that only correct and accepted items are used or installed. Identification should be maintained either on the items or in documents traceable to the items.

Items with a limited calendar or operating life should be identified and controlled to prevent their use after their life has expired. For instance, batteries, some adhesives, rubber products, chemicals, and radioactive sources may degrade in storage as well as in use and may need to be controlled to ensure their effectiveness when needed.

14.4.9 Control of Special Processes

Measures should be established and documented to ensure that special processes such as welding, heat treating, cleaning, nondestructive examinations, and analytical evaluations are carried out by qualified personnel and under controlled conditions, in accordance with applicable codes, standards, and specifications, and other special requirements. The qualifications of personnel performing special processes should comply with the requirements of applicable codes and standards. If no such codes or standards exist, the requirements for personnel qualifications should be defined and documented.

14.4.10 Control of Inspections and Tests

Inspections and tests to verify that an item or operation conforms to specified requirements should be planned and documented. The characteristics to be inspected or tested, the methods of inspection or testing, and the criteria for evaluating the results and documenting whether the item or operation is acceptable should be identified.

Records of inspections and tests should include the identity of the item or operation involved, the date, the name of the inspector, the type of inspection or test given, and the results.

14.4.11 Control of Measuring and Test Equipment

Tools, gauges, instruments, and other measuring and test equipment used for operations affecting quality should be controlled to ensure that they meet the defined specifications, are used as designed, and provide the necessary quality of measurement and test data. Measuring and testing equipment should be of the type, range, accuracy, and tolerance needed to accomplish the function intended. At prescribed intervals, or before its use, or whenever its accuracy is suspect, measuring and test equipment should be calibrated and adjusted against certified equipment that has known valid relationships to nationally recognized standards.

Devices that are out of adjustment should be tagged or segregated and not used until they have been recalibrated. Equipment should be properly handled and stored to maintain its accuracy. Records should be kept and equipment should be suitably marked to indicate its calibration status.

14.4.12 Handling, Storage, and Shipment

To prevent damage or deterioration of material and equipment, measures should be established for their handling, storage, shipping, cleaning, and preservation in accordance with work and inspection instructions. When necessary for particular products, special protective environments such as an inert-gas atmosphere, specific temperature levels, absorbent material, and shielding should be specified and provided.

Instructions for marking and labeling items for packaging, shipping, handling, and storage should be established. Any need for special environments or controls should be indicated on the label.

14.4.13 Inspection, Test, and Operating Status

Measures for identifying the inspection and test status of equipment should be established and documented. The status should be known throughout the manufacturing, installation, and operation of the equipment. The inspection and test status should be maintained through the use of status indicators such as physical location, tags, markings, stamps, or inspection and test records. Only items that have passed the required inspections should be installed or operated.

Procedures should be developed to ensure that operations are conducted in accordance with applicable documented instructions and procedures and that items perform satisfactorily in service. Measures such as tagging should also be used to indicate the operating status of systems and components, and to prevent any inadvertent, unplanned use of equipment.

The emergency response capability of the facility (personnel and equipment) should be included in this program. Annual testing of emergency response must be conducted and adequate performance verified.

14.4.14 Nonconformance and Corrective Action

Controls should be established to ensure that failures, malfunctions, and defects in equipment and nonconformances to procedures and processes are promptly identified and corrected. In the case of a significant problem, the controls should ensure that the cause of the problem is determined and that corrective action is taken. The problem, its cause, and the corrective actions needed should be documented and reported to appropriate levels of management. Follow-up action should be taken to verify implementation of corrective action.

Items that do not conform to requirements should be controlled to prevent their inadvertent use. Control provisions should include identifying and disposing of the items and notifying affected organizations.

14.4.15 Quality Assurance Records

Records should be kept identifying operations that affect quality and showing that regulatory and license requirements have been met. The records should be legible, identifiable, and retrievable, and should be protected against damage, deterioration, or loss. Quality assurance records should be centrally maintained by the individual or organization assigned the responsibility for the quality assurance program. Alternate designees may be acceptable. However, in all programs, requirements and responsibilities for record transmittal, distribution, retention, maintenance, and disposition should be established and documented.

The types of records needed for verification of the radiation protection program include radiation exposure records, bioassay data, radiation and contamination survey reports, calibration records, and training records. A more complete listing of required radiation protection records is located in ANSI N13.6-1972.

14.4.16 Audits

Audits by personnel responsible for quality assurance should be scheduled periodically (depending on the importance of the activity being audited) to verify compliance with all aspects of the quality assurance program and to determine the effectiveness of the program. Trained auditors who are not

directly responsible for the areas being audited should follow written procedures or checklists. Audit results should be documented and reviewed by responsible management, and any necessary follow-up action should be taken.

REFERENCES

American National Standards Institute (ANSI). 1972. Practice for Occupational Radiation Exposure Records Systems. ANSI N13.6-1966, Rev. 1972, New York.

CHAPTER 15. APPRAISAL OF RADIATION PROTECTION PROGRAMS

15.1 CONDUCTING A TECHNICAL APPRAISAL 15.5

15.1.1 The Appraisal Team 15.6

15.1.2 The Appraisal Process 15.6

15.1.3 Report of Appraisal Findings 15.7

15.2 PROGRAM AREAS THAT SHOULD BE APPRAISED 15.8

15.2.1 The Radiation Protection Organization 15.8

15.2.2 The Selection and Training of Personnel 15.10

A. Selection of the Radiation Protection Staff . . 15.10

B. Routine Training Programs 15.11

C. Emergency Preparedness Training 15.13

15.2.3 The Radiation Survey Program 15.13

A. Responsibilities and Scope of the Program . . . 15.14

B. Instrumentation Suitability and Use 15.14

C. Records 15.15

15.2.4 The Program for Internal-Exposure Control . . . 15.16

A. Exposure Limitation Methods 15.16

B. Dosimetry Program 15.18

C. Exposure Review 15.19

D. Quality Assurance Program for Internal Dosimetry . 15.19

15.2.5 The Program for External-Exposure Control . . . 15.20

A. Exposure Limitation Methods 15.21

B. Dosimetry Program 15.21

C. Exposure Review 15.22

D. Quality Assurance Program for External Dosimetry . 15.22

15.2.6 The ALARA Program 15.22

15.2.7 Facilities and Equipment 15.23

A. Facilities 15.23

B. Protective Equipment 15.24

15.2.8 Management of Radioactive Waste 15.25

15.2.9 Records and Audits 15.25

15.3 CHECKLIST OF QUESTIONS FOR APPRAISING A RADIATION PROTECTION PROGRAM 15.26

15.3.1 The Radiation Protection Organization 15.26

15.3.2 The Selection and Training of Personnel 15.27

15.3.3 The Radiation Survey Program 15.28

15.3.4 The Program for Internal-Exposure Control . . . 15.29

15.3.5 The Program for External-Exposure Control . . . 15.31

15.3.6 The ALARA Program 15.32

15.3.7 Facilities and Equipment 15.33

15.3.8 Management of Radioactive Waste 15.33

15.3.9 Records and Audits 15.34

15.4. NETWORK TECHNIQUES FOR PLANNING APPRAISALS 15.35

15.4.1 The Function of Networks and Logic Trees 15.35

15.4.2 Using Logic Trees to Plan a Radiation Protection Appraisal 15.38

REFERENCES 15.43

FIGURES

15.1 Critical Paths for an Adequate Survey 15.36

15.2 MORT Logic Tree 15.37

15.3 Logic Tree for a Process To Be Operationally Ready . . . 15.37

15.4 Radiation Protection Program, First Tier 15.38

15.5 Radiation Protection Program, Second Tier--Routine Operations 15.39

15.6 Radiation Protection Program, Second Tier--Emergency Operations 15.39

15.7 Upper Tiers for Logic Tree Depicting Radiation Protection Program 15.40

15.8 Logic Tree Tiers Depicting Internal-Exposure Control Program 15.41

CHAPTER 15. APPRAISAL OF RADIATION PROTECTION PROGRAMS

A variety of methods can be used to ensure that a radiation protection program is providing a reasonable degree of safety. One method, a quality assurance program, was discussed earlier. This chapter focuses on the use of a comprehensive appraisal.

An appraisal is a means of comprehensively evaluating the overall adequacy and effectiveness of the radiation protection program. Unlike a compliance inspection, which is an evaluation of a program by discrete subject areas, an appraisal is an integrated look at the total program. That is, it looks at the total program needs, not just at regulatory compliance. It is focused on identifying and correcting the underlying causes of deficiencies rather than on identifying failures to follow specific procedures or regulatory requirements.

The routine appraisal of a radiation protection program entails verifying that the program is effective in protecting personnel, property, and the environment. This goal can be accomplished through a thorough, technical health physics appraisal by experts, and follow-up by management to ensure that any problems found during the appraisal have been corrected and that staff members are being protected.

This chapter includes a brief overview of the steps for conducting a technical appraisal; a discussion of the areas of a radiation protection program that should be included in an appraisal; a checklist of questions for use during appraisals; and an introduction to network techniques that can be used to help plan an appraisal.

Section 15.1 CONDUCTING A TECHNICAL APPRAISAL

A thorough technical appraisal usually begins with the selection of a team of individuals who are familiar with the requirements of a health physics program and with applicable standards and regulations, and who have the ability

to conduct appraisals. The team members review site documents and then conduct an onsite appraisal that includes discussions with personnel, observation of work practices, and reviews of procedures and reports. Their findings are then reported in writing.

15.1.1 The Appraisal Team

In order to characterize the radiation protection program and identify any deficiencies, it may be necessary to expand the onsite staff with additional personnel who are experts in the field of health physics or to bring in a team of outside consultants who have experience in broad-based health physics programs and who have conducted appraisals. This expanded-team approach, using outside expertise, provides objective viewpoints and reduces the time required for the technical appraisal. In addition, a team approach allows team members with varying backgrounds to interact as they investigate deficiencies and recommend solutions. Their interactions and discussions can help identify problem areas and clarify the causes of symptomatic deficiencies.

The members of the appraisal team should be selected based on the type and size of the radiation protection program to be evaluated. Each team member should have both a broad and thorough knowledge of health physics, and an area of expertise that complements those of the rest of the team. The appraisers should be familiar with current standards, regulatory guides, and regulations, and should have shown through prior appraisal experience that they have an aptitude for conducting appraisals.

A leader of the appraisal team should be selected. This individual disseminates documents, briefs the installation commander, assigns areas of responsibility to other team members, and functions as the team coordinater to ensure that all areas are covered.

15.1.2 The Appraisal Process

The appraisal process begins with a thorough review of site documents, which are distributed to the appropriate team members by the appraisal team leader. These documents should include: 1) the operating license, 2) the environmental impact statement or environmental analysis, 3) program objectives, 4) related missions, 5) organizational charts, 6) job descriptions,

7) performance objectives, 8) training records, 9) work utilization, scheduling, and budget documents, 10) radiation safety manuals, 11) health physics procedures, 12) chemistry procedures, 13) respiratory protection programs, 14) applicable regulations, 15) the emergency plan, 16) procedures for implementing the emergency plan, 17) dosimetry records, 18) survey records, 19) minutes of meetings of the radiation protection committee, 20) reports on previous inspections and appraisals, and 21) any other documents needed to complete the appraisal. During the review and preparation period, each team member should:

1. review the documents received from the team leader to identify tasks that are crucial to detecting and assessing radiation levels, notifying appropriate staff and officials, and implementing protective action
2. identify the individuals responsible for crucial tasks
3. identify the minimum equipment, procedures, and instruments required for the performance of those tasks
4. identify any deficiencies in standard operating procedures (SOPs)
5. identify any deficiencies in emergency plans and procedures.

The time planned for the appraisal should be long enough to allow the team to talk with installation personnel and radiation workers, review and observe work practices, and review onsite radiation protection procedures and records relating to exposures, incidents, etc. The appraisal team should also meet with the installation commander and any other managers between the radiation protection staff and the commander, to ensure that the radiation protection staff has sufficient support to carry out the routine ALARA program (keeping exposures as low as is reasonably achievable) and to handle any abnormal occurrences.

15.1.3 Report of Appraisal Findings

At the completion of the appraisal, a report should be written specifying whether each major component of the radiation protection program was found to be adequate. The total program should also be rated as acceptable, adequate for present operations but having significant weaknesses, or not acceptable.

Deficiencies or weaknesses are considered significant when they have a direct effect on the level of protection provided or when they play a critical part in whether a portion of the program is judged acceptable. For example, failure to calibrate instruments or provide adequate dosimetry would be a significant deficiency that would make all or part of the program unacceptable depending on the necessity of the devices to the overall safety of the program. Isolated weaknesses and minor problems should not be judged as representing a significant finding. However, if a number of deficiencies are found within a particular phase of the program, then an assessment that significant problems exist may be warranted for that phase. If a deficiency or weakness requires immediate attention, the problem should be discussed with the Radiation Protection Officer (RPO) and the cognizant manager, and an immediate solution should be agreed on.

Section 15.2 PROGRAM AREAS THAT SHOULD BE APPRAISED

The elements that make up an effective radiation protection program are the radiation protection organization, the selection and training of personnel, survey programs, programs for the control of internal and external exposure, the ALARA program, facilities and equipment, waste management, and records and audits. Some of the aspects of each area that should be covered both in management reviews and in technical appraisals by health physics experts (members of the appraisal team) are discussed below.

15.2.1 The Radiation Protection Organization

The appraisal of a health physics program begins with an evaluation of the radiation protection organization. Both onsite and offsite support for the radiation protection program should be reviewed. For example, if the Ballistics Research Laboratory has an agreement with ARRADCOM, Dover, New Jersey, or with the Material Test Directorate, Aberdeen, Maryland, to provide health physics support either routinely or during emergencies, then the appraisers should ensure that the supporting organization is aware of the

magnitude of support needed by the requesting organization. The RPO's management should ensure that there are written agreements delineating responsibilities. Additionally, if offpost use of radionuclides is authorized, the appraisers should review the procedures and licenses involved to ensure that they are adequate.

To ensure awareness of responsibilities, an organizational chart depicting the onsite and offsite radiation protection organization, together with the total command, should be available to everyone. This chart should clearly show that the RPO has a direct reporting chain to the base commander. The purpose of this direct access is to ensure the authority to stop work in the event of potential or actual hazardous situations. A written statement of the duties, authorities, and responsibilities of the RPO and the radiation protection staff should also be available. If contractors and private organizations (e.g., fire departments or hospital emergency staff) provide technical assistance to and augmentation of the emergency organization, they should be specified and their roles clearly defined.

Within the radiation protection organization itself, authorities and responsibilities should be clearly assigned. Job descriptions are frequently useful in delineating the scope of responsibilities and ensuring a thorough transition during staff turnovers. The appraisers should also ensure that the radiation protection staff feel they have the authority to implement the radiation protection program. The management review would include a check to ensure that the RPO and the staff have job descriptions, are aware of their responsibilities, and are fulfilling those responsibilities.

The responsibility for preparing emergency plans and procedures is frequently assigned to an individual, in addition to his or her primary duties, without any allocation of the authority, manpower, time, or money needed to accomplish the task. Because the emergency planning program involves a number of persons and organizations, the extent of emergency planning necessary at each site should be carefully evaluated, and the organizations participating in the planning should be aware of who in the radiation protection organization is responsible for coordinating the program.

The appraisers should ensure that the staff of managers, supervisors, and radiation workers is adequate for the amount of radiation work performed at the site, both for operations during the day and for operations after normal working hours. There should be enough radiation protection technicians to perform assigned responsibilities for routine operations, and at installations with a large radiation work force, the staff of radiation protection technicians should include specialists in such areas as dosimetry, respiratory protection, and ALARA review. The technical support personnel should be relieved from clerical duties as much as possible by administrative support personnel, especially during emergencies. There should be emergency plans for supplementing the radiation protection staff within 18 hours of a major accident. This procedure will reduce the potential for mistakes caused by fatigue.

15.2.2 The Selection and Training of Personnel

The quality of the radiation protection program depends on the qualifications of the RPO and on the support the RPO receives from management and the staff. During an appraisal, therefore, the appraisers should review the criteria used to select the site's RPO and radiation protection staff, verify that the RPO and the staff meet these criteria, and assess the programs used to train personnel.

The routine management review should include verification that there are job descriptions for the RPO and the radiation protection staff. These descriptions should be discussed with the individuals to ensure that they are up-to-date and accurately reflect the current work assignments. In conjunction with the work assignment, emergency and routine training should be reviewed. This review would include verification that:

1. training classes are scheduled
2. training is provided as specified
3. radiation workers receive annual training
4. training records are up-to-date.

A. Selection of the Radiation Protection Staff. The criteria used in selecting a site's RPO should be based on the type of work conducted at the installation and the size and type of radiation program involved. However, in all instances, the qualification criteria should include consideration of the

individual's formal education, continuing education, work experience, previous management experience, and technical understanding of health physics. The individual selected should have demonstrated experience in the area that he or she is to manage.

The RPO should be responsible for developing selection criteria for each position in the radiation protection organization and for selecting the technicians who help run the program. The appraisers should ascertain whether the selection criteria are related to the individual jobs and whether they include an assessment of formal education and experience. These criteria should be used for both hiring and promotions, and the staff should be aware of the promotion requirements.

B. Routine Training Programs. The members of the appraisal team who are responsible for appraising a site's training program should have considerable experience in radiation protection training. This experience is necessary in determining whether the training provided is adequate in content, nature, and length. The training must be assessed against 10 CFR 19, against the training requirements for and the complexity of a program, and against the authority for the program. Consideration must be given to the type of work authorized for and conducted on the site.

The training program should be assessed in two parts: training for radiation workers and other staff members, such as medical personnel, public information officers, and security support staff, and training for the radiation protection staff. Training for both groups should include the following:

1. a defined scope and written content for the program
2. instructors qualified in the subjects they are teaching
3. instruction schedules and lesson plans
4. objectives for trainee performance
5. demonstration of standards attained by trainees
6. frequency of required attendance
7. documentation of attendance (including test results, dates, subjects, etc.).

Formal on-the-job retraining should be provided periodically for all individuals.

The following topics should be included in each training program:

1. the specific duties and responsibilities of those being trained
2. the site's reporting or communications chain
3. site-specific or job-specific hazards
4. industrial and radiation safety
5. special procedures
6. special protection (e.g., the use of respirators and protective clothing)
7. the ALARA philosophy.

Training should include instruction in the capabilities and limitations of any instruments to be used. Special procedures and the reasons the procedures are needed should be written down and explained to everyone involved.

An adequate training program should not consist solely of classroom instruction, demonstrations of equipment to the group, and the use of maps or building drawings to point out the location of equipment, work stations, or emergency response duty stations. Rather, training should include hands-on use of equipment and tours of areas that the trainees may need to enter in the course of their work.

The individuals evaluating the training program should attend the training classes to verify the level of instruction. Their evaluation should also include a thorough review of class records for the previous 2 years, discussions with randomly selected individuals to verify that they received and understood the training shown in their records, evaluation of the training aids used, and discussions with the instructors, the supervisors of radiation workers, the radiation protection staff, and the RPO. In evaluating training for the radiation protection staff, the appaisers should also ascertain whether the operators of counting and analysis systems are qualified to operate them and are using them properly. The appraisers should verify that

when new instrumentation is put into use, the staff is retrained in the state of the art for that instrumentation and the range of its capabilities.

C. Emergency Preparedness Training. Training the staff, especially the radiation protection staff, for emergencies is extremely important because emergency situations precipitate changes in reporting chains, the scope and nature of duties, and the perceptions of individuals. Individuals under stress may revert to established behavior patterns; training can help establish patterns appropriate to emergencies and eliminate the randomness of purpose that is characteristic of such situations. The appraisal of the emergency preparedness training program should involve ascertaining whether individuals will respond appropriately when under stress.

The emergency preparedness training program should contain provisions for training the members of support organizations (e.g., the fire department and ambulance service). The purpose of the training should be to ensure mutual understanding of roles, procedures, and interfaces. Although the command cannot always require offsite groups to participate in training sessions, the appraisers should assess the capabilities of these groups to support the RPO and the radiation protection staff in emergencies.

15.2.3 The Radiation Survey Program

The purpose of the radiation survey program is to evaluate actual or potential radiation hazards at facilities where radiation sources are used. The scope of survey activities should be clearly stated for all installations.

The primary emphasis of management's review of the survey program should be verification that survey procedures exist in written form and that the procedures are followed when surveys are conducted. Records should contain the latest surveys and include all required information. The instrument storage facility, the general condition of the instruments, the condition of the emergency kit, the records showing dates for instrument calibration, whether the dates are being met, and whether outdated instruments are being used should also be reviewed.

A. Responsibilities and Scope of the Program. The RPO should be responsible for the design, development, and maintenance of the survey program and should ensure that there are procedures for performing routine and periodic surveys of airborne and surface contamination. The extent of the surveys should be consistent with the hazards and work conditions at the installation. If any special or unusually complex surveys are performed by an offsite team or consultant, the RPO should ensure that the agreement for this work is well defined and should specify the individual or individuals responsible for monitoring the work.[1]

The appraisers should ensure that the RPO has adequately defined the scope of the survey program to include all potential radiological hazards at the installation. They should review the scope and the frequency of the survey routines to ensure that they are adequate for the needs of the program and consistent with regulatory requirements. The appraisers should also determine whether the radiation protection staff and/or the RPO review the routine and periodic survey data and assess the need for possible additional actions.

B. Instrumentation Suitability and Use. The appraisers should determine whether the instrumentation used in the survey program meets the minimum standards required by regulations and the site's license. The instrument technician or RPO should be required to demonstrate that the quantity, type, range, and sensitivity of portable instruments are sufficient for the scope of routine and nonroutine health physics activities. Instruments should provide the type of measurements required for the program.

The appraisers should evaluate the calibration program using reference documents such as Standard N323-1978 of the American National Standards Institute (ANSI). This standard is a general document on instrument testing and calibration that contains extensive technical information. It includes functional testing criteria and calibration methods, and specifies sources, calibration facilities, calibration frequencies, and required records. All calibration sources should be traceable to the National Bureau of Standards (NBS).

The RPO should be responsible for ensuring that a thorough evaluation of the best location is made before a fixed or semifixed instrument is set up. These instruments should be positioned to allow for ease in operational checks, calibrations, and maintenance.

Monitoring for airborne radioactive materials should involve the use of breathing-zone samplers, area air samplers, portable and semiportable air samplers, and grab air samples. The appraisers should observe several air samples being taken and should review air-sampling records to ensure that the proper procedures are being followed and that the air samples taken are representative of the air being breathed by workers. If the persons taking the samples fail to consider air currents and the dilution and turbulence caused by work activities, the samples taken may not represent the air being breathed.

The appraisers should determine whether emergency kits and survey instruments have been placed at appropriate locations. If so, the instruments should be evaluated to determine their suitability for each location.

The RPO should be responsible for specifying the methods and equipment to be used for routine surveys of offsite locations and for emergency offsite radiological surveys. For all onsite and offsite surveys, each member of the survey team should be required to record the following information:

1. date and time of each survey
2. location of each survey
3. name(s) of the individual(s) who performed the survey
4. the instrument used, identified by type and serial number
5. the mode in which the instrument was used (i.e., window open or closed)
6. the duration of the meter or instrument reading
7. air sampler flow rates
8. background radiation levels at the time of air sample counting
9. sample count time
10. work condition at the time of sampling.

C. Records. The appraisers should ensure that the RPO verifies the documentation of all surveys. Survey reports should be clearly written and traceable as to instrument, date, time, location, and project. The records of SOPs should correctly reflect the job and work conditions. The appraisers

should thoroughly review the records to determine whether the RPO ensures that survey results are distributed to staff members and supervisors as necessary.

15.2.4 The Program for Internal-Exposure Control

Management review of the program for internal-exposure control recuires both a walk-through and a review of records. The purpose of the walk-through is to ensure proper posting; proper cleanup of contaminated areas; proper storage of respirators (individually wrapped and stored in a closed container); proper wearing of respirators; storage of radiaoctive liquids in nonbreakable containers or in locked storage containers; proper wearing of lapel air samplers; proper positioning of breathing-zone samplers; and proper storage of air-monitoring equipment. In addition to the walk-through reviews, management should ensure that internal-dosimetry records are maintained for everyone who has received an internal dose, is suspected of having received an internal dose, or has entered an area containing airborne radioactivity, whether with or without a respirator. The manager should also review individual dose records to ensure that they are up-to-date; calibration records for bioassay, air-monitoring, and air-sampling equipment to ensure that they are up-to-date; the RPO's trend analysis for indication of increased activity; all operations to ensure that there are procedures for each; and the RPO's records of surveys versus maximum permissible concentration-hours (MPC-hrs) to ensure that the RPO has a method for interpreting whole-body-counting data that relate to the working environment.

Individuals working with radioactive materials may work with unencapsulated sources in physical forms or in chemical solutions. When these materials are unintentionally released from their containers, they can be inhaled, ingested, or absorbed through the skin. Therefore, radiation protection programs for such workers should include 1) methods to limit internal exposures, 2) an internal-dosimetry program, 3) reviews of exposures, their causes, and the corrective actions taken, and 4) a quality assurance program. All of these aspects of the program for internal-exposure control should be reviewed during the technical appraisal.

A. Exposure Limitation Methods. Two important methods of limiting internal exposures are administrative and engineered safeguards.

(1) Administrative Safeguards. The administrative approach to controlling internal exposures usually consists of site-assigned dose limits and written procedures. The limits should be considered in the establishment of procedural and physical controls. The written procedures should be well disseminated and read by all radiation workers and support personnel who may have reason to go into an area of potential airborne radioactivity. The appraisers should ensure that the procedures define clearly when protective clothing and equipment are needed and include a means of ensuring that only qualified personnel use respirators.

The procedures should define the requirements for posting controlled-access areas and areas where airborne or other contamination is known to exist. The appraisers should ensure that suitable measures are taken to minimize leakage, control local releases, and clean up contaminated areas, and that there are adequate plans for expanding the respiratory protection program in the event of an accident.

(2) Engineered Safeguards. Engineered safeguards against internal exposure are provided by containment and ventilation systems, contamination control, alarm systems, and respirators. The reviewers appraising the control of internal exposure should begin by reviewing the first three of these items to ensure that every effort has been made to minimize the number and size of areas containing airborne radioactivity.

Respirators are the primary physical device for minimizing internal exposures. The use of respirators in either an NRC-approved or a nonapproved program to reduce the potential for inhalation of radioactive material constitutes a respiratory protection program. The commitment to a quality respiratory protection program should begin with a written policy statement on respirator usage issued by a high management level (e.g., by the installation commander). This policy statement should discuss the objectives of the program and assign the responsibility for its operation to the RPO.

The issuance, maintenance, and repair of respirators, and the training of personnel for their use, should meet the guidelines found in such documents as the Nuclear Regulatory Commission's NUREG-0041 (NRC 1976). Before beginning the appraisal of the respiratory protection program, the appraisers should

ensure that they are intimately familiar with these support documents. The degree to which NUREG-0041 is applied at a site will depend on the peculiarities of the individual program. However, the appraisers should ensure that every program includes at least the following items: medical examination of each respirator user by a qualified physician, including pulmonary measurements; training in proper respirator use; use of only those respirators approved by the National Institute of Occupational Safety and Health (NIOSH); an inspection program to ensure that breathing air meets the requirements of ANSI Z88.2 (1980) and the Occupational Safety and Health Administration (OSHA); and a program for cleaning and maintaining respirators for both hygienic and contamination control purposes.

The individuals responsible for training radiation workers in the proper use of respirators should have received their training directly from a certified respirator manufacturer. Their training should have included proper fitting of masks and repair procedures.

B. Dosimetry Program. An internal-dosimetry program consists of measurements of the concentration of airborne radioactive materials in the workplace; bioassay measurements, for estimating the quantity of radioactive materials deposited in various body organs; measurements for determining ionizing-radiation doses to body organs; and techniques for assessing these measurements.

The appraisers should determine whether the bioassay techniques and counting facilities used at an installation are sufficient to permit a reasonable assessment of the internal burdens of the radionuclides used at that installation. The bioassay techniques should include the use of models or calibrations to ensure the accuracy and reproducibility of measured findings. The operating manual at each site should state, for each technique used, the type of radiation detectable by the technique, the sensitivity and accuracy of the system, the calibration sources used and the activity and intensity of each, and whether the system is sensitive enough to detect a concentration equivalent to 5% of the maximum permissible body burden (MPBB) for the most restrictive radionuclide in a mixture of radionuclides. This determination must be within a 95% confidence level.

Appraising an internal-dosimetry program is a detailed and complex process that requires the knowledge of an expert with many years of practical experience. The appraiser needs to use reference documents such as ANSI N343-1978 and Publication 2 (1959) of the International Commission on Radiological Protection (ICRP).

C. Exposure Review. The appraisers should determine whether radiation exposure and/or dose limits for routine operations and nonroutine events are maintained ALARA and whether survey and internal-exposure data on individuals are routinely compared with each other and with the limits. When the limits are exceeded or closely approached, the appraisers should determine whether the RPO takes corrective action and how effective that action is. To support the RPO, managers, supervisors, and foremen of operations and support groups should strive to keep both individual and group exposures, and the number of workers exposed, at a minimum. The existence of SOPs that require the signature of the RPO or a designee, the radiation worker, and the worker's supervisor is a good indicator of such an effort.

D. Quality Assurance Program for Internal Dosimetry. The primary purpose of the quality assurance program is to ensure that the data gathered in the internal-dosimetry program represent the best efforts possible in dose assessment. To this end, the RPO should establish calibration frequencies for, and the quality assurance staff should review, each dosimetry system and dose assessment technique. The appraisers should ascertain whether the RPO periodically evaluates the quality assurance and calibration reports to determine whether the established calibration frequency is adequate for each system used.

The appraisers should ensure that whole-body counting equipment is calibrated using sources traceable to the NBS. These sources should cover the entire spectrum of radionuclides currently in use at the installation and should vary in strength from the lower limit of detection of the counting system to realistic accident levels. The appraisers should also determine whether the whole-body counting system is calibrated at least annually. The routine calibration program should include an interim calibration with tolerance limits that, if exceeded, require recalibration of the entire system.

Guidance on the calibration of whole-body counting systems can be found in documents such as ANSI N343-1978.

The appraisers should determine whether the installation has a procedure for estimating MPC-hr exposures from whole-body-counting data. Because 10 CFR 20.103 expresses standards for internal emitters in terms of time-integrated concentrations (MPC-hrs) and intakes rather than permissible body burdens or doses, it is important that the RPO 1) maintain a comprehensive breathing-zone air-sampling program, and 2) be able to compare whole-body or organ burden data with the data generated by the air-sampling program. To accomplish this, the RPO must have a method for interpreting whole-body-counting data in terms of the MPC-hrs of exposure needed to produce the measured burden. One of the main reasons for relating the data base on whole-body counting to the data base on air sampling is to determine the effectiveness of the respiratory protection program.

15.2.5 The Program for External-Exposure Control

Management review of the program for controlling external exposure, like that of the internal-exposure program, involves observation of work practices and review of records. Management can perform an informal, walk-through review by being aware of whether radiation areas are posted properly, dosimeters are worn properly where they are required, radioactive waste is stored properly, and waste containers are labeled. Managers who are not familiar with proper procedures in these areas can consult AR 40-14, AR 385-11, and the RPO. In addition to the walk-through reviews, management should ensure that dosimetry records are maintained for everyone issued a dosimeter; that supervisors use dosimeter results when planning jobs and staff assignments; that all personnel are given the results of their annual dosimeter reading; that the RPO knows the procedure for reporting an overexposure; and that a sufficient number of dosimeters are available for routine and emergency use as well as for visitors.

The technical appraisal of the external-exposure control program should include review of 1) the methods used to limit exposures, 2) the dosimetry program, 3) the reasons for exposures and any corrective actions taken, and 4) the quality assurance program.

A. Exposure Limitation Methods. Both administrative and engineered safeguards should be reviewed as part of the appraisal. The administrative means of controlling external exposures usually consist of site-assigned dose limits and written procedures for minimizing exposures. The appraisers should review the dose limits to determine their usefulness and the ability of the staff to meet them. They should also talk with randomly selected radiation workers to verify their awareness of the administrative guidelines. These guidelines should clearly reflect existing regulations and recognize the ALARA concept.

The use of physical barriers for exposure control should be reviewed by the RPO on a regular basis and the results should be documented. The appraisers should evaluate the use of barriers and talk with radiation workers to determine their effectiveness. If remote-operating and remote-handling devices are available, the appraisers should ensure that the individuals authorized to use them have received special training and that the devices are well maintained. In areas with access alarms, periodic tests of the alarms should be performed to ensure their operation, and placards showing the potential hazards of the areas should be clearly displayed.

B. Dosimetry Program. Before beginning this phase of the appraisal, the appraisers should assure themselves that they are familiar with the current standards in the area of external dosimetry, including ANSI N13.11-1980.

The appraisers should review all sources licensed for use at the installation to ensure that the dosimetry program is suitable for the types and levels of radiation exposure anticipated during routine and nonroutine work. They should also evaluate the personnel responsible for the dosimetry function to determine whether they have adequate knowledge to perform routine duties and to recognize unusual events that may require special interpretations or evaluations. Appraisals frequently reveal that the readings from film or thermoluminescence dosimeters are not compared with the readings from secondary dosimeters (e.g., pocket ionization chambers). When comparisons are made, an acceptance criterion, or level at which follow-up action is required, should be specified.

An installation that sends dosimeters offsite for calibration and/or processing should have a quality assurance program. This program should include the use of spiked dosimeters and blanks. Secondary dosimeters should be carefully screened before they are put into service. The acceptance of offsite work without an independent quality control check represents a failure by the RPO to take responsibility for the accuracy of the dosimetry program.

The appraisers should ensure that the equipment and facilities available are adequate for nonroutine dosimetry and exposure control. Enough dosimeters of acceptable quality and sensitivity should be available for short-term use by personnel or visitors to areas requiring dosimeters. Exposure records should be kept current and should be sent to workers and their supervisors frequently and promptly enough to ensure their usefulness.

C. Exposure Review. The appraisers should determine whetner the exposure data generated by dosimeters and instruments are routinely reviewed by management and whether any discrepancies between the primary and secondary dosimeter readings that exceed the acceptance criterion are followed up by an investigation of the exposure conditions.

The RPO should maintain a plot of exposures that shows trends and indicates whether doses are being kept ALARA. These plots can be cross-referenced by job, location, profession, and total work force. The RPO should also have records of each review of the trend plot and the results of that review.

D. Quality Assurance Program for External Dosimetry. The quality assurance organization should play an active role in the program for controlling external exposures. The appraisers should assess the quality assurance functions performed by the RPO and determine whether the quality assurance representative assists in reviewing procedures and ensures that there is suitable feedback from management. For onsite calibration of instruments, devices, and processes, the quality assurance representative should assist in establishing acceptance criteria. The appraisers of the quality assurance program should pay careful attention to the records maintained by the quality assurance office.

15.2.6 The ALARA Program

The appraisers should verify that management has a written policy showing commitment to ALARA and administrative procedures to implement the policy.

The RPO should be responsible for overseeing the ALARA program as described in NRC Regulatory Guide 8.10 (1975). However, an individual in management should be responsible for working with the RPO to ensure that mechanisms for keeping exposures ALARA are instituted at the site.

The appraisers should determine whether an adequate system has been established to avoid unnecessary or inadvertent personnel exposures. Shielding should be used when equipment is being serviced; measures should be taken to provide distance from sources, when possible; and easy access to equipment should be provided. The appraisers should determine whether remote-handling tools or remote readouts are used when necessary. They should also thoroughly review the entire radiation protection program to determine the effectiveness of the ALARA program in reducing exposures.

The appraisers should interview radiation workers to determine their concept of ALARA, whether adequate training, preparation, and planning are incorporated into work activities, whether the radiation protection staff become involved early in the planning of work, and whether a debriefing is held when a job is completed to determine more effective means of reducing exposures.

Management review of this area should be limited to ensuring that there is an ALARA program review committee, that exposure information is used for job planning, and that personnel are familiar with the ALARA principle.

15.2.7 Facilities and Equipment

Management review of facilities and equipment should include a walk-through and visual inspections of equipment. The walk-through should center around the availability of sufficient space for calibrations, sample analysis, and the use of laboratory counters. Management should also inspect the condition of support equipment (e.g., protective clothing). The technical appraisal should cover the topics discussed below.

A. Facilities. At each installation, the appraisers should evaluate whether there are sufficient locations and space for the following: counting room, calibration of instruments, personnel decontamination, access control, offices, equipment decontamination, instrument storage, external dosimetry,

internal dosimetry, the fitting, testing, and cleaning of respirators, training, contaminated-equipment storage, and laundry. When a new facility is being designed, the RPO should be involved in an ALARA review of that structure.

If the installation uses large enough quantities of radioactive material so that the potential for offsite releases is a concern, the appraisers should ensure that the RPO has made provisions for offsite decontamination of personnel and has determined whether local hospitals have sufficient space and equipment to handle emergencies involving contaminated victims.

B. Protective Equipment. Respirators, protective clothing, temporary shielding, and containment materials should all be reviewed as part of the equipment appraisal.

(1) Respirators. The supply of respirators should be adequate for handling routine and abnormal operations. The installation should have an agreement with a commercial company or another command for the rapid procurement of extra respirators and for the expansion of decontamination and repair services in the event of an emergency.

(2) Protective Clothing. Protective clothing should be stored in a number of locations so that all of it is not lost in the event of a fire or accident. The supply should be adequate for handling routine and nonroutine operations. For accident situations, special clothing such as disposable paper and plastic suits should be available. Contamination limits for reusable clothing should be established. When the level of contamination on the clothing exceeds the limit, the clothing should be disposed of.

(3) Temporary Shielding. The appraisers should ensure that an adequate supply of temporary lead shielding, such as bricks, blankets, lead shot, and lead sheets, is available. The radiation protection staff should be trained in the proper use of these supplies and instructed to carefully survey the temporary shielding before removing it to avoid spreading contamination.

(4) Containment Materials. The supply of containment materials (e.g., heavy-gauge plastic sheeting, plastic windows, and nonskid floor covering) should be adequate for handling routine and nonroutine operations. The RPO should carefully analyze these materials for compatibility with the work

environment they will be used in. The site should have detailed procedures on the use of these materials, and the radiation protection staff should be trained in their use.

15.2.8. Management of Radioactive Waste

Appraisal of the waste management program should include a review of records and a walk-through inspection of all areas where waste is either generated or stored. All waste should be stored in authorized, appropriately labeled containers free of exterior contamination, rust, and corrosion. The appraisers should ensure that radioactive waste is collected separately from nonradioactive waste and that it is promptly removed from the generator's location and stored in properly posted areas apart from work locations. Control procedures should be used to minimize personnel exposures.

The appraisers should inspect waste that is ready for transport to determine whether it has been packaged and labeled accoording to Department of Transportation (DOT) and Department of the Army (DA) regulations. The appraisers should verify the availability of suitable packaging material, as well as packaging procedures. Trucks holding waste for transport should be inspected to determine that they are in compliance with DOT and DA regulations.

Waste records should be reviewed to ensure that an inventory of all waste generated and disposed of is maintained. The total quantity of radioactive material disposed of into the sanitary sewage system, the air, and nearby streams as a result of all activities at an installation must not exceed the quantity for a single licensee given in 10 CFR 20. Records for the transport of waste should be reviewed to determine whether they meet DOT and DA regulations.

15.2.9 Records and Audits

The records management system should be reviewed to determine whether records of each component of the radiation protection program are maintained. In addition, the appraisers should review the procedures for records disposition, traceability, retrievability, and physical protection. Audit records should be specifically reviewed to determine whether the program is periodically audited by individuals with the appropriate technical expertise and to verify that all audit findings have been corrected promptly.

Section 15.3 CHECKLIST OF QUESTIONS FOR APPRAISING A RADIATION PROTECTION PROGRAM

A checklist of questions should be developed for use during appraisals. The example checklist presented in this section is not comprehensive, but is intended to provide an overview of the areas of interest in an appraisal, based on the discussion in the preceding section.

15.3.1 The Radiation Protection Organization

1. Is there an organizational chart depicting the installation's interrelationship with the radiation protection organization?
2. Does the base commander have a working relationship with the RPO?
3. Does the organizational chart show that the RPO has a direct reporting chain to the base commander?
4. Does the RPO's manager exhibit a clear understanding of the goals of the radiation protection organization?
5. Is there evidence of strong management commitment to radiation protection (e.g., written policies or administrative procedures)?
6. Is there a clear assignment of authority and responsibility within the radiation protection organization?
7. Does the radiation protection staff have adequate authority to ensure that the radiation protection program is implemented?
8. If classified work is being done, does the RPO have adequate clearance and unfettered access to ensure that the work is being conducted safely?
9. Is there sufficient staffing within the radiation protection organization to provide adequate coverage of all work with radiation?
10. Is the RPO included in the design phase of operations involving radioactive material?
11. Is the RPO or a designee required to authorize all SOPs?
12. Does there appear to be open communication between the RPO and both radiation workers and other staff members?

13. Is there adequate administrative support to relieve technical personnel from clerical duties?

14. Has a management level individual (e.g., the RPO or a higher-level person) been designated the responsibility for emergency preparedness?

15. Are written emergency plans and procedures available that are commensurate with the degree of hazard?

16. Are there established procedures for obtaining offsite support?

15.3.2 The Selection and Training of Personnel

1. Is there a radiation safety training program for staff members commensurate with their responsibilities?

2. Is there a training program for the radiation protection staff?

3. Does training for the general staff members and the radiation protection staff include the following?
   a. a defined scope and written content for the program
   b. instructors qualified in the subjects they are teaching
   c. instruction schedules and lesson plans
   d. objectives for trainee performance
   e. demonstration of standards attained by trainees
   f. frequency of required attendance
   g. documentation of attendance (including test results, dates, and subjects).

4. Is the scope of the training adequate in content, nature, and length?

5. Do training programs include hands-on use of equipment and tours of areas that the trainee may need to enter in the course of work?

6. Are the operators of the various counting and analytical systems properly and adequately trained in the use of the systems?

7. Is formal on-the-job training available at appropriate intervals for all individuals?

8. Are requalification and retraining in the state of the art of instrumentation available for personnel?

9. Is there a documented training program covering emergency preparedness?

10. Are operators of computer-based analysis systems capable of manual calculations in the event of a power loss?

11. Are training records maintained for a minimum of 5 years?

12. Are the training records complete enough so that the quality, duration, location, and content of training can be ascertained?

15.3.3 The Radiation Survey Program

1. Is there a clear definition of and basis for the survey program?

2. Are procedures for performing routine and periodic surveys well defined?

3. Does each survey record contain as a minimum the following?
   a. survey purpose
   b. survey frequency and location
   c. survey technique
   d. instrument selection, calibration, and use
   e. data and records disposition
   f. status of follow-up actions.

4. Do procedures or policy statements delegate to the radiation protection organization the responsibility for reviewing all SOPs?

5. Are the data from routine and periodic surveys reviewed by the RPO for technical content and possible additional action?

6. Are all surveys well documented?

7. Do SOPs correctly reflect job and work conditions?

8. Is there timely and adequate feedback of analytical results to staff personnel?

9. Is the recordkeeping system commensurate with the guidelines outlined in Chapter 13 of this manual and those in ANSI N13.6-1966?

10. Are radiation areas properly posted in accordance with 10 CFR 20.203?

11. Are portable instruments of sufficient number, type, range, and sensitivity available for routine and nonroutine activities?

12. Do instruments have a calibration sticker that specifies the date the instrument should be recalibrated, the name or initials of the person that performed the calibration, the actual calibration date, the source used for calibration, and the location of the calibration facilities?

13. Are air-sampling instruments sufficient in number, sampling range, and type for the scope of routine and nonroutine activities?

14. Are there procedures that specify the calibration frequency for all instruments?

15. Are calibration sources traceable to NBS?

16. Are inoperative instruments properly marked, stored, and repaired?

17. Are instruments dedicated to sample analysis properly maintained?

18. Are instrument dials and scales clearly legible?

19. Are survey results plotted and reviewed for possible trends?

15.3.4 The Program for Internal-Exposure Control

1. Is there a bioassay program commensurate with the level of hazard at the installation?

2. Are baseline whole-body counts or urinanlyses performed on personnel before they begin work with radioactive material?

3. Are the bioassay techniques used at the site based on the radionuclides used there?

4. Are the sensitivities of the bioassay procedures adequate for assessing maximum permissible body burdens and maximum permissible concentrations?

5. Is there a written procedure for correlating air-sampling results and bioassay results?

6. Are internal-dose limits for routine operations and nonroutine events maintained ALARA?

7. Are incidents of personnel contamination documented, and are the causes investigated?

8. Are adequate records maintained on all individuals who have received an internal deposition of radioactive material?

9. Are uptake limits considered in the establishment of administrative and engineered safeguards?

10. Are there procedures that aid in determining the need for protective clothing and equipment?

11. Are there well-defined procedures for posting controlled-access areas and areas where airborne or other contamination is known to exist?

12. Are proper measures taken to minimize leakage, control local releases, and clean up contaminated areas?

13. Are there adequate procedures for preventing or controlling cross-contamination of samples?

14. Are air flows from areas of low to areas of high airborne radioactivity?

15. Has management issued a written policy statement on the use of respirators?

16. Are there methods of ensuring that only qualified personnel use respirators?

17. Does the person responsible for the respiratory protection program have the ability, training, and experience to do the following?
    a. evaluate total hazard
    b. recommend engineering controls
    c. specify appropriate respiratory protection factors and equipment
    d. forbid use of equipment when conditions warrant.

18. Are sufficient records maintained to evaluate the effectiveness of the respiratory protection program?

19. Do the issuance, maintenance, and repair of respirators, and the training of personnel for their use, meet the guidelines found in such documents as NUREG-0041?

20. Do all personnel who wear respirators have documentation of a complete bronchio-pulmonary examination?

21. Are all respirators used at the installation of the type approved by NIOSH?

22. Are there provisions to ensure the proper fit of respirators?

23. Are medical personnel given enough guidance to adequately evaluate the ability of wearers to use the equipment?

24. Are respirators fitted, inspected, tested, and repaired, and are the wearers trained, in accordance with NUREG-0041 or its equivalent?

15.3.5 The Program for External-Exposure Control

1. Is the dosimetry program suitable for the types and levels of radiation exposure anticipated during routine and nonroutine operations?

2. Are there suitable devices, exposure models, and data bases for measuring or calculating extremity exposures?

3. Can skin exposures be determined by modeling or measurement?

4. Are there suitable techniques, devices, or instruments for measuring neutron exposures?

5. Are dosimeters of acceptable quality and sensitivity available for short-term use by personnel or visitors to areas requiring dosimeters?

6. Are dosimeters being worn in the proper position on the body and/or extremities?

7. Are exposure records on all personnel wearing dosimeters kept up-to-date?

8. Are exposure data reviewed routinely by management, and are the reviews documented?

9. Are discrepancies between the readings of primary and secondary dosimeters reviewed by management (RPO or higher levels)?

10. Are exposure results and exposure histories evaluated against the ALARA requirements of AR 40-14 and 10 CFR 20 as part of a routine review?

11. Do administrative procedures clearly establish action levels and required actions in the event of an exposure that exceeds administrative limits?

12. Do procedures clearly reference and reflect existing regulations and recognize and incorporate the ALARA concept?

13. Are there written procedures for the posting of various hazardous or potentially hazardous areas in accordance with 10 CFR 20?

14. Is the RPO thoroughly familiar with the location of all radioactive material used at the installation?

15. Does the dosimetry program include the use of dosimeters spiked with known types and quantities of radiation, to provide a quality assurance check during processing?

16. Are dosimeters stored in a controlled location to reduce adverse environmental effects?

17. Are control dosimeters included in all shipments to the dosimeter processor?

18. Is the RPO responsible for the control, issuance, and evaluation of all dosimeters?

19. Are there routine quality assurance reviews of the dosimetry program?

20. Is quality assurance extended to the review of procedures?

15.3.6 The ALARA Program

1. Is there a written management policy showing commitment to ALARA?

2. Are there written administrative procedures to implement the ALARA policy?

3. Do facility and equipment design features incorporate ALARA concerns?

4. Is work adequately prepared and planned for?

5. Is the radiation protection staff involved in the planning of work?

6. Are formal or informal postoperational briefings held?

7. Are engineered safeguards used to keep exposures ALARA?

8. Is surface contamination controlled adequately?

9. Are remote readouts available?

10. Are unnecessary exposures during routine surveys minimized?

15.3.7 Facilities and Equipment

1. Are there sufficient locations and space for the following: sample counting, calibrations, personnel and equipment decontamination, access control, offices, instrument storage, external and internal dosimetry, fitting, testing, and cleaning of respirators, training, contaminated-equipment storage, and laundry?
2. If a new facility has been designed, was an ALARA review of the structure performed?
3. Are adequate supplies of protective clothing, respirators, temporary shielding, and containment materials available, and is the radiation protection staff trained in their use?
4. Are all radiation areas posted and isolated from controlled areas?
5. Is access to radiation areas controlled?
6. Are sinks, drain lines, and water supplied to a radiation area isolated from the sanitary sewer?
7. Are radiation areas ventilated to prevent the flow of air into uncontrolled areas?
8. Is emergency equipment available (e.g., fire extinguishers, safety showers, telephones)?
9. If a potential for offsite releases exists, have provisions been made for offsite decontamination of personnel, and do local hospitals have sufficient space to handle emergencies involving contaminated patients?

15.3.8 Management of Radioactive Waste

1. Is the use of radioactive material planned so that a minimum of radioactive waste is generated?
2. Is radioactive waste separated from nonradioactive waste?
3. Is waste segregrated by physical form, half-life, and type of nuclide?
4. Are containers used for temporary storage properly labeled, strong, leaktight, and free of exterior contamination, rust, and corrosion?

5. Is radioactive waste stored away from the work area?

6. Are appropriate control procedures used to minimize personnel exposure?

7. Are all waste generation and storage areas monitored to ensure contamination control?

8. Is waste for transport packaged and labeled according to DOT and DA regulations?

9. Is the total quantity of radioactive material disposed of into the sanitary sewage systems, the air, and nearby streams as a result of all activities at the installation less than the quantity for a single licensee given in 10 CFR 20?

15.3.9 Records and Audits

1. Are records maintained for each component of the radiation protection program?

2. Does the records management system include the identification of specific records, the disposition of records (review, storage, retention period), traceability to the originator, retrievability for audits or investigations, provisions for periodic audits, and physical protection for legal records?

3. Are there complete and up-to-date personnel files for all radiation workers?

4. Is DD Form 1141 (or the automated dosimetry records) filed in each individual's personnel file?

5. Are records maintained in accordance with the guidance in Chapter 13 of this manual?

6. Are records maintained in accordance with the guidance in 10 CFR 19 and 10 CFR 20?

7. Is the radiation protection program audited periodically?

8. Does the quality assurance staff conduct performance audits?

9. Are previous audit reports reviewed before new audits are conducted?

10. Are audit findings corrected within a reasonable time?

11. Are technical audits performed by individuals with extensive experience in the areas in question?

Section 15.4 NETWORK TECHNIQUES FOR PLANNING APPRAISALS

The manager or command group that is looking for an appraisal technique to aid in planning a radiation protection appraisal is faced with a bewildering family of network methods. A network is an organized way of thinking about complex problems by using common sense to determine a sequence of logical steps. Managers (such as RPOs) today face a great increase in the complexity of their work; because they are often dealing with the future (limiting future exposure, planning future facilities), they also face uncertainty. Network techniques were designed specifically to deal with the factors of complexity and uncertainty.

15.4.1 *The Function of Networks and Logic Trees*

The first network method for controlling projects, PERT (Program Evaluation and Review Technique), was developed for use on the Polaris Submarine program by the U.S. Navy in 1958. The second, more successful method was developed by the DuPont Company and is called the Critical Path Method (CPM). A critical path is defined as a sequence of elements of a program that are dependent upon one another. For example, the radiological survey of a waste container is dependent upon the training of the staff members and the proper response of the survey instruments. In turn, the proper response of a survey instrument is dependent upon its calibration, physical condition (whether it is damaged), and power source (strength of batteries). Therefore, an adequate survey is dependent on several critical paths. The critical paths for this particular example are shown in Figure 15.1 by the use of arrows. Although the PERT and CPM networks cannot be used directly in planning appraisals, they demonstrate the value of logically displaying the relationships among the basic elements of a program, and thus they led to the development of more useful methods such as MORT (Management Oversight and Risk Tree Analytical Logic Methodology).

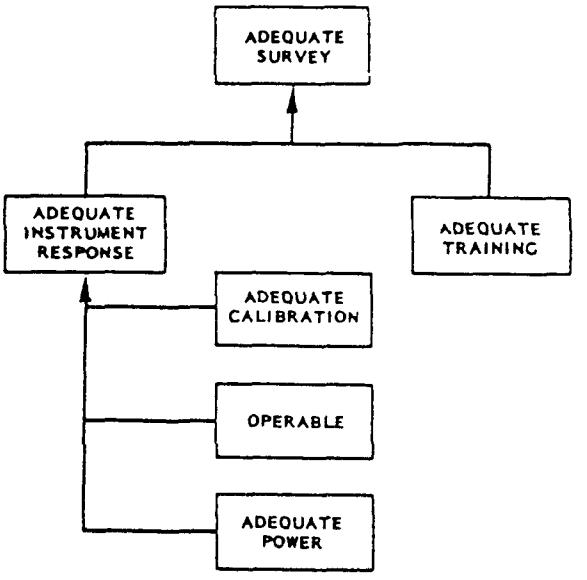


FIGURE 15.1. Critical Paths for an Adequate Survey

The MORT system is a logic tree network that was designed for use in investigating the causes of accidents, or undesirable conditions. However, this system and others like it can be modified to graphically depict a single desirable condition, the starting point for the tree, and systematically proceed through lower levels or tiers until all important factors that produce the desirable condition have been identified. This concept is shown in Figure 15.2, where a tier may be dependent upon several critical paths, as shown by an "AND" gate, or may be dependent upon only one critical path, as shown by an "OR" gate. An example of a logic tree structure is shown in Figure 15.3, where the desirable condition is for a process to be operationally ready.

An appraisal program developed using logic trees would be broken down into many branches, each specific to a single desirable condition or set of related conditions. Each branch would have some point of interface with at least one other branch or tree. The interfaces between branches or trees are important in the evaluation process: data collected from the appraisal of one area must be transferred to another area and considered in the evaluation of both. Through this process, the impact of a particular finding can be assessed in a systematic way, with a minimum expenditure of time and effort. The examples of logic trees presented in this section are a combination of several

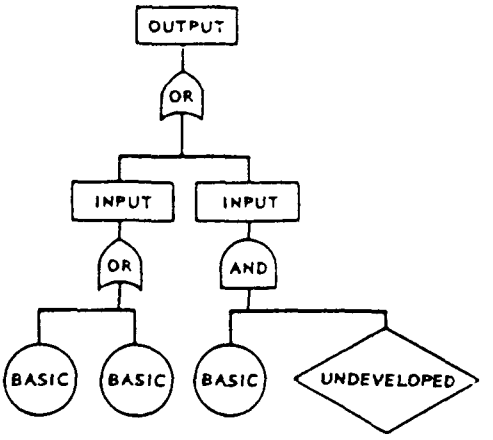


FIGURE 15.2. MORT Logic Tree

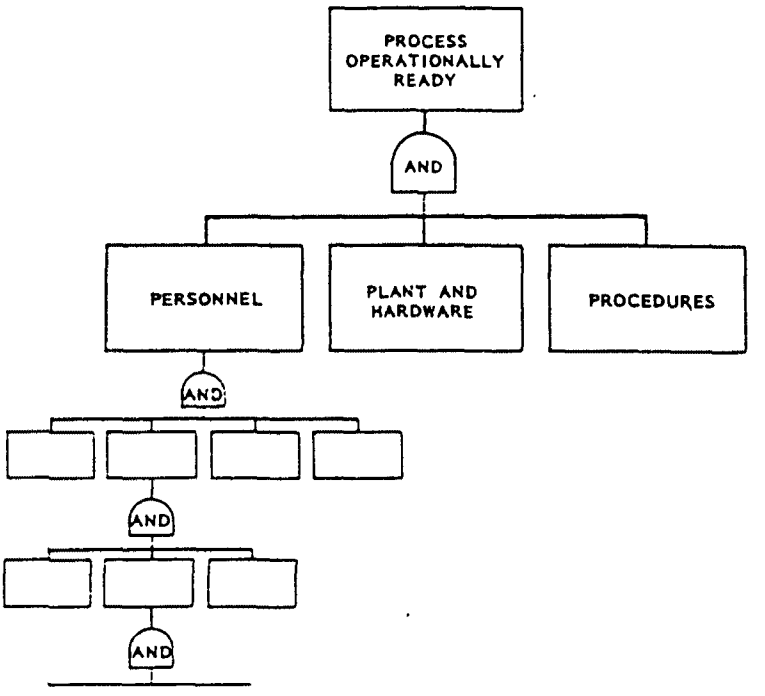


FIGURE 15.3. Logic Tree for a Process To Be Operationally Ready

network systems. They are intended not as an all-inclusive listing of factors related to a radiation protection appraisal, but rather as a means of acquainting the reader with the system of logic trees and their use in developing an appraisal program.

15.4.2 Using Logic Trees to Plan a Radiation Protection Appraisal

The first step in developing an appraisal program is to establish the objectives of the radiation protection program (e.g., to keep exposures as low as is reasonably achievable (ALARA) and to minimize the potential for accidental exposures). On the diagram of the logic tree, this objective is placed in a box that becomes the goal of the total logic tree (see Figure 15.4). Accomplishing such an objective requires both a routine operation and an emergency operation. This dual requirement is shown by the "AND" gate beneath the top box in Figure 15.4. Figure 15.5 shows the further subdivision of an effective routine program into its major components. A deficiency in any of these components could cause the entire routine program to be inadequate. Therefore, an "AND" gate is used to show the relationship of the routine program to its major components. The emergency operation, however, can be satisfied by either a modified routine operation or a special emergency program. Therefore, the emergency operation diagrammed in Figure 15.6 has an "OR" gate to show its relationship to its components. The combination of Figures 15.4, 15.5, and 15.6 yields the logic tree structure for the first two tiers of the radiation protection program, as shown in Figure 15.7.

In a complete appraisal program developed using logic trees, each of the components of a routine program would be further subdivided from two to eight times. The subdivisions of the component "Internal-Exposure Controls" are shown in Figure 15.8. The degree of subdivision into lower tiers depends on the complexity of the radiation protection program. A recent appraisal of the radiation protection programs at operating power reactors involved the use of

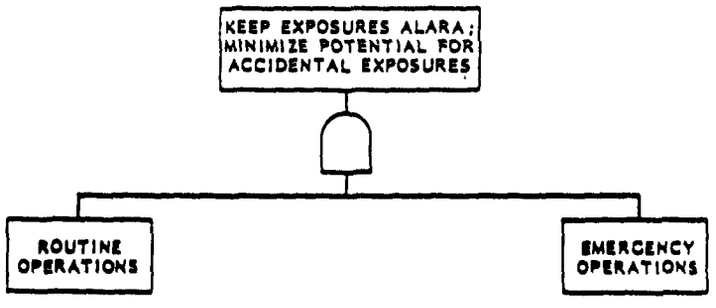


FIGURE 15.4. Radiation Protection Program, First Tier

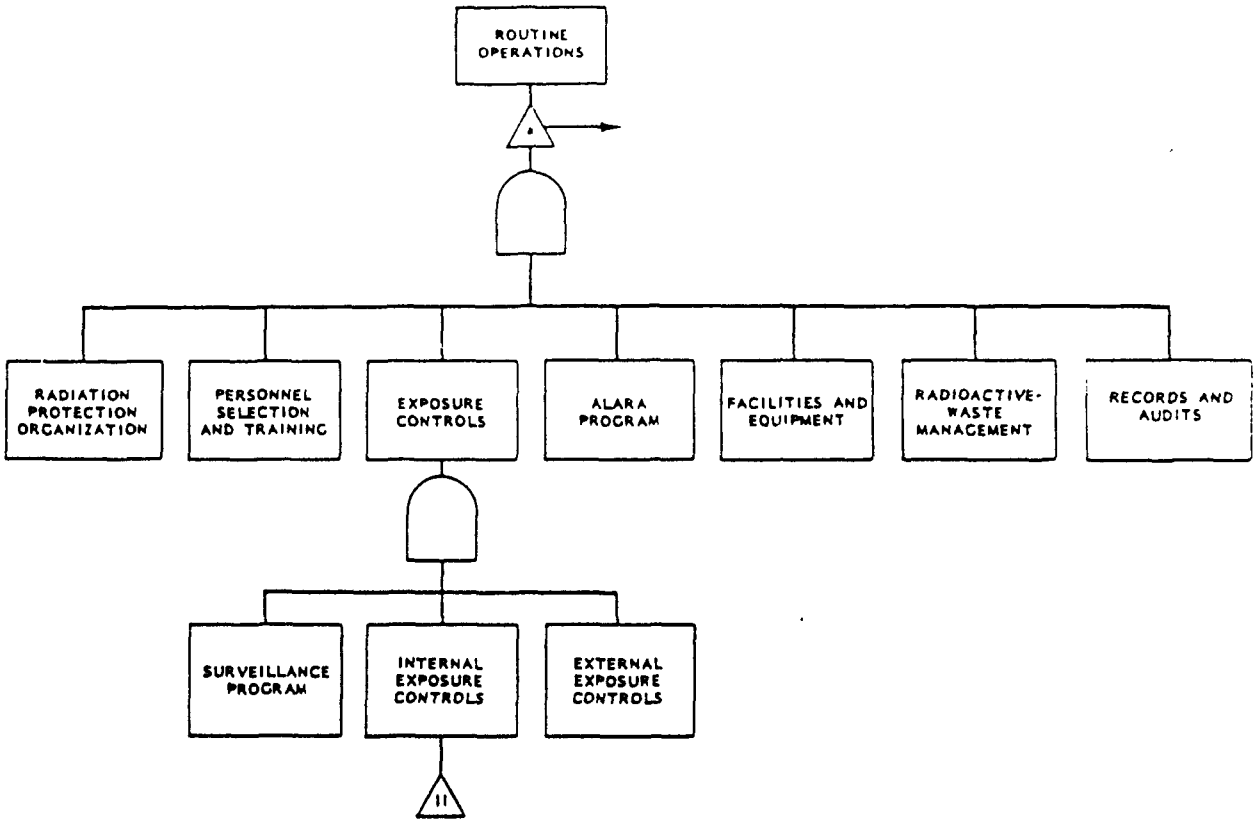


FIGURE 15.5. Radiation Protection Program, Second Tier--Routine Operations

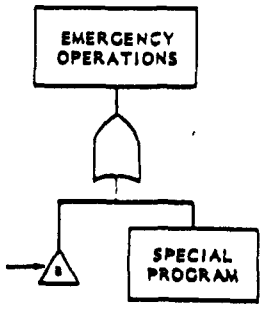


FIGURE 15.6. Radiation Protection Program, Second Tier--Emergency Operations

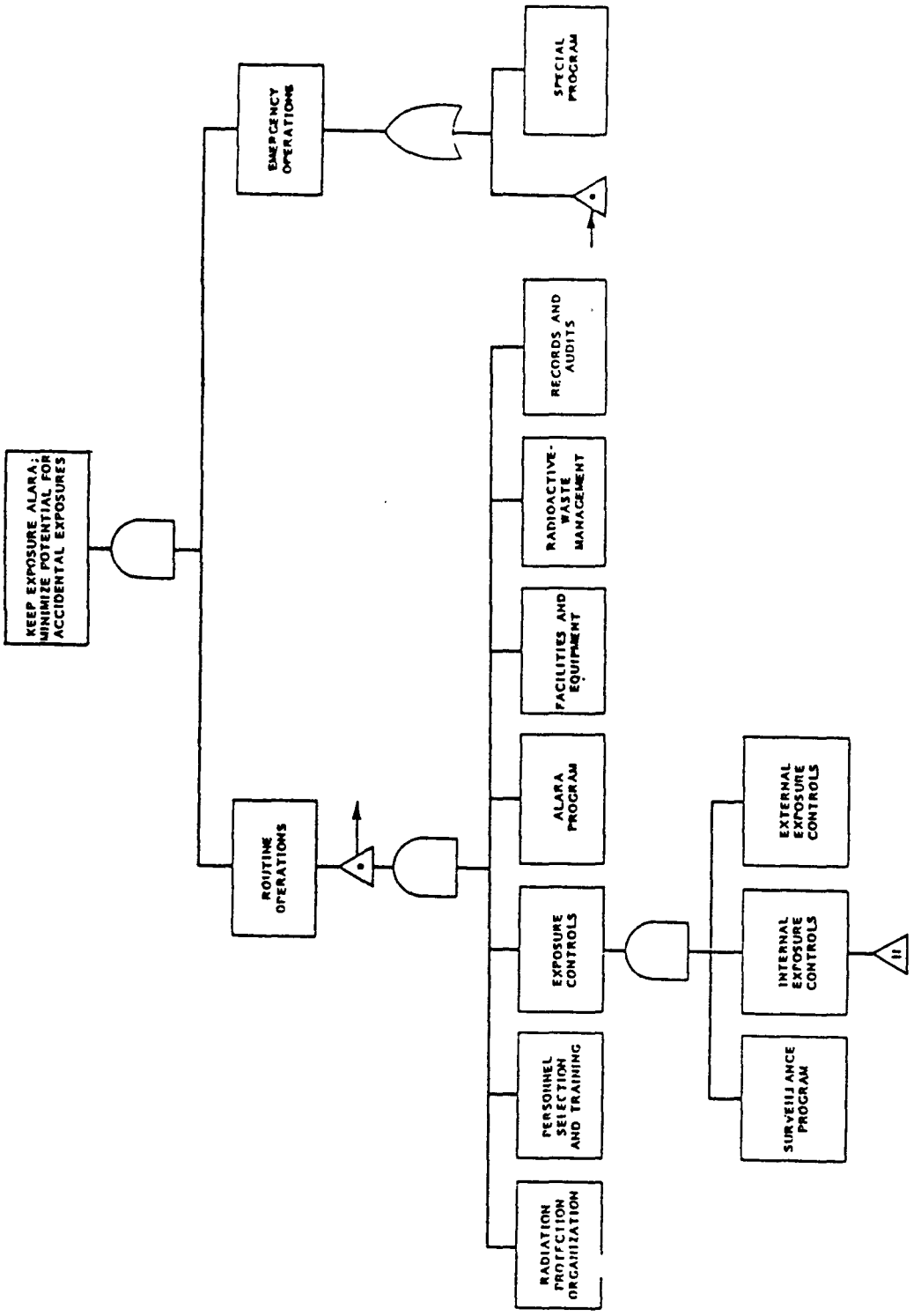


FIGURE 15.7. Upper Tiers for Logic Tree Depicting Radiation Protection Program

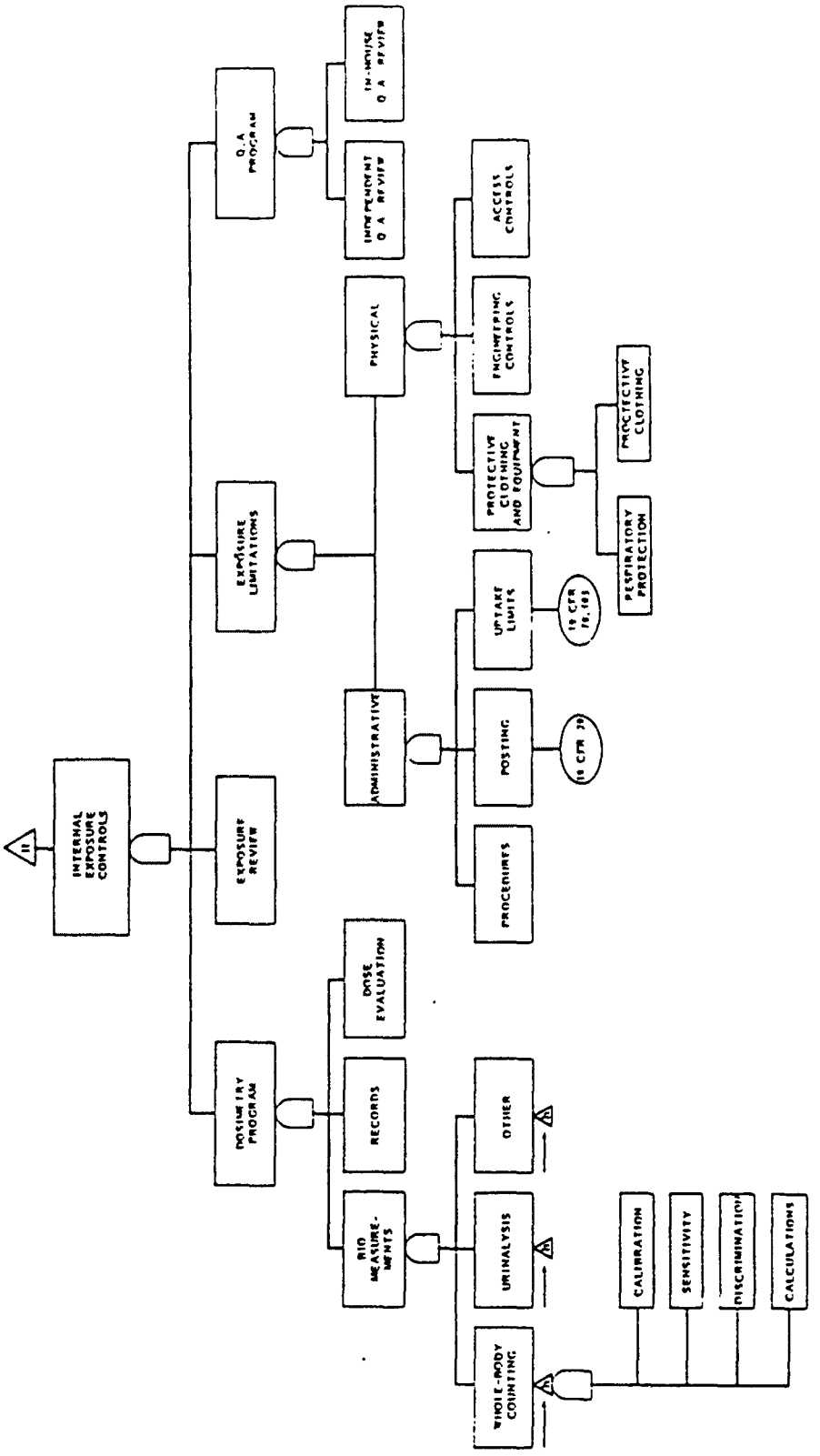


FIGURE 15.8. Logic Tree Tiers Depicting Internal-Exposure Control Program

18 trees, two of which interfaced with each of the remaining 16. The interfaces are usually designated by transfer functions (triangles with arrows and a letter or number) that indicate when data from one area should be used in the evaluation of another.

The analytical trees should be designed so that they graphically depict the total radiation protection program. To help the appraisers properly evaluate each area included in the trees, a checklist of questions, such as those in the previous section, is designed to accompany each element in every tier. The questions define the scope of the appraisal and ensure consideration of the essential elements of a radiation protection program. They are not intended to be an all-inclusive listing of the significant items for appraisal, but should provide the appraisers with the foundation upon which to evaluate the program. The appraisers should find that the answers to some questions lead them to a series of other questions that are not written in the appraisal guide.

The complexity of the appraisal process requires that the appraisers be familiar with a large number of regulations, regulatory guides, and industry standards. These documents will be useful in judging the adequacy of all or part of a specific area (e.g., dosimetry). In addition, the criteria used for designing the logic trees and for evaluating the program should be taken from DA and NRC rules and regulations, ANSI standards, National Council on Radiation Protection and Measurements (NCRP) guides, and recommendations of the ICRP and the International Commission on Radiation Units and Measurements (ICRU). However, the use of the logic tree system does not eliminate the need for professional judgment where standards and regulations do not provide sufficient detail; rather, its purpose is to help the appraisers clarify where their judgment is needed.

REFERENCES

American National Standards Institute (ANSI). 1966. Practice for Occupational Radiation Exposure Records Systems. ANSI N13.6, New York.

American National Standards Institute (ANSI). 1978. American National Standard for Internal Dosimetry for Mixed Fission and Activation Products. ANSI N343, New York.

American National Standards Institute (ANSI). 1978. Radiation Protection Instrumentation Test and Calibration. ANSI N323, New York.

American National Standards Institute (ANSI). 1980. American National Standard Criteria for Testing Personnel Dosimeter Performance. ANSI N13.11, New York.

American National Standards Institute (ANSI). 1980. Practices for Respiratory Protection. ANSI Z88.2, New York.

International Commission on Radiological Protection (ICRP). 1959. Report of Committee II on Permissible Dose for Internal Radiation. ICRP 2, Pergamon Press, Oxford.

U.S. Code of Federal Regulations. 1982. Title 10, Part 19, "Notices, Instructions and Reports to Workers; Inspections." U.S. Government Printing Office, Washington, D.C.

U.S. Code of Federal Regulations. 1982. Title 10, Part 20, "Standards for Protection Against Radiation." U.S. Government Printing Office, Washington, D.C.

U.S. Department of the Army, Headquarters. Safety - Ionizing Radiation Protection (Licensing, Control, Transportation, Disposal, and Radiation Safety). AR 385-11, Washington, D.C.

U.S. Department of the Army and Defense Logistics Agency. Medical Services - Control and Recording Procedures for Exposure to Ionizing Radiation and Radioactive Materials. AR 40-14, DLAR 1000.28, Washington, D.C.

U.S. Nuclear Regulatory Commission (NRC). 1975. "Operating Philosophy for Maintaining Occupational Radiation Exposure As Low As Reasonably Achievable." Regulatory Guide 8.10, Washington, D.C.

U.S. Nuclear Regulatory Commission (NRC). 1976. Manual of Respiratory Protection Against Radioactive Materials. NUREG-0041, Washington, D.C.

CHAPTER 16. REFERENCE DATA

16.1 LIST OF ELEMENTS 16.3
16.2 GREEK ALPHABET 16.4
16.3 ACRONYMS 16.5
16.4 ABBREVIATIONS AND SYMBOLS 16.7
16.5 SELECTED CONVERSIONS 16.11
16.6 FREQUENTLY USED CONSTANTS 16.14
16.7 ADDRESSES FOR ORDERING REFERENCE DOCUMENTS 16.15
16.8 GLOSSARY 16.16

Section 16.1 LIST OF ELEMENTS

Atomic Number	Symbol	Name	Atomic Number	Symbol	Name
1	H	hydrogen	53	I	iodine
2	He	helium	54	Xe	xenon
3	Li	lithium	55	Cs	cesium
4	Be	beryllium	56	Ba	barium
5	B	boron	57	La	lanthanum
6	C	carbon	58	Ce	cerium
7	N	nitrogen	59	Pr	praseodymium
8	O	oxygen	60	Nd	neodymium
9	F	fluorine	61	Pm	promethium
10	Ne	neon	62	Sm	samarium
11	Na	sodium	63	Eu	europium
12	Mg	magnesium	64	Gd	gadolinium
13	Al	aluminum	65	Tb	terbium
14	Si	silicon	66	Dy	dysprosium
15	P	phosphorus	67	Ho	holmium
16	S	sulfur	68	Er	erbium
17	Cl	chlorine	69	Tm	thulium
18	Ar	argon	70	Yb	ytterbium
19	K	potassium	71	Lu	lutetium
20	Ca	calcium	72	Hf	hafnium
21	Sc	scandium	73	Ta	tantalum
22	Ti	titanium	74	W	tungsten
23	V	vanadium	75	Re	rhenium
24	Cr	chromium	76	Os	osmium
25	Mn	manganese	77	Ir	iridium
26	Fe	iron	78	Pt	platinum
27	Co	cobalt	79	Au	gold
28	Ni	nickel	80	Hg	mercury
29	Cu	copper	81	Tl	thallium
30	Zn	zinc	82	Pb	lead
31	Ga	gallium	83	Bi	bismuth
32	Ge	germanium	84	Po	polonium
33	As	arsenic	85	At	astatine
34	Se	selenium	86	Rn	radon
35	Br	bromine	87	Fr	francium
36	Kr	krypton	88	Ra	radium
37	Rb	rubidium	89	Ac	actinium
38	Sr	strontium	90	Th	thorium
39	Y	yttrium	91	Pa	protactinium
40	Zr	zirconium	92	U	uranium
41	Nb	niobium	93	Np	neptunium
42	Mo	molybdenum	94	Pu	plutonium
43	Tc	technetium	95	Am	americium
44	Ru	ruthenium	96	Cm	curium
45	Rh	rhodium	97	Bk	berkelium
46	Pd	palladium	98	Cf	californium
47	Ag	silver	99	Es	einsteinium
48	Cd	cadmium	100	Fm	fermium
49	In	indium	101	Md	mendelevium
50	Sn	tin	102	No	nobelium
51	Sb	antimony	103	Lw	lawrencium
52	Te	tellurium			

Section 16.2 GREEK ALPHABET

Name	Upper Case	Lower Case
Alpha	Α	α
Beta	Β	β
Gamma	Γ	γ
Delta	Δ	δ
Epsilon	Ε	ε
Zeta	Ζ	ζ
Eta	Η	η
Theta	Θ	θ
Iota	Ι	ι
Kappa	Κ	κ
Lambda	Λ	λ
Mu	Μ	μ
Nu	Ν	ν
Xi	Ξ	ξ
Omicron	Ο	ο
Pi	Π	π
Rho	Ρ	ρ
Sigma	Σ	σ
Tau	Τ	τ
Upsilon	Υ	υ
Phi	Φ	φ
Chi	Χ	χ
Psi	Ψ	ψ
Omega	Ω	ω

Section 16.3 ACRONYMS

AEC	U.S. Atomic Energy Commission
ALARA	as low as is reasonably achievable
ALI	annual limit of intake
AMC	Army Material Command
ANSI	American National Standards Institute
CAM	continuous air monitor
CFR	U.S. Code of Federal Regulations
CP	Cutie Pie
DA	U.S. Department of the Army
DAC	derived air concentration
DCP	disaster control plan
DD	U.S. Department of Defense
DF	decontamination factor
DOP	dioctyl-phthalate
DOT	U.S. Department of Transportation
DSA	Defense Supply Agency
DU	depleted uranium
EAL	emergency action level
ECC	emergency control center
ED	emergency director
EDTA	ethylene-diamine-tetra-acetic acid
EPA	U.S. Environmental Protection Agency
EPZ	emergency planning zone
GM	Geiger-Mueller
HEPA	high-efficiency particulate air
HEW	U.S. Department of Health, Education, and Welfare
HHS	Health and Human Services
HQ	Headquarter
HVL	half-value layer
IAEA	International Atomic Energy Agency
IATA	International Air Transport Association
ICRP	International Commission on Radiological Protection
ICRU	International Commission on Radiation Units and Measurements
IMCO	Inter-Governmental Maritime Consultative Organization
IRCC	Ionizing Radiation Control Committee
LET	linear energy transfer
LSA	low specific activity

MPBB	maximum permissible body burden
MPC	maximum permissible concentration
MSHA	Mine Safety and Health Administration
NBS	U.S. National Bureau of Standards
NCRP	National Council on Radiation Protection and Measurements
NIOSH	National Institute of Occupational Safety and Health
NRC	U.S. Nuclear Regulatory Commission
NTA	nuclear track emulsion
NTIS	National Technical Information Service
OSHA	Occupational Safety and Health Administration
PF	protection factor
RAC	radiological assessment and control
RAM	remote area monitor
RBE	relative biological effectiveness
RPO	Radiation Protection Officer
RSR	radioactive shipment record
SEE	specific effective energy
SI	international system of measurement units
SOP	standing operating procedure
STP	standard temperature and pressure (0°C, 760 mm Hg)
TI	transport index
TL	thermoluminescence
TLD	thermoluminescence dosimeter
TVL	tenth-value layer
WB	whole body

Section 16.4 ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

A	mass number
A	radionuclide activity or source activity
AF(T←S)	absorbed fraction of emitted energy, target from source
bis-MSB	p-bis-(O-methylstyryl) benzene
Bq	becquerel
Butyl-PBD	[2-(4'-tert-butylphenyl), 5-(4"-biphenylyl) - 1,3,4-oxadiazole]
C	Celsius
C	centigrade
c	centi- (10^{-2})
cc	cubic centimeter
Ci	Curie
cm_2	centimeter
cm^2	square centimeter
cpm_1	counts per minute
cm^{-1}	reciprocal centimeter or 1/cm
D	radiation dose or absorbed radiation dose
$\dot{D}$	radiation dose rate
d	day
dis	disintegration
dpm	disintegrations per minute
dps	disintegrations per second
dx	differential of x
E	radiation energy
e	base of natural logarithms (2.71828)
e.g.	exempli gratia (for example)
esu	electrostatic unit
eV	electron volt
F	Fahrenheit
f_2	fraction of body burden in a given organ
ft	foot
g	gram
gal	gallon
Gy	gray
H	dose equivalent
H_T	committed dose equivalent to a target organ
$\dot{H}_T$	dose-equivalent rate to a target organ
h	Planck's constant
hr	hour
Hz	hertz

I	photon flux
I	radiation intensity
I_o	original radiation intensity
i.d.	inside diameter
i.e.	id est (that is)
in.	inch
J	joule
k	kilo- (10^3)
kg	kilogram
keV	kiloelectron volt
kV	kilovolt
L	liter
lb	pound
ln	natural logarithm
M	mega- (10^6)
m	mass
m	meter
m_2	milli- (10^{-6})
m^3	square meter
max	cubic meter
mCi	maximum
MeV	millicurie
min	million electron volt
ml	minute
mm	milliliter
mR	millimeter
mrad	milliroentgen
mrem	millirad
	millirem
N	neutron number
N	number of radioactive atoms present at a time t
N	product of modifying factors
N_o	number of radioactive atoms originally present
n^o	any number
o.d.	outside diameter
oz	ounce
P	specific ionization, or number of ion pairs produced by radiation per path length
p	pico- (10^{-12})
pCi	picocurie
PPO	2,5-diphenyloxazole
POPOP	1,4-bis-[2-(5-phenyloxazolyl)]-benzene

Q	quality factor
q(t)	body burden at time t
R	roentgen
r	radius of a circle
S	source
S	surface area
s	distance
s	thickness
sec	second
SEE(T←S)	specific effective energy per disintegration, target from source
Sv	sievert
T	kinetic energy
T	target
t	time
$t_{1/2}$	radionuclide half-life
U	number of transformations in a source organ
u	mass unit
V	volt
v	velocity
wk	week
X	exposure
$\dot{X}$	exposure rate
x	times (multiplication)
Y	radiation yield
yr	year
Z	atomic number

GREEK SYMBOLS

α	alpha particle
β	beta particle
γ	gamma ray
Γ	gamma-ray constant
ϵ	effective absorbed energy per disintegration
ϵ	energy imparted by ionizing radiation
Θ	angle
λ	effective decay constant
λ	wavelength
λ_p	radionuclide decay constant

μ	linear attenuation coefficient
μ	micro- (10^{-6})
μ_{en}	mass energy absorption coefficient
μ_m	mass attenuation coefficient
μCi	microcurie
μm	micrometer
ν	frequency
ν	neutrino
π	pi (3.1416)
ρ	density
Σ	summation of

MATHEMATICAL SYMBOLS

$^\circ$	degree
%	percent
$\propto$	proportional to
$\cdot$	times (multiplication)

Section 16.5 SELECTED CONVERSIONS

MULTIPLY	BY	TO OBTAIN
Length		
centimeters	0.3937	inches
	3.28×10^{-2}	feet
feet	30.48	centimeters
	0.3048	meters
inches	2.54	centimeters
meters	3.281	feet
	39.37	inches
miles	5280	feet
Area		
barns	10^{-24}	square centimeters
square centimeters	10^{24}	barns
	1.076×10^{-3}	square feet
	0.155	square inches
square feet	929	square centimeters
	144	square inches
	9.29×10^{-2}	square meters
square inches	6.452	square centimeters
	6.944×10^{-3}	square feet
	6.452×10^{-4}	square meters
square meters	10.76	square feet
Volume		
cubic centimeters	6.102×10^{-2}	cubic inches
	3.531×10^{-5}	cubic feet
	2.642×10^{-4}	U.S. gallons
	10^{-3}	liters
cubic feet	2.832×10^{-2}	cubic meters
	7.481	U.S. gallons
	28.32	liters
cubic inches	16.39	cubic centimeters
	5.787×10^{-4}	cubic feet
	1.639×10^{-2}	liters
	4.329×10^{-3}	U.S. gallons
cubic meters	35.31	cubic feet
	2.642×10^{2}	U.S. gallons

MULTIPLY	BY	TO OBTAIN
Volume (cont'd)		
gallons, U.S.	231	cubic inches
	0.1337	cubic feet
	3.785×10^{3}	cubic centimeters
	3.785	liters
liters	3.53×10^{-2}	cubic feet
	61.02	cubic inches
	0.2642	U.S. gallons
	10^{3}	cubic centimeters
Mass		
grams	2.205×10^{-3}	pounds
kilograms	2.205	pounds
ounces	28.35	grams
	6.25×10^{-2}	pounds
pounds	453.6	grams
Energy		
British thermal units	1.055×10^{3}	joules
	0.252	kilogram-calories
electron volts	1.6×10^{-12}	ergs
	$1.6_{7} \times 10^{-19}$	joules
ergs	10^{-7}	joules
	6.24×10^{11}	electron volts
	6.24×10^{5}	megaelectron volts
gram-calories	3.968×10^{-3}	British thermal units
joules	10^{7}	ergs
	9.48×10^{-4}	British thermal units
kilogram-calories	3.968	British thermal units
megaelectron volts	1.6×10^{-6}	ergs
Radiation		
curies	3.7×10^{10}	becquerels
	2.22×10^{12}	disintegrations/minute
	3.7×10	disintegrations/second
	10^{3}	millicuries
	10^{6}	microcuries
	10^{-3}	kilocuries
becquerels	1	disintegrations/second
	2.7×10^{-11}	curies
disintegrations/minute	4.55×10^{-10}	millicuries
	4.55×10^{-7}	microcuries
disintegrations/second	2.7×10^{-8}	millicuries
	2.7×10^{-5}	microcuries
	1	becquerels

MULTIPLY	BY	TO OBTAIN
Radiation (cont'd)		
gray	10^2	rad
	1	joules/kilogram
microcuries	3.7×10^4	disintegrations/second
	2.22×10^6	disintegrations/minute
milliciuries	3.7×10^7	disintegrations/second
	2.22×10^4	disintegrations/minute
rad	10^{-2}	gray
	10^{-2}	joules/kilogram
	10^2	ergs/gram
rem	10^{-2}	sievert
	10^{-2}	joules/kilogram
roentgen	2.58×10^{-4}	coulombs/kilogram
	1	electrostatic units/ cubic centimeter air (at STP)
	2.082×10^9	ion pairs/cubic centimeter air (at STP)
	1.61×10^{12}	ion pairs/gram air
	7.03×10^4	MeV/cubic centimeter air (at STP)(a)
	5.44×10^7	MeV/gram air(a)
	87	ergs/gram air(a)
sievert	10^2	rem
	1	joules/kilogram
Temperature		
degrees Celsius	1.8	degrees Fahrenheit - 32
degrees Fahrenheit - 32	0.5555	degrees Celsius

(a) Assuming that the average energy expended per ion pair formed is 5.4×10^{-11} ergs (34 eV).

Section 16.6 FREQUENTLY USED CONSTANTS

Avogadro's number	$N = 6.0220 \times 10^{23}\ mol^{-1}$
Velocity of light	$c = 2.997925 \times 10^{8}\ m/sec$
Electronic charge	$e = 0.16022 \times 10^{-18}\ C$
Planck's constant	$h = 6.626 \times 10^{-34}\ J \cdot sec$
	$= 6.626 \times 10^{-27}\ erg \cdot sec$
	$= 0.41355 \times 10^{-14}\ eV \cdot sec$
Mass of electron	$m_e = 0.910953 \times 10^{-30}\ kg$
Mass of proton	$m_p = 0.167265 \times 10^{-26}\ kg$
Mass of neutron	$m_n = 0.167495 \times 10^{-26}\ kg$

Section 16.7 ADDRESSES FOR ORDERING REFERENCE DOCUMENTS

American National Standards Institute (ANSI)
Sales Department
American National Standards Institute
1430 Broadway
New York, NY 10018

Code of Federal Regulations (CFR)
Superintendent of Documents
U.S. Government Printing Office
Washington, DC 20402

International Atomic Energy Agency (IAEA)
UNIPUB
345 Park Avenue South
New York, NY 10010

International Commission on Radiation Units and Measurements (ICRU)
ICRU Publications
P.O. Box 30165
Washington, DC 20014

International Commission on Radiological Protection (ICRP)
Pergamon Press
Maxwell House
Fairview Park
Elmsford, NY 10523

National Council on Radiation Protection and Measurements (NCRP)
NCRP Publications
P.O. Box 30175
Washington, DC 20014

National Technical Information Service (NTIS)
U. S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22151

U.S. Department of Transportation (DOT)
Superintendent of Documents
U.S. Printing Office
Washington, DC 20402

U.S. Nuclear Regulatory Commission (NRC)
Superintendent of Documents
U.S. Printing Office
Washington, DC 20402

Section 16.8 GLOSSARY

ABSORPTION:	The process by which radiation imparts some or all of its energy to any material through which it passes.
ACCELERATOR (PARTICLE ACCELERATOR):	A device for imparting large quantities of kinetic energy to electrically charged particles such as electrons, protons, and helium ions.
ACTIVATION:	The process of inducing radioactivity by irradiation.
ACTIVITY:	The number of nuclear transformations occurring in a given quantity of material per unit time. The unit of measure is the curie (Ci).
ACUTE EXPOSURE:	Radiation exposure of short duration.
AGREEMENT STATE:	Any state in the United States with which NRC has made an effective agreement under Subsection 274(b) of the Atomic Energy Act of 1954, as amended, relative to the licensing and control of radioactive material used or produced within that state.
AIRBORNE CONTAMINATION:	The term applied to radioactive contamination loose in the air, filtered from the air, or deposited from the air, as contrasted with contamination spread by splashing, dripping, etc.
AIR-WALL IONIZATION CHAMBER:	An ionization chamber in which the materials of the wall and electrodes are so selected as to produce ionization essentially equivalent to that in a free-air ionization chamber. This is possible only over limited ranges of photon energies. Such a chamber is more appropriately termed an "air-equivalent ionization chamber."
ALARA:	An acronym for "as low as is reasonably achievable"; refers to an operating philosophy in which occupational exposures are reduced as far below specified limits as is reasonably achievable.
ALPHA PARTICLE:	A charged particle that is emitted from the nucleus of an atom and that has a mass and charge equal in magnitude to those of a helium nucleus, i.e., two protons and two neutrons.

AMPLIFICATION: As related to radiation detection instruments, the process (gas, electronic, or both) by which ionization effects are magnified to a degree suitable for their measurement.

ANALYZER, PULSE HEIGHT: An electronic circuit that sorts and records pulses according to their height.

ANGULAR DEPENDENCE: The varying ability of an instrument to accurately measure radiation, depending on its orientation with respect to the radiation field.

ANODE: A positive electrode; the electrode to which negative ions are attracted.

APPRAISAL: A comprehensive evaluation of the overall adequacy and effectiveness of a radiation protection program.

ARTIFICAL RADIOACTIVITY: Manmade radioactivity produced by particle bombardment or electromagnetic irradiation, as opposed to natural radioactivity.

ATOM: The smallest unit of an element that is capable of entering into a chemical reaction.

ATOMIC NUMBER: The number of protons in the nucleus of a neutral atom of a nuclide.

ATTENUATION: The process by which a beam of radiation is reduced in intensity or energy when passing through some material.

AUTHORIZED MATERIAL: Radioactive material not requiring a specific NRC license. The receipt, possession, use, or transfer of radioactive material requires specific authorization or permit by a specific agency or service organization.

AVALANCHE: The multiplicative process in which a single charged particle accelerated by a strong electric field produces additional charged particles through collision with neutral gas molecules. This cumulative increase of ions is also known as "Townsend ionization" or "Townsend avalanche."

BACKGROUND RADIATION: Radiation arising from radioactive material other than the one directly under consideration. Background radiation due to cosmic rays

and natural radioactivity is always present. There may also be background radiation due to the presence of radioactive substances in other parts of a building, in the building material itself, etc.

BEAM: A unidirectional or approximately unidirectional flow of electromagnetic radiation or of particles.

BECQUEREL: The SI unit of activity equal to a nuclear disintegration rate of 1 disintegration per second.

BETA PARTICLE: A charged particle emitted from the nucleus of an atom, with a mass and charge equal in magnitude to those of the electron.

BIOASSAY: An evaluation of the amount of radioactivity taken into the body.

BREMSSTRAHLUNG: Secondary photon radiation produced by the deceleration of charged particles passing through matter.

BYPRODUCT MATERIAL: Any material (except special nuclear material) made radioactive by either exposure to radiation, or the process of producing or using special nuclear material.

CALIBRATION: The determination of a measuring instrument's variation from a standard, to ascertain necessary correction factors.

CATHODE: A negative electrode; the electrode to which positive ions are attracted.

CELL (BIOLOGICAL): The fundamental unit of structure and function in organisms.

CHAIN REACTION): Any chemical or nuclear process in which some products or energy released by the process are instrumental in the continuation or magnification of the process.

CHARACTERISTICS (DISCRETE) RADIATION: Radiation originating from an atom after the removal of an electron or the excitation of the nucleus. The wavelength of the emitted radiation is specific, depending only on the nuclide and the particular energy levels involved.

CHRONIC EXPOSURE: Radiation exposure of long but not necessarily continuous duration.

COLLECTIVE DOSE EQUIVALENT: The sum of dose equivalents received by a given population or group of workers, expressed in units of person-rem.

COLLISION: An encounter between two subatomic particles (including photons) that changes the initial momentum and energy conditions. The products of the collision need not be the same as the initial systems.

COMMODITY (RADIOACTIVE): An item of government property made up in whole or in part of radioactive materials. A national stock number (NSN) (formerly called a federal stock number (FSN)) or part number is assigned to items that contain radioactive material in excess of 0.01 μCi.

COMPOUND: A distinct substance formed by the union of two or more ingredients in definite proportions by weight.

COMPTON EFFECT: An attenuation process observed for x or gamma radiation in which an incident photon interacts with an orbital electron of an atom to produce a recoil electron and a scattered photon with an energy less than that of the incident photon.

CONDENSER R-METER: An instrument consisting of an air-wall ionization chamber together with auxiliary equipment for charging and measuring its voltage. It is used as an integrating instrument for measuring the exposure of x or gamma radiation in roentgens (R).

CONTAMINATION (RADIOACTIVE): The deposition of radioactive material in any place where it is not desired, and particularly in any place where its presence might be harmful.

COUNT (RADIATION MEASUREMENTS): The external indication of a device designed to enumerate ionizing events. It may refer to a single detected event or to the total number registered in a given period of time. The term is often used erroneously to designate a disintegration, ionizing event, or voltage pulse.

COUNTER: A gas-filled radiation detector (chamber or tube) connected to an auxiliary electronic circuit in such a way that individual pulses from ionization events inside the chamber register in an external counting device.

CRITICAL: Capable of sustaining (at a constant level) a chain reaction. "Prompt critical" means sustaining a chain reaction without the aid of delayed neutrons.

CRITICAL ORGAN: The organ of the body receiving a specified radioisotope that results in the greatest physiological damage to the body. For exposure to ionizing radiation from external sources, the critical organs are the skin, blood-forming organs, gonads, and eyes.

CROSS-CONTAMINATION: Contamination not from an original source, but acquired from another contaminated object. The term is used in laboratory, bioassay, and counting-room work to refer to the spread of contamination from contaminated samples to relatively uncontaminated samples, thus giving erroneously high readings to the latter.

CUMULATIVE DOSE (RADIATION): The total dose resulting from repeated exposures to radiation.

CURIE: The special unit of activity (abbreviated Ci). One curie equals exactly 3.7×10^{10} nuclear disintegrations per second.

DAUGHTER: Synonym for decay product.

DECAY CONSTANT: The fraction of the number of atoms of a radioactive nuclide that decay per unit time.

DECAY, RADIOACTIVE: The disintegration of the nucleus of an unstable nuclide by the spontaneous emission of charged particles and/or photons.

DECONTAMINATION: The reduction or removal of radioactive contamination from any given surface.

DELTA RAY: Any secondary ionizing particle ejected by recoil when a primary ionizing particle passes through matter.

DETECTOR, Ge(Li): A solid-state detector in which the crystal used is germanium (Ge) with a minute quantity of lithium (Li) impurity added to stabilize the action. (It is sometimes referred to as a "jelly" detector.)

DETECTOR, INTEGRATING: A detector that measures a total accumulated radiation quantity (such as exposure or dose) rather than the rate of accumulation of the radiation. Devices that accumulate and hold charges (e.g., electrometers) and that indicate measures proportional to the total dose are of this type. Examples of integrating detectors are electrometers, film badges, pocket dosimeters, and neutron activation detectors.

DETECTOR, RADIATION: Any device for converting radiant energy to a form more suitable for observation. An instrument used to determine the presence, and sometimes the amount, of radiation.

DETECTOR, SCINTILLATION: A radiation detector whose response is a light signal generated by the incident radiation and a scintillating medium. The light signal is transformed into an electronic signal through an adjacent, optically coupled, photo-sensitive device such as a photomultiplier tube.

DETECTOR, SOLID-STATE: A generic name for a radiation detector that uses solid-state devices, such as the semiconductors germanium or silicon, which respond to incident radiation with an electronically measurable pulse.

DETECTOR, TRACK (ETCH): A device that records the paths of heavy charged particles in a transparent solid. The tracks may be directly visible, or they may be enhanced by etching with an appropriate reagent (such as potassium hydroxide for etching cellulose acetate).

DISINTEGRATION, NUCLEAR: A spontaneous nuclear transformation (radioactivity) characterized by the emission of energy and/or mass from the nucleus. When numbers of nuclei are involved, the process is characterized by a definite half-life.

DOSE: A general term denoting the quantity of radiation or energy absorbed. For special purposes, the term must be appropriately qualified. If unqualified, it refers to absorbed dose.

DOSE, ABSORBED: The amount of energy imparted to matter in a volume element by ionizing radiation, divided by the mass of irradiated material in that element. Also called dose. The common unit of absorbed dose is the rad, which is equal to 100 ergs of absorbed energy per gram of material (or 0.01 J/kg). The SI unit of absorbed dose is the gray, which is equal to 100 rad or to 1 joule of absorbed energy per kilogram of material.

DOSE, WHOLE-BODY: The average uniform absorbed dose or dose equivalent received by a person whose whole body is exposed to ionizing radiation from an external source.

DOSE EQUIVALENT: The product of the absorbed dose, the quality factor, and other modifying factors necessary to evaluate the effects of irradiation received by exposed persons. This unit of measure takes into account the particular characteristics of the exposure. The common unit of dose equivalent is the rem. The SI unit is the sievert. Absorbed doses of different types of radiation are not additive, but dose equivalents are, because they express on a common scale the amount of damage incurred.

DOSE METER, INTEGRATING: An ionization chamber and measuring system designed to determine the total radiation administered during an exposure. In medical radiology, the chamber is usually designed to be placed on the patient's skin. A device may be included to terminate the exposure when it has reached a particular value.

DOSIMETER: An instrument to detect and measure accumulated radiation exposure. In common usage, a pencil-sized ionization chamber with a self-reading electrometer, used for personnel monitoring.

DOSIMETER, PERSONAL: A dosimeter of small size carried by a person to determine the exposure, absorbed dose, and/or dose equivalent received during the carrying time. Also called personal exposure meter.

DOSIMETER, POCKET: A dosimeter the shape and size of a fountain pen with a clip, to be worn in the pocket like a fountain pen.

DOSIMETER, THERMOLUMINESCENCE: An integrating detector that utilizes a phosphor sensitive to ionizing radiation. The phosphor stores the energy of the ionization within itself and releases it as low-energy photons (light) when heated. The total amount of light released is proportional to the total absorbed dose.

DOSIMETRY, PHOTOGRAPHIC: The determination of cumulative radiation dose using photographic film and density measurement.

EFFICIENCY (OF COUNTERS): A measure of the probability that a count will be recorded when radiation is incident on a detector. Uses of this term vary considerably, so it is well to ascertain which factors (window transmission, sensitive volume, energy dependence, etc.) are included in a given case.

ELASTIC COLLISION: A collision in which there is no change either in the internal energy of each participating system or in the sum of their kinetic energies of translation.

ELECTRODE: A conductor used to establish electrical contact with a nonmetallic part of a circuit.

ELECTRON: A stable elementary particle that has an electric charge equal to $\pm 1.60210 \times 10^{-19}$ coulomb and a rest mass equal to 98.1091×10^{-31} kg.

ELECTRON VOLT: A unit of energy equivalent to the energy gained by an electron in passing through a potential difference of 1 volt. Larger multiple units of the electron volt are frequently used: keV for thousand or kilo-electron volts; MeV for million or mega-electron volts. 1 eV = 1.6×10^{-12} erg.

ELEMENT: A category of atoms all of which have the same atomic number.

EMULSION, NUCLEAR: A photographic emulsion specially designed to permit observation of the individual tracks of ionizing particles.

ENERGY DEPENDENCE: The characteristic response of a radiation detector to a given range of radiation energies or wavelengths, compared with the response of a standard free-air chamber.

ENRICHED MATERIAL: (1) Material in which the relative amount of one or more isotopes of a constituent has been increased.

(2) Uranium in which the abundance of the ^{235}U isotope is increased above normal.

EXCITED STATE (OF A NUCLEUS): An unstable condition of the nucleus of an atom after the entrance of a nuclear particle or gamma-ray photon.

EXPOSURE: (1) The incidence of radiation upon inanimate or living matter by intent or accident.

(2) For x or gamma radiation, the sum of the electrical charges of all the ions of one sign produced in air when all electrons liberated by photons in a suitable small volume of air are completely stopped in air, divided by the mass of air in the volume.

The unit of exposure is the roentgen (R).

EXPOSURE RATE: (1) The exposure divided by the time over which it was accumulated.

(2) The increment of exposure during a suitably small interval of time, divided by that interval of time.

The usual unit of exposure rate is roentgens per hour (R/hr).

EXTERNAL RADIATION: Radiation from a source outside the body.

FALLOUT: Radioactive debris from a nuclear detonation, which is airborne or has been deposited on the earth. Special forms of fallout are "dry fallout," "rainout," and "snowout."

FILTER (RADIOLOGY): Primary--A sheet of material, usually metal, placed in a beam of radiation to absorb preferentially the less penetrating components.

Secondary--A sheet of material of low atomic number (relative to the primary filter) placed in the filtered beam of radiation to remove characteristic radiation produced by the primary filter.

FINGER DOSIMETER: A dosimeter in the form of a ring to be worn by personnel to determine radiation doses to the hands.

FISSILE: A nuclide capable of undergoing fission by interaction with slow neutrons.

FISSILE MATERIAL: Plutonium-238, plutonium-239, plutonium-241, uranium-233, uranium-235, or any material containing any of the foregoing [49 CFR 173.389(a) and 173.398(a)].

FISSION (NUCLEAR): A nuclear transformation characterized by splitting of a nucleus into at least two other nuclei and the release of a relatively large amount of energy.

FISSIONABLE: Pertaining to a nuclide that is capable of undergoing fission by any process.

FISSION PRODUCTS: Elements or compounds resulting from fission.

FLUENCE: The number of particles passing through a unit cross-sectional area.

FLUORESCENCE: The emission of radiation of particular wavelengths by a substance as a result of the absorption of radiation of shorter wavelengths. This emission occurs essentially only during the irradiation.

FLUOROSCOPE: A fluorescent screen, suitably mounted with respect to an x-ray tube for ease of observation and protection, used for indirect visualization (by x rays) of internal organs in the body or internal structures in apparatus or in masses of material.

GAS AMPLIFICATION: As applied to gas-ionization instruments for detecting radiation, the ratio of the charge collected to the charge produced by the initial ionizing event.

GEIGER-MUELLER COUNTER: A highly sensitive, gas-filled radiation-measuring device. It operates at voltages high enough to produce avalanche ionization.

GEOMETRY, GOOD: In nuclear physics measurements, an arrangement of source and detecting equipment that introduces little error when a finite source size and finite detector aperture are used.

GEOMETRY, POOR: In a nuclear experiment, an arrangement in which the angular aperture between the source and detector is large, introducing into the measurement a comparatively large uncertainty for which a correction may be necessary.

GEOMETRY (RADIATION): A nuclear physics term referring to the physical relationship and symmetry of the parts of a radiation detection assembly. Counting efficiency is closely related to geometry.

GLOW CURVE: In thermoluminescence dosimetry, a graph of the released luminescence photon fluence as a function of temperature or time of heating. The area under the bell-shaped curve plotted against time is proportional to the total absorbed dose or exposure.

GLOW PEAK: In thermoluminescence dosimetry, the time or temperature during heating of a thermoluminescence phosphor at which the release rate of the luminescence photons is maximum.

GRAY: The SI unit of absorbed dose, equal to the absorbed energy from ionizing radiation of 1 joule/kg, and equal to 100 rads.

GROUND STATE: The state of a nucleus, atom, or molecule at its lowest energy. All other states are "excited."

HALF-LIFE, BIOLOGICAL: The time required for the body to eliminate one-half of an administered dosage of any substance by processes of elimination. Approximately the same for both stable and radioactive isotopes of a particular element.

HALF-LIFE, EFFECTIVE: The time required for a radioactive element in an animal body to be diminished 50% as a result of the combined action of radioactive decay and biological elimination.

$$\text{Effective half-life} = \frac{\text{Biological half-life} \times \text{Radioactive half-life}}{\text{Biological half-life} + \text{Radioactive half-life}}$$

HALF-LIFE, RADIOACTIVE: The time required for a radioactive substance to lose 50% of its activity by decay. Each radionuclide has a unique half-life.

HALF-VALUE LAYER (HALF THICKNESS) (HVL): The thickness of a specified substance that, when introduced into the path of a given beam of radiation, reduces the exposure rate by one-half.

HEALTH PHYSICS: A science and profession devoted to protecting man and the environment against unnecessary radiation exposure.

HOLE (SOLID-STATE THEORY): A position in the valence bands of semiconductor or insulating materials denoting the absence of an electron. Such a position carries a positive charge that (like an electron) is able to migrate within the band.

INDUCED RADIOACTIVITY: Radioactivity produced in a substance after bombardment with neutrons or other particles. The resulting activity is "natural radioactivity" if formed by nuclear reactions occurring in nature, and "artificial radioactivity" if the reactions are caused by man.

INELASTIC COLLISION: A collision in which there are changes both in the internal energy of one or more of the colliding systems and in the sums of the kinetic energies of translation before and after the collision.

INFRARED RADIATION: Invisible thermal radiation whose wavelength is longer than the red segment of the visible spectrum.

INGESTION (OF RADIOACTIVITY): The entry of radioactivity into the body through the mouth.

INHALATION (OF RADIOACTIVITY): The entry of radioactivity into the body through the breathing of airborne radioactive particulate matter.

INTENSITY: The amount of energy per unit time passing through a unit area perpendicular to the line of propagation at the point in question.

INTENSITY, RADIATION: A generic term for the magnitude of a radiation quantity.

INTENSITY, SOURCE: A generic term for the magnitude of a source emission rate. The source intensity of a radioisotope source is related to its disintegration rate in curies or bequerels.

INTERNAL RADIATION: Radiation from a source within the body (as a result of the deposition of radionuclides in body tissues).

IN-VIVO COUNTING: Measurements of internal radiation made at the surface (outside) of the body and based on the fact that radioisotopes emit radiation that can traverse the tissues and be measured outside the organism. In-vivo counting is synonymous with whole-body counting.

ION: An atomic particle or atom bearing an electric charge, either negative or positive.

IONIZATION: The process by which a neutral atom or molecule acquires a positive or negative charge.

IONIZATION CHAMBER: An instrument designed to measure a quantity of ionizing radiation in terms of the charge of electricity associated with ions produced within a defined volume.

IONIZING RADIATION CONTROL COMMITTEE: A group of qualified personnel officially appointed by a commander to set local policy and to guide the radiation protection program.

IONIZING-RADIATION-PRODUCING DEVICES: Electronic devices that are capable of making ionizing radiation. Examples are x-ray machines, linear accelerators, and electron microscopes.

ION PAIR: Two particles of opposite charge, usually referring to the electron and the positive atomic or molecular residue resulting from the interaction of ionizing radiation with the orbital electrons of atoms.

ISOMERS: Nuclides with the same number of neutrons and protons but capable of existing, for a measurable time, in different quantum states with different energies and radioactive properties. Commonly, the isomer of higher energy decays to one with lower energy by the process of isometric transition.

ISOTOPES:	Nuclides that have the same number of protons in their nuclei, hence the same atomic number, but that differ in the number of neutrons and therefore in the mass number. Isotopes of a particular element have almost identical chemical properties. The term should not be used as a synonym for nuclide.
JOULE:	The unit for work and energy, equal to 10^7 ergs.
LATENT PERIOD:	The interval of seeming inactivity between the time of irradiation and the appearance of an effect.
LEAKAGE RADIATION:	Radiation emerging from a surface, a body of material, or a region in space.
LICENSE (SPECIFIC):	A document issued by NRC under 10 CFR that gives the bearer the right to procure, receive, store, transfer, use, export, and import specified radioactive items under specific terms.
LICENSE-EXEMPT MATERIAL ITEMS:	Radioactive material not subject to NRC regulations, or exempt from NRC licensing under 10 CFR.
LICENSED MATERIAL:	Source, special nuclear, or byproduct material received, stored, possessed, used, or transferred under a general or specific license issued by NRC or an Agreement State.
LINEAR ACCELERATOR:	A device for accelerating charged particles. It employs alternate electrodes and gaps arranged in a straight line, so proportioned that when potentials are varied in the proper amplitude and frequency, particles passing through the waveguide receive successive increments of energy.
LINEAR ENERGY TRANSFER (LET):	The linear rate of loss of energy (locally absorbed) over distance by an ionizing particle moving in a material medium. The usual unit of LET is keV/μm.
MANIPULATOR:	Mechanical hands or some other device for performing work behind a barrier or in a glove box.
MAN-REM:	A unit of population dose equivalent or collective dose equivalent. The number of man-rems of dose equivalent is equal to the product of the population and the average dose equivalent in rem common to that population.

MAXIMUM CREDIBLE ACCIDENT: The worst accident in a reactor or nuclear energy installation that, by agreement, need be taken into account in devising protective measures.

MICROWAVE: An electromagnetic wave with a wavelength of approximately 1 millimeter to 1 meter and corresponding to frequencies of about 300 to 300,000 megacycles per second.

MOLECULE: The smallest unit of a compound, consisting of two or more atoms held together by chemical bonds.

MONITORING: Periodic or continuous determination of the amount of ionizing radiation or radioactive contamination present in an occupied region.

MONTE CARLO METHOD: A method permitting the computer solution of physics problems, such as those of neutron transport, by determining the history of a large number of elementary events by the application of the mathematical theory of random variables.

NATURAL RADIOACTIVITY: The property of radioactivity exhibited by more than 50 naturally occurring radionuclides.

NATURALLY OCCURRING RADIOACTIVE MATERIALS: Radioactive isotopes, such as radium and radon, that are found in nature but are not classified as source material.

NEUTRINO: A neutral particle of very small rest mass originally postulated to account for the continuous distribution of energy among particles in the beta-decay process.

NEUTRON: One of three elementary particles, which is part of all nuclei heavier than hydrogen.

NUCLEON: The common name for a constituent particle of the nucleus. Applied to a proton or neutron.

NUCLEUS (NUCLEAR): That part of an atom in which the total positive electric charge and most of the mass are concentrated.

NUCLIDE: A species of atom characterized by the constitution of its nucleus. The nuclear constitution is specified by the number of protons (Z), number of neutrons (N), and energy content; or, alternatively, by the atomic number (Z), mass number (A = N + Z), and atomic mass. To be

regarded as a distinct nuclide, the atom must be capable of existing for a measurable time. Thus, nuclear isomers are separate nuclides, whereas promptly decaying excited nuclear states and unstable intermediates in nuclear reactions are not so considered.

PAIR PRODUCTION: An absorption process for x and gamma radiation in which the incident photon is annihilated in the vicinity of the nucleus of the absorbing atom, with subsequent production of an electron and positron pair. This reaction occurs only for incident photon energies exceeding 1.02 MeV.

PARENT: A radionuclide which, upon disintegration, yields a specified nuclide, either directly or as a later member of a radioactive series.

PERSONNEL MONITOR: An instrument that measures a radiation quantity proportional to dose equivalent, for use by an individual working in a radiation area.

PHANTOM: A volume of material approximating as closely as possible the density and effective atomic number of body tissue. Ideally, a phantom should absorb radiation in the same way tissues does. Radiation dose measurements made within or on a phantom provide a means of determining the radiation dose within or on a body under similar exposure conditions. Some materials commonly used in phantoms are water, Masonite, pressed wood, and beeswax.

PHOSPHORESCENCE: The emission of radiation by a substance as a result of the previous absorption of radiation of shorter wavelength. In contrast to fluorescent emissions, the phosphorescent emissions may continue for a considerable time after cessation of the exciting irradiation.

PHOTOELECTRIC EFFECT: The process by which a photon ejects an electron from an atom. All the energy of the photon is absorbed in ejecting the electron and in imparting kinetic energy to it.

PHOTON: A quantity of electromagnetic energy (E) whose value in joules is the product of its frequency (O) in hertz and Planck's constant (h). The equation is $E = hO$.

PIG: A container, usually lead, used to ship or store radioactive materials.

PRIMARY IONIZATION: (1) In collision theory: the ionization produced by primary particles, as contrasted with total ionization, which includes the secondary ionization produced by delta rays.

(2) In counter tubes: the total ionization produced by incident radiation without gas amplification.

PROPORTIONAL COUNTER: A gas-filled radiation detector tube operated in that range of applied voltage in which the charge collected per isolated count is proportional to the charge liberated by the original ionizing event. The range of applied voltage depends upon the type and energy of the incident radiation.

PROTECTIVE CLOTHING: The clothing worn by radiation workers to prevent radioactive contamination of the body or personal clothing.

PROTECTIVE EQUIPMENT: Safety devices such as goggles or clothing used to do a job safely.

PROTON: An elementary nuclear particle with a positive electric charge equal numerically to the charge of the electron and a mass of 1.007277 mass units.

PURGING: The removal of material from a system or pipe by adding another material, such as blowing with air.

PYROPHORIC: Igniting spontaneously on exposure to air.

QUALITY FACTOR (Q): The factor dependent on linear energy transfer by which absorbed doses are multiplied to obtain (for radiation protection purposes) a quantity that expresses the effect of the absorbed dose on a common scale for all ionizing radiations.

QUENCHING: The process of inhibiting continuous or multiple discharge in a counter tube that uses gas amplification.

RAD: The unit of absorbed dose equal to 0.01 J/kg in any medium.

RADIATION: Energy traveling through space in the form of waves, particles, or bundles called photons.

RADIATION AREA: An area or item of equipment requiring access control for personnel protective purposes; an area or item of equipment presenting personnel hazards due to radiation or contamination.

RADIATION, DIRECT: Radiation reaching a given location directly from an emitting source without collision or energy degradation. Also called unscattered or uncollided radiation.

RADIATION, INDIRECT: Radiation reaching a given location after having been scattered at least once. Also called scattered radiation.

RADIATION, IONIZING: Radiation composed of particles that are themselves ionized (directly ionizing radiation) or that are able to ionize other atoms by reaction with them (indirectly ionizing radiation).

RADIATION, PRIMARY: (1) Radiation emitted by a primary nuclear reaction source (as opposed to radiation emitted by subsequent nuclear or atomic interactions as a result of primary radiation interactions).

(2) Radiation originating within an emitting source (such as the core of a nuclear reactor).

RADIATION, SCATTERED: Radiation reaching a given location after having undergone at least one scattering. See also radiation, indirect.

RADIATION, SECONDARY: Radiation emitted by some nuclear or atomic process as a result of previous nuclear or atomic interactions by a primary radiation source. Example: capture-gamma radiation.

RADIATION CONTROL OFFICER: An officer, enlisted person, or DA civilian employee appointed by each major Army commander to manage the radiation protection program for the major command.

RADIATION HAZARD: The presumed risk or deleterious effects attributable to deliberate, accidental, or natural exposure to radiation.

RADIATION PROTECTION OFFICER: A person appointed by the commander to give advice on the hazards of ionizing radiation and to supply effective ways to control these hazards.

RADIOACTIVE CONTROLLED ITEMS: All commodities, components, and end items containing radioactive material that are controlled with respect to maintenance, disposal, and bulk storage. Items requiring additional controls are listed in 10 CFR 30.71.

RADIOACTIVE INDIVIDUALLY CONTROLLED ITEMS: Items that are assigned national stock numbers and must be controlled to the extent that their integrity and location are known by the licensee or designated agent (control point) at all times.

RADIOACTIVE MATERIAL: Any material or combination of materials that spontaneously gives off ionizing radiation. This includes natural elements such as radium, and accelerator-made radionuclides.

RADIOACTIVE MATERIAL CONTROL POINT: Any Army element (including the RCO) that has been designated by a major Army commander to control radioactive items within the command.

RADIOACTIVE WASTE: Waste materials that include the following:

a. property contaminated to the extent that decontamination is economically unsound
b. surplus radioactive material whose sale, transfer, or donation is prohibited
c. surplus radioactive material that is determined to be unwanted after being advertised as surplus
d. waste that is radioactive due to production, possession, or use of radioactive material.

RADIOACTIVITY: A natural and spontaneous process by which the unstable atoms of an element emit or radiate excess energy from their nuclei as particles or photons and thus change (or decay) to atoms of a different element or to a lower energy form of the original element.

RADIOBIOLOGY: The branch of biology that deals with the effects of radiation on biological systems.

RADIOCHEMISTRY: The aspects of chemistry connected with radionuclides and their properties, with the behavior of minute quantities of radioactive materials, and with the use of radionuclides in the study of chemical problems.

RADIOGRAPH: A shadow picture produced by passing x rays or gamma rays through an object and recording the variations in the intensity of the emergent rays on photographic or sensitized film.

RADIOLOGY: The branch of medicine that deals with the diagnostic and therapeutic applications of radiant energy, including x rays and radionuclides.

RADIOPHARMACEUTICAL: A pharmaceutical compound that has been tagged with a radionuclide.

RADIOSENSITIVITY: The relative susceptibility of cells, tissues, organs, organisms, or any living substance to the injurious action of radiation.

REM: A special unit of dose equivalent. The dose equivalent in rems is numerically equal to the absorbed dose in rads multiplied by the quality factor and any other necessary modifying factors.

RESTRICTED AREA: Any area in a radiation facility to which access is controlled by the licensee for purposes of protecting individuals from exposure to radiation and radioactive materials.

ROENTGEN: One roentgen is the quantity of charge liberated by x or gamma radiation and is equal to 2.58 x 10^{-4} coulombs per kilogram of dry air. It is equivalent to the energy absorption of x or gamma radiation of 87.7 ergs/g of air or 96.5 ergs/g of tissue (0.00877 J/kg and 0.00965 J/kg).

SATURATION (IONIZATION CHAMBER): The condition in an ionization chamber when the applied voltage is sufficient to collect all the ions formed from the absorption of radiation, but insufficient to cause ionization by collisions.

SCATTERING: Change of direction of subatomic particles or photons as a result of a collision or interaction.

SEALED SOURCE: Any radioactive material that is permanently bonded or fixed in a capsule or matrix designed to prevent the release or dispersal of the material under the most severe conditions encountered in normal use or handling.

SECONDARY IONIZATION: Ionization produced by delta rays.

SELF-ABSORPTION: The absorption of radiation (emitted by radioactive atoms) by the material in which the atoms are located; in particular, the absorption of radiation within a sample being assayed.

SERIES, RADIOACTIVE: A succession of nuclides, each of which transforms by radioactive disintegration into the next until a stable nuclide results. The first member is called the "parent," the intermediate members are called "daughters," and the final stable member is called the "end product."

SHIELD: A body of material used to prevent or reduce the passage of particles or radiation.

SIEVERT: The SI unit of dose equivalent equal to the absorbed dose in grays multiplied by the quality factor and any other necessary modifying factors.

SOURCE, RADIATION: Materials or devices that make or are capable of making ionizing radiation, including:

a. naturally occuring radioactive materials
b. byproduct materials
c. source materials
d. special nuclear materials
e. fission products
f. materials containing induced or deposited radioactivity
g. radiographic and fluoroscopic equipment
h. particle generators and accelerators
i. electronic equipment that uses klystrons, magnetrons, or other electron tubes that produce x rays.

SOURCE GEOMETRY: The shape, size, and configuration of a radiation source, taken as a whole.

SOURCE MATERIAL: Uranium or thorium or a combination of both, in any physical form, or ores that contain one-twentieth or more by weight of uranium or thorium or any combination. Source material does not include special nuclear material.

SPECIAL NUCLEAR MATERIAL: Plutonium or uranium enriched in isotope 233 or 235, and any other material NRC determines to be special nuclear material. Any material (except source material) artificially enriched by either isotope.

SPECIFIC ACTIVITY: The total activity of a given nuclide per gram of a compound, element, or radioactive nuclide.

SPECIFIC IONIZATION: The number of ion pairs produced per unit path length of ionizing radiation in a medium (e.g., per cm of air or per micron of tissue).

SPECTROMETER (NUCLEAR): A device or instrument, usually electronic, capable of measuring the energy distribution of nuclear radiations.

STABLE ISOTOPE: A nonradioactive isotope of an element.

SURVEY (RADIATION): An evaluation of the radiation hazard associated with the production, use, or existence of radioactive materials or other sources of radiation under specific conditions. The evaluation usually includes:

a. a physical survey of the disposition of materials and equipment
b. measurements or estimates of the levels of radiation involved
c. predictions of hazards resulting from expected or possible changes in materials or equipment.

THIMBLE IONIZATION CHAMBER: A small cylindrical or spherical ionization chamber, usually with walls of organic material.

THRESHOLD DOSE: The minimum absorbed dose that produces a detectable effect.

TISSUE DOSE: The absorbed dose received by tissue in a region of interest, expressed in rads.

TISSUE-EQUIVALENT IONIZATION CHAMBER: An ionization chamber in which the material of the walls, electrodes, and gas are so selected as to produce a response to radiation similar to the response of tissue.

TISSUE-EQUIVALENT MATERIAL: A liquid or solid whose absorbing and scattering properties for a given radiation simulate as closely as possible those of a given biological material, such as fat, bone, or muscle. For muscle or soft tissue, water is usually the best tissue-equivalent material.

TRACK: The visual manifestation of the path of an ionizing particle in a chamber or photographic emulsion.

USE FACTOR: For a mechanical radiation source, the fraction of the workload during which the useful beam is pointed toward the area in question.

USEFUL BEAM: The radiation that passes through the window, aperture, cone, or other collimating device of the housing for a radiation source. Sometimes called "primary beam."

VALENCE: The number representing the combining or displacing power of an atom; the number of electrons lost, gained, or shared by an atom in a compound; the number of hydrogen atoms with which an atom will combine or which it will displace.

VAN DE GRAAFF ACCELERATOR: An electrostatic machine in which electrical charge is carried into the high-voltage terminal by a belt made of an insulating material moving at a high speed. The particles are then accelerated along a discharge path through a vacuum tube by the potential difference between the insulated terminal and the grounded end of the accelerator.

VOLUME, SENSITIVE: The portion of a counter tube or ionization chamber that responds to a specific radiation.

WORKLOAD: A quantity indicating the average weekly output of a mechanical radiation source. For example, for a clinical x-ray apparatus, the workload can be specified in milliampere-minutes per week, at a particular (usually maximum) x-ray tube voltage.

X-RAYS: Penetrating electromagnetic radiations whose wavelengths are shorter than those of visible light. They are usually produced by bombarding a metallic target with fast electrons in a high vacuum. In nuclear reactions, it is customary to refer to photons originating in the nucleus as gamma rays, and those originating in the extranuclear part of the atom as x rays. These rays are sometimes called roentgen rays after their discoverer, W. K. Roentgen.

BIBLIOGRAPHY

ALARA A-2
ARMY REGULATIONS A-2
CONTAMINATION AND DECONTAMINATION A-3
DOSE CALCULATIONS A-4
EMERGENCY PREPAREDNESS A-6
ENVIRONMENTAL MONITORING A-9
FACILITY DESIGN A-10
GENERAL HEALTH PHYSICS PROGRAMS A-12
GENERAL TEXTBOOKS A-14
INSTRUMENTATION AND DOSIMETRY A-15
QUALITY ASSURANCE/QUALITY CONTROL A-17
RADIATION-GENERATING DEVICES A-18
RADIOCHEMICAL ANALYSIS A-19
RECORDS A-19
SHIELDING A-20
STATISTICS A-21
SURVEYING AND MONITORING A-21
TRAINING A-23
TRANSPORTATION A-24
WASTE MONITORING A-25

BIBLIOGRAPHY

ALARA

International Commission on Radiological Protection. 1973. Implications of Commission Recommendations that Doses be Kept as Low as Readily Achievable. ICRP 22, Pergamon Press, New York.

Kathren, R. L., et al. 1980. A Guide to Reducing Radiation Exposures to As Low As Reasonably Achievable (ALARA). DOE/EV/1830-T5, National Technical Information Service, Springfield, Virginia.

Mauro, J. J., and J. Porrovecchio. 1976. "Numerical Criteria for In-Plant 'As Low As Is Reasonably Achievable,'" in Proceedings of the 9th Midyear Topical Symposium of the Health Physics Society on Operational Health Physics. Rocky Mountain Chapter, Health Physics Society, P.O. Box 3229, Boulder, Colorado 80303.

Munson, L. H., and L. A. Freytag. 1976. "An Audible Program of Compliance with ALAP," in Proceedings of the 9th Midyear Topical Symposium of the Health Physics Society on Operational Health Physics. Rocky Mountain Chapter, Health Physics Society, P.O. Box 3229, Boulder, Colorado 80303.

U.S. Nuclear Regulatory Commission. 1975. "Operating Philosophy For Maintaining Occupational Radiation Exposures As Low As Reasonably Achievable." Regulatory Guide 8.1, Washington, D.C.

U.S. Nuclear Regulatory Commission. 1977. "Information Relevant to Ensuring that Occupational Radiation Exposures at Nuclear Power Stations Will be as Low as Reasonably Achievable." Regulatory Guide 8.8, Washington, D.C.

ARMY REGULATIONS

U.S. Department of Defense. Military Standard - Radioactive Materials: Marking and Labeling of Items, Packages, and Shipping Containers for Identification in Use, Storage, and Transportation. MIL-STD-1458, Washington, D.C.

U.S. Department of Defense, Defense Supply Agency. Radioactive Commodities in the DOD Supply Systems. DSAM 4145.8, AR 700-64, Alexandria, Virginia.

U.S. Department of Defense, Defense Supply Agency. Chemical, Biological and Radiological (CBR) Decontamination. TM 3-2300, Washington, D.C.

U.S. Department of the Army, Headquarters. Handling and Disposal of Unwanted Radioactive Material. TM 3-261, Washington, D.C.

U.S. Department of the Army, Headquarters. "Maintenance and Disposition of General Personnel Management and Safety Functional Files." In Army Functional File System. AR 340-11, Washington, D.C.

U.S. Department of the Army, Headquarters. Medical Support - Nuclear/Chemical Accidents and Incidents. AR 40-13, Washington, D.C.

U.S. Department of the Army, Headquarters. Military Traffic Management Regulation. AR 55-355, Washington, D.C.

U.S. Department of the Army, Headquarters. Safety - Accident Reporting and Records. AR 385-40, Washington, D.C.

U.S. Department of the Army, Headquarters. Safety - Ionizing Radiation Protection (Licensing, Control, Transportation, Disposal, and Radiation Safety). AR 385-11, Washington, D.C.

U.S. Department of the Army, Headquarters, Army Materiel Command. Safety - Radiation Protection. DARCOM-R 385-25, Washington, D.C.

U.S. Department of the Army and Defense Lositics Agency. Medical Services - Control and Recording Procedures for Exposure to Ionizing Radiation and Radioactive Materials. AR 40-14, DLAR 1000.28, Washington, D.C.

CONTAMINATION AND DECONTAMINATION

Ayres, J. A. 1970. Decontamination of Nuclear Reactors and Equipment. The Ronald Press Company, New York.

Bost, W. E. 1959. Radioactive Decontamination, A Literature Search. TID-3535, Division of Technical Information Extension, Oak Ridge, Tennessee.

Healy, J. W. 1980. Proposed Policy for Decontamination and Decommissioning. Proceedings of DOE Decommissioning Criteria Workshop in Kansas City, April 15-16, 1980.

International Atomic Energy Agency. 1969. Environmental Contamination by Radioactive Materials. IAEA Publication No. STI/PUB/226, Vienna.

Januska, A. G., W. J. Tyrrell and G. A. Bennett. 1974. Decontamination of Plutonium Contaminated Gloveboxes. ANL-8124, Argonne National Laboratory, Argonne, Illinois.

MacFarlane, C. J., and R. J. Beal. 1962. Special Equipment for Decontamination and Control of Radiation Hazards at Chalk River. ERRISD-1071, Atomic Energy of Canada Limited, Chalk River, Ontario.

Manion, W. J., and Thomas S. LaGuardia. 1980. Decommissioning Handbook. DOE/EV/10128-1, U.S. Department of Energy, Washington, D.C.

Maugham, G. I. 1960. Biological and Radioactive Decontamination of Areas and Equipment. DEG Information Series 147(R), United Kingdom Atomic Energy Association, Risely, Warrington, Lancashire, England.

Philipp, H. 1963. Bibliographic Review of Selected Subjects, Decontamination. German Report AED-C-13-02.

Philipp, H. 1963. Bibliographic Review of Selected Subjects, Decontamination. German Report AED-C-13-03.

Philipp, H. 1966. Bibliographies in Nuclear Science and Technology, Decontamination. German Report AED-C-13-04.

Tompkins, P. C. 1959. "Surface Contamination and Decontamination," in Radiation Hygiene Handbook, 1st ed., H. Blatz, ed. McGraw-Hill, Inc., New York.

DOSE CALCULATIONS

Arras, J. M. 1981. Concentric Cylinder Set Model for Estimating Dose from Gamma-Emitting Cloud. AFRRITN 81-1, Armed Forces Radiobiology Research Institute, Bethesda, Maryland.

Brodsky, A. 1969. "Data and Methods for Estimating Radiation Exposures from Internal and External Radiation Sources," in Handbook of Radioactive Nuclides, Y. Wang, ed. Chemical Rubber Company, Cleveland, Ohio.

Bunch, D. F. 1967. "Dose to Various Body Organs from Inhalation or Ingestion of Soluble Radionuclides," in Handbook of Laboratory Safety, N. V. Steere, ed. Chemical Rubber Company, Cleveland, Ohio.

Cooper, R. E. 1967. RADOS, A Code to Estimate Gamma Dose from a Cloud of Radioactive Gases. DP-1098, Savannah River Laboratory, Aiken, South Carolina.

Cooper, R. E. 1976. "A Computer Code to Provide Emergency Response Capabilities to Estimate Whole Body Gamma Dose," in Savannah River Laboratory Environmental Transport and Effects Research Annual Report, FY-1975. DP-1412, Savannah River Laboratory, Aiken, South Carolina.

Garfield, D. K. 1976. "Estimation of ^{125}Iodine Thyroid Burden from Air Monitoring and Urinalysis Data," in Proceedings of the 9th Midyear Topical Symposium of the Health Physics Society on Operational Health Physics. Rocky Mountain Chapter, Health Physics Society, P.O. Box 3229, Boulder, Colorado 80303.

Healy, J. W., and R. E. Baker. 1968. "Radioactive Clouddose Calculations," in Meteorology and Atomic Energy 1968, D. H. Slade, ed. U.S. Atomic Energy Commission, Washington, D.C.

Houston, J. R., D. L. Strenge and E. C. Watson. 1974. DACRIN: A Computer Program for Calculating Organ Dose from Acute or Chronic Radionuclide Inhalation. BNWL-B-389, Pacific Northwest Laboratory, Richland, Washington.

International Atomic Energy Agency. 1974. Population Dose Evaluation and Standards for Man and His Environent. IAEA Publication No. STI/PUB/375, Vienna.

International Commission on Radiation Units and Measurements. 1964. Physical Aspects of Irradiation. ICRU 106, also published as NBS Handbook 85, U.S. Government Printing Office, Washington, D.C.

International Commission on Radiological Protection. 1960. Report of Committee II on Permissible Dose for Internal Radiation. ICRP 2, Pergamon Press, New York.

International Commission on Radiological Protection. 1968. Report of Committee IV on Evaluation of Radiation Doses to Body Tissues from Internal Contamination Due to Occupational Exposure. ICRP 10, Pergamon Press, New York.

International Commission on Radiological Protection. 1971. Report of Committee V on the Assessment of Internal Contamination Resulting from Recurrent or Prolonged Uptakes. ICRP 10A, Pergamon Press, New York.

International Commission on Radiological Protection. 1972. Alkaline Earth Metabolism in Adult Man. ICRP 20, Pergamon Press, New York.

International Commission on Radiological Protection. 1972. The Metabolism of Compounds of Plutonium and Other Actinides. ICRP 19, Pergamon Press, New York.

International Commission on Radiological Protection. 1978. Limits for Intakes of Radionuclides by Workers. ICRP 30, Part 1 and Supplement to Part 1, Pergamon Press, Oxford.

International Commission on Radiological Protection. 1980. Limits for Intakes of Radionuclides by Workers. ICRP 30, Part 2, Pergamon Press, Oxford.

Jenkins, T. M. 1974. "Accelerator Boundary Doses and Skyshine." Health Phys. 27:251.

Kase, K. R. 1972. Concepts of Radiation Dosimetry. SLAC-153, National Technical Information Service, Springfield, Virginia.

Killough, G. G., and G. R. McKay. 1976. A Methodology for Calculating Radiation Doses from Radioactivity Released to the Environment. ORNL-4992, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Lahti, G. P., R. S. Hubner and J. C. Golden. 1981. "Assessment of γ-Ray Exposures Due to Finite Plumes." Health Phys. 41:319-340.

Moe, H. J. 1981. "Contact, or Near Contact, External Dose Estimates." Continuing Education Lecture-Health Physics Society Meeting, 1981.

National Council on Radiation Protection and Measurements. 1959. Maximum Permissible Body Burdens and Maximum Permissible Concentration of Radionuclides in Air and in Water for Occupational Exposures. NCRP 22, also published as National Bureau of Standards Handbook 69, Washington, D.C.

Rider, J. L., and S. K. Beal. 1977. Model to Estimate the Local Radiation Doses to Man from the Atmospheric Release of Radionuclides (LWBR Development Program). WAPD-TM-1273, Bettis Atomic Power Laboratory, West Mifflin, Pennsylvania.

Rohrer, R. H. 1970. "Activities of the Medical Internal Radiation Dose Committee (MIRD) of the Society of Nuclear Medicine," in Medical Radionuclides: Radiation Dose and Effects. USAEC Symposium Series No. 20, CONF-691212, National Technical Information Service, Springfield, Virginia.

Scherpelz, R. I., F. J. Borst and G. R. Hoenes. 1980. WRAITH - A Computer Code Which Calculates Internal and External Doses Resulting From Atmospheric Releases of Radioactive Material. PNL-3382, Pacific Northwest Laboratory, Richland, Washington.

Stephens, L. D., R. H. Thomas and S. B. Thomas. 1975. "Population Exposure From High-Energy Accelerators." Health Phys. 29:853.

EMERGENCY PREPAREDNESS

Aldrich, D. C., and J. D. Johnson. 1978. Public Protection Strategies for Potential Nuclear Reactor Accidents: Sheltering Concepts with Existing Public and Private Structures. SAND-77-1725, Massachusetts Institution of Technology, Cambridge, Massachusetts.

American National Standards Institute. 1979. Facilities and Medical Care for On-Site Nuclear Power Plant Radiological Emergencies. ANSI/ANS-3.7.1, American Nuclear Society, LaGrange Park, Illinois.

Benton and Franklin Counties, Washington State. Peace-Time Radiological Training for Firefighting and Paramedic Staff. Benton County, Department of Emergency Services.

Bowers, P. R. 1976. "Emergency Plans - Window Dressing or Workable?" in Proceedings of the 9th Midyear Topical Symposium of the Health Physics Society on Operational Health Physics. Rocky Mountain Chapter, Health Physics Society, P.O. Box 3229, Boulder, Colorado 80303.

Brodsky, A. 1965. "Criteria for Acute Exposure to Mixed Fission-Product Aerosols." Health Phys. 11:1017-1032.

Clarke, R. H. 1973. "The WEERIE Program for Assessing the Radiological Consequences of Airborne Effluents from Nuclear Installations." Health Phys. 25:267.

Dabberdt, W. F., et al. 1982. Workshop on Meteorological Aspects of Emergency Response Plans for Nuclear Power Plants: Proceedings and Recommendations. Final Report, SRI Project 3689, SRI International, Menlo Park, California.

Dickey, B. B. 1976. "The Importance of Coordinated Planning for the Medical Management of Irradiated or Radioactively Contaminated Patients," in Proceedings of the 9th Midyear Topical Symposium of the Health Physics Society on Operational Health Physics. Rocky Mountain Chapter, Health Physics Society, P.O. Box 3229, Boulder, Colorado 80303.

Fitzgerald, J. J. 1970. "Emergency Planning Considerations," page 701 in Applied Radiation Protection and Control, Vol. II. Gordon and Breach Science Publishers, New York.

Gallagher, R. G. 1969. "Emergency Planning and Procedures," in Handbook of Radioactive Nuclides, Y. Wang, ed. Chemical Rubber Company, Cleveland, Onio.

International Atomic Energy Agency. 1969. Planning for the Handling of Radiation Accidents. IAEA Safety Series No. 32, Vienna.

International Atomic Energy Agency. 1969. Symposium on the Handling of Radiation Accidents. International Atomic Energy Agency, Vienna.

International Atomic Energy Agency. 1974. Evaluation of Radiation Emergencies and Accidents - Selected Criteria and Data. IAEA Technical Report No. 152, Vienna, Austria.

MacDonald, H. F. 1971. "Assessment of Environmental Hazards Following Nuclear Reactor Accidents," in Rapid Methods for Measuring Radioactivity in the Environment. Symposium Proceedings, STI/PUB/289, International Atomic Energy Agency, Vienna, Austria.

McBride, J. A., and R. E. Cunningham. 1972. "The Role of Radiation Monitoring in Emergency Preparedness," in Health Physics Operational Monitoring, Vol. III, C. A. Willis and J. S. Handloser, eds. Gordon and Breach Science Publishers, New York.

Moeller, D. W., and J. M. Selby. 1976. "Planning for Nuclear Emergencies." Nucl. Saf. 17:1.,

Montgomery, J. L. 1976. "The Colorado Radiological Response Plan," in Proceedings of the 9th Midyear Topical Symposium of the Health Physics Society on Operational Health Physics. Rocky Mountain Chapter, Health Physics Society, P.O. Box 3229, Boulder, Colorado 80303.

National Council on Radiation Protection and Measurements. 1980. Management of Persons Accidentally Contaminated with Radionuclides. NCRP 65, Washington, D.C.

Pohl, W. K. 1971. "Emergency Organization and Planning." Health Phys. 21:3.

Saenger, E. L. 1963. Medical Aspects of Radiation Accidents: A Handbook for Physicians, Health Physicists, and Industrial Hygienists. U.S. Government Printing Office, Washington, D.C.

Unruh, C. M. 1973. Checklist for Radiological Emergency Preparedness. RS2-158, Pacific Northwest Laboratory, Richland, Washington.

U.S. Department of Energy. 1979. Emergency Handling of Radiation Accident Cases - FIREMEN. DOE/EV-0023, Washington, D.C.

U.S. Department of Energy. 1979. Emergency Handling of Radiation Accident Cases - NURSES. DOE/EV-0018, Washington, D.C.

U.S. Department of Energy. 1979. Emergency Handling of Radiation Accident Cases - PHYSICIANS. DOE/EV-0017, Washington, D.C.

U.S. Department of Energy. 1979. Emergency Handling of Radiation Accident Cases - POLICE. DOE/EV-0021, Washington, D.C.

U.S. Environmental Protection Agency. 1975. Manual of Protective Action Guides and Protective Actions for Nuclear Incidents. EPA-520/1-75-001, revised June 1979 and February 1980, Washington, D.C.

U.S. Nuclear Regulatory Commission (NRC). 1975. Guide and Checklist for Development and Evaluation of State and Local Government Radiological Emergency Response Plans in Support of Fixed Nuclear Facilities. NUREG-71/111, National Technical Information Service, Springfield, Virginia.

U.S. Nuclear Regulatory Commission. 1981. Radiation Protection Plans for Nuclear Power Reactor Licensees. NUREG-0761, U.S. Government Printing Office, Washington, D.C.

U.S. Nuclear Regulatory Commission. 1981. Standard Review Plan for the Review and Evaluation of Emergency Plans for Research and Test Reactors. NUREG-0849, National Technical Information Service, Springfield, Virginia.

Wald, N. 1969. "Radiation Injury and Its Management," in Handbook of Radioactive Nuclides, Y. Wang, ed. Chemical Rubber Company, Cleveland, Ohio.

Washington State Department of Social and Health Services. 1979. Radiation Emergency Handbook, Olympia, Washington.

ENVIRONMENTAL MONITORING

Adams, J. A., W. M. Lowder and T. Gessell, eds. 1972. The Natural Radiation Environment II. CONF-720805, U.S. Energy Research and Development Administration, Washington, D.C.

Cheremisinaff, P. N., and A. C. Morresi. 1977. Environmental Assessment and Impact Statement Handbook. Ann Arbor Science Publishers, Ann Arbor, Michigan.

Corley, J. P., P. H. Denham, D. E. Michels, A. R. Olsen and D. A. Waite. 1976. A Guide for Environmental Radiological Surveillance at ERDA Installations. ERDA-77-24, National Technical Information Service, Springfield, Virginia.

Daly, J. C., and J. J. Gabay. 1971. "Rapid Screening of Environmental Samples Using Gamma Spectrometry." Health Phys. 20:640.

Eisenbud, M. 1973. Environmental Radioactivity. Academic Press, New York.

Hoffman, F. O., C. W. Miller, D. L. Shaeffer and C. T. Garten, Jr. 1977. "Computer Codes for the Assessment of Radionuclides Released to the Environment." Nuclear Safety 18(3):343-354.

Hoy, J. E. 1971. "Environmental Radiation Monitoring with Thermoluminescent Dosimeters." Health Phys. 21:860.

International Atomic Energy Agency. 1966. Environmental Monitoring in Emergency Situations. IAEA Safety Series No. 18, Vienna.

International Atomic Energy Agency. 1966. Manual of Environmental Monitoring in Normal Operations. IAEA Safety Series No. 16, Vienna.

International Atomic Energy Agency. 1975. Objectives and Design of Environmental Monitoring Programmes for Radioactive Contaminations. IAEA Safety Series No. 41, Vienna.

International Atomic Energy Agency. 1978. Monitoring of Airborne and Liquid Radioactive Releases from Nuclear Facilities to the Environment. IAEA Safety Series No. 46, Vienna.

International Atomic Energy Agency. 1978. Principles for Establishing Limits for the Release of Radioactive Releases from Nuclear Facilities to the Environment. IAEA Safety Series No. 45, Vienna.

International Commission on Radiological Protection. 1966. Principles of Environmental Monitoring Related to the Handling of Radioactive Materials. ICRP 7, Pergamon Press, New York.

National Council on Radiation Protection and Measurements. 1976. Environmental Radiation Measurements. NCRP 50, Washington, D.C.

Reinig, W. C., ed. 1970. Environmental Surveillance in the Vicinity of Nuclear Facilities. Charles C. Thomas Publishers, Springfield, Illinois.

U.S. Environmental Protection Agency. 1972. Environmental Radioactivity Surveillance Guide. Report No. ORP/SID 72-2, Washington, D.C.

U.S. Nuclear Regulatory Commission. 1975. "Programs for Monitoring Radioactivity in the Environs of Nuclear Power Plants." Regulatory Guide 4.1, Washington, D.C.

U.S. Nuclear Regulatory Commission. 1975. "Environmental Radiological Monitoring Program." Regulatory Guide 4.8. Washington, D.C.

World Health Organization. 1968. Routine Surveillance for Radionuclides in Air and Water. World Health Organization, Geneva.

FACILITY DESIGN

American Conference of Governmental Industrial Hygienists. 1974. Industrial Ventilation, 13th ed. Committee on Industrial Ventilation, P.O. Box 453, Lansing, Michigan 48902.

American National Standards Institute. 1972. Efficiency Testing of Air Cleaning Systems Containing Devices for Removal of Particles. ANSI N101.1, New York.

Brandt, A. D. 1947. Industrial Health Engineering. John Wiley and Sons, New York.

Burchsted, C. A., A. E. Fuller and J. E. Kahn. 1976. Nuclear Air Cleaning Handbook. ERDA 76-21, U.S. Energy Research and Development Administration, Washington, D.C.

Coco, L. M. 1976. "An Analysis of Facility Design and Operation for Maintaining Personnel Exposures as Low as Reasonably Achievable," in Proceedings of the 9th Midyear Topical Symposium of the Health Physics Society on Operational Health Physics. Rocky Mountain Chapter, Health Physics Society, P.O. Box 3229, Boulder, Colorado 80303.

Hatch, T. 1954. Industrial Dust, 2nd ed. McGraw-Hill, Inc. New York.

Hawkins, M. D. 1959. "Equipment for Handling, Storage, and Transportation of Radioactive Materials," page 17-2 in Radiation Hygiene Handbook, 1st ed., H. Blatz, ed. McGraw-Hill, Inc., New York.

Hemeon, W. C. L. 1954. Plant and Process Ventilation. The Industrial Press, New York.

International Atomic Energy Agency. 1966. Technique for Controlling Air Pollution from the Operation of Nuclear Facilities. IAEA Safety Series No. 17, Vienna.

National Council on Radiation Protection and Measurements. 1977. Radiation Protection Design Guidelines for 0.1-100 MeV Particle Accelerator Facilities. NCRP 51, Washington, D.C.

National Institute for Occupational Safety and Health. 1976. A Guide to Industrial Respiratory Protection. HEW Publication No. 76-189, National Institute for Occupational Safety and Health, Cincinnati, Ohio.

Odor, D. L. 1975. "The Health Physicist and Nuclear Power Plant Design." Health Phys. 29:799.

Patty, F. A., ed. 1958. "Ventilation," in Industrial Hygiene and Toxicology. Interscience Publishers, Inc., New York.

U.S. Nuclear Regulatory Commission. 1975. Design, Testing and Maintenance Criteria for Atmospheric Clean-Up System Air Filtration and Adsorption Units of Light-Water-Cooled Nuclear Power Plants. Regulatory Guide 1.52, Washington, D.C.

Werling, J. P., Jr., D. G. Oliver, Jr., and E. B. Moore. 1973. "A Storage and Handling Facility for Californium-252 Medical Sources." Health Phys. 25:163.

GENERAL HEALTH PHYSICS PROGRAMS

American National Standards Institute. 1976. Glossary of Terms in Nuclear Science and Technology. ANSI-N1.1, Washington, D.C.

Amtey, S. R., and M. D. Allen. 1976. "Personnel, Space, and Budget Needs of a University Radiation Safety Program," in Proceedings of the 9th Midyear Topical Symposium of the Health Physics Society on Operational Health Physics. Rocky Mountain Chapter, Health Physics Society, P.O. Box 3229, Boulder, Colorado 80303.

Belvin, E. A., and G. F. Stone. 1972. "Management and Health Physics Interaction in a Large Federal Agency," in Health Physics Operational Monitoring, Vol. 3, C. A. Willis and J. S. Handloser, eds. Gordon and Breach Science Publishers, New York.

Boggs, R. F., W. E. Gundaker, W. M. Brobeck and R. G. Altes. 1972. "Health Physics Programs at Low Energy Particle Accelerator Facilities," in Health Physics Operational Monitoring, Vol. 1, C. A. Willis and J. S. Handloser, eds. Gordon and Breach Science Publishers, New York.

Brodsky, A. 1965. "Determining Industrial Hygiene Requirements for Installations Using Radioactive Materials." Amer. Ind. Hyg. Ass. J. 26:294-310.

Ebert, H., H. Eriskat, A. Oudig and G. Uzzan, eds. 1981. Radiation Protection Optimization, Present Experience and Methods. Pergamon Press, New York.

Evans, E. A., M. Muranotsu, et al. 1977. Radiotracer Techniques and Applications. Marcel Dekker, Inc., New York.

Fitzgerald, J. J. 1969. Applied Radiation Protection and Control. Gordon and Breach Science Publishers, New York.

Ice, R. D. 1971. "Establishment of a University Radiation Safety Office." Health Phys. 20:444.

International Atomic Energy Agency. 1965. Provision of Radiological Protection Services. IAEA Safety Series No. 13, Vienna.

International Atomic Energy Agency. 1973. Radiation Protection Procedures. IAEA Safety Series No. 38, Vienna.

International Atomic Energy Agency. 1973. Safe Handling of Radionuclides. IAEA Safety Series No. 1, Vienna.

International Commission on Radiological Protection. 1971. Data for Protection Against Ionizing Radiation from External Sources. ICRP 21, supplement to ICRP 15. Pergamon Press, New York.

Lindell, B. 1971. "Professional Responsibilities of the Health Physicist in Relation to the Medical Profession." Health Phys. 20:475.

McConnon, D. 1972. "A Health Physics Program for a Plutonium Fuel Fabrication Facility," in Health Physics Operational Monitoring, Vol. 1, C. A. Willis and J. S. Handloser, eds. Gordon and Breach Science Publishers, New York.

Miller, K. L. 1976. "A Radiation Safety Program for a New Medical Center," in Proceedings of the 9th Midyear Topical Symposium of the Health Physics Society on Operational Health Physics. Rocky Mountain Chapter, Health Physics Society, P.O. Box 3229, Boulder, Colorado 80303.

National Council on Radiation Protection and Measurements. 1971. Basic Radiation Protection Criteria. NCRP 39, NCRP Publications, Washington, D.C.

National Council on Radiation Protection and Measurements. 1971. Protection Against Neutron Radiation. NCRP 38. Washington, D.C.

National Council on Radiation Protection and Measurements. 1978. Operational Radiation Safety Program. NCRP 59, Washington, D.C.

Norwood, W. D. 1975. Health Protection of Radiation Workers. Charles C. Thomas, Publisher, Springfield, Illinois.

Patterson, H. W., and R. H. Thomas. 1973. Accelerator Health Physics. Academic Press, New York.

Remley, M. E. 1972. "Management Requirements on Health Physics," in Health Physics Operational Monitoring, Vol. 3, C. A. Willis and J. S. Handloser, eds. Gordon and Breach Science Publishers, New York.

Tolen, J. H. 1972. "Organization of a Small-Scale Radiation Safey Program," in Health Physics Operational Monitoring, Vol. 1, C. A. Willis, and J. S. Handloser, eds. Gordon and Breach Science Publishers, New York.

Unruh, C. M. 1972. Problems for Radiation Protection Specialists for Safety Evaluations. BNWL-SA-4459, Pacific Northwest Laboratory, Richland, Washington.

U.S. Code of Federal Regulations. 1982. Title 10, Parts 0 to 199. U.S. Government Printing Office, Washington, D.C.

U.S. Code of Federal Regulations. 1982. Title 10, Part 20, "Standards for Protection Against Radiation." Washington, D.C.

U.S. Code of Federal Regulations. 1982. Title 10, Part 30, "Rules of General Applicability to Licensing of Byproduct Material." Washington, D.C.

GENERAL TEXTBOOKS

Adams, A. S., and W. M. Lowder, eds. 1964. The Natural Radiation Environment. University of Chicago Press, Chicago, Illinois.

Arena, V. 1971. Ionizing Radiation and Life. The C. B. Mosby Company, St. Louis, Missouri.

Attix, F. H., E. Tochilin and W. C. Roesch, eds. 1968. Fundamentals. Vol. 1 of Radiation Dosimetry, 2nd ed. Academic Press, New York.

Attix, F. H., E. Tochilin and W. C. Roesch, eds. 1968. Instrumentation, Vol. 2 of Radiation Dosimetry, 2nd ed. Academic Press, New York.

Blatz, H. 1964. Introduction to Radiological Health. McGraw-Hill, New York.

Bushong, S. C. 1975. Radiological Science for Technologists. The C.V. Mosby Company, St. Louis, Missouri.

Cember, H. 1969. Introduction to Health Physics. International Series of Monographs in Nuclear Energy, Volume 105. Pergamon Press, New York.

Eisenbud, M. 1973. Environmental Radioactivity, 2nd ed. Academic Press, New York.

Fitzgerald, J. J. 1969. Applied Radiation Protection and Control, Vol. I and II. Gordon and Breach Science Publishers, New York.

Fitzgerald, J. J., G. L. Brownell and F. J. Mahoney. 1967. Mathematical Theory of Radiation Dosimetry. Gordon and Breach Science Publisners, New York.

Gloyna, E. F., and J. O. Ledbetter. 1969. Principles of Radiological Health. Marcel Dekker, Inc., New York.

Hall, E. J. 1978. Radiobiology for the Radiologist, 2nd ed. Harper and Row, Hagerstown, Maryland.

Hendee, W. R. 1970. Medical Radiation Physics. Year Book Medical Publishers, Inc., Chicago, Illinois.

Henry, H. F. 1969. Fundamentals of Radiation Protection. Wiley-Interscience, New York.

Hine, J. G., and G. L. Brownell, eds. 1956. Radiation Dosimetry. Academic Press, New York.

Johns, H. E., and J. R. Cunningham. 1974. The Physics of Radiology, 3rd ed. Charles C. Thomas, Springfield, Illinois.

Knoll, G. F. 1979. Radiation Detection and Measurement. John Wiley and Sons, New York.

Lapp, R. E., and H. L. Andrews. 1972. Nuclear Radiation Physics, 4th ed. Prentice-Hall, Englewood Cliffs, New Jersey.

Lederer, C.M., and V. S. Shirley, eds. 1978. Table of Isotopes. John Wiley and Sons, New York.

Moe, J. J., S. R. Lusuk, M. C. Shumacher and H. M. Hunt. 1972. Radiation Safety Technician Training Course. ANL-7291, Rev. 1, Argonne National Laboratory, Argonne, Illinois.

Morgan, K. Z., and J. E Turner, eds. 1967. Principles of Radiation Protection. John Wiley and Sons, New York.

Norwood, W. D. 1975. Health Protection of Radiation Workers. Charles C. Thomas, Springfield, Illinois.

Radiological Health Handbook. 1970. U.S. Department of Health, Education and Welfare, Bureau of Radiological Health. U.S. Government Printing Office, Washington, D.C.

Shapiro, J. 1972. Radiation Protection. Harvard University Press, Cambridge, Massachusetts.

Shapiro, J. 1981. Radiation Protection, A Guide for Scientists and Physicians. Harvard University Press, Cambridge, Massachusetts.

INSTRUMENTATION AND DOSIMETRY

American National Standards Institute. 1972. Criteria for Film Badge Performance. ANSI N13.7, New York.

American National Standards Institute. 1975. Performance, Testing, and Procedural Specifications for Thermoluminescent Dosimetry: Environmental Applications. ANSI N5.45, New York.

American National Standards Institute. 1978. Radiation Protection Instrumentation Test and Calibration. ANSI N323, The Institute of Electrical and Electronics Engineers, Inc., New York.

Apt, K. E., and K. J. Schiager. 1975. "A Passive Environmental Neutron Dosimeter." Health Phys. 28:474.

Becker, K. 1972. "The Future of Personnel Dosimetry." Health Phys. 23:729.

Boyns, P. K. 1976. The Aerial Radiological Measuring System (ARMS)--Systems, Procedures and Sensitivity. EGG 1183-1691, EG&G Energy Measurements Group, Las Vegas, Nevada.

Brackenbush, L. W., et al. 1980. Personnel Neutron Dosimetry at Department of Energy Facilities. PNL-3213, Pacific Northwest Laboratory, Richland, Washington.

Brodsky, A. 1969. "Personnel Dosimetry," in Handbook of Radioactive Nuclides, Y. Wang, ed. Chemical Rubber Company, Cleveland, Ohio.

Budnitz, R. J. 1974. "Radon-222 and Its Daughters - A Review of Instrumentation for Occupational and Environmental Monitoring." Health Phys. 26:145.

Budnitz, R. J. 1974. "Tritium Instrumentation for Environmental and Occupational Monitoring-A Review." Health Phys. 26:165.

Dudley, R. A. 1966. "Dosimetry with Photographic Emulsions," in Radiation Dosimetry, Vol. IId, F. H. Attix, W. C. Roesch, and E. E. Tochilin, eds. Academic Press, New York.

Eichholz, G. G., and J. W. Poston. 1979. Principles of Nuclear Radiation Detection. Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan.

European Nuclear Energy Agency. 1963. Proceedings of a Symposium on Personnel Dosimetry Techniques for External Radiation. McGraw-Hill, Inc., New York.

Fitzgerald, J. J. 1969. "Instruments for Radiation Detection and Measurement," in Applied Radiation Protection and Control, Vol. I. Gordon and Breach Science Publishers, New York.

Gessell, T. F., G. de P. Burke and K. Becker. 1976. "An International Intercomparison of Environmental Dosimeters." Health Phys. 30:125.

Gibbs, W. D., and C. C. Lushbaugh. 1969. "Whole-Body Counter System," in Handbook of Radioactive Nuclides, Y. Wang, ed. Chemical Rubber Company, Cleveland, Ohio.

Hankins, D. E. 1973. "Progress in Personnel Neutron Dosimetry," in Proceedings of the 3rd International Congress of the International Radiation Protection Association." CONF-730907, National Technical Information Service, Springfield, Virginia.

Hart, J. C. 1972. "Legal and Administrative Aspects of Personnel Dosimetry." Health Phys. 23:343.

Howard, L. E. Jr., J. H. Spickard and M. Wilhelmsen. 1971. "A Human Radioactivity Counter and Medical Van." Health Phys. 21:417.

Hoy, J. E. 1972. "An Albedo-Type Personnel Neutron Dosimeter." Health Phys. 24:385.

International Atomic Energy Agency. 1970. Nuclear Accident Dosimetry Systems. IAEA Publication No. STI/PUB/241, Vienna.

International Atomic Energy Agency (IAEA). 1970. Personnel Dosimetry Systems for External Radiation Exposures. IAEA Publication No. 109, Vienna.

Joanes, A. P. 1975. "A Personal Contamination Monitor Using Large Area Geiger Counters." Health Phys. 28:521.

Kocher, L. F., L. L. Nichols, G. W. R. Endres, D. V. Shipler and A. J. Haverfield. 1973. "The Hanford Thermoluminescent Multipurpose Dosimeter." Health Phys. 25:567.

Knoll, G. F. 1979. Radiation Detection and Measurements. John Wiley and Sons, New York.

National Council on Radiation Protection and Measurements. 1978. Instrumentation and Monitoring Methods for Radiation Protection. NCRP 57. Washington, D.C.

Oshino, M. 1973. "Response of NTA Personnel Neutron Monitoring Film Worn on Human Phantom." Health Phys. 24:71.

Price, W. J. 1964. Nuclear Radiation Detection. 2nd ed. McGraw-Hill Inc., New York.

Rich, B. L., and B. G. Samardzich. 1973. "Organizational Aspects of a Personnel Dosimetry Service." Health Phys. 24:95.

Sommers, J. F. 1975. "Sensitivity of the G-M and Ion Chamber Beta-Gamma Survey Instruments." Health Phys. 28, 755.

Technical Education Research Center-S.W. 1980. Course II, Radiation Detection and Measurements. Waco, Texas.

U.S. Department of Defense, Dense Civil Preparedness Agency. 1977. Handbook for Aerial Radiological Monitors. CPG-2-6.2.3, Washington, D.C.

U.S. Nuclear Regulatory Commission (NRC). 1973. "Film Badge Performance Criteria." Regulatory Guide 8.3, Washington, D.C.

QUALITY ASSURANCE/QUALITY CONTROL

American National Standards Institute. 1973. Quality Assurance Terms and Definitions. ANSI N45.2.10, New York.

American National Standards Institute. 1974. Quality Assurance Requirements for the Design of Nuclear Power Plants. ANSI N45.2.11, New York.

American National Standards Institute. 1976. Administration Controls and Quality for Operational Place of Nuclear Power Plants. ANSI N18.7, New York.

American National Standards Institute and American Society of Mechanical Engineers. 1979. Quality Assurance Program Requirements for Nuclear Facilities. ANSI/ASME N45.2, New York.

International Atomic Energy Agency. 1979. Quality Assurance in the Procurement of Items and Services for Nuclear Power Plants. IAEA Safety Series No. 50-SG-QA3, Vienna.

International Atomic Energy Agency. 1979. Quality Assurance Records Systems. IAEA Safety Series No. 50-SG-QA2, Vienna.

U.S. Atomic Energy Commission, Division of Reactor Research and Development. 1973. Quality Assurance Program Requirements. RDT Standard F2-2, Washington, D.C.

U.S. Code of Federal Regulations. 1982. Title 10, Part 50, Appendix B, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants." Washington, D.C.

U.S. Nuclear Regulatory Commission. 1974. "Quality Assurance Terms and Definitions." Regulatory Guide 1.74, Washington, D.C.

U.S. Nuclear Regulatory Commission. 1975. "Quality Assurance Requirements for the Design of Nuclear Power Plants." Regulatory Guide 1.64, Rev. 1, Washington, D.C.

U.S. Nuclear Regulatory Commission. 1979. "Quality Assurance for Radiological Monitoring Programs (Normal Operations) - Effluent Streams and the Environment." Regulatory Guide 4.15, Rev. 1, Washington, D.C.

U.S. Nuclear Regulatory Commission. 1979. "Quality Assurance Program Requirements (Operation)." Proposed Revision 3 of Regulatory Guide 1.33, Washington, D.C.

U.S. Nuclear Regulatory Commission. 1980. "Auditing of Quality Assurance Programs for Nuclear Power Plants." Regulatory Guide 1.144, Rev. 1, Washington, D.C.

RADIATION-GENERATING DEVICES

American National Standards Institute. 1967. Immediate Evacuation Signal for Use in Industrial Installations Where Radiation Exposure May Occur. ANSI N2.3, New York.

American National Standards Institute. 1975. General Safety Standard for Installations Using Non-Medical X-Ray and Sealed Gamma-Ray Sources, Energies up to 10 MeV. ANSI N543, also published as National Bureau of Standards Handbook No. 114, Washington D.C.

American National Standards Institute. 1976. Radiological Safety Standards for the Design of Radiographic and Fluoroscopic Industrial X-Ray Equipment. ANSI N537, New York.

American National Standards Institute. 1977. Radiation Safety for X-Ray Diffraction and Fluorescence Analysis Equipment. ANSI No. N43.2, also published as National Bureau of Standards Handbook No. 111, Washington, D.C.

Devanney, J. A., and C. J. Daniels. 1976. "Radiation Leakage from Electron Microscopes." Health Phys. 20:231.

International Atomic Energy Commission. 1979. Radiological Safety Aspects of the Operation of Electron Linear Accelerators. Vienna.

National Council on Radiation Protection and Measurements. 1968. Medical X-Ray and Gamma-Ray Protection for Energies up to 10 MeV - Equipment Design and Use. NCRP 33, Washington D.C.

RADIOCHEMICAL ANALYSIS

International Atomic Energy Agency. 1966. Quick Methods for Radiochemical Analysis. IAEA Technical Report No. 95, Vienna.

RECORDS

American National Standards Institute. 1972. Practice for Occupational Radiation Exposure Records Systems. ANSI N13.6-1966, Rev. 1972, New York.

Boiter, H. P. 1976. "Radiation Exposure Records Management," in Proceedings of the 9th Midyear Topical Symposium of the Health Physics Society on Operational Health Physics. Rocky Mountain Chapter, Health Physics Society, P.O. Box 3229, Boulder, Colorado 80303.

Eastman Kodak Company. 1978. Storage and Preservation of Microfilms. Kodak Pamphlet D-31, Rochester, New York.

Matterazzi, A. R. 1978. Archival Stability of Microfilm - A Technical Review. Technical Report No. 18, U.S. Government Printing Office, Washington, D.C.

U.S. Department of Energy. 1980. "Micrographics Management." DOE Order 1300.1, Washington, D.C.

SHIELDING

Blizard, E. P., and L. S. Abbot, eds. 1962. Reactor Handbook, 2nd ed., Vol. III, Part B, "Shielding." Interscience Publishers, Inc., New York.

Borak, T. B. 1975. "A Simple Approach to Calculating Gamma-Ray Skyshine for Reduced Shielding Applications." Health Phys. 29:423.

Bozyap, O., and L. R. Day. 1975. "Attenuation of 15 MeV Neutrons in Shields of Concrete and Paraffin Wax." Health Phys. 28:101.

Burson, Z. G., and A. E. Profio. 1975. Structure Shielding from Cloud and Fallout Gamma Ray Sources for Assessing the Consequences of Reactor Accidents. EGG-1183-1670, EG&G, Inc., Las Vegas, Nevada.

DeAlmeida, C. E., S. A. Rosanky, J. R. Marbach and P. R. Almond. 1975. "Transmission in Concrete and Scatter Angular Distribution of 25-MV X Rays from a Betatron and a Linear Accelerator." Health Phys. 28:771.

Jaeger, R. G., ed. 1968. Engineering Compendium on Radiation Shielding - Fundamentals and Methods, Vol. I. Springer-Verlag, New York.

Jaeger, R. G., ed. 1970. Engineering Compendium on Radiation Shielding - Shielding Design and Engineering, Vol. III. Springer-Verlag, New York.

Jaeger, R. G., ed. 1975. Engineering Compendium on Radiation Shielding - Shielding Materials, Vol. II. Springer-Verlag, New York.

Jones, T. D., and F. F. Haywood. 1975. "Transmission of Photons Through Common Shielding Media." Health Phys. 28:630.

National Council on Radiation Protection and Measurements. 1976. Structural Shielding Design and Evaluation for Medical Use of X-Rays and Gamma Rays of Energies Up to 10 MeV. NCRP 49, Washington, D.C.

Patterson, H. W., and R. H. Thomas. 1973. "Accelerator Shielding," in Accelerator Health Physics. Academic Press, New York.

Price, B. T., C. C. Horton and K. T. Spinney. 1957. Radiation Shielding. Pergamon Press, New York.

Rockwell, T., III, ed. 1956. Reactor Shielding Design Manual, 1st ed. Van Nostrand, Princeton.

Schaeffer, N. M., ed. 1973. Reactor Shielding for Nuclear Engineering, TID-25951, National Technical Information Service, Springfield, Virginia.

Trout, E. D., J. P. Kelley and G. L. Herbert. 1975. "X-Ray Attenuation in Steel-50 to 300 kVp." Health Phys. 29:163.

U.S. Nuclear Regulatory Commission. 1975. "Concrete Radiation Shields for Nuclear Power Plants." Regulatory Guide 1.69. Washington, D.C.

STATISTICS

Ostle, B., and R. W. Mensing. 1975. Statistics in Research, 3rd. ed. Iowa State University Press, Iowa.

Speer, D. R., and D. A. Waite. 1976. "Statistical Distributions as Applied to Environmental Surveillance Data," in Proceedings of the 9th Midyear Topical Symposium of the Health Physics Society on Operational Health Physics. Rocky Mountain Chapter, Health Physics Society, P.O. Box 3229, Boulder, Colorado 80303.

SURVEYING AND MONITORING

American National Standards Institute. 1969. Administrative Practices in Radiation Monitoring (A Guide for Management). ANSI N13.2, New York.

American National Standards Institute. 1969. Guide for Administrative Practices in Radiation Monitoring. ANSI N13.2, New York.

Diegl, H. 1972. "Guidelines for Determining Frequency of Wipe Surveys," in Health Physics Operational Monitoring, Vol. I, C. A. Willis and J. S. Handloser, eds. Gordon and Breach Science Publishers, New York.

Feldman, A. 1976. "Factors and Strategies in Selection of Instruments for Radiation Surveys Around Medical X-Ray Installations," in Proceedings of the 9th Midyear Topical Symposium of the Health Physics Society on Operational Health Physics. Rocky Mountain Chapter, Health Physics Society, P.O. Box 3229. Boulder, Colorado 80303.

Fish, B. R., ed. 1964. Surface Contamination. Pergamon Press, New York.

Gaeta, N. A., and M. H. Repacholi. 1975. "A Standard Survey Procedure for Photofluorographic X-Ray Machines." Health Phys. 28:763.

Iacovino, J. M. 1976. "Radiation Monitoring Systems in a Changing Regulatory Environment," in Proceedings of the 9th Midyear Topical Symposium of the Health Physics Society on Operational Health Physics. Rocky Mountain Chapter, Health Physics Society, P.O. Box 3229. Boulder, Colorado 80303.

International Atomic Energy Agency. 1979. Radiological Surveillance of Airborne Contaminants in the Working Environment. IAEA Safety Series No. 49, Vienna.

International Atomic Energy Association. Particle Size Analysis in Estimating the Significance of Airborne Contamination. IAEA Safety Series No. 179, Vienna.

Katz, M. 1977. Methods of Air Sampling and Analysis. R. R. Donnelley and Sons Company, Crawfordsville, Indiana.

McClelland, T. W., and E. D. McFall. 1976. "Radiation Monitoring Considerations for Radiobiology Facilities," in Proceedings of the 9th Midyear Topical Symposium of the Health Physics Society on Operational Health Physics. Rocky Mountain Chapter, Health Physics Society, P.O. Box 3229, Boulder, Colorado 80303.

Moghissi, A. A., and M. W. Carter. 1973. Tritium. Messenger Graphics, Phoenix, Arizona.

National Council on Radiation Protection and Measurements. 1976. Tritium Measurement Techniques. NCRP 47, Washington, D.C.

National Council on Radiation Protection and Measurements. 1978. A Handbook of Radioactivity Measurement Procedures. NCRP 58, Washington, D.C.

National Council on Radiation Protection and Measurements. 1978. Instrumentation and Monitoring Methods for Radiation Protection. NCRP 57, Washington, D.C.

Noll, K. E., and T. L. Miller. 1977. Air Monitoring Survey Design. Ann Arbor Science Publishers Inc., Ann Arbor, Michigan.

Olson, O. L. 1976. "A Determination of Criteria for a Bioassay Program," in Proceedings of the 9th Midyear Topical Symposium of the Health Physics Society on Operational Health Physics. Rocky Mountain Chapter, Health Physics Society, P.O. Box 3229, Boulder, Colorado 80303.

Orvis, A. L. 1970. "Whole Body Counting," in Medical Radionuclides: Radiation Dose and Effects. USAEC Symposium Series No. 20, CONF-691212, National Technical Information Service, Springfield, Virginia.

Unruh, C. M. 1970. "Radiation Protection Practices for Tritium - A Manual of Good Practice." BNWL-SA-3390, Pacific Northwest Laboratory, Richland, Washington.

U.S. Nuclear Regulatory Commission. 1975. "Acceptable Concepts, Models, Equations and Assumptions for a Bioassay Program.J Regulatory Guide 8.9. Washington, D.C.

Wade, J. E., and G. E. Cunningham. 1967. Radiation Monitoring: A Programmed Instruction Book. Division of Technical Information, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

TRAINING

American National Standards Institute (ANSI). American National Standard for Selection and Training of Nuclear Power Plant Personnel. ANSI/ANS-3.1, American Nuclear Society, LaGrange Park, Illinois.

American National Standards Institute. 1979. Proposed American National Standard for the Qualification and Training of Personnel for Nuclear Power Plants. ANSI/ANS-3.1, American Nuclear Society, LaGrange Park, Illinois.

American National Standards Institute. 1980. Practices for Respiratory Protection. ANSI-Z88.2, New York.

American Nuclear Society (ANS). 1976. Proposed American National Standard for the Qualification and Training of Personnel for Research Reactors. ANS-15.4, LaGrange Park, Illinois.

Brown, B. 1971. "A New 2-Year Part-Time Modular MSc Source in Health Physics at the University of Salford." Health Phys. 20:663.

International Atomic Energy Agency. 1964. Training in Radiological Protection: Curricula and Programming. IAEA Technical Report No. 31, Vienna.

Medina, L. C., W. D. Kittinger and R. M. Vogel. 1976. "Radiation Monitor Training Program at Rocky Flats," in Proceedings of the 9th Midyear Topical Symposium of the Health Physics Society on Operational Health Physics. Rocky Mountain Chapter, Health Physics Society, P.O. Box 3229, Boulder, Colorado 80303.

National Council on Radiation Protection and Measurements (NCRP). 1978. Radiation Safety Training Criteria for Industrial Radiography. NCRP 61, Washington, D.C.

U.S. Code of Federal Regulations. 1982. Title 10, Part 19, "Notices, Instructions and Reports to Workers; Inspections." Washington, D.C.

U.S. Nuclear Regulatory Commission. 1979. Information Relevant to Ensuring That Occupational Radiation Exposures at Nuclear Power Stations Will Be As Low As Reasonably Achievable (ALARA)." Regulatory Guide 8.8, Washington, D.C.

U.S. Nuclear Regulatory Commission. 1980. "Personnel Qualification and Training." Second Proposed Revision to Regulatory Guide 1.8, Washington, D.C.

U.S. Nuclear Regulatory Commission. 1981. "Instruction Concerning Risks From Occupational Radiation Exposure." Regulatory Guide 8.29, Washington, D.C.

U.S. Nuclear Regulatory Commission. 1981. "Radiation Protection Training for Personnel At Light-Water-Cooled Nuclear Power Plants." Regulatory Guide 8.27, Washington, D.C.

Vetter, R. J., and P. L. Ziemer. 1976. "Operational Training in the Health Physics Curriculum," in Proceedings of the 9th Midyear Topical Symposium of the Health Physics Society on Operational Health Physics. Rocky Mountain Chapter, Health Physics Society, P.O. Box 3229, Boulder, Colorado 80303.

Williams, S. L. 1976. "Meaningful Radiation Worker Training for Temporary Craftsmen," in Proceedings of the 9th Midyear Topical Symposium of the Health Physics Society on Operational Health Physics. Rocky Mountain Chapter, Health Physics Society, P.O. Box 3229, Boulder, Colorado 80303.

TRANSPORTATION

American National Standards Institute. 1973. Administrative Guide for Packaging and Transporting Radioactive Materials. ANSI N14.10.1, New York.

American National Standards Institute. 1975. Administrative Guide for Verifying Compliance with Packaging Requirements for Shipments of Radioactive Materials. ANSI N14.10.3, New York.

International Atomic Energy Agency. 1979. Regulations for the Safe Transport of Radioactive Materials. IAEA Safety Series No. 6, Vienna.

U.S. Code of Federal Regulations. 1982. Title 49, Parts 100-199. Washington, D.C.

U.S. Code of Federal Regulations. 1982. Title 10, Part 71, "Packaging of Radioactive Materials for Transport and Transportation of Radioactive Materials Under Certain Conditions." Washington, D.C.

U.S. Department of Transportation. 1977. A Review of the Department of Transportation (DOT) Regulations for Transportation of Radioactive Materials. Washington, D.C.

U.S. Nuclear Regulatory Commission. 1975. "Administrative Guide for Obtaining Exemptions from Certain NRC Requirements over Radioactive Materials Shipment." Regulatory Guide 7.5, Washington, D.C.

U.S. Nuclear Regulatory Commission. 1975. "Leakage Tests on Packages for Shipment of Radioactive Materials." Regulatory Guide 7.4, Washington, D.C.

U.S. Nuclear Regulatory Commission. 1975. "Procedures for Picking Up and Receiving Packages of Radioactive Material." Regulatory Guide 7.3, Washington, D.C.

U.S. Nuclear Regulatory Commission. 1977. "Administrative Guide for Verifying Compliance with Packaging Requirements for Shipment of Radioactive Materials." Regulatory Guide 7.7, Washington, D.C.

WASTE MONITORING

Bradley, F. J. 1969. "Radioactive Waste Disposal," in Handbook of Radioactive Nuclides, Y. Wang, ed. Chemical Rubber Company, Cleveland, Ohio.

Cardozo, R. L. 1973. "The Dispersal of Radioactive Matter by Evaporation." Health Phys. 25:593.

Gallagher, F. E., III. 1976. "A New Facility for Processing and Storage of Radioactive and Toxic Chemical Waste," in Proceedings of the 9th Midyear Topical Symposium of the Health Physics Society on Operational Health Physics. Rocky Mountain Chapter, Health Physics Society, P.O. Box 3229, Boulder, Colorado 80303.

Gera, F. 1974. "The Classification of Radioactive Waste." Health Phys. 27:113.

Gregory, W. D., and H. D. Maillie. 1975. "Incinceration of Animal Radioactive Waste: A Comparative Cost Analysis." Health Phys. 29:389.

International Atomic Energy Agency. 1965. Management of Radioactive Wastes Produced by Radioisotope Users. IAEA Safety Series No. 12, Vienna.

International Atomic Energy Agency. 1966. Management of Radioactive Wastes Produced by Radioactive Users-Technical Addendum. IAEA Safety Series No. 19, Vienna.

Mawson, C. A. 1965. Management of Radioactive Waste. Van Nostrand, New York.

Murphy, P. H., and N. S. Anderson. 1975. "Inexpensive, Convenient Xenon Disposal." Health Phys. 29:779.

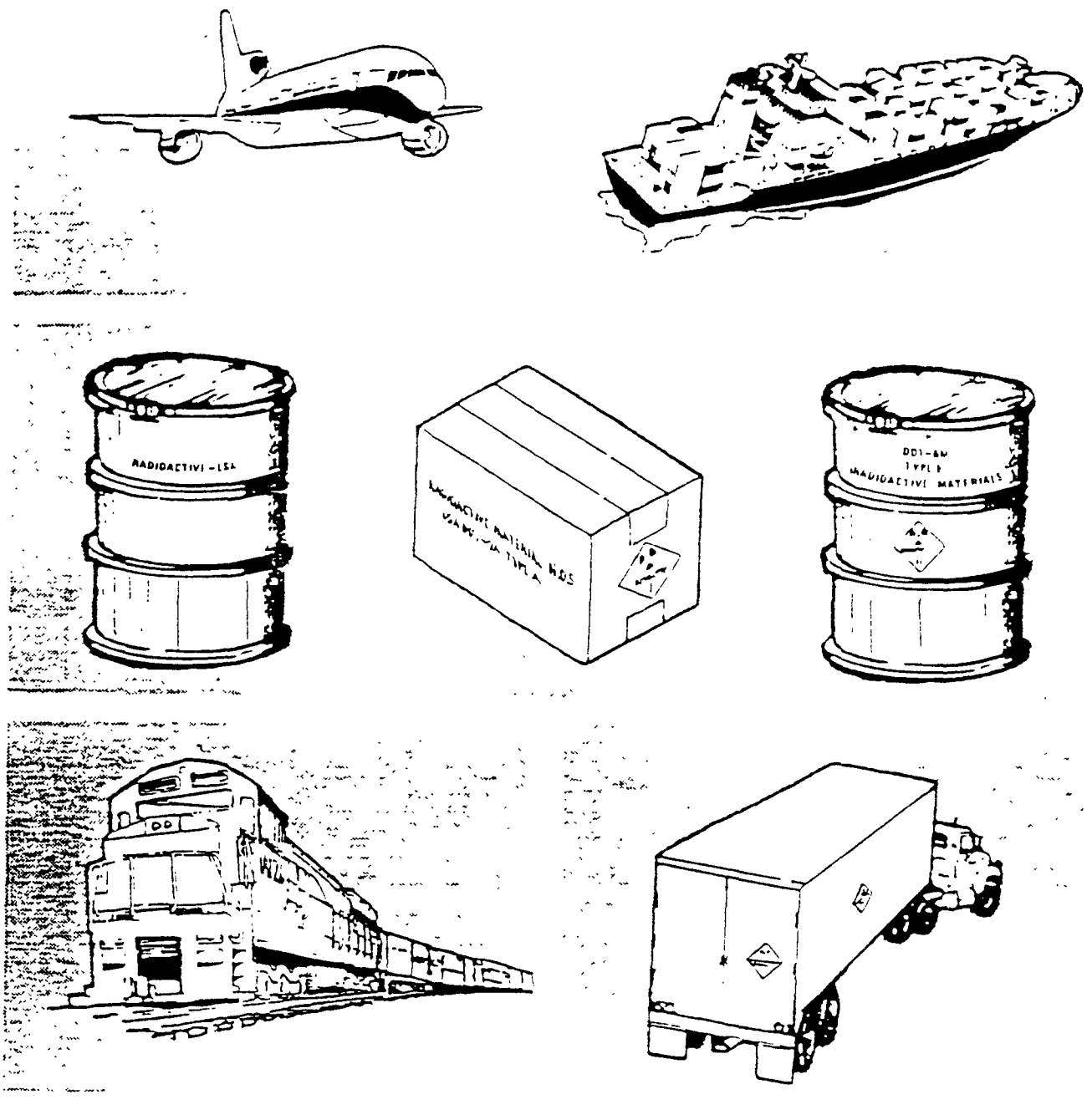
Port, E. A. 1975. "An Improved Receptacle for Radioactive Waste." Health Phys. 29:801.

U.S. Nuclear Regulatory Commission. 1975. "Evaluating and Reporting Radioactivity in Solid Wastes and Releases of Radioactive Materials in Liquid and Gaseous Effluents from Light-Water-Cooled Nuclear Power Plants." Regulatory Guide 1.21, Washington, D.C.

* U.S. GOVERNMENT PRINTING OFFICE: 1984-441-740

US Department
of Transportation
Research and
Special Programs
Administration
Materials Transportation
Bureau
Washington DC 20590

A Review of The Department of Transportation Regulations for Transportation of Radioactive Materials



REVISED 1983

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

A REVIEW OF THE DEPARTMENT OF TRANSPORTATION (DOT) REGULATIONS FOR TRANSPORTATION OF RADIOACTIVE MATERIALS

Rev. Summer 1983

For sale by the Superintendent of Documents, U. S. Government Printing Office,
Washington, D. C. 20402

TO THE READER:

The United States Department of Transportation(U.S.D.O.T.) promotes the safe transportation of hazardous materials by all modes. One evidence of this commitment to safety is this review of the U.S.D.O.T. regulations for the transportation of radioactive materials. Compliance with these regulations is a legal responsibility; more importantly, radioactive materials packaged, labeled, marked and transported in accord with these regulations have had an excellent safety record.

These regulations also require shippers, carriers, and manufacturers of radioactive materials to train their staff. They are required by the Code of Federal Regulations, Title 49 (CFR 49) to "instruct each of his officers, agents, and employees having any responsibility for preparing hazardous materials for shipment, as to the applicable regulations."

It is our hope that this document will increase the safe transportation of radioactive materials. Any of the materials may be reproduced and/or used in the training of your staff.

Comments, suggestions, corrections and/or requests for additional training aids should be mailed to: U.S. Department of Transportation, Information Service Division, DMT-11, 400 Seventh Street, S.W., Washington, D.C. 20590.

Within U.S.D.O.T., the Material Transportation Bureau(MTB) staff involved in the publication of this Review, include:

Sponsor and Approval:	L. D. Santman, Director Dr. R. L. Paullin, Assoc. Director, Office of Operations and Enforcement(OOE) Alan I. Roberts, Assoc. Director, Office of Hazardous Materials Regulation(OHMR)
Technical Review:	Richard R. Rawl, OHMR
Education Director:	Dr. Virginia T. Litres, OOE
Review Panel:	
OOE -	J. M. Shuler, F. G. Punch, R. McKinley
OHMR -	Thomas Allan, Wendell Carriker
NRC -	Alfred Grella, U.S.Nuclear Regulatory Commission, Office of Inspection and Enforcement

TABLE OF CONTENTS

		Page
	List of Tables and Illustrations	(iii)
	Title and Preamble	1
I.	BACKGROUND DISCUSSION	2
	A. General	2
	B. Historical	3
II.	SUMMARY OF RADIOACTIVE MATERIALS TRANSPORTATION REGULATIONS	5
	A. Organizations	5
	B. Federal Regulations	6
	C. International Regulations	9
	D. Other Sources of Regulations and Tariffs	10
III.	SUMMARY OF PRINCIPAL SHIPPER'S REQUIREMENTS IN PREPARATION AND OFFERING OF RADIOACTIVE MATERIALS FOR SHIPMENT	11
	A. Definition of Radioactive Material Subject to the Regulations	11
	B. Best Approach to Using the Regulations	12
	C. Special Form Radioactive Materials	12
	D. Normal Form Radioactive Materials	15
	E. Quantity Limits and Packagings	16
	F. Limited Quantities, Instruments and Articles	18
	G. Low-Specific Activity (LSA) Materials	21
	H. Type A Packaging	24
	I. Type B Packaging	26
	J. Fissile Radioactive Materials	27
	K. Highway Route Controlled Quantities	28

TABLE OF CONTENTS (Cont.)

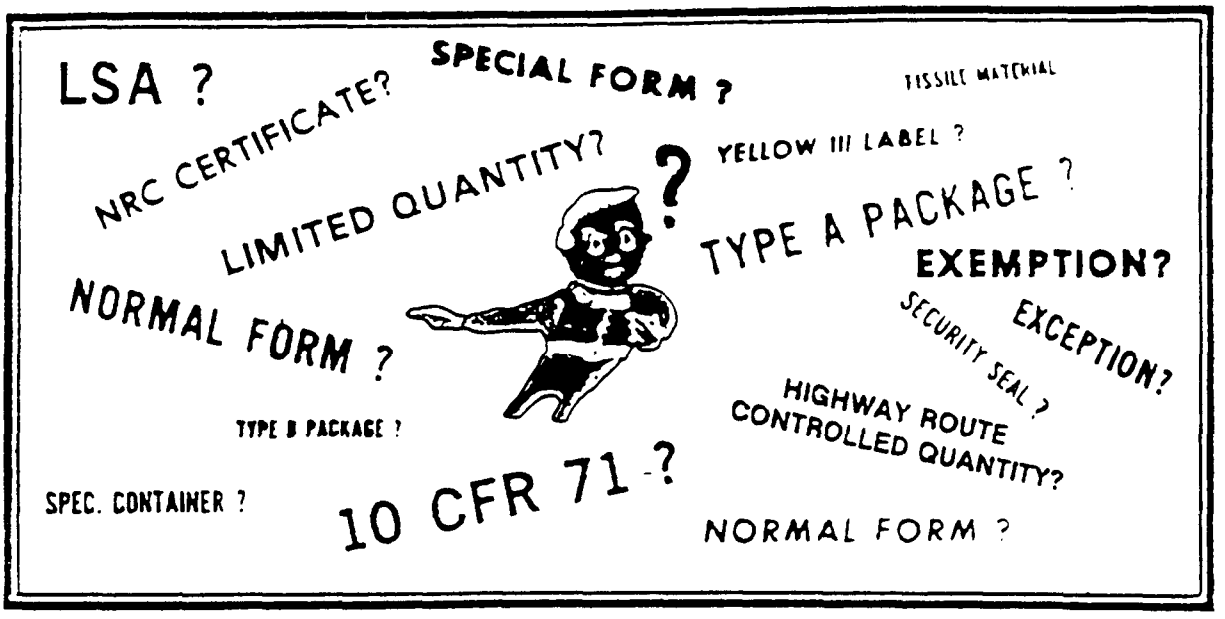
		Page
L.	Control of Radiation During Transport - Transport Index (T.I.), Vehicle Limits, and Separation Distances	29
M.	Warning Labels	31
N.	Contamination Control	34
O.	Other Shipper Requirements	35
1.	Package Markings	35
2.	Shipping Papers	37
3.	Shipper's Certification	43
4.	Security Seal	44
5.	Small Dimension	45
6.	Liquid Packaging Provision	45
7.	Surface Temperature of Package	45
8.	Quality Control Requirements	
IV.	CARRIER REQUIREMENTS IN HANDLING OF RADIOACTIVE MATERIALS PACKAGES	46
A.	Shipping Papers and Certification by Shipper	46
B.	Placarding	47
C.	Radiation Exposure Control by Maximum Total Transport Index vs. Distance	48
D.	Reporting of Incidents	49
E.	Notification to Pilot (for Aircraft Shipments)	51
V.	MOST FREQUENTLY NOTED DISCREPANCIES IN RADIOACTIVE MATERIALS SHIPMENTS	51
A.	By Shippers	51
B.	By Carriers	55
VI.	IAEA REGULATIONS (AS AMENDED)	57
VII.	DEFINITIONS	58
VIII.	REFERENCES	63

TABLES AND ILLUSTRATIONS

		Page
	Tables	
Table 1	Sources of Federal Regulations	8
Table 2	Availability of International Regulations	9
Table 2A	Other Sources of Regulations and Tariffs	11
Table 3	Type A Package Quantity Limits for Selected Radionuclides	18
Table 4	Activity Limits for Limited Quantities, Instruments and Articles	20
Table 5	Radioactive Materials Packages Maximum Radiation Level Limitations	24
Table 6	Shipment Controls for Fissile Radioactive Materials	28
Table 7	Radioactive Materials Packages Labeling Criteria	33
Table 8	Removable External Radioactive Contamination Limits	35
Table 9	Most Commonly Used Shipping Names for Radioactive Materials	37
	Illustrations	
Figure 1	"What Must I Do to Make a Safe and Legal Shipment of Radioactive Materials?"	1
Figure 2	NRC Agreement States as of July 1, 1983	7
Figure 3	Special Form Radioactive Material	13
Figure 4	Normal Form Radioactive Material	15
Figure 5	Typical Type A Packaging Schemes	25
Figure 6	Typical Type B Packaging Schemes	26
Figure 7	Package Labels	32
Figure 8	A Word of Caution on Terminology	34
Figure 9	Vehicle Placards for Radioactive Materials	47
Figure 10	DOE Regional Coordinating Offices for Radiological Assistance	50

A REVIEW OF THE DEPARTMENT OF TRANSPORTATION (DOT) REGULATIONS FOR TRANSPORTATION OF RADIOACTIVE MATERIALS

Figure 1 - **"What Must I Do to Make a Safe and Legal Shipment of Radioactive Materials?"**



Perhaps some persons who have made shipments of radioactive materials may have felt like the person illustrated above. The purpose of this Review is to summarize the basic requirements of the Department of Transportation (DOT) regulations governing the packaging and shipment of radioactive materials. It provides guidance toward more correctly and easily applying those regulations in actual practice.

This Review is a reference and guidance type document for training purposes. It is not intended to be an official interpretation or restatement of the regulations. Any material herein may be reproduced without special permission from the Department.

Users of this Review are strongly encouraged to obtain from the Government Printing Office the latest copy of the DOT Hazardous Materials Regulations in 49 CFR Parts

100-177 and 178-179. Amendments to the regulations are published in the Federal Register.

I. BACKGROUND DISCUSSION

A. General

Since the beginning of the atomic energy industry about forty years ago, there has been an excellent record of safety. Approximately 2,500,000 packages of radioactive materials are shipped per year in the United States. Thus far, based on the best available information concerning accidents in transportation, there have been no known deaths or serious injuries to the public or to the transportation industry personnel as a result of the radioactive nature of any radioactive material involved in an accident. This claim can generally be attributed to the close attention given by the shippers to the proper packaging of radioactive materials, and to the effectiveness of the transportation safety standards and regulations.

Even with this excellent past record of safety, the term "radioactive" makes many people concerned or fearful. Still very vivid in the minds of many is the memory of devastating destruction and violent deaths caused by the atomic bomb near the end of World War II. The more recent debate regarding the effects of nuclear power plants on the environment and the ecology have added to this concern.

The vast majority of shipments of radioactive materials involves small or intermediate quantities of material in relatively small packages. Many of these packages involve radioisotopes which are intended for medical diagnostic or therapeutic applications. They are used by thousands of doctors and hospitals throughout

the United States and abroad. Many such materials are quite often of very short "half-life." Therefore, for reasons of safety and economy, they are supplied by the producer to the user by the most rapid means of transportation. Thus, the majority of these packages are shipped air freight or air express on passenger-carrying or cargo aircraft or by other rapid delivery services. Such shipments are often transported by both aircraft and motor vehicle.

Other uses for radioactive materials include industrial applications for inspection and "gauging" operations such as examining the integrity of welded joints or in measuring the thickness of paper as it is produced. Each year there are new applications of nuclear technology. These necessarily involve the shipment of radioactive materials. DOT updates the transport regulations to keep pace with the changing transportation scene and to maintain the existing safety record.

B. Historical

In the early 1950's, the Interstate Commerce Commission (ICC)) first established regulations governing the shipment of radioactive materials. These regulations were intended to protect property and individuals from excessive exposure to radiation resulting from the transport of radioactive materials. These early regulations were designed to protect radiation-sensitive cargo, such as photographic film in the mail, which might also be transported in proximity to those radioactive materials packages. The ICC established limits on radiation levels that emanate from packages. By protecting such radiation-sensitive cargo, there was also protection provided to the people who transported it or were passengers in the vehicle or plane.

In 1961, the International Atomic Energy Agency (IAEA) adopted regulations for the transport of radioactive materials which were based on the ICC rules. These IAEA regulations became the first international regulations for radioactive materials and the IAEA suggested that member states adopt the regulations as a basis for national requirements.

In 1967, a comprehensive revision of the IAEA regulations took place. This revision included consideration of a new category of materials--large radioactive sources. This category was considered special because of the large amount of radioactivity involved and the heat that might be generated by such very large sources. The 1967 IAEA regulations served as the basis for a major revision of DOT regulations in 1968 governing radioactive materials. Revisions that were adopted at that time brought DOT's regulations into essential conformity with the suggested international standards and, therefore, harmony existed for some period of time between the domestic and international requirements. However, in 1973, the IAEA made a complete revision of its regulations which included a new system for classifying radionuclides, known as the A_1-A_2 system. Elimination of the "large-source" designation was possible because the special characteristics of large sources are now considered routinely for all packages containing greater than a Type A quantity of radioactive material.

The 1973 IAEA standards include the unilateral and multilateral concepts for Type B packages which determine the extent to which each country must approve a package design. In March 1983, DOT adopted regulations which are in essential conformity with the 1973 edition of the IAEA requirements. This eliminated most differences that existed between international and domestic regulations since the 1973 edition of the IAEA was published. Although the revisions adopted by DOT are

in essential conformance with IAEA's 1973 standards, there are certain exceptions between the DOT and the IAEA requirements, which are noted in this Review.

II. SUMMARY OF RADIOACTIVE MATERIALS TRANSPORTATION REGULATIONS

A. Organizations

Under the Department of Transportation Act of 1966, the U. S. Department of Transportation has regulatory responsibility for safety in the transportation of all hazardous materials, including radioactive materials. This includes shipments by all modes of transport in interstate or foreign commerce (rail, highway, air, water), and by all means (truck, bus, auto, ocean vessel, airplane, river barge, railcar, etc.) except for postal shipments. Postal shipments come under the jurisdiction of the U. S. Postal Service.

The ICC formerly had jurisdiction over both the safety and economic aspects of the transport of radioactive materials by surface modes. The jurisdiction over safety was transferred to the Department of Transportation when it was formed in April 1967. However, the ICC still exercises jurisdiction over the economic aspects of radioactive materials transport through the issuance of operating authorities to carriers.

Under the Atomic Energy Act of 1954, as amended, the U. S. Nuclear Regulatory Commission (NRC) also has responsibility for safety in the possession, use and transfer (including transport) of by-product, source, and special nuclear materials. Except for certain small quantities and specific products, a license is required from the NRC for possession and use of such materials. The NRC has promulgated, in 10 CFR Part 71, requirements which must be met for licensees to deliver licensed

material to a carrier for transport--if fissile material or quantities exceeding Type A are involved. The NRC also assists and advises DOT in the establishment of both national and international safety standards and in the review and evaluation of packaging designs. In 1979, NRC adopted by reference portions of the DOT regulations. Now NRC inspects its licensees for compliance with DOT regulations applicable to shippers.

Several states have entered into formal agreements with the NRC whereby the regulatory authority over by-product, source, and less than critical quantities of special nuclear material has been transferred to the states from the NRC. These "Agreement States" have adopted uniform regulations pertaining to intrastate transportation of radioactive materials. These regulations require the shipper to conform to the packaging, labeling, placarding, and marking requirements of the U. S. Department of Transportation. Additionally, many states have formally adopted the DOT regulations and apply these requirements to both intrastate and interstate transportation.

B. Federal Regulations*

The principal sources of Federal regulations pertaining to the transport of radioactive materials are listed in Table 1. The regulations of the United States of America are published by three agencies--the U. S. Department of Transportation, the U. S. Nuclear Regulatory Commission, and the U. S. Postal Service This Review is concerned primarily with those regulations of the U. S. Department of Transportation, as published in Title 49, Code of Federal Regulations, Parts 100-177 and Parts

---

* Throughout this Review, the Section references listed apply to pertinent Sections in Title 49, Code of Federal Regulations, Parts 100-199, unless otherwise specified.

178-199. Persons involved as actual shippers, package designers, or carriers are advised to maintain a current copy of these regulations (all in two bound volumes). The dated versions are published as of October 1st each year by the Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. 20402. As of 1982, the cost was $9.00 per volume. Changes to these regulations are published in the daily Federal Register. Regulatory changes in the form of amendments or notices of proposed rulemaking are issued by the Materials Transportation Bureau (MTB) of the Department of Transportation. Another means of keeping abreast of changes is to request, in writing, to be placed on the DOT mailing list for hazardous materials amendments. Send requests to: U. S. Department of Transportation, Materials Transportation Bureau, Information Services Division, DMT-11, Washington, D. C. 20590.

Figure 2 - NRC Agreement States as of July 1, 1983

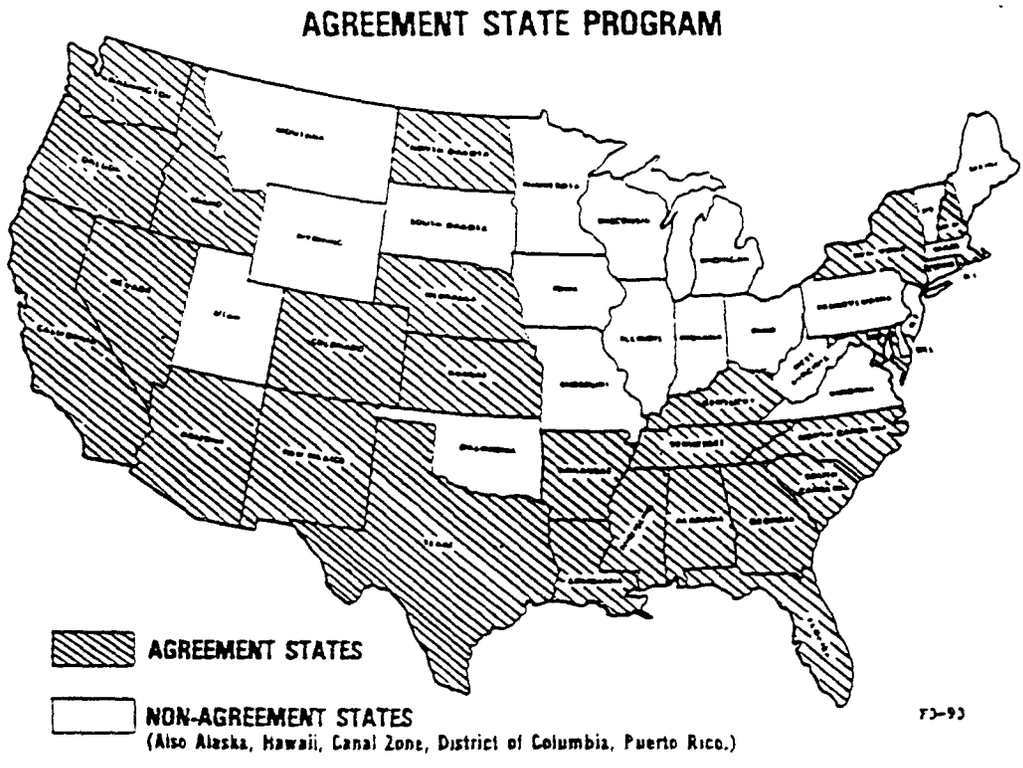


TABLE I

SOURCES OF FEDERAL REGULATIONS

Title 49

U. S. Department of Transportation's Hazardous Materials Regulations, Parts 100-177 and 178-199

Main Headings

49 CFR 106	-	Rulemaking Procedures
49 CFR 107	-	Hazardous Materials Program Procedures
49 CFR 171	-	General Information, Regulations and Definitions
49 CFR 172	-	Hazardous Materials Tables and Hazardous Materials Communications Regulations
49 CFR 173	-	Shippers - General Requirements for Shipments and Packagings
49 CFR 174	-	Carriage by Rail
49 CFR 175	-	Carriage by Aircraft
49 CFR 176	-	Carriage by Vessel
49 CFR 177	-	Carriage by Public Highway
49 CFR 178	-	Shipping Container Specifications
49 CFR 179	-	Specifications for Tank Cars

Title 10

U. S. Nuclear Regulatory Commission

10 CFR 71	-	Packaging of Radioactive Materials for Transport and Transportation of Radioactive Materials Under Certain Conditions

Title 39

U. S. Postal Service

Domestic Mail Manual, U. S. Postal Service Regulations, Part 124. (Postal Regulations for Transport of Radioactive Matter are published in U. S. Postal Service Publication #6, and in the U. S. Postal Manual.)

C. International Regulations

TABLE 2

AVAILABILITY OF INTERNATIONAL REGULATIONS

1. "Regulations for the Safe Transportation of Radioactive Materials," as amended, Safety Series #6, 1973 Revised Edition - International Atomic Energy Agency (IAEA), Vienna, Austria. Available from UNIPUB, 1180 Avenue of the Americas, New York, New York 10038.

2. International Civil Aviation Organization (ICAO), Technical Instructions for the Safe Transport of Dangerous Goods by Air, 1983 Edition. Available from INTEREG, P. O. Box 60105, Chicago, Illinois 60660.

3. International Maritime Organization (IMO), formerly Intergovernmental Maritime Consultative Organization (IMCO). International Maritime Dangerous Goods (IMDG) Code.

4. International Air Transport Asssociation (IATA), Restricted Articles Regulations, 25th Edition, plus Supplement and Amendment issued March 1, 1981, effective December 1982. International Air Transport Association, 2000 Peel Street, Montreal, Quebec, Canada H3A 2R4.

There are a number of international bodies and organizations which deal with the transportation of radioactive materials. The majority of these international bodies are sanctioned by or affiliated with the United Nations. These agencies promulgate regulations which are recommended to member states as a basis for adoption of national regulations. The primary agency for the promulgation of radioactive materials transport standards is the International Atomic Energy Agency (IAEA) located in Vienna, Austria. The IAEA has been the primary body for the establishment of radioactive materials regulations which have served as the basis of all other international regulations and requirements. In the air transport mode, the International Civil Aviation Organization (ICAO), an intergovernmental body, is active in regulating the transport of dangerous materials, including radioactive materials. The ICAO requirements have been adopted by nearly all countries and deal with the air carriage of radioactive and other hazardous materials. The

International Air Transport Association (IATA), a body of member air carriers, also publishes regulations for air transport of restricted articles including radioactive materials. In the water mode, the International Maritime Organization (IMO), formerly the International Maritime Consultative Organization (IMCO), publishes regulations which deal with the carriage of radioactive materials by vessel. The IMO regulations and the ICAO regulations are based on the regulations of the IAEA, but are more explicit in the compliance actions and requirements for shippers and carriers.

D. Other Sources of Regulations and Tariffs

There are a number of other agencies or organizations which publish regulations or tariffs on the transportation of radioactive materials. A word of caution is in order here. A tariff is not an official regulation. These tariffs are merely a publication by an organization or association which reprints certain Federal or international regulations. It shows the application and acceptance of those regulations by the carriers who participate in the tariffs. As such, tariffs are binding only on the organization or association or member carrier. If a person chooses to utilize the widely used Bureau of Explosives (B of E 6000) as a source of regulations, it is suggested that the subscription be for the quarterly updated version so that the current requirements will be used. (See Table 2A)

TABLE 2A

OTHER SOURCES OF REGULATIONS AND TARIFFS

1. "Official Air Transport Restricted Articles Tariff No. 6-D" and "Air Transport Restricted Articles Circular 6-D" - Airline Tariff Publishing Co., Washington, D. C.

2. "BOE 6000," Hazardous Materials Regulations of the Department of Transportation, including Specifications for Shipping Containers - Bureau of Explosives, Association of American Railroads, Washington, D. C.

3. "ATA Hazardous Materials Tariff III," Department of Transportation Regulations for Governing Transportation of Hazardous Materials by Air, Motor, Rail, and Water, Including Specifications for Shipping Containers - American Trucking Associations, Inc., Washington, D. C.

NOTE: Refer to the current edition of the above references.

III. SUMMARY OF PRINCIPAL SHIPPER'S REQUIREMENTS IN PREPARATION AND OFFERING OF RADIOACTIVE MATERIALS FOR SHIPMENT

A. Definition of Radioactive Materials Subject to the Regulations

For purposes of transportation, radioactive materials are defined as those materials which spontaneously emit ionizing radiation and have a specific activity in excess of 0.002 microcuries per gram of material. All materials are to some degree radioactive. THE DEMARCATION OF 0.002 MICROCURIES PER GRAM ALLOWS A DISTINCTION BETWEEN MATERIALS NOT NORMALLY CONSIDERED RADIOACTIVE AND THOSE WHICH ARE REGULATED AS RADIOACTIVE IN TRANSPORTATION. Materials with a specific activity lower than 0.002 microcuries per gram are not regulated by DOT or IAEA. These materials ARE NOT SUBJECT TO THE RADIOACTIVE MATERIAL PROVISIONS OF THE DOT REGULATIONS, however, they may be subject to use or transfer regulations issued by the NRC or EPA.

B. Best Approach to Using the Regulations

A primary consideration for achievement of safety in the transportation of radioactive materials is the use of proper packaging for the specific radioactive material to be transported. In order to determine the packaging requirements, a prospective shipper or package designer must answer ALL of these questions:

1. What radionuclides are being shipped? Section 173.435 contains a listing of over 250 specific radionuclides. Certain "ground rules" for dealing with unlisted or unknown radionuclides, or with mixtures of radionuclides, appear in Section 173.433.

2. What quantity of the radionuclides is being shipped? As you will see, the packaging requirements are related to the quantity (activity of material). They are generally structured about the total quantity in a package in terms of activity (curies, millicuries, and microcuries).

3. What is the form of the radionuclide?

   a. Is the material in special form?; or

   b. Is it in normal form?

The terminology which has been introduced in asking these three questions is explained in the succeeding paragraphs.

C. Special Form Radioactive Materials

What is meant by "special form" radioactive material? As illustrated in Figure 3, "special form" materials are limited to materials which, if released from a package, might present a hazard of direct external radiation. However, due to their "high physical integrity," they would present very little hazard, if any, as a result of the spread of loose radioactive material (contamination). This high physical integrity could be the result of a natural property of the material, such as its being in massive,

nondispersable solid form, or an acquired characteristic, such as being sealed into a very durable capsule (encapsulated).

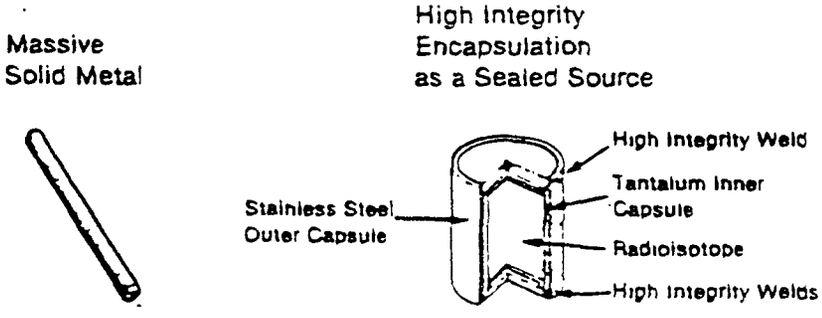
Special form encapsulations must have at least one external physical dimension which exceeds 5mm. This minimum dimension requirements makes the capsule more easily seen and recovered in the event of an accident/incident.

Special form encapsulations are required to be so constructed that they can only be opened by destroying the capsule. This requirement is intended to prevent the inadvertent loosening or opening of the capsule, either during transport or following an accident. The "special form" materials are much less likely to spread contamination in the event of package failure. Therefore, the regulations generally allow substantially larger quantities of such materials to be placed in given packagings than when the materials are in "normal form."

Figure 3 - **"Special Form" R.A.M. (173.403 (z) and 173.469 (a))**

May Present a Direct Radiation Hazard if Released From Package, but Little Hazard Due to Contamination

"Special Form" R.A.M. May Be "Natural" Characteristic, i.e., Massive Solid Metal, or "Acquired" Through High Integrity Encapsulation



For purposes of export, a shipper must furnish to the foreign consignee a certificate of competent authority for the special form material. Such a certificate will only be issued by the DOT, Office of Hazardous Materials Regulation, upon receipt of a specific petition and only when a certificate is required by a shipper to fulfill a need. Such a need will be in the case of foreign shipments only, such as pursuant to paragraph 803 of the International Atomic Energy Agency (IAEA) regulations. Section 173.476, relating to certain special form requirements, is quoted below:

"Section 173.476 Approval of special form radioactive materials.

(a) Each shipper of special form radioactive materials shall maintain on file for at least one year after the latest shipment, and provide to the MTB on request, a complete safety analysis, including documentation of any tests, demonstrating that the special form material meets the requirements of Section 173.469. An IAEA Certificate of Competent Authority issued for the special form material may be used to satisfy this requirement.

(Approved by the Office of Management and Budget under OMB control number 2137-0516.)

(b) Prior to the first export shipment of a special form radioactive material from the United States, each shipper shall obtain a U. S. Competent Authority Certificate for the specific material. Each petition shall be submitted in accordance with Section 173.471(e) and must include the following information:

(1) A detailed description of the material, or if a capsule, a detailed description of the contents. Particular reference must be made to both physical and chemical states:

(2) If a capsule is to be used, a detailed statement of its design and dimensions, including complete engineering drawings and schedules of material, and methods of construction; and

(3) A statement of the tests that have been made and their results; evidence based on calculative methods to show that the material is able to pass the tests; or other evidence that the special form radioactive material complies with Section 173.469.

(c) Paragraphs (a) and (b) of this section do not apply in those cases where A_1 equals A_2 and the material is not described on the shipping papers as "Radioactive Material Special Form, n.o.s."

In determining if an encapsulation passes the test requirements for special form (Section 173.469), an option is available. In addition to the leaching acceptance test which is performed over a seven-day period, some capsules may be acceptance tested by volumetric means. If an encapsulation has an internal void of at least 0.1 ml (.006 in $^{-3}$), it may be leak tested using techniques such as the vacuum bubble or helium leak tests. Any volumetric leak testing technique may be utilized, provided that it has a sensitivity of at least:

(1) 1.3×10^{-4} atm - cm^3/s for solid contents; or

(2) 1.3×10^{-6} atm - cm^3/s for liquids or gaseous contents.

All tests are based on air at 77° and one atmosphere pressure differential.

D. Normal Form Radioactive Materials

Illustrated in Figure 4 are "normal form" radioactive materials which are, therefore, ANY radioactive materials that do not qualify as "special form."

Figure 4 - **Normal Forms Radioactive Materials 49 CFR 173.403(s)**

Normal Form Materials May Be Solid, Liquid or Gaseous and Include any Material Which Has Not Been Qualified as Special Form

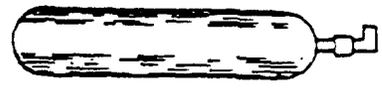
Type A Package Limits are A_2 Values

Waste Material in Plastic Bag

Liquid in Bottle Within Metal Container

Powder in Glass or Plastic Bottle

Gas in Cylinder



E. Quantity Limits and Packagings

Having considered the type, quantity, and form of the radioactive material, it is now appropriate to consider the packaging requirements. Packaging types are "Type A," "Type B," "excepted," and "strong, tight," all of which will be explained.

THE A_1 and A_2 SYSTEM

The present regulations use A_1 and A_2 values as points of reference for quantity limitations for every radionuclide. This system replaces the former Transport Group system that was used for limitations when the radioactive materials were in normal form.

Every radionuclide is now assigned an A_1 and an A_2 value. These two values (in curies) are simply the maximum activity of that radionuclide that may be transported in a TYPE A package. Table 3 gives examples of A_1 and A_2 values for typical radionuclides. The A_1 value is the number of curies for a particular radionuclide when in Special Form. The A_2 value is the number of curies if the radionuclide is not in Special Form--i.e., the material is in Normal Form.

In previous regulations, the activity limitations for Special Form was the same for all radionuclides. Now the limitation for each radionuclide depends primarily on the penetrating radiation emitted by the material when encapsulated.

Under the former regulations, every radionuclide was assigned to one of seven transport groups (I through VII). The assignment of a radionuclide to a group

was based on the radiation hazard that would occur if some of the material was taken into a person's body. The activity limit for all radionuclides in a transport group was established by the radiotoxicity of the most hazardous radionuclide in the group. Under the present system, the A_2 limit for each radionuclide is established on the basis of the hazard that would result if that individual radionuclide was ingested, inhaled or absorbed through the skin.

The Limited Quantity, Low Specific Activity (LSA), Type A, Type B, and Highway Route Controlled Quantity provisions in the regulations all relate to A_1 and A_2 values as points of reference for activity limits or thresholds. In the case of Type B quantities, they are simply defined as a quantity exceeding the appropriate A_1 or A_2 value for the radionuclide(s) of interest.

For mixtures of radionuclides, certain rules are specified for determining whether the Type A quantity has been exceeded (see Section 173.433(b)). In most cases, the "ratio rule" may be applied. This involves dividing the activity of each radionuclide present by its A_1 or A_2 value (as appropriate) and summing the resulting fractions. If the sum is 1.0 or less, then the mixture does not exceed a Type A quantity.

TABLE 3

TYPE A PACKAGE QUANTITY LIMITS FOR SELECTED RADIONUCLIDES
(ADDITIONAL RADIONUCLIDES ARE LISTED IN SECTION 173.435)

SYMBOL OF RADIONUCLIDE	ELEMENT AND ATOMIC NUMBER	A_1 (Ci) (Special Form)	A_2 (Ci) (Normal Form)
^{14}C	Carbon (6)	1000	60
^{137}Cs	Cesium (55)	30	10
^{99}Mo	Molybdenum (42)	100	20
^{235}U	Uranium (92)	100	0.2
^{226}Ra	Radium (88)	10	0.05
^{201}Pb	Lead (82)	20	20

NOTE 1: Quantities exceeding Type A package limits require Type B packaging.

NOTE 2: Highway Route Controlled Quantities are defined in Section 173.403(l).

"Type B Packages," "Highway Route Controlled Quantities," and "Fissile Radioactive Materials" present more unusual and specific problems for packaging and carrier's operational controls. These materials are additionally controlled by the packaging standards as promulgated by the Nuclear Regulatory Commission in Title 10 CFR Part 71.

F. Limited Quantities, Instruments and Articles

The A_1 and A_2 values are also used as a basis for defining the package quantity limits for limited quantities and both the item and package limits for instruments, as illustrated in Table 4. Packages containing materials within these quantity limits are excepted from some of the requirements which apply to Type A

packages. These exceptions include not having to provide specification packaging, shipping papers, certification, marking or labeling. However, there are a number of conditions which the limited quantity, instrument or article must meet. They include:

1. Activity limits per package and, if appropriate, per instrument or article;

2. The materials must be packed in strong, tight packages that will not leak ANY of the radioactive material during conditions normally incident to transportation;

3. The radiation level at any point on the external surface of the package cannot exceed 0.5 millirem per hour;

4. The external surface of the package must be free of significant removable contamination;

5. For instruments or articles, the radiation level at 4 inches from any point on the surface of the unpackaged instrument or article may not exceed 10 millirem per hour; and

6. A prescribed description of the contents on a document which is in or on the package or forwarded with it.

TABLE 4

ACTIVITY LIMITS FOR LIMITED QUANTITIES, INSTRUMENTS AND ARTICLES

Nature of Contents[1]	Instruments and Articles		Materials
	Instrument and article limits[1]	Package limits	Package limits
Solids			
Special form	$10^{-2}A_1$	A_1	$10^{-3}A_1$
Other forms	$10^{-2}A_2$	A_2	$10^{-3}A_2$
Liquids			
Tritiated water			
< 0.1 Ci/liter	-	-	1,000 curies
0.1 Ci to 1.0 Ci/l	-	-	100 curies
> 1.0 Ci/liter	-	-	1 curie
Other liquids	$10^{-3}A_2$	$10^{-1}A_2$	$10^{-4}A_2$
Gases			
Tritium[2]	20 curies	200 curies	20 curies
Special form	$10^{-3}A_1$	$10^{-2}A_1$	$10^{-3}A_1$
Other forms	$10^{-3}A_2$	$10^{-2}A_2$	$10^{-3}A$

1/ For mixture of radionuclides see Section 173.433(b).

2/ These values also apply to tritium in activated luminous paint and tritium adsorbed on solid carriers.

Refer to Sections 173.421 through 173.424 for the complete requirements pertaining to these materials.

The U. S. Postal Service has revised its rules for mailable radioactive materials. The mailable amounts of material are one-tenth the values listed in the DOT regulations. Other additional restrictions apply to mailable materials and the Postal Regulations should be consulted for complete specifications.

C. Low Specific Activity (LSA) Materials

Low specific activity materials are those materials which present a relatively low hazard as a result of their limited radioactive concentration. Some of these materials are listed by name, such as uranium ores and concentrates, as well as unirradiated natural or depleted uranium. Other materials must meet certain limitations related to their radioactive concentration. For example, tritium oxide in aqueous solutions (tritiated water) cannot exceed 5.0 millicuries per milliliter. The allowable radioactive concentration for other materials with uniformly dispersed activity is related to the A_2 values of the radionuclides present. The relation is as follows:

If the A_2 of the radionuclide is:	The maximum activity PER GRAM of material is:
not more than 0.05 curie	0.0001 millicurie
more than 0.05 to 1.0 curie	0.005 millicurie
over 1.0 curie	0.3 millicurie

When mixtures of radionuclides are present, they must be subjected to the "ratio" rule to determine if the mixture is LSA. For uniform mixtures of nuclides, the following formula will determine if the mixture is defined as LSA:

$$\frac{APG_1}{0.0001} + \frac{APG_2}{0.005} + \frac{APG_3}{0.03} \leq 1.0$$

Where:

APG_1 = the total activity (in millicuries) per gram of material of all nuclides present with an A_2 value of less than 0.05 curie.

APG_2 = the total activity (in millicuries) per gram of material of all nuclides present with an A_2 value of more than 0.05 but less than 1.0 curie.

APG_3 = the total activity (in millicuries) per gram of material of all nuclides present with an A_2 value exceeding 1.0 curie.

If the above summation for a given uniform mixture is less than or equal to 1, then the mixture may be classified as LSA.

Because of their low radioactive concentration, these materials usually can be safely carried without regard to the total activity of the material in a single package. Most low-level radioactive waste shipments are comprised of LSA materials. There are TWO WAYS in which LSA materials can be transported.

o Nonexclusive use shipments - "essentially Type A packages"

The first method, "nonexclusive use" transportation, requires that the material be transported in essentially a Type A package. "Essentially a Type A" package means a package that must survive the physical tests, such as the drop and compression tests for Type A packages - but which is excepted from some of the general Type A requirements. The actual test requirements are found in Section 173.465. Although the packages are excepted from certain design requirements, their integrity must be equal to a Type A.

- Exclusive use - "strong, tight package."

LSA materials which are transported by conveyances assigned for the "exclusive use" of the consignor may be shipped in packages that are of less rigorous construction. Users of the exclusive use provision MUST ENSURE that there will be no loading or unloading of the material except under the direction of the consignee or consignor. The limitation on loading and unloading, plus the requirement that the material be in exclusive use, safely allows the exception from certain packaging test requirements. Exclusive use LSA, therefore, is allowed to be made in the so-called strong, tight package.

There are no specific test requirements for the strong, tight packages. However, a performance criteria must be met--there can be no release of radioactive content during transportation and like any other package of hazardous material, the requirements of Section 173.24 must be met. Materials which are consigned as exclusive use LSA shipments MUST have the packages marked "Radioactive LSA." And the vehicle on which they are being transported MUST be placarded with the RADIOACTIVE MATERIAL placard.

TABLE 5

RADIOACTIVE MATERIALS PACKAGES
MAXIMUM RADIATION LEVEL LIMITATIONS
(SEE SECTIONS 173.441(a) AND (b)

RADIATION LEVEL (DOSE) RATE AT ANY POINT ON EXTERNAL SURFACE OF ANY PACKAGE OF R.A.M. MAY NOT EXCEED:

A. 200 MILLIREM PER HOUR.
B. 10 MILLIREM PER HOUR AT ONE METER* (TRANSPORT INDEX MAY NOT EXCEED 10).

UNLESS THE PACKAGES ARE TRANSPORTED IN AN "EXCLUSIVE USE" CLOSED TRANSPORT VEHICLE (AIRCRAFT PROHIBITED) - THEN THE MAXIMUM RADIATION LEVELS MAY BE:

A. 1000 MILLIREM PER HOUR ON THE ACCESSIBLE EXTERNAL PACKAGE SURFACE.
B. 200 MILLIREM PER HOUR AT EXTERNAL SURFACE OF THE VEHICLE.
C. 10 MILLIREM PER HOUR AT TWO METERS** FROM EXTERNAL SURFACE OF THE VEHICLE.
D. 2 MILLIREM PER HOUR IN ANY POSITION OF THE VEHICLE WHICH IS OCCUPIED BY A PERSON.

* 3.3 feet.
** 6.6 feet.

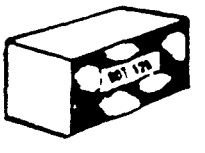
H. Type A Packaging

In Figure 5, there is an illustration of "Typical Type A Packaging Schemes." Type A packaging is that which must be designed in accordance with the applicable general packaging requirements as prescribed in the regulations (Sections 173.24, 173.411, 173.412), and which must be adequate to prevent the loss or dispersal of its radioactive contents and to maintain its radiation shielding properties if the package is subjected to normal conditions of transport. The regulations prescribe (Section 173.465) the performance criteria to simulate normal and rough handling conditions of transport. Typically, the Type A packaging prescribed in the regulations is the performance-based DOT Spec. 7A (Section 178.350) Type A general packaging for which each shipper must make his own assessment and certification of the particular

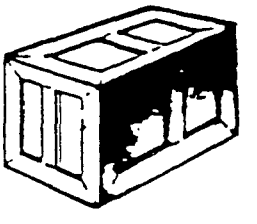
package design against the performance requirements. The regulatory framework, therefore, provides for the use of Type A packaging without prior specific approval by DOT of the package designs vic the use of DOT Spec. 7A performance specification. Additionally, foreign-made Type A packages are acceptable internationally, provided they are so marked as Type A and comply with the requirements of the country of origin. It should be noted that the shipper of each DOT Spec. 7A is required to maintain on file for at least one year after the latest shipment, and be prepared to provide to the Department, a complete certification and supporting safety analysis demonstrating that the construction methods, packaging design, and materials of construction are in compliance with the specification (see Section 173.415). The information in this file must show, through any of the methods given in Section 173.461, that all of the requirements of Sections 173.24, 173.463 and 173.465 are met. The file must also relate the contents of the package(s) being shipped to the contents which were used for testing purposes.

Figure 5 - Typical Type A Packaging

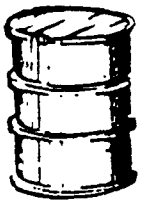
Package Must Withstand Normal Conditions (173.465) of Transport Only Without Loss or Dispersal of the Radioactive Contents.



Fiberboard Box



Wooden Box



Steel Drum

Typical Schemes

Dot Specification 7A
Type "A" Package

NOTE:

A useful reference in evaluating whether certain DOT specification package designs meet the requirements of DOT Spec. 7A is listed in Section VIII, Reference 10. It is the shipper's responsibility to ensure that all details of the package which is offered for transport complies with the Spec. 7A requirements. This includes ensuring that the package evaluation is complete (Section 173.415(a)) and that the packaging and contents offered for transport have been included in the evaluation.

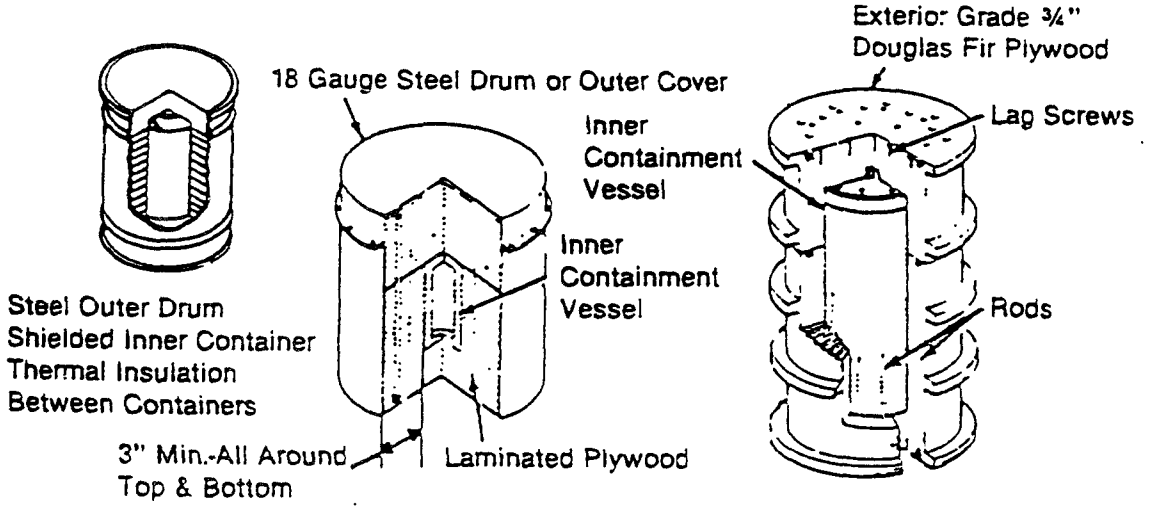
I. Type B Packaging

Type B Packaging (see Figure 6), must meet the general packaging requirements and all of the performance standards for Type A packages. In addition, it must withstand certain serious accident damage test conditions. After the tests, there must be only limited loss of shielding capability and essentially no loss of containment. The performance criteria which the package designer must use to assess Type B packaging against these empirically established hypothetical accident test conditions of the transport are prescribed in the Nuclear Regulatory Commission regulations (10 CFR 71.73) and include the following:

1. A 30-foot free drop onto an unyielding surface.
2. A puncture test which is a free drop (over 40 inches) onto a six-inch diameter steel pin.
3. Thermal exposure at 1,475°F for 30 minutes.
4. Water immersion for eight hours (for fissile materials packaging only).

Figure 6 - Typical Type B Packagings

Package Must Stand Both Normal (173.465) and Accident (10 CFR Part 71) Test-Conditions Without Loss of Contents.



Except for a limited number of specification Type B packagings (e.g., DOT-6M) described in the regulations, all Type B package designs require PRIOR APPROVAL of the U. S. Nuclear Regulatory Commission or Department of Energy (DOE). (See Section 173.471 for standard requirements and conditions pertaining to NRC approved packages and Section 173.7 for DOE certified packages.)

J. Fissile Radioactive Materials

In addition to considerations for the radioactive content, shippers of fissile radioactive material must also take into account certain other packaging and shipment requirements to ensure against nuclear criticality due to the fissile (fissionable) nature of the materials. The design of the packaging for fissile radioactive material, the transport index to be assigned (if Fissile Class II), and any special procedures for packaging are prescribed in 49 CFR 173.451 through 173.459 of the DOT regulations and in 10 CFR 71 of the USNRC regulations. Each fissile radioactive materials package design (except for the DOT Spec. 6L, 6M, and Spec. 20 PF-1, 20 PF-2, 20 PF-3, and 21 PF-1 and 21 PF-2) must be reviewed and approved by the USNRC prior to its first use. The packaging must be such to ensure against nuclear criticality (an unplanned nuclear chain reaction) under both normal and hypothetical accident test conditions, and prevent loss of contents in transportation. Fissile radioactive material packages are classified into one of three groups, according to the degree of control which must be exercised to assure nuclear criticality safety, as shown in Table 6.

TABLE 6

SHIPMENT CONTROLS FOR FISSILE RADIOACTIVE MATERIALS (SECTION 173.455)
1. Fissile Class I - Packages may be transported in unlimited numbers (Transport Index is based only on external radiation levels).
2. Fissile Class II - Number of packages limited by aggregate maximum of transport indexes of 50 (50 unit rule). No single package may exceec a transport index of 10. Transport index shall be based on criticality or external radiation level basis, whichever is most restrictive.
3. Fissile Class III - Shipments of packages which do not meet the requirements of Fissile Class I or II. Controlled by specific arrangements between the shipper and carrrier. (See Section 173.457(b).)

K. Highway Route Controlled Quantities

Certain quantities of radioactive materials known as "Highway Route Controlled Quantities" are subject to additional controls during transportation. A Highway Route Controlled Quantity is defined as an amount of material in a single package which exceeds either: (1) 3,000 times the A_1 quantity, for special form material; (2) 3,000 times the A_2 quantity, for normal form materials; or (3) 30,000 curies, WHICHEVER IS LEAST. Packages containing a Highway Route Controlled Quantity of radioactive material are subject to specific routing controls which apply to the highway carrier. The carrier must operate on preferred routes that are in conformance with Section 177.825. The carrier must report to the shipper the route used in making the shipment. The shipper is required to report the routing information to the Materials Transportation Bureau (MTB) per Section 173.22(c).

In determining if a package contains a Highway Route Controlled Quantity of material, first identify the radionuclide being transported. After identifying

the radionuclide, determine if it is in special form or normal form. If the material is in special form, multiply the A_1 value for the radionuclide by 3,000. Compare this answer with 30,000 curies. The lower of the two values is the Highway Route Controlled Quantity for that radionuclide in special form. If the contents of the package being shipped exceeds the Highway Route Controlled Quantity, the package must be transported under the specific route control requirement. For example, suppose a shipper has a package of Cobalt 60 in special form. The A_1 value for Cobalt 60 is seven curies--7 x 3,000 = 21,000 curies; 21,000 curies is less than 30,000 curies. Therefore, 21,000 is the Highway Route Controlled Quantity for Cobalt 60. Packages containing 21,000 or more curies of Cobalt 60 in special form are subject to specific routing controls. Treat other radionuclides similarly in deciding if the package is subject to specific routing controls. Remember, the Highway Route Controlled Quantity relates to the content of a package--not to the sum of contents of all packages in a shipment.

L. Control of Radiation During Transport - Transport Index (T.I.), Vehicle Limits, and Separation Distances

The regulations prescribe that the maximum permissible dose rate for packages of radioactive materials offered for transport shall not exceed 200 millirem per hour at any point on the external surface of the package, and the transport index may not exceed 10. The highest dose rate at one meter away from any accessible exterior surface of the package equals the "Transport Index," or T.I. If the shipper assures that the package will be transported on a conveyance as "exclusive use," a higher maximum dose rate is allowed. The radiation level limitations are summarized in Table 5. (See page 24)

To control the radiation level resulting from accumulations of multiple numbers of packages in the transportation environment, the regulations require that the carrier shall maintain certain prescribed separation distances between radioactive materials packages and other areas occupied by persons and/or photographic film (since film may be fogged by radiation). For film, these separation distances are based on the storage time and the transportation index; and for separation from people, the distances are based solely on the T.I. No package offered for transport (on other than "exclusive use" vehicles) may have a T.I. exceeding 10. However, the T.I. per package limit is decreased to 3.0 for packages carried aboard passenger-carrying aircraft. T.I.'s of 10 and 3 are based on standards for limiting personnel exposure, and to prevent "fogging" of "fast" photographic film.

The total of the T.I. of all packages in any single transport vehicle or storage location generally may not exceed 50. Exceeding the 50 T.I. per vehicle limit is authorized only for certain specific types of shipments which are carried under the special requirements of "exclusive use" vehicles (Section 173.403(i)), which impose additional responsibilities on the shipper. The shipments that qualify most often for the 50 T.I. exception are "exclusive use" shipments of low specific activity radioactive materials (Sections 173.425(b) and (c)) or the occasional "hot" package that cannot meet the 10 T.I. limit (Section 173.441(b)). In either case, the special arrangements between the shipper and carrier must satisfy all requirements, including those of Sections 173.403(i) and 173.441(b).

The regulations provide graded tables of stowage distances for stowage in accordance with the cumulative transport index. These tables are found in the carrier sections of the regulations (Sections 174.700, 175.701 through 175.703, 176.708, and 177.842).

The transport index (T.I.) system, together with tables of separation distances, provides control by the carrier over the radiation exposures to personnel handling the packages, and to casually exposed persons in the vicinity of accumulations of packages.

The T.I. system is also designed to provide the means to assure criticality safety. It limits the amount of fissile materials in one location under nonexclusive use conditions (the 50 T.I. upper limit). This prevents conditions that would support a nuclear "chain reaction," or "go critical." For such fissile materials, the shipper must determine, in accordance with regulatory criteria (Section 173.455(b)), the appropriate T.I. based on nuclear criticality safety. For purposes of transportation, the shipper then must assign to the package the T.I. value. Use of the higher T.I. value based on either the nuclear criticality safety criteria or the radiation level limitation (as described earlier) is required.

During transportation, the carrier still makes reference to the T.I. and stowage tables, even though the T.I. for fissile materials may be based on criteria other than the external radiation levels. For this reason, the absence of measurable external radiation from certain types of fissile radioactive materials packages would not necessarily constitute an "overlabeling" violation.

M. Warning Labels

Each package of radioactive material, unless excepted, must be labeled (Section 172.403) on two opposite sides, with a distinctive warning label. Each of the three label types bears the unique trefoil symbol (Figure 7) recommended by the International Commission on Radiation Protection (ICRP) in 1956. It has been

adopted by the American National Standards Institute as the standard radiation symbol (N2.1-1969). The labels alert persons that the package contains radioactive materials and that the package may require special handling. A label with an all white background color indicates that the external radiation level is low and no special handling is required. If the upper half of the label is yellow, the package may have an external radiation level or fissile properties requiring consideration during transportation. If the package bears a yellow label with three stripes, the transport vehicle must be placarded RADIOACTIVE. Placarding is discussed in more detail in Section IV. The criteria which the shipper must consider in choosing the appropriate label are listed in Table 7.

Figure 7 - Package Labels

Radioactive-White I
(See §172.436)

Radioactive-Yellow II
(See §172.438)

Radioactive-Yellow III
(See §172.440)

For all labels, vertical bars on each label are in red. Each label is diamond-shaped, four inches on each side, and has a black solid-line border one-fourth inch from the edge. The background color of the upper half (within the black line) is white for the "I" label. It is yellow for the "II" and "III" labels.

The regulatory provisions in Sections 172.403(f) and (g) applicable to the use of these labels are:

Each package required by this Section to be labeled with a RADIOACTIVE label must have two of these labels affixed to opposite sides of the package.

The following applicable items of information must be entered in the blank spaces on the RADIOACTIVE label by legible printing (manual or mechanical) using a durable weather resistant means of marking.

"Contents" - The name of the radionuclide, as taken from the listing of radionuclides in Section 173.435 (symbols which conform to established radiation protection terminology are authorized, i.e., ^{99}Mo, ^{60}Co, etc.). For mixtures of radionuclides, the most restrictive radionuclides on the basis of radiotoxicity must be listed as space on the label allows.

"Activity" - Units shall be expressed in appropriate curie units, i.e., curies (Ci), millicuries (mCi) or microcuries (uCi) (abbreviations are authorized). For a fissile material, the weight in grams or kilograms of the fissile radioisotope also may be inserted in addition to the activity.

"Transport Index" - (See Section 173.403(bb)).

TABLE 7

RADIOACTIVE MATERIALS PACKAGES LABELING CRITERIA
SECTION 172.403

Transport Index (T.I.)	Radiation Level at Package Surface (RL)	Fissile Criteria	Label Category 1/
N/A	RL $\leq$ 0.5 millirem per hour (mrem/h)	Fissile Class I Only No Fissile Class II or III	White - I
T.I. $\leq$ 1.0	0.5 mrem/h $<$ RL $\leq$ 50	Fissile Class I, Fissile Class II with T.I. $\leq$ 1.0, No Fissile Class III	Yellow - II
1.0 $<$ T.I.	50 mrem/h $<$ RL	Fissile Class II with 1.0 $<$ T.I., Fissile Class III	Yellow - III

1/ Any package containing a "Highway Route Controlled Quantity" (Section 173.403 of this subchapter) must be labeled as Radioactive Yellow - III.

At this point, it is appropriate to offer the following word of caution:

Figure 8 - **Caution — Do Not Confuse the Following:**

Radioactive Materials Package Labels (172.403 and 172.436 Through 172.440)

- Radioactive White-I
- Radioactive Yellow-II
- Radioactive Yellow-III

With:

- Fissile Classes I, II, or III (173.455)

N. Contamination Control

The regulations prescribe limits (Section 173.443) for control of removable (non-fixed) radioactive contamination, as shown in Table 8. In general, the contamination levels MUST be kept as low as reasonably achievable and the significant contamination level LIMIT is applicable to any package offered for transportation. It also applies to any transport vehicle which is being released after having been used to transport either an "exclusive use" load under the provisions of Section 173.443(c) or a bulk shipment of LSA materials (Section 173.425(c)).

The limits shown in Table 8 (and Section 173.443) are for the activity measured on a wipe taken on the package surface. Measuring techniques other than wiping may be used in accordance with Section 173.443.

TABLE 8

REMOVABLE EXTERNAL RADIOACTIVE CONTAMINATION - WIPE LIMITS

Contaminant	Maximum Permissible Limits	
	uCi/cm^2	dpm/cm^2
Beta/gamma-emitting radionuclides; all radionuclides with half-lives less than ten days; natural uranium; natural thorium; uranium-235; uranium-238; thorium-232; thorium-228 and thorium-230 when contained in ores or physical concentrates.....	10^{-5}	22
All other alpha-emitting radionuclides.....	10^{-6}	2.2

uCi/cm^2 = microcuries per square centimeter.
dpm/cm^2 = disintegrations per minute per square centimeter.

O. Other Shipper Requirements

As a brief review, the shipper must (1) select the proper packaging for the specific contents; (2) consider the radiation level limits; (3) consider the contamination limits; and (4) label correctly. In addition, the shipper must also ensure compliance with the following:

1. Package Markings - The outside of the package must be marked with (a) proper shipping name; (b) identification number as shown in the list of hazardous materials (see Section 172.101); and (c) the appropriate specification number (see Section 173.24(c)(1)(i)) OR Type B or fissile packaging certificate number, when applicable. Most of the pertinent regulatory requirements for marking of all hazardous materials packages are found in Sections 172.300 through 172.308. The special requirements for radioactive materials are quoted below:

"Section 172.310 Radioactive materials.

(a) In addition to any other markings required by this subpart, each package containing radioactive materials must be marked as follows:

Gross Weight

(1) Each package of radioactive materials in excess of 110 pounds (50 kilograms) must have its gross weight plainly and durably marked on the outside of the package.

Type A and Type B

(2) Each package of radioactive materials which conforms to the requirements for Type A or Type B packaging (Section 173.403 of this subchapter) must be plainly and durably marked on the outside of the package in letters at least 1/2-inch (13 mm.) high, with the words "TYPE A" or "TYPE B," as appropriate. A packaging which is not in compliance with these requirements may not be so marked.

Exports USA (with specification or certificate identification)

(3) Each package of radioactive material destined for export shipment must also be marked "USA" in conjunction with the specification marking, or other package certificate identification (see Sections 173.471, 173.472, and 173.473 of this subchapter.)"

The proper shipping names for radioactive materials are listed in Table 9.

Spec. 7A must also be marked in accordance with Section 178.350-3. Where a duplication of marking requirements exists (such as between the Section 178.350-3(a) requirement to mark the package "Radioactive Material" and when the marked shipping name contains the words "Radioactive Material"), the markings need not be duplicated.

TABLE 9

MOST COMMONLY USED SHIPPING NAMES FOR RADIOACTIVE MATERIALS* (FROM HAZARDOUS MATERIALS TABLE, SECTION 172.101)	
Radioactive Material, Limited Quantity, n.o.s.**	UN 2910
Radioactive Material, Instruments, and Articles***	UN 2911
Radioactive Material, Fissile, n.o.s.	UN 2918
Radioactive Material, Low Specific Activity or LSA, n.o.s.	UN 2912
Radioactive Material, Special Form, n.o.s.	UN 2974
Radioactive Material, n.o.s.	UN 2982
Uranium Hexafluoride, Fissile (Containing more than 1% U-235)	UN 2977
Uranium Hexafluoride, Low Specific Activity	UN 2978

* Refer to Section 172.101 for other proper shipping names.
** n.o.s. means "not otherwise specified."
*** Underlined words are not part of the proper shipping name.

2. Shipping papers - As with other hazardous materials shipments, certain essential elements of information must be included on the shipping papers (see Sections 172.200 through 172.204).

The information required on the shipping papers is important to the carrier and consignee. It also is of great value to emergency response personnel in the event of an accident.

a. Requirements (Section 172.202(a)(1))

NOTE: Enter in order listed below:

(1) Proper shipping name from Section 172.101;

(2) Hazard class (see Section 172.202(a)(2)), hazard class from Column 3, Section 172.101, except when the hazard class is contained in the shipping name;

(3) Identification number (see Section 172.202(a)(3) from Column 3A, Section 172.101);

(4) Net quantity of material by weight or volume as stated in Sections 172.202(a)(4) and (c). For most radioactive materials packages, it is not required to list the weight or volume. The requirements of Section 172.203(d) provide better indications of potential hazards and controls required. These requirements include the package contents as measured in curies and the transport index. A listing of weight or volume measurements for radioactive materials is usually needed only for establishing transportation charges;

(5) Radionuclide(s) contained in package (abbreviations are allowed). For a mixture of radionuclides, only those radionuclides which comprise 1% or more of the total activity in the package must be listed;

(6) Physical and chemical form of material, or statement that the material is "special form" (if it is special form). A generic description of material, such as protein, carbohydrate, enzyme, or organic salt, is authorized if exact chemical form is difficult to specify;

(7) Activity in curies (Ci), millicuries (mCi), or microcuries (uCi). If the package contains a "Highway Route Controlled Quantity," those words must also be shown on the shipping papers;

(8) Category of RADIOACTIVE labels applied to package;

(9) Transport index of the package if labeled RADIOACTIVE Yellow-II or RADIOACTIVE Yellow-III;

(10) The information required in Section 172.203(d)(1)(vi) must be included if the shipment is "fissile" radioactive material;

(11) The identification markings shown on the package must appear on the shipping paper if the package is approved and certified by the Nuclear Regulatory Commission or the Department of Energy, OR is certified by DOT or other National Competent Authority for international shipment.

(12) Other information as required by the mode of transportation or subsidiary hazard of the material. (See Section 172.203.)

b. Other Information and Examples of Shipping Paper Entries

The regulations require that certain specific descriptive information must be included on shipping papers. While there is no specification for shipping paper format, the first three entries of the description must be in a specific order (see above). Other descriptive information is allowed, such as the functional description of the product. However, other information must not confuse or detract from the required descriptions of the hazarous materials.

The following are some example entries of different ways shipments can be described on shipping papers:

(1) One (1) box, Radioactive material, special form, n.o.s., UN 2974, Radiographic camera, Iridium-192, 60 Ci, Radioactive Yellow-II, 0.6 transport index, USA/9028/B(U), Cargo aircraft only.

NOTES:

Physical and chemical form is not listed since material is "special form."

The Hazard class is not listed following the proper shipping name since it is contained in the shipping name.

(2) One (1) carton, Radioactive material, n.o.s., UN 2982, ^{60}Co, 30 mCi, liquid, cobalt in 50 ml 5% hydrochloric acid solution, transport index 1.8, Radioactive Yellow-III and corrosive.

(3) One (1) box, Thorium nitrate, Radioactive material, UN 2976, 15 kg, Th natural, solid (powder), thorium nitrate, 1.3 mCi, Radioactive White-I and Oxidizer labels, Cargo aircraft only.

NOTES:

Since the material is specifically listed in Section 172.101, there is no "n.o.s." in the proper shipping name and the hazard class Radioactive material is entered.

Although this material meets the definition of LSA (Section 173.403), it must be packaged and shown on shipping papers as specifically listed material. It must meet packaging requirements as an oxidizer as required in Section 173.419.

(4) Three (3) drums, Radioactive material, LSA, n.o.s., UN 2912, non-compacted solid debris and waste, ^{137}Cs, ^{60}Co, and ^{90}Sr, *solid as inorganic salts or elemental*, 0.04, 0.01, and 0.005 mCi total, respectively; Drum Nos. 731, 680, and 541. See attached forms for details. Exclusive use instructions attached.

NOTES:

This entry is appropriate for describing drums that are shipped as part of an "exclusive use" vehicle shipment. Drums must be marked "Radioactive LSA" and the vehicle must be placarded RADIOACTIVE. Package labels are not required but are not forbidden. The detailed contents of each drum would be on a sheet attached to the sheet with the basic description.

(5) Three (3) cartons, Radioactive Material, n.o.s., UN 2982, Material to be used in physical chemistry research project at university.

Carton No. 1, catalytic specimen, ^{35}S, 70 mCi, solid, metal oxide matrix, Radioactive White-I label. 60 lb.

Carton No. 2, Tagged solvent, ^{30}Cl, 3 mCi, liquid non-flammable organic, Radioactive White-I label. 50 lb.

Carton No. 3, converter element, ^{59}Fe and ^{55}Fe, 30 mCi and 20 mCi, solid, steel part, T.I. 1.6, Radioactive Yellow-II label. 80 lb.

NOTES:

This is an example of how one basic entry can be used along with three different packages. Detailed information is given on the content, labels, and T.I. of each package.

c. Documentation for Limited Quantity Packages, Instruments or Articles, and Articles Manufactured from Natural or Depleted Uranium or Natural Thorium.

These items are addressed in Sections 173.421-173.424 and are excepted from the detailed shipping paper description. They must be documented for transport as required by Section 173.421-1 by including a notice in, on, or forwarded with the package. The notice must include the name and address of the consignor or consignee and a specific statement which is selected on the basis of the proper shipping name for the package. The following example illustrates the notice on a shipping paper. The specific statement required by Section 173.421-1 is shown in quotes.

One (1) carton, Ajax Model 123 Monitor, "This package conforms to the conditions and limitations specified in 49 CFR

173.422 for excepted radioactive material, instrument, UN 2911." 45 lb.

3. Shipper's Certification - The shipping papers must include a certificate signed by the shipper. This certification must appear on the paper that lists the required shipping description.

a. The following statement is required by Section 172.204(a) and must be used for all hazardous materials shipments except for those by air.

> "This is to certify that the above-named (or herein-named) materials are properly classified, described, packaged, marked, and labeled, and are in proper condition for transportation according to the applicable regulations of the Department of Transportation.

b. For air transportation, the following language may be included on shipping papers in place of the statement in example (a) above.

> "I hereby certify that the contents of this consignment are fully and accurately described above by proper shipping name and are classified, packed, marked, and labeled, and in proper condition for carriage by air according to applicable national governmental regulations."

The requirements and limitations for carriage of radioactive materials aboard aircraft are prescribed in Sections 175.75(a)(3), 175.700 through 175.705. The following statement is required:

For packages not acceptable for transportation on passenger-carrying aircraft:

"This shipment is within the limitations prescribed for ~~passenger aircraft~~/cargo-only aircraft." (delete non-applicable)

For packages acceptable for transportation on passenger-carrying aircraft:

This shipment is within the limitations prescribed for passenger aircraft/~~cargo-only aircraft~~." (delete non-applicable)

Since radioactive materials (other than Limited Quantities) can be carried on a passenger-carrying aircraft only if they are intended for use in research or medical applications, a statement to that effect must be included in the signed certification for shipment by passenger-carrying aircraft.

4. Security Seal - The outside of each Type A or Type B radioactive materials package must incorporate a feature, such as a seal, which is (a) not readily breakable and which, while intact, (b) will be evidence that the package has not been illicitly opened (Section 273.412(b)). For this requirement, the package designer may need to be skilled and creative. This is espeacially true for packages, such as fiberboard cartons and wooden boxes. The regulations also require that "inner shield closures must be positively closed to prevent loss of contents." A padlock is not effective as both a security seal and a closure mechanism. Most padlocks are not even a good security seal, let alone a closure device. It is usually not possible with most types of padlocks to ascertain if they have been illicitly opened. The best approach toward meeting the dual requirements, especially for Type B packages, is: (a) serially numbered lead wire seals, IN COMBINATION WITH (b) such closure mechanisms as slotted screw-in plugs, bolted flanges, and positive action shutter mechanisms.

5. Small Dimension - The smallest outside dimension of any radioactive materials package (other than excepted quantities) must be four inches or greater (Section 173.412(a)).

6. Liquid Packaging Provision (Section 173.412(n)) - Liquid radioactive material must be packaged in a leak-resistant inner container. In addition, the packaging must be adequate to prevent loss or dispersal of the radioactive contents from the inner container if the package were subjected to the 30-foot drop test prescribed in Section 173.466; and enough absorbent material must be provided to absorb at least twice the volume of the radioactive liquid contents. Care should be exercised by the package designer to assure that the positioning of the absorbent material about the liquid-containing vessel is such that the "absorber will absorb" in the event of leakage from the vessel. For packages with liquid contents exceeding 50 cm^3, an alternative is provided to the use of the absorbent in that a secondary outer leak-resistant containment vessel may be utilized. The outer containment vessel must have the ability to retain the radioactive contents under normal conditions of transport, assuming the failure of the innermost primary containment vessel. The package also requires a marking indicating the upward position of the inside packaging (Section 172.312).

7. Surface Temperature of Package - Maximum surface temperature limits on packages, resulting from radioactive thermal decay energy of the contents, are prescribed in Section 173.442. The limit is either 122°F or, in the case of exclusive use shipments, 180°F.

8. Quality Control Requirements (Sections 173.474 and 173.475) - The regulations also prescribe certain quality control requirements for the construction of radioactive materials packagings (Section 173.474) and before each shipment of a package (Section 173.475). With regard to packages of liquids containing in excess of Type A quantity, destined for shipment by air, an additional requirement (Section 173.475(g)) is imposed such that the containment system of each package offered for shipment must be tested to assure that it will remain leak-free in a specified ambient reduced atmosphere (0.25 atmosphere).

For Type A packages of the fiberboard box variety, sealing tape and the consignor's labels offer opportunities for compliance IF they can provide positive evidence that the package has not been opened.

IV. CARRIER REQUIREMENTS IN HANDLING OF RADIOACTIVE MATERIALS PACKAGES

Up to this point, this Review of the regulations has been concerned principally with the regulatory requirements applicable to the shipper, and/or the package designer. The reason for this is simple. Most of the regulatory requirements for the assurance of safety in the transport of radioactive materials are directed towards safety through proper packaging. Thus, the majority of these requirements apply to the shipper. In transport of radioactive materials, the principal carrier responsibilities are as follows:

A. Shipping Papers and Certification by Shipper

Carriers may not knowingly accept for transport packages of radioactive materials which have not been properly described and certified by the shipper

pursuant to Section 172.204. This certificate is relied upon by the carrier, as evidence that the packaging is in accordance with the regulatory requirements. In the case of air shipments, one signed copy of the shipping paper must accompany the shipment (Section 175.35(a)). The originating air carrier must retain a second copy (Section 175.30(a)(2)).

Carriers may prepare and carry with the shipments appropriate bills of lading, waybills, etc., based on the information derived from the shippers' shipping papers (Sections 174.24, 175.35, 176.24, and 177.817). For shipments by vessel, a Dangerous Cargo Manifest or storage plan is also required (Section 176.30).

B. Placarding

The carrier must apply the RADIOACTIVE placard to the transport vehicle (rail or highway) if ANY radioactive material package on board bears a "Radioactive YELLOW-III" label (Section 172.440). The format for the placard is illustrated in Figure 9. The requirements for placarding are in Section 172.504 and Table 1 footnotes of that Section.

Figure 9

(The background color for the black trefoil in the upper half of this 12" x 12" placard is yellow.)

Highway Route Controlled Quantity Placarding

Vehicles transporting ANY package which contains a highway route controlled quantity must also display the square white background as specified in Section 172.507.

A Word of Caution - Placarding of LSA Radioactive Materials

Questions occasionally arise about the placarding requirements for "Exclusive Use" (sometimes referred to as "full-load" or "sole-use") shipments of low specific activity radioactive materials (LSA). Under the shipper requirements of Sections 173.415(b) and (c), transport vehicles must be placarded by the shipper with the placard which is normally required to be applied by the carrier (pursuant to Sections 172.504(a) or 172.556). Some persons have apparently misinterpreted the provisions of Section 173.415(b)(7) assuming that if the shipment of LSA materials bears no packages with Radioactive Yellow-III labels, then placarding is not required. This is not the case. In fact, the packages in such shipments are excepted ONLY FROM specification packaging, marking, and labeling pursuant to Section 173.425(b). The requirement to placard is, therefore, imposed on the shipper rather than the carrier. This is consistent with the higher external radiation levels of Section 173.441(b) which are allowed for such shipments. To some degree, the requirement for the shipper to placard the vehicle is imposed instead of requiring the radioactive material warning labels on each package.

C. Radiation Exposure Control by Maximum Total Transport Index vs. Distance

For any group of "yellow-labeled" packages in a single conveyance or storage location, the carrier must assure that the total transport index does not

exceed 50. The carrier must assure that such groups of yellow-labeled packages are kept separated from undeveloped film shipments and areas normally occupied by persons. The minimum separation distance must be in accordance with a table of distances based on the graded total transport index (Sections 174.700(c), 175.701 through 175.703, 176.708, and 177.842(b)). This separation reduces the rate of exposure to radiation.

D. Reporting of Incidents

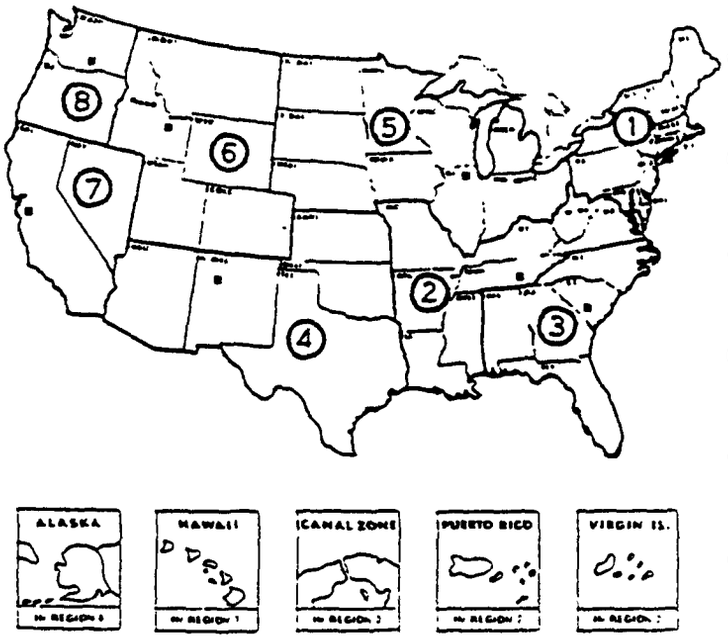
The carrier must assure that DOT and the shipper are notified in the event of fire, breakage, spillage, or suspected radioactive contamination involving a shipment of radioactive material. Also, carriers must assure that vehicles, areas, or equipment in which radioactive material may have spilled are not placed in service again until they have been surveyed and decontaminated (Sections 171.15, 171.16, 174.750, 175.45(a)(4), 176.48(b), and 177.861(a)).

The reporting requirement cited above is not necessarily a means of receiving technical assistance in radiological monitoring in the event of a transportation incident. To obtain technical assistance, carriers may call upon the services of local or state radiological authorities.

Federal assistance in resolving a radiological emergency may be provided if requested by state or local authorities. As with emergencies of nature (floods, fires, tornados, etc.), the responsibilities for resolutions of radiological or other hazardous materials emergencies belong basically with state and local governments. Federal involvement is limited unless requested. When technical advice or assistance is needed for a radiological or other hazardous materials accident and the state or local radiological authority is not known, help can be obtained by contacting the

Chemical Transportation Emergency Center (CHEMTREC) at (800) 424-9300. For emergencies involving radioactive materials, CHEMTREC will refer the problem to state or local authorities and/or to the Department of Energy's (DOE) Radiological Assistance Coordinating Offices. The DOE radiological experts will determine the nature of the problem. Based upon their assessment, they will provide advice, arrange for state or local assistance, or dispatch a DOE team of radiological experts to assist in the emergency. The map of the DOE Regions showing the telephone numbers of the Coordinating Offices is shown in Figure 10. These offices can also be called directly for radiological assistance.

Figure 10 - **Regional Coordinating Offices for Radiological Assistance and Geographical Areas of Responsibility**



	REGIONAL COORDINATING OFFICE	POST OFFICE ADDRESS	TELEPHONE for ASSISTANCE
1	BROOKHAVEN AREA OFFICE	UPTON, L. I. NEW YORK 11973	(516) 345-2200
2	OAK RIDGE OPERATIONS OFFICE	P. O. BOX E OAK RIDGE, TENNESSEE 37830	(615) 576-1005 or (615) 525-7885
3	SAVANNAH RIVER OPERATIONS OFFICE	P. O. BOX A AIKEN, S. C. 29801	(803) 725 3333
4	ALBUQUERQUE OPERATIONS OFFICE	P. O. BOX 5400 ALBUQUERQUE, NEW MEXICO 87115	(505) 844-4667
5	CHICAGO OPERATIONS OFFICE	9800 S. CASS AVE. ARGONNE, ILLINOIS 60439	Duty Hrs. (312) 972-4800 Off Hrs. -5731
6	IDAHO OPERATIONS OFFICE	550 SECOND ST IDAHO FALLS, IDAHO 83401	(208) 526-1515
7	SAN FRANCISCO OPERATIONS OFFICE	1333 BROADWAY OAKLAND CALIFORNIA 94612	(415) 273-4237
8	RICHLAND OPERATIONS OFFICE	P. O. BOX 550 RICHLAND WASHINGTON 99352	(509) 376-7381

E. Notification to Pilot (to Aircraft Shipments)

The aircraft operator must provide, in writing, the pilot in command of the aircraft the following information: (a) the name, (b) type of label, (c) quantity, and (d) location of any "hazardous material," such as radioactive materials packages. The cargo load manifest must be conspicuously marked to indicate the presence of such packages (49 CFR 175.33).

V. DISCREPANCIES IN RADIOACTIVE MATERIALS SHIPMENTS

This discussion is intended to serve as an aid to both shippers and carriers. Noncompliance in radioactive materials shipments is generally either of a safety related nature, i.e., improper packaging, excessive radiation or contamination, or an administrative nature, i.e., improper shipping paper description, illegible labels, etc. Items of noncompliance which deserve special attention in order to avoid are:

A. By Shippers

1. Excess radiation levels (Section 173.403(bb)) - Fortunately, this item is not noted frequently. It is one of the most serious type of shipper violations of the safety requirements for transportation of radioactive materials. Excessive radiation levels on packages of radioactive materials indicate inadequate planning, procedures, and/or practices. They are generally the result of:

   a. An unsatisfactory monitoring of the entire package.

   b. Using inadequate radiation measuring instruments.

c. Using instruments that are not properly calibrated.

d. A failure to properly secure a shielded closure mechanism, a faulty closure mechanism, etc.

e. Use of packagings for materials for which they were not designed. For example, putting radioactive materials into a container that exceeds the shielding capabilities of the package, or placing materials into a container that is not compatible with the material's physical or chemical properties. For "special form" sources, this results in a potential for excessive radiation levels. For dispersible, normal form radioactive materials, a hazard may be present due to both excessive radiation, as well as possible dispersal of loose contamination. The very short half-life of some radioisotopes occasionally presents problems in transportation. Some suppliers load more than the total quantity allowed for shipment, so that the radiation levels at the actual time of shipment will be within the limits, taking into account radioactive decay. This is a violation if the package is offered for shipment too soon, that it, before the material has decayed to legal limits.

2. Improper Packaging - This is also a most serious safety item. It is closely related to the excessive radiation level in that an improper package may not incorporate sufficient thickness of shielding for the material. Another example of improper packaging is the use of a packaging not authorized in the regulations or under an exemption or other specific approval.

Safety may be affected even when an approved package is utilized, IF IT IS NOT IN ITS PROPER CONDITION AS REQUIRED BY ITS DESIGN. Good quality control practices by shippers of radioactive materials are of paramount importance. A relevant requirement of Section 173.22 reads as follows:

> "The person shall determine that the packaging or container has been manufactured, assembled, and marked . . . "

The above provision is cited as a reminder to shippers. No package will perform during transportation as intended by its original design, unless it is in its proper design condition. It must be "as good as new" when offered for transportation. The quality control requirements of Sections 173.474 and 173.475 serve to clarify these aspects.

3. Lack of Security Seal (Section 173.412(b)) - This requirement is sometimes misunderstood by shippers of radioactive material. It is really a performance type requirement, wherein--

> "The outside of the packaging incorporates a feature, such as a seal, that is not readily breakable, and that, while intact, is evidence that the package has not been opened."

On some types of packages, i.e., steel drums, hinged lid boxes, etc., provision for a security seal is fairly simple. On many other types, i.e., wooden boxes, fiberboard cartons, much more thought and ingenuity in designing a seal to meet the requirements will be necessary. The use of padlocks as a security seal may not, in all cases, be appropriate. Many types of padlocks may be opened and closed again without knowledge of the consignee.

4. Improper Labels - Incorrect labeling of radioactive materials packages is a common deficiency. The most frequent error is "overlabeling." A YELLOW-III label is used where a WHITE-I or YELLOW-II label is prescribed. The three labels are used to indicate the degree of control the package requires. "Overlabeling" signals incorrect hazard warning information.

5. Illegible/Incorrect Label Notations - This item should speak for itself. Needless to say, shippers should exercise care to insert legible, durable entries on the labels. These entries call for noting the "contents," "activity," and "transport index." The name of the radionuclide or its abbreviation must be entered on the Contents line exactly as on the list of radionuclides in Section 173.435. Clearly indicate the exact number of curies, millicuries or microcuries on the Activity line. Finally, the "transport index" must be rounded up to the next highest tenth as prescribed in Section 173.403(bb).

6. Improper or Incomplete Shipping Paper Description - The basic requirements for the shipping paper description are prescribed in Subpart C of 49 CFR Part 172. The first, second, and third elements on the shipping paper must always be the applicable "proper shipping name," "hazard class," and "identification number," exactly as listed in the table in Section 172.101. Any other required description or information (not inconsistent therewith) may follow. However, there are at present 16 different proper shipping names for radioactive materials in the hazardous materials table. The most commonly used names are listed in Table 9. The most appropriate name must be used. Care should be exercised to

properly enter the other information as required by Section 172.203(d). When the shipment involves a radioactive material prohibited from transport by passenger-carrying aircraft, the description shall also include the words "cargo aircraft only."

7. Inadequate Provision for Liquid Contents - The regulations prescribe certain additional packaging requirements for liquid radioactive materials. As required by Section 173.412(n) and Section 173.466(a)(1), these are basically the "performance" requirements. The package must withstand a 30-foot-drop test without loss of liquid contents. Absorbent material must be present to absorb the liquid contents in the event of breakage of the primary liquid container for contents which do not exceed 50 cm^3. A double containment vessel system that will survive all applicable testing may be used as an alternate packaging when the contents exceed 50 cm^3. The package orientation marking (example: "This side up ↑ ") is also required.

B. By Carriers

1. Acceptance of Consignments Without Shipper's Certification - The regulations applicable to the carrier specify that shipments of regulated hazardous materials may NOT be accepted unless accompanied by the appropriate certification. The shipper must certify that the material has been properly packaged, marked and labeled in accordance with the regulations. This certification must be signed by the shipper. It is a legal representation to the carrier that the safety requirements of the shipment are in order. Needless to say, originating carriers must not accept hazardous materials which are offered to them without this certification.

2. Failure to Prepare Proper Shipping Paper Description - Each of the carrier regulations permit carrier-prepared manifest, way bills, etc., to include the proper shipping description and an indication of the type of label applied. In many cases, carriers, in preparing their shipping papers, do not accurately copy these essential items of information from the shippers' papers.

3. Acceptance of Radioactive Materials Consignments Exceeding the 50 Transport Index Maximum Per Vehicle and Inadequate Separation Distances - In many cases, carriers either do not appear to be aware of this limitation or they blatantly fail to follow it. Each of the carrier regulations contain a table which prescribes certain segretation distances and in certain cases, stowage times for accumulations of radioactive materials packages. These distances and times are based on the total transport index. These segregation controls are intended to provide a safe separation distance of radioactive materials packages from areas occupied by persons or photographic film.

4. Failure to Properly Placard Transport Vehicles - For any rail or highway vehicle transporting any quantity of radioactive materials packages bearing the radioactive YELLOW-III label, the carrier is required to display the RADIOACTIVE placard. Intentional failure to placard vehicles is a very serious offense.

5. Inadequate Vehicle Safety - Other safety regulations, such as those of the Bureau of Motor Carrier Safety, 49 CFR Parts 390-397, play an important role in the safe transport of radioactive and other hazardous materials. Even though shippers and carriers may be in full compliance

with the Hazardous Materials Regulations, an unsafe vehicle can increase the risks to the public and the transport workers. Inspections have often disclosed vehicle safety violations of greater possible consequence than the hazardous materials violations. Be certain that the transporting vehicle is in proper condition before accepting a shipment.

VI. IAEA REGULATIONS (AS AMENDED)

The IAEA (International Atomic Energy Agency) has published the "Regulations for the Safe Transport of Radioactive Materials, Safety Series No. 6, 1973 Edition (as amended)". These regulations have now been accepted and adopted (either wholly or in part) by most nations as their standard for both national and international regulations. The United States revised the DOT regulations as of July 1, 1983, to achieve a substantial conformity with the 1973 IAEA standards.

During September 1980, the IAEA convened a panel of experts from its member countries for the purpose of considering proposed changes to the IAEA regulations. These proposed changes had been submitted in advance of the convening of the panel by each member country. As a result of that panel, drafts of comprehensive revisions to Safety Series No. 6 were were subsequently prepared. The second draft was submitted to each IAEA member country and various international organizations in May 1981. Official comments on it were then submitted to IAEA in 1981. Another meeting of the review panel was then convened to finalize the revisions. The IAEA regulations in Safety Series No. 6 should be revised in 1983. Following these changes, DOT will propose changes, if needed.

VII. DEFINITIONS

The following definitions are derived from the Code of Federal Regulations, Title 49 - Transportation, Section 173.403.

CLOSED TRANSPORT VEHICLE - A vehicle equipped with a securely attached exterior enclosure. which during normal transport restricts the access of unauthorized persons to the cargo space containing the radioactive material. The enclosure may be permanent or temporary, may be of the "see-through" type and must limit access from the top, side, and ends. (Section 173.403(c))

FISSILE CLASSES - The groupings into which radioactive material packages are classified according to the controls needed to provide nuclear criticality safety during transportation. (Section 173.455)

FISSILE MATERIAL - Plutonium-238, plutonium-239, plutonium-241, uranium-233, uranium-235, or any material containing any of the foregoing. (Section 173.403(j))

LIMITED QUANTITY RADIOACTIVE MATERIALS - A quantity of radioactivity which does exceed the limits specified in Section 173.423. Limited quantities and certain radioactive instruments and articles (Sections 173.421 through 173.424) are excepted from specification packaging, shipping paper and certification, marking and labeling requirements, but are still subject to certain requirements as specified in Sections 173.421 through 173.424.

LOW SPECIFIC ACTIVITY MATERIAL - Material in which the activity is essentially uniformly distributed and in which the estimated average concentration per gram of contents does not exceed the specifications of Section 173.403(n).

SPECIAL FORM RADIOACTIVE MATERIALS - Those materials which, by nature of their physical form or encapsulation, if released from a package might present some direct radiation hazard but would present little hazard from the possibility of contamination. (Section 173.403(z))

NORMAL FORM RADIOACTIVE MATERIALS - Those materials which do not meet the requirements of Special Form Radioactive Materials. (Section 173.403(s))

TRANSPORT INDEX - A number placed on a package of "Yellow-Label" radioactive materials by the shipper to denote the degree of control to be exercised by the carrier, i.e., to determine the number of yellow-labeled packages which may be placed in a single vehicle or storage location. The transport index is either the highest measured dose rate of radiation at three feet from the surface of the package, or a number assigned for criticality control purposes. (Section 173.403(bb))

TYPE "A" PACKAGING - Packaging which is designed in accordance with the general packaging requirements of Sections 173.24 and 173.412, and which is adequate to prevent the loss or dispersal of the radioactive contents and to retain the efficiency of its radiation shielding properties if the package is subject to the tests prescribed in Section 173.465.

TYPE "B" PACKAGING - Packaging which meets the standards for Type "A" packaging and, in addition, meets the standards for the hypothetical accident conditions of transport as prescribed in 10 CFR Part 71.

The following definitions, though not derived from the Code of Federal Regulations, Title 49, are held as generally accepted meanings of the terms listed.

ALPHA PARTICLES - One of the three primary forms of radioactive emissions from radioactive atoms. Alpha particles are positively charged particles emitted from the nucleus of a radioactive atom and have a mass and charge equal to the nucleus of a helium atom (2 protons + 2 neutrons). Alpha particles have very little penetrating ability and, therefore, are chiefly internal radiation hazards. They travel very short distances in air and are shielded very easily.

BETA PARTICLES - One of three primary forms of radioactive emissions from radioactive atoms. Beta particles are negatively charged particles emitted from the nucleus of a radioactive atom and have a mass and charge equal to that of an electron. They usually travel greater distances in air than alpha particles, have an intermediate penetrating ability, but still can be easily shielded with common materials.

GAMMA RAYS - One of three primary forms of radioactive emissions from radioactive atoms. Gamma rays are not particulate (as opposed to alpha and beta particles), but are short-wave length electromagnetic radiations from the nucleus of radioactive atoms. Except for their origin (the nucleus of the atom rather than the outer shell), they are identical in characteristics to X-rays. Gamma rays are the most penetrating form of radiation and travel great distances in air before absorption. They require heavy shielding materials, such as lead, to attenuate the radiation.

CURIE - An expression of the quantity of radioactive material in terms of the number of atoms which disintegrate (decay) per second. A curie (Ci) is that quantity of radioactive material which decays such that 37 billion atoms disintegrate per second with each disintegration resulting in the emission of alpha or beta particles and/or gamma rays. One thousandth of a curie is a millicurie (mCi); one millionth of a curie is a microcurie (uCi).

RADIATION LEVEL - A term sometimes used instead of radiation "dose rate" or "exposure rate." It generally refers to the effect of radiation on matter, that is, the energy imparted to and absorbed by matter due to emitted radiation per unit of time.

MILLIREM (One one-thousandth of a rem) - The rem is a unit sometimes used to express radiation level or dose rate (millirem per hour). Technically speaking, the rem is an expression of "radiation dose equivalent" which considers the biological effect of the absorbed radiation. Do not confuse millirem with curie.

ENCAPSULATION - The term used to denote an additional fabrication technique often used in preparation of radiation sources, wherein the basic material is physically placed within sealed, high physical integrity capsules or envelopes to provide further assurance that in the event a package breaks and the capsule escapes, there would be little possibility of a spread of radioactive contamination.

NUCLEAR CRITICALITY - This term denotes the occurence of a chain reaction with fissile radioactive materials. The purpose of the Fissile Classes is to prevent the occurrence of nuclear criticality during the transport of Fissile

Materials. (Controlled nuclear criticality is the objective within a nuclear power reactor.)

RADIOISOTOPE AND RADIONUCLIDE - For the purpose of transportation, these terms are synonymous with "Radioactive Materials" and identify specific isotopes of chemical elements that have radioactive properties.

RADIOTOXICITY - A term used to denote the relative hazards of the various radionuclides, that is, their internal radioactive effect within the body.

WIPE SAMPLE - A test for loose or removable radioactive contamination on surfaces (also sometimes referred to as a "smear" test).

This material may be reproduced without special permission from this office and is available from:

Department of Transportation
Research and Special Programs Administration
Materials Transportation Bureau
Information Services Division (DMT-11)
Washington, D. C. 20590

VIII. REFERENCES

To supplement this review, the following publications relating to transportation of radioactive materials are listed:

1. IAEA "Regulations for the Safe Transportation of Radioactive Materials, Safety Series No. 6, 1973 Edition (as amended)," International Atomic Energy Agency, Vienna, Austria.

   Availability: Unipub, Inc.
   1180 Avenue of the Americas
   New York, New York 10038

2. "The Safe Transport of Radioactive Materials," edited by R. Gibson, 1966.

   Availability: Pergamon Press, Inc.
   44-01 21st Street
   Long Island City, New York 11101

3. "Environmental Survey of Transportation of Radioactive Materials To and From Nuclear Power Plants," U. S. Atomic Energy Commission (NRC), Wash-1238, December 1972.

4. "Draft Environmental Impact Statements on Transportaiton of Radioactive Materials by Air and Other Modes," (NUREG-0170), U. S. Nuclear Regulatory Commission, Office of Standard Development, March 1976.

5. "Survey of Radioactive Material Shipment In the United States," BNWL-1972, Battelle Pacific Northwest Laboratories, Richland, Washington.

6. "Evaluation of Radiation Emergencies and Accidents--Selected Criteria and Data," Technical Report Series No. 152, IAEA, Vienna, Austria, 1974.

7. "Certification of ERDA Contractors' Packaging With Respect to Compliance with DOT Specification 7A Performance Requirements," - Two reports by Mound Laboratory, Monsanto Research Corporation, as follows:

Phase II Summary Report - June 12, 1979, MLM 2228.

Phase II Summary Report (Supplement No. 1) - April 15, 1976, MLM 2228, (Suppl. 1).

Availability: National Technical Information Service
U. S. Department of Commerce
Springfield, Virginia 22161
(703) 557-4650

* U.S. GOVERNMENT PRINTING OFFICE 1985—616-010—00012

Federal Specification RR-C-901c, paragraphs 3.7.2 and 3.8.2. Cleaning agents equivalent to those specified in RR-C-901b may be used; however, any cleaning agent must not be capable of reacting with oxygen. One cylinder selected at random from a group of 200 or less cleaned at the same time must be tested for oil contamination in accordance with Specification RR-C-901b paragraph 4.4.2.3 and meet the standard of cleanliness specified therein

[Amdt 173-224, 55 FR 52669, Dec 21, 1990]

§ 173.337 Nitric oxide.

Nitric oxide must be packed in Specification 3A1800, 3AA1800, 3E1800, or 3AL1800 cylinders charged to a pressure of not more than 5,170 kPa (750 psi) at 21 °C (70 °F). Cylinders must be equipped with a valve of stainless steel and valve seat of material which will not be deteriorated by contact with nitric oxide or nitrogen dioxide. Cylinders or valves may not be equipped with pressure relief devices of any type. Valve outlets must be sealed by a solid threaded cap or plug and an inert gasketing material. In addition—

(a) Specification 3E1800 cylinders must be overpacked in strong wooden boxes of such design as to protect valves from injury or accidental functioning under conditions incident to transportation. Each overpack must conform to § 173.25.

(b) Specification 3A, 3AA, and 3AL cylinders must have their valves protected by metal caps or other equally protective guards securely attached to the cylinders and be of sufficient strength to protect the valves from injury during transit, or by overpacking in strong wooden boxes of such design as to protect valves from injury or accidental functioning under conditions incident to transportation. Each overpack must conform to § 173.25. Transportation in 3AL cylinders is authorized only by highway or rail.

(c) Each cylinder must be cleaned in compliance with the requirements of Federal Specification RR-C-901C, paragraphs 3.7.2 and 3.8.2. Cleaning agents equivalent to those specified in RR-C-901C may be used; however, any cleaning agent must not be capable of reacting with oxygen. One cylinder selected at random from a group of 200 or less cleaned at the same time must be tested for oil contamination in accordance with Specification RR-C-901C paragraph 4.4.2.3 and meet the standard of cleanliness specified therein.

[Amdt. 173-224, 55 FR 52669, Dec. 21, 1990]

§ 173.338 Tungsten hexafluoride.

Tungsten hexafluoride must be packed in specification 3A, 3AA, 3BN, or 3E (§§ 178.36, 178.37, 178.39, 178.42 of this subchapter) cylinders. Cylinders must be equipped with a valve protection cap or be packed in a strong outside container complying with the provisions of § 173.40. Outlets of any valves must be capped or plugged. As an alternative, the cylinder opening may be closed by the use of a metal plug. Specification 3E cylinders must be shipped in an overpack that complies with the provisions of § 173.40.

[Amdt. 173-224, 55 FR 52669, Dec. 21, 1990]

§ 173.340 Tear gas devices.

(a) Packagings for tear gas devices must be approved prior to initial transportation by the Associate Administrator for Hazardous Materials Safety.

(b) Tear gas devices may not be assembled with, or packed in the same packaging with, mechanically- or manually-operated firing, igniting, bursting, or other functioning elements unless of a type and design which has been approved by the Associate Administrator for Hazardous Materials Safety.

(c) Tear gas grenades, tear gas candles, and similar devices must be packaged in one of the following packagings conforming to the requirements of part 178 of this subchapter at the Packing Group II performance level:

(1) In UN 4C1, 4C2, 4D, or 4F metal-strapped wooden boxes. Functioning elements not assembled in grenades or devices must be in a separate compartment of these boxes, or in inner or separate outer boxes, UN 4C1, 4C2, 4D, or 4F, and must be so packed and cushioned that they may not come in contact with each other or with the walls of the box during transportation. Not more than 50 tear gas devices and 50 functioning elements must be packed in one box, and the gross weight of the outer box may not exceed 35 kg (77 pounds).

(2) In a UN 1A2 metal drum. Functioning elements must be packed in a separate inner packaging or compartment. Not more than 24 tear gas devices and 24 functioning elements must be packed in one outer drum, and the gross weight of the drum may not exceed 35 kg (77 pounds).

(3) In a UN 4G fiberboard box with inside tear gas devices meeting Specifications 2P or 2Q. Each inside packaging must be placed in fiberboard tubes fitted with metal ends or a fiber box with suitable padding. Not more than 30 inner packagings must be packed in one outer box, and the gross weight of the outer box may not exceed 16 kg (35 pounds).

(4) In other packagings of a type or design which has been approved by the Associate Administrator for Hazardous Materials Safety.

(d) Tear gas devices may be shipped completely assembled when offered by or consigned to the U.S. Department of Defense, provided the functioning elements are so packed that they cannot accidentally function. Outer packagings must be UN 4C1, 4C2, 4D, or 4F metal-strapped wooden boxes.

[Amdt. 173-224, 55 FR 52669, Dec. 21, 1990]

Subpart H—[Reserved]

Subpart I—Radioactive Materials

AUTHORITY: 49 U.S.C. 1803, 1804, 1808; 49 CFR 1.53, app. A to part 1.

SOURCE: Amdt. 173-162, 48 FR 10226, Mar. 10, 1983, unless otherwise noted.

§ 173.401 Scope.

(a) This subpart sets forth requirements for the transportation of radioactive materials by carriers and shippers subject to this subchapter. The requirements prescribed in this subpart are in addition to, but not in lieu of, other requirements set forth in this subchapter and in 10 CFR part 71 for the packaging and transportation of radioactive materials.

(b) This subpart does not apply to:

(1) Radioactive materials produced used, transported, or stored within an establishment other than during the course of transportation.

(2) Radioactive materials contained in a medical device, such as a heart pacemaker, which is implanted in a human being or live animal.

(3) Radiopharmaceuticals that have been injected into, or ingested by, and are still in human beings or live animals.

§ 173.403 Definitions.

In this subpart:

(a) A_1 means the maximum activity of special form radioactive material permitted in a Type A package.

(b) A_2 means the maximum activity of radioactive material, other than special form or low specific activity radioactive material, permitted in a Type A package. These values are either listed in § 173.435 or may be derived in accordance with the procedure prescribed in § 173.433.

(c) *Closed transport vehicle* means a transport vehicle equipped with a securely attached exterior enclosure that during normal transportation restricts the access of unauthorized persons to the cargo space containing the radioactive materials. The enclosure may be either temporary or permanent, and in the case of packaged materials may be of the 'see-through' type, and must limit access from the sides, and ends.

(d) *Containment system* means the components of the packaging intended to retain the radioactive contents during transportation.

(e) *Conveyance* means:

(1) For transport by public highway or rail: any transport vehicle or large freight container;

(2) For transport by vessel: any vessel, or any hold, compartment, or defined deck area of a vessel; and

(3) For transport by aircraft: any aircraft.

(f) *Depleted uranium* means uranium containing less uranium-235 than the naturally occurring distribution of uranium isotopes.

(g) *Design* means the description of a special form material, a package, or a packaging, that enables those items

to be fully identified. The description may include specifications, engineering drawings, reports showing compliance with regulatory requirements, and other relevent documentation.

(h) *Enriched uranium* means uranium containing more uranium-235 than the naturally occurring distribution of uranium isotopes.

(i) *Exclusive use* (also referred to in other regulations as *sole use* or *full load*') means the sole use of a conveyance by a single consignor and for which all initial, intermediate, and final loading and unloading are carried out in accordance with the direction of the consignor or consignee. Any loading or unloading must be performed by personnel having radiological training and resources appropriate for safe handling of the consignment. Specific instructions for maintenance of exclusive use shipment controls must be issued in writing and included with the shipping paper information provided to the carrier by the consignor.

(j) *Fissile material* means any material consisting of or containing one or more fissile radionuclides. Fissile radionuclides are plutonium-238, plutonium-239, plutonium-241, uranium-233 and uranium-235. Neither natural nor depleted uranium are fissile material. Fissile materials are classified according to the controls needed to provide nuclear criticality safety during transportation, as provided in § 173.455. Certain exclusions are provided in § 173.453.

(k) *Freight container* means a reusable container having a volume of 1.81 cubic meters (64 cubic feet) or more, designed and constructed to permit being lifted with its contents intact and intended primarily for containment of packages in unit form during transportation. A small freight container is one which has either one outer dimension less than 1.5 meters (4 9 feet) or an internal volume of not more than 3.0 cubic meters (106 cubic feet). All other are designated as *large freight containers.*

(l) *Highway route controlled quantity* means a quantity within a single package which exceeds:

(1) 3000 times the A_1 value of the radionuclides as specified in § 173.433 for special form radioactive material;

(2) 3000 times the A_2 value of the radionuclides as specified in § 173.433 for normal form radioactive material; or

(3) 30,000 curies, whichever is least.

(m) *Limited quantity of radioactive material* means a quantity of radioactive material not exceeding the materials package limits specified in § 173.423 and which conform with requirements specified in § 173.421.

(n) *Low specific activity material* (*LSA*) means any of the following:

(1) Uranium or thorium ores and physical or chemical concentrates of those ores.

(2) Unirradiated natural or depleted uranium or unirradiated natural thorium.

(3) Tritium oxide in aqueous solutions provided the concentration does not exceed 5.0 millicuries per milliliter.

(4) Material in which the radioactivity is essentially uniformly distributed and in which the estimated average concentration of contents does not exceed:

(i) 0.0001 millicurie per gram of radionuclides for which the A_2 quantity is not more than .05 curie;

(ii) 0.005 millicurie per gram of radionuclides for which the A_2 quantity is more than .05 curie, but not more than 1 curie; or

(iii) 0.3 millicurie per gram of radionuclides for which the A_2 quantity is more than 1 curie.

(5) Objects of nonradioactive material externally contaminated with radioactive material, provided that the radioactive material is not readily dispersible and the surface contamination, when averaged over an area of 1 square meter, does not exceed 0.0001 millicurie (220,000 disintegrations per minute) per square centimeter of radionuclides for which the A_2 quantity is not more than .05 curie, or 0.001 millicurie (2,200,000 disintegrations per minute) per square centimeter for other radionuclides.

(o) *Multilateral approval* means approval by both the appropriate competent authority of the country of origin and of each country through or into which the shipment is to be transported. This definition does not imply approval from countries over which radioactive materials are carried in aircraft, if there is no scheduled stop in that country.

(p) *Natural thorium* means thorium with the naturally occuring distribution of thorium isotopes (essentially 100 weight percent thorium-232).

(q) *Natural uranium* means uranium with the naturally occuring distribution of uranium isotopes (approximately 0.711 weight percent uranium-235 and the remainder essentially uranium-238).

(r) *Non-fixed radioactive contamination* means radioactive contamination that can be readily removed from a surface by wiping with an absorbent material. Non-fixed (removable) radioactive contamination is not significant if it does not exceed the limits specified in § 173.443.

(s) *Normal form radioactive material* means radioactive material which has not been demonstrated to qualify as *special form radioactive material.*

(t) *Package* means, for radioactive materials, the packaging together with its radioactive contents as presented for transport.

(u) *Packaging* means, for radioactive materials, the assembly of components necessary to ensure compliance with the packaging requirements of this subpart. It may consist of one or more receptacles, absorbent materials, spacing structures, thermal insulation, radiation shielding, and devices for cooling or absorbing mechanical shocks. The conveyance, tie-down system, and auxiliary equipment may sometimes be designated as part of the packaging.

(v) *Radiation level* means the radiation dose-equivalent rate expressed in millirem per hour (mrem/h). Neutron flux densities may be converted into radiation levels according to Table 1:

TABLE 1—NEUTRON FLUX DENSITIES TO BE REGARDED AS EQUIVALENT TO A RADIATION LEVEL OF 1 MILLIREM PER HOUR (MREM/H)[1]

Energy of neutron	Flux density equivalent to 1 mrem/h (Neutrons per square centimeter per second)(n/cm²/s)
Thermal	268 0
5 keV	228.0
20keV	112.0

TABLE 1—NEUTRON FLUX DENSITIES TO BE REGARDED AS EQUIVALENT TO A RADIATION LEVEL OF 1 MILLIREM PER HOUR (MREM H)[1]—Continued

Energy of neutron	Flux density equivalent to 1 mrem/h (Neutrons per square centimeter per second)(n/cm²/s)
100 keV	[illegible]
500 keV	12
1 MeV	
5 MeV	
10 MeV	

[1] Flux densities equivalent for energies between those listed above may be obtained by linear interpolation

(w) *Radioactive article* means manufactured instruments and articles such as an instrument, clock, electronic tube or apparatus, or similar instruments and articles having radioactive material as a component part.

(x) *Radioactive contents* means the radioactive material, together with any contaminated liquids or gases, within the package.

(y) *Radioactive material* means any material having a specific activity greater than 0.002 microcuries per gram (uCi/g)(see definition of *specific activity*).

(z) *Special form radioactive material* means radioactive material which satisfies the following conditions:

(1) It is either a single solid piece or is contained in a sealed capsule that can be opened only by destroying the capsule;

(2) The piece or capsule has at least one dimension not less than 5 millimeters (0.197 inch); and

(3) It satisfies the test requirements of § 173.469. Special form encapsulations designed in accordance with the requirements of § 173.389(g) in effect on June 30, 1983, and constructed prior to July 1, 1985 may continue to be used. Special form encapsulations either designed or constructed after June 30, 1985 must meet the requirements of this paragraph.

(aa) *Specific activity* of a radionuclide, means the activity of the radionuclide per unit mass of that nuclide. The specific activity of a material in which the radionuclide is essentially

uniformly distributed is the activity per unit mass of the material.

(bb) *Transport index* means the dimensionless number (rounded up to the first decimal place) placed on the label of a package to designate the degree of control to be exercised by the carrier during transportation. The transport index is determined as follows.

(1) The number expressing the maximum radiation level in millirem per hour at one meter (3.3 feet) from the external surface of the package; or

(2) For Fissile Class II packages or packages in a Fissile Class III shipment, the number expressing the maximum radiation level at one meter (3.3 feet) from the external surface of the package, or the number obtained by dividing 50 by the allowable number of packages which may be transported together, whichever is larger.

(cc) *Type A package* means a Type A packaging together with its limited radioactive contents. A Type A package does not require competent authority approval, since its contents are limited to A_1 or A_2.

(dd) *Type B package* means a Type B packaging together with its radioactive contents.

(ee) *Type B(M) package* means a Type B packaging, together with its radioactive contents, that for international shipments requires multilateral approval of the package design, and may require approval of the conditions of shipment. Type B(M) packages are those Type B package designs which have a maximum normal operating pressure of more than 7 kilograms per square centimeter (100 pounds per square inch) gauge or a relief device which would allow the release of radioactive material to the environment under the hypothetical accident conditions specified in 10 CFR part 71.

(ff) *Type B(U) package* means a Type B packaging, together with its radioactive contents, that for international shipments, requires unilateral approval only of the package design and of any stowage provisions that may be necessary for heat dissipation.

(gg) *Type A packaging* means a packaging designed to retain the integrity of containment and shielding required by this part under normal conditions of transport as demonstrated by the tests set forth in § 173.465 or § 173.466, as appropriate.

(hh) *Type B packaging* means a packaging designed to retain the integrity of containment and shielding required by this part when subjected to the normal conditions of transport and hypothetical accident test conditions set forth in 10 CFR part 71.

(ii) *Uncompressed gas* means, for the purposes of this subpart, gas at a pressure not exceeding the ambient atmospheric pressure at the time and location the containment system is closed. All other radioactive gases are considered to be compressed.

(jj) *Unilateral approval* means approval by the competent authority of the country of origin only.

(kk) *Unirradiated thorium* means thorium containing not more than 10^{-7} grams uranium-233 per gram of thorium-232.

(ll) *Unirradiated uranium* means uranium containing not more than 10^{-6} grams plutonium per gram of uranium-235 and a fission product activity of not more than 0.25 millicuries of fission products per gram of uranium-235.

[Amdt. 173-162, 48 FR 10226, Mar. 10, 1983; 48 FR 13431, Mar. 31, 1983, as amended at 48 FR 31217, July 7, 1983; Amdt. 173-193, 50 FR 41898, Oct. 16, 1985; Amdt. 173-207, 53 FR 38274, Sept. 29, 1988; Amdt. 173-219, 54 FR 40069, Sept. 29, 1989]

§ 173.411 General design requirements.

Except for a package that contains a limited quantity or excepted instrument or article under §§ 173.421 through 173.424, each package used for shipment of radioactive materials shall be designed so that:

(a) The package can be easily handled and properly secured in or on a conveyance during transport;

(b) A package with a gross weight exceeding 10 kilograms (22 pounds) and up to 50 kilograms (110 pounds) has a means for manual handling;

(c) A package with a gross weight of 50 kilograms (110 pounds) or more can be safely handled by mechanical means;

(d) Each lifting attachment on the package, when used in the intended manner, with a minimum safety factor

of three, does not impose an unsafe stress on the structure of the package. In addition, the lifting attachment shall be so designed that failure under excessive load would not impair the ability of the package to meet all other requirements of this subpart. Each attachment or other feature on the outer surface of the packaging that could be used to lift the package must be removable or otherwise capable of being made inoperable for transport, or shall be designed with strength equivalent to that required for lifting attachments;

(e) The external surface, as far as practicable, may be easily decontaminated;

(f) The outer layer of packaging will avoid, as far as practicable, pockets or crevices where water might collect; and

(g) Each feature that is added to the package at the time of transport, and that is not a part of the package, will not reduce the safety of the package.

[Amdt. 173-162, 48 FR 10226, Mar. 10, 1983, as amended at 48 FR 31218, July 7, 1983]

§ 173.412 Additional design requirements for Type A packages.

In addition to meeting the general design requirements prescribed in § 173.411, each Type A packaging shall be designed so that:

(a) The smallest overall external dimension of the package is not less than 10 centimeters (4 inches);

(b) The outside of the packaging incorporates a feature, such as a seal, that is not readily breakable, and that, while intact, is evidence that the package has not been opened. In the case of packages shipped in exclusive use closed transport vehicles, the cargo compartment may be sealed instead of the individual packages;

(c) As far as practicable, the external surfaces are free from protrusions and are designed and finished so that they can be easily decontaminated;

(d) Containment and shielding would be maintained during transportation and storage in a temperature range of −40°C (−40°F) to 70°C (158°F) with account being taken of the possibility of brittle fracture;

(e) It is able to withstand the effects of any acceleration, vibration, or vibration resonance that may arise during normal transportation, without any deterioration of the effectiveness of closing devices or of the integrity of the package as a whole and without loosening or unintentional release of nuts, bolts, or other securing devices even after repeated use;

(f) It includes a containment system securely closed by a positive fastening device that cannot be opened unintentionally or by pressure that may arise within the package during normal transport. Special form, as demonstrated in accordance with § 173.469 may be considered as a component of the containment system;

(g) The materials of the packaging and any components or structures are physically and chemically compatible with each other and with the contents taking into account the behavior of each under irradiation;

(h) For each component of the containment system account is taken where applicable, of radiolytic decomposition of materials and the generation of gas by chemical reaction and radiolysis;

(i) The containment system will retain its radioactive contents under the reduction of ambient pressure to .25 kilograms per square centimeter (3.5 pounds per square inch);

(j) Each valve through which the radioactive contents could otherwise escape is protected against damage and unauthorized operation and except for a pressure relief device, has an enclosure to retain any leakage;

(k) Any radiation shield that encloses a component of the packaging specified as part of the containment system will prevent the unintentional escape of that component from the shield;

(l) Failure of any tie down attachment on the packaging under excessive load will not impair the ability of the package to meet other requirements of this subpart;

(m) When subjected to the tests specified in § 173.465 or evaluated against these tests by any of the methods authorized by § 173.461(a), the packaging will prevent:

(1) Loss or dispersal of the radioactive contents; and

U.S. Nuclear Regulatory Commission
and Agreement State Offices 09/09/90

USNRC REGION I	215-337-5000 475 Allendale Road King of Prussia, Pennsylvania 19406
USNRC REGION II	404-331-5500 101 Marietta Street, NW Suite 2900 Atlanta, Georgia 30323
USNRC REGION III	312-790-5500 799 Roosevelt Road Building 4 Glen Ellyn, Illinois 60137
USNRC REGION IV	817-860-8900 611 Ryan Plaza Drive Suite 1000 Arlington, Texas 76011
USNRC REGION V	415-943-3700 1450 Maria Lane Suite 210 Walnut Creek, Calif. 94596
Alabama	205-261-5315 Aubrey Godwin, Director Division of Radiological Health Department of Public Health Room 510, State Office Building Montgomery, Alabama 36130
Arizona	602-255-4845 Charles F. Tedford, Director Arizona Radiation Regulatory Agency 925 South 52nd Street Phoenix, Arizona 85040
Arkansas	501-661-2301 Greta Bicus, Director Div. of Radiation Control and Emerg. Man. Department of Health 4815 West Markham Little Rock, Arkansas 72205
California	916-445-0931 (License Insp.) Jack McGurk, Chief Radiological Health Board State Dept.of Health Services 714 P Street, Office Bldg. #8 Sacramento, California 95814

Colorado	303-331-8480 Robert Quillin, Director Radiation Control Division Department of Health 4210 East 11th Avenue Denver, Colorado 80220
Florida	904-487-1004 Mary E. Clark, Ph.D. Office of Radiation Control Dept. of Health & Rehabilitative Services 1317 Winewood Blvd. Tallahassee, Florida 32399-0700
Georgia	404-894-5795 Thomas E. Hill, Acting Director Radiological Health Section Department of Human Resources 878 Peachtree Street, Room 600 Atlanta, Georgia 30309
Idaho	208-334-5879 Ernie Ranieri, Prog. Man. Radiation Control Section Department of Health and Welfare Third Floor, 450 West State Street Boise, Idaho 83720
Illinois	217-785-9947 Steve Collins Division of Radioactive Materials Department of Nuclear Safety 1035 Outer Park Drive Springfield, IL 62704
Iowa	515-281-3478 Don Flater, Director Environmental Health Section Bureau of Radiological Health Iowa Dept. of Public Health Lucas State Office Building Des Moines, Iowa 50319
Kansas	913-296-1560 John Erwin, Manager Bureau of Radiation Control Dept. of Health & Environment Building 740, Forbes Field Topeka, Kansas 66620

Kentucky	502-564-3700 Donald R Hughes, Manager Radiation Control Branch Cabinet for Human Resources 275 East Main Street Frankfort, Kentucky 40601
Louisiana	504-925-4518 William H. Spell, Administrator Nuclear Energy Division Office of Air Quality & Nuclear Energy P.O. Box 14690 Baton Rouge, Louisiana 70898-4690
Maryland	301-631-3300 Roland G. Fletcher, Administrator Radiological Health Program Dept. of the Environment 2500 Broening Highway Baltimore, Maryland 21224
Mississippi	601-354-6657/6670 Eddie S. Fuente, Director Division of Radiological Health P.O. Box 1700 State Board of Health Jackson, Mississippi 39215
Nebraska	402-471-2168 Harold Borchert, Director Division of Radiological Health State Department of Health 301 Centennial Mall South P.O. Box 95007 Lincoln, Nebraska 68509
Nevada	702-885-5394 Stanley Marshall, Supervisor Radiological Health Section Dept. of Human Resources 505 East King Street, Room 203 Carson City, Nevada 89710
New Hampshire	603-271-4588 Diane Tefft, Program Manager Radiological Health Program P.O. Box 148 Concord, New Hampshire 03301

New Mexico	505-827-2940 (Ext. 279) Richard Mitzelfelt Radiation Protection and Licensing Environmental Improvement Division Harold-Rennel Building 1190 St. Francis Drive Santa Fe, New Mexico 87504
New York	518-458-6461 Karim Rimawi, Director Bureau of Environmental Radiation Protection State Health Department University Plaza, Western Avenue Albany, New York 12205
North Carolina	919-733-4283 Dayne H. Brown, Director Division of Radiation Protection N.C. Dept. of Env. Health and Natural Resources 701 Barbour Drive Raleigh, North Carolina 27603
North Dakota	701-224-2348 Dana Mount, Director Div. of Environmental Engineering N.D. State Department of Health P.O.Box 5520 1200 Missouri Avenue Bismarck, North Dakota 58502-5520
Oregon	503-229-5797 Ray D. Paris, Manager Radiation Control Section Division of Health Dept. of Human Resources 1400 South West Fifth Avenue Portland, Oregon 97201
Rhode Island	401-277-2438 Charles C. McMahon, Acting Supervisor Div. of Occupational and Radiological Health Rhode Island Dept. of Health 206 Cannon Building 3 Capitol Hill Providence, Rhode Island 02908
South Carolina	803-734-4700 Heyward Shealy, Chief Bureau of Radiological Health State Dept. of Health and Env. Control J. Marion Sims Building 2600 Bull Street Columbia, South Carolina 29201

Tennessee	615-741-7812 Michael H. Mobley, Director Division of Radiological Health Terra Building, 150 Ninth Ave. North Nashville, Tennessee 37219-5404
Texas	512-835-7000 David K. Lacker, Chief Bureau of Radiation Control Texas Department of Health 1100 W. 49th Street Austin, Texas 78756-3189
Utah	801-538-6734 Larry Anderson, Director Bureau of Radiation Control State Department of Health P.O. Box 16690 288 North, 1460 West Salt Lake City, Utah 84116-0690
Washington	206-753-3468 T.R. Strong, Chief Department of Health/ Radiation Protection Mail Stop LE-13 Air Industrial Park-Building 5 Olympia, Washington 98504

SUPPLIERS

Instrument

Eberline Instrument Corp.
504 Airport Road
P.O. Box 2108
Santa Fe, NM 87504-2108
800-678-7088
505-471-3232

Ludlum Measurements, Inc.
501 Oak St.
Sweetwater, TX 79556
915-235-5494

Canberra Industries, Inc.
1 State St.
Meriden, CT 06450
800-243-4422

Dosimeter Corp.
P.O. Box 42377
(11286 Grooms Rd.)
Cinti., OH 45242
513-489-8100
800-543-4976

EG&G ORTEC
100 Midland Rd.
Oak Ridge, TN 37830
615-482-4411

EG&G Instruments
Nuclear Products Group
P.O. Box 486
Lenoir City, TN 37771
615-986-4212
800-251-9750

Tennelec Inc.
601 Oak Ridge Turnpike
P.O. Box 2560
Oak Ridge, TN 37830
615-483-8405

Victoreen
6000 Cochran Road
Cleveland, OH 44139-3395
216-248-9300
fax 216-248-9301

Sources

The Nucleus, Inc.
P.O. Box 2561
761 Emory Valley Rd.
Oak Ridge, TN 37830
615-482-4041
615-483-0008

Services

Teledyne Isotopes
50 VanBuren Ave.
Westwood, NJ 07675
201-664-7070
fax 201-664-5586

Diagnostic Engineering, Inc.
347 Stanley Ave.
Cinti., OH 45226
513-271-3737

General Dynamics
14 Holmes Street
Mystic, CT 06355-2644
203-572-8971

Environmental Dimensions, Inc.
3939A San Pedro Drive, N.E.
Albuquerque, NM 87110
505-881-9427

Duratek Corp.
6700 Alexander Bell Drive
Columbia, MD 21046
301-290-2340

Contamination Control Equipment

Defense Apparel (D.A. Services Inc.)
247 Addison Road
Windsor, CT 06095
800-243-3847
203-285-0808
fax 203-688-5787

Lanc's Industries, Inc.
12704 NE 124th Street
Kirkland, WA 98034
206-823-6634

Nuclear Power Outfitters (NPO)
Division of PPI Industries
P.O. Box 737
Crystal Lake, IL 60014
815-455-3777

Frham Safety Products, Inc.
P.O. Box 101177
318 Hill Ave
Nashville, TN 37210
615-254-0841

Totes
10078 E. Kemper Rd
Loveland, OH 45140
513-583-2327

Bortek Systems
P.O. Box 355
Royersford, PA 19468
215-948-9696

Nilfisk of America, Inc.
20566 White Bark Drive
Strongsville, OH 44136
or
224 Great Valley Parkway
Malvern, PA 19355
800-645-3475

Pertex, Inc.
P.O. Box 579
Franklin, MI 48025
313-737-6900

ORR Safety Equipment Company
11379 Grooms Road
Cinti., OH 45242
513-489-0800

RADIATION SAFETY AT SUPERFUND SITES (165.11)

WORKBOOK

CONTENTS

Page

RADIATION SURVEY INSTRUMENTS

1. Exposure Rate Meters/Dosimeters 1
2. Count Rate Meters 3
3. Bench Counters 6

CHARACTERISTICS OF UNKNOWN SOURCES AND DOSE ASSESSMENT 9

PROBLEM SESSION: DECONTAMINATION 11

RADIOACTIVE MATERIAL PACKAGING AND LABELING 13

SITE WORK DAY

1. Initial Entry and Count Room 14
2. Contamination Survey Station 22
3. Simple Soil and Water Sampling Protocol 24

RADIATION SURVEY METERS

Lab 1: Exposure Rate Meters/Dosimeters

I. Objectives

At the end of this lab the student shall be able to:

A. Operate a dose rate meter.
B. Perform simple dose rate calculations.
C. Measure dose using a pocket dosimeter.

II. Dosimeter Calibration and Use

Calibration Source _____ Type _____

Measure dose using a pocket dosimeter.

Projected Dosimeter Reading _____ mR

Dose Rate: Inner Ring _____mR/Hr Outer Ring _____mR/Hr

Start Time	Dosimeter Reading	Stop Time	Dosimeter Reading
_____	_____	_____	_____

III. Dose Rate Measurement

Source

Type _____

Activity _____ μCi

Dose Rate (w/ASP-1 using HP270 probe)

Contact _____

1 in. _____

6 in. _____

1 ft. _____

RADIATION SURVEY METERS

Calculate the following exposures

	8 hrs	1wk (168 hrs)	1 month (730 hrs)	1 year (8766 hrs)
Contact	_____	_____	_____	_____
1 in.	_____	_____	_____	_____
6 in.	_____	_____	_____	_____
1 ft.	_____	_____	_____	_____

RADIATION SURVEY METERS

Lab 2: Count Rate Meters

I. Objectives

At the end of this lab the student shall be able to:

A. Operate a count rate meter.
B. Perform count rate measurements using alpha, and beta/gamma detectors.
C. Calculate detector efficiencies relative to source size and distance from detectors.

II. Count Rates/Detector Efficiency

Instruments: Eberline ASP-1 with HP-210L Detector

Instrument I.D. _____ Calibration date _____

Background (max.reading over 30 sec.) _____

(note: 1ci = 2.2×10^{12} dpm)

Strontium-90 (2-inch diameter)

Source I.D. _____ Source Size _____ Activity (dpm)_____

Meter Reading (slow response, max.reading over 30 sec.) _____

Detector Efficiency (meter reading-bkgd/activity) _____

Technetium-99 (2-inch diameter)

Source I.D. _____ Source Size _____ Activity _____

Meter Reading (slow response, max.reading over 30 sec.)_____

Detector Efficiency _____

Technetium-99 (1-inch diameter)

Source I.D. _____ Source Size _____ Activity _____

Meter Reading (slow response, max.reading over 30 sec.)_____

Detector Efficiency _____

III. 60 Second Integrated Measurement (integrate response, reading after 1 minute.)

Technetium-99 (2-inch diameter)

Source I.D. _____ Source Size _____ Activity _____

Expected Integrated Value _____

Actual Integrated Value _____

IV. Count Rates/Detector Efficiency

Instruments: Eberline ASP-1 with AC-3 Probe

Instrument I.D. _____ Background _____

Response to gamma source

Source I.D. _____ Reading _____

Response to beta source

Source I.D. _____ Reading _____

Response to alpha source

Source I.D. _____ Activity _____

Meter Reading _____

Detector Efficiency _____

RADIATION SURVEY METERS

Thorium-230 (2-inch diameter)

Source I.D. _____ Activity _____

Meter Reading _____

Detector Efficiency _____

Instruments: PAC-4G-3 Gas Proportional Meter

Instrument I.D. _____ Calibration date _____

Background _____

Response to gamma source

Source I.D. _____ Activity _____

Meter Reading _____

Response to beta source

Source I.D. _____ Activity _____

Meter Reading _____

Response to alpha source

Source I.D. _____ Activity _____

Meter Reading _____

Detector Efficiency _____

RADIATION SURVEY METERS

Lab 3: Bench Counters

I. Objectives

At the end of this lab the student shall be able to:

A. Operate bench counter instruments.
B. Perform air sample volume calculations.
C. Perform half life calculations.

II. Air Sample Data Sheet

Sample Date:_____ Sample No.:_____
Time:_____
Location:_____
Sampled by:_____

Air Sample Data

Air Sampler #:_____
Flow Rate:_____cfm
Time: Start_____
Stop_____
Sample Duration:_____min

Sample Volume Calculation

$$(\textit{Flow Rate}\ \frac{ft^3}{\text{min}})\ (\textit{Sample Duration}\ \ \text{min})\ (\frac{28.32\ell}{1ft^3})\ (\frac{1000ml}{\ell}) = \textit{Sample Volume (ml)}$$

$$(\qquad \frac{ft^3}{\text{min}})\ (\qquad \text{min})\ (\frac{28.32\ell}{1ft^3})\ (\frac{1000ml}{\ell}) = \qquad ml$$

Sample Fraction Calculation

$$\textit{Sample Fraction} = \frac{A_s}{A_T} = \frac{\pi\ r_s^2}{\pi\ r_T^2} = \left(\frac{r_s}{r_T}\right)^2 = (\qquad)^2 =$$

Volume of Count Sample

(Sample Volume ml) (Sample Fraction) = Volume of Count Sample (ml)

(ml) ( ) = ml

III. Count Room Data Sheet

Count Date:_____ Sample No.:_____
Time:_____
Counted by:_____
Instrument:_____ Serial No.:_____

Background:_____cpm
Efficiency:_____

	Count #1	Count #2
Time of Count	_____	_____
Count Duration	_____	_____
Total Counts	_____	_____
Count Rate	_____	_____

t _____min.

Air Activity Calculation

$$\frac{(Sample\ \ cpm - Background\ \ cpm)}{(Sample\ \ Volume\ \ ml)(\ Eff)}\left(\frac{1Ci}{2.22 \times 10^{12}\ dpm}\right)\left(\frac{1 \times 10^{6}\ uc}{Ci}\right) = Air\ Activity\ \ \frac{uc}{ml}$$

$$\frac{(\quad cpm - \quad cpm)}{(\quad ml)\ (0.\quad)}\left(\frac{1Ci}{2.22 \times 10^{12}\ dpm}\right)\left(\frac{1 \times 10^{6} uc}{Ci}\right) = \quad \frac{uc}{ml}$$

Half Life Calculation

$$A = Ao\ e^{-\lambda t}$$

$$\frac{A}{Ao} = e^{-\lambda t}$$

$$\ln\frac{A}{Ao} = -\lambda t$$

$$since\ \lambda = \frac{.693}{T_{1_{/2}}}$$

$$\ln\frac{A}{Ao} = \frac{-.693}{T_{1_{/2}}}t$$

$$T_{1_{/2}} = -\frac{.693t}{\ln\ (A/Ao)}$$

CHARACTERISTICS OF UNKNOWN SOURCES AND DOSE ASSESSMENT

I. Objectives

At the end of this exercise the student shall be able to:

A. Determine the general area dose rates in the vicinity of the unknown boards and establish any necessary stay times.

B. Locate all radioactive sources on the unknown board and chart their location.

C. Determine what types of radiation(s) is being emitted from each source.

II. Exercise

A. Initial Survey

1. Inspect the dose rate meter (ASP-1 w/HP270 probe)

   a. battery check
   b. calibration sticker check
   c. response check

2. Perform a general area survey

   a. starting with meter on the top scale, shift down in scale until you obtain a reading
   b. survey the area, staying 12 inches away from any object

   Note: The 12 inches is established in OSHA's regulation on the requirements for a radiation area in 29 CFR 1910.96.

3. Document the results of the survey

B. Draw a map of the unknown board

1. Note any unusual characteristics of the board

C. Survey the board for hidden sources

1. Select the survey meter

Note: We recommend the ASP-1 w/HP260 be used. This probe will conveniently scan for both beta and gamma and will also pick up high-energy alphas; alphas which are >3 meV.

2. Inspect the survey meter

   a. battery check
   b. calibration sticker check
   c. response check

3. Scan the board as if you are cutting grass in a manner which will reduce overlaps and minimize large gaps

4. Document source locations on the map

D. Evaluate each source location for types of emission

1. Beta or gamma or both

   a. using the ASP-1 w/HP270 probe, evaluate each of the source locations
   b. at each location start with an open window to locate the source and obtain the highest possible reading
   c. hold the probe firmly in place and slide the window shut

   Note: Any decrease in readings can be attributed to beta radiation being shielded out.

   d. compare your three readings; open window, close window, and background; you can determine if you are dealing with beta, gamma, or both

   e. document the results

2. Alpha

   a. Inspect the alpha survey meter (ASP-1 w/AC-3 probe)

      - battery check
      - calibration sticker check
      - response check

   b. perform survey with the alpha survey meter

   c. document the results

RADIATION SURVEY METERS

PROBLEM SESSION: DECONTAMINATION

Problem Session (Decontamination exercise)

Instructions: For each scenario, use your judgement and the information provided in the decontamination lecture to select the method(s) and techniques for decontamination. All of the radioactive material involved in the incidents is Uranium-238. There will be a group discussion upon completion of the problem session.

Manual Reference Section: Chapter 7 of Darcom P385-1

Personnel:

Methods - Table 7.1
Procedures (techniques) - Appendix 1

Equipment and Material:

Methods - Table 7.2 and Table 7.4
Procedures (techniques) - Appendix C

1. An employee accidently contaminated the back of his/her right hand while removing protective gloves after working in a contaminated area.

2. A 55-gallon radioactive material drum accidently fell off a transport vehicle onto a smooth, stainless steel truck scale. A dry, powder-like radioactive material was spilled over a 20-square-foot area. A response team arrived and uprighted the drum, put the breached drum in an overpack drum, secured and posted the area as contaminated, and transported the overpack drum to a storage area. The bulk of the spilled material is right in the middle of the contaminated area.

3. A laboratory worker accidently spilled some fine form radioactive material on a smooth porcelain laboratory countertop. All of the material is contained in a 1-square-foot area on the countertop.

4. A mechanic working on a contaminated vehicle got some of his tools contaminated and wants to have them decontaminated so he can take them back to his shop. The tools were a screwdriver, wrench, and pliers. The tools also became slightly greasy from working on the contaminated vehicle.

RADIOACTIVE MATERIAL PACKAGING AND LABELING

I. Objectives

At the end of this lab the student shall be able to:

A. Determine the package type based on curie amount of given radionuclides.

B. Given the dose rates of a package containing radioactive materials, determine the appropriate radioactive warning label.

II. Type Quantity Exercise

Indicate the quantity type for each of the radionuclides. All radionuclides are normal form unless otherwise indicated.

Radionuclide		Activity	Type Quantity
1.	Ca-14	63 Ci	_____
2.	Mo-99	1980 mCi	_____
3.	Ra-226	18 Ci (Special Form)	_____

1. Soil samples were taken from an area thought to be contaminated by small amounts of Sr-90 and Co-60. The samples will be sent to an off-site lab for radiological assaying. The dose rate at the surface of the sample jar was 0.4 millirem per hour and not detectable at 1 meter.

   a. What type of radioactive label would be affixed to the sample package?

   Radioactive Label:_____

2. The developer for a newly planned residential community has been advised by some senior citizens that the land in which he planned to build the community on was an old land fill. Soil samples were extracted from depths of 1 to 3 feet. The dose rate at the surface of the sample jar was 18 millirem per hour and 1.6 millirem per hour at 1 meter. The dose rate at the surface of the sample package on the other hand was 16.5 millirem per hour and 1 millirem per hour at 1 meter.

   a. What type of radioactive label would be affixed to the sample package?

   Radioactive Label:_____

SITE WORK DAY

Lab 1: Initial Entry and Count Room

I. Objectives

At the end of this lab the student shall be able to:

A. Don and doff protective clothing.
B. Post suspected contaminated area.
C. Perform initial entry monitoring techniques.
D. Setup count room.
E. Perform count rate measurements.

II. Post the Contaminated Area

A. String ropes

1. yellow and magenta rope or ribbon
2. waist high
3. sturdy enough to hold signs

B. Put up radiation signs

1. select appropriate inserts

a. contamination area
b. airborne radioactivity area
c. radiation area
d. dress out requirements

C. Lay down step off pads

1. the step off pad is outside of the contaminated area
2. ropes do not cross the step off pad
3. tape the step off pad to the floor so it doesn't slide around

D. Exit containers

1. containers needed for respirators, laundry, and waste

2. containers need to be well supported to handle the weight of the material placed in them (usually plastic bags are used as containers)

E. Set up a decon area

1. usually a table top will be sufficient

2. place a protective covering on the table to prevent contaminating the table

3. establish three "zones" on the table

a. contaminated area

b. to be surveyed area

c. clean area

4. set out decon equipment

a. absorbents

b. decon spray

c. soap and water

F. Step off support area

1. bags should be available to receive contaminated material being brought out of the contaminated area

2. frisking station

3. staging of additional supplies; extra smears, absorbent, tape, etc.

III. Set up the Count Room

A. Select instruments

1. alpha frisker (ASP-1 w /AC-3 probe)

2. beta/gamma frisker (ASP-1 w/HP210L probe)

3. alpha bench counter (SAC-4)

4. beta/gamma bench counter (BC-4)

B. Perform instrument checks

1. battery check

2. calibration sticker

3. efficiency determination

a. use a ^{230}Th source for the efficiency determination of alpha detection instruments

b. use a ^{99}Tc source for the efficiency determination of beta/gamma instrument

C. Lay out the count room into areas for handling both clean and contaminated items. The following needs should be addressed:

1. smear/air sample handling area

2. clean area for notes and maps

3. clean waste bags

4. contaminated waste bags

D. Assemble all of the support supplies which should be available at this station, the following items should be considered:

tape	paper	clipboards
tweezers	pens	calculator
bags	blotter paper	calculation forms
gloves	paper towels	source sets
smears	decon spray	rad rope
clock	envelopes	rad signs

IV. Prepare Survey Equipment

A. Map

1. draw a map of the area

2. if the area has not been seen yet, prepare the materials required to draw a map during the survey (clip board, paper, pen, etc.)

B. Contamination survey materials

1. number smears

2. prepare envelopes

C. Radiation survey materials

1. select instrument

2. inspect instrument

a. battery check

b. calibration check

c. response check

D. Air sample materials

1. load filter into the air sampler

2. prepare air sample envelope

3. have a bag ready to remove the air sampler from the contaminated area

V. Anti-Contamination Clothing

A. Select anti-c's

1. minimum dress is one full set of anti-c's

a. plastic shoe covers

b. cotton glove

c. coveralls

d. hood or skull cap

e. heavy shoe covers

f. rubber gloves

g. tape gloves and plastic shoe covers

2. add additional anti-c's based upon need

   a. wet

   b. high contamination

   c. airborne contamination

B. Don anti-c's (in the same order listed in step 1 above)

VI. Enter Area and Perform Initial Entry Surveys

A. Start the air sampler

1. enter area taking dose rates

2. move to the place where the air sample is to be drawn

3. lay down a clean cloth or piece of plastic; away from the floor

4. set the air sampler down on the cloth and start it

5. record start time

B. Take radiation survey of the rest of the room

1. take radiation readings

2. record dose rate

   a. general area dose rates are taken 12 inches from any surface and at waist level

   b. contact dose rates are marked with an asterisk (*)

3. remove the radiation survey instrument from the contaminated area

   a. if the radiation instrument has not come into contact with anything in the contaminated area it can be placed in the section marked "to be surveyed"

   b. if the instrument has come into contact with something it must be wiped down before it is placed in the "to be surveyed" area

C. Perform a contamination survey of the room

1. scan the room for high probability contamination locations and high traffic areas

2. take smear samples in those areas

   a. each smear should be ~100 square centimeters, or 4 inches by 4 inches square

3. mark the smear locations on the map using sequentially numbered circles (i.e., ①, ②, ③)

4. ensure each smear is physically separated from the others to prevent cross contamination

   a. folding smear papers

   b. individual smear envelopes

   c. paper dividers

5. place all of the smears in an envelope

6. pass the envelope out of the area

D. Secure the air sampler

1. turn the air sampler off and record the time

2. using a clean pair of gloves, remove the air sample and place it in its envelope

3. pass the air sample out of the area

4. reassemble the air sampler and remove it from the area

   a. wipe down the air sampler

   b. place air sampler in the "to be surveyed" area

E. Exit the contaminated area

1. Remove anti-c's

a. all tape

b. rubber shoe covers

c. rubber gloves

d. hood

e. coveralls

f. plastic shoe covers

g. cotton liners

F. Frisk

1. go to the nearest frisker and perform a whole body frisk

a. probe should be held ¼ - ½ inch from surface being monitored

b. move probe at 2 - 3 inches/second

c. entire frisk should last 2 - 3 minutes

d. pay particular attention to high probability areas such as hands and feet, elbows, knees, face, or any area which was uncovered

VII. Evaluate the Smears

A. Count the smears

1. do a field evaluation of the smears for both alpha and beta/gamma using friskers

2. document the results in both cpm and dpm

3. if the smears have very low levels of contamination on them, a frisker may not show it; therefore, you may wish to bench count the smears

a. bench counters are more accurate for determining the exact number of emissions from a source over a specific period of time

b. bench counters allow you to extend the count time which dampens the effect of the random nature of radiation emissions

B. Count the air sample

1. mark the air sample size using a 2 inch planchet and pen

2. cut the air sample out with a pair of scissors

3. count the air sample for alpha contamination using a one minute count time

4. record the alpha counts and calculate the curie content in microcuries per milliliter

5. count the air sample for beta contamination using a one minute count time

6. record the beta counts and calculate the curie content in microcuries per milliliter

C. Survey the equipment which must be removed from the contaminated area

1. take smears on each piece and count the smears on both alpha and beta-gamma friskers

2. if no contamination is found on the smears, pick up each piece and frisk it for fixed contamination

VIII. Break down the areas and put the equipment away

SITE WORK DAY

Lab 2: Contamination Survey Station

I. Objective

At the end of this lab the student shall be able to:

A. Detect very low levels of contamination.

II. Exercise

A. Perform instrument preparation (RM-14S or ASP-1 w/HP260 probe)

1. calibration check
2. battery check
3. high voltage (900 volts)
4. response check
5. measure (30 sec.) background radiation and record result

B. Make a drawing of the item to be surveyed

C. Frisk low contamination boards

1. mark all areas on the drawing that are contaminated (100 counts above background)
2. turn item over to verify areas of contamination
3. refrisk any areas that are contaminated but were not detected

D. Frisk high contamination board

1. mark all areas on the drawing that are contaminated (100 counts above your background)
2. turn item over to verify areas of contamination
3. refrisk any areas that are contaminated but were not detected

F. Frisk articles

1. boxes

   a. mark all areas on the drawing that are contaminated (100 counts above background)

   b. open box to verify areas of contamination

   c. refrisk any areas that are contaminated but were not detected

2. flashlights

   a. mark all areas on the drawing that are contaminated (100 counts above background)

   b. do not disassemble flashlights

G. Answer the following questions.

1. What may account for the sporatic increases in cpm when a probe is not in contact with contamination?

2. Is it always appropriate to rely solely on your meter reading and not the audio speaker of a detector when surveying for contamination? Explain your answer.

3. What may cause a meter reading greater than 100 counts above background but no counts above background based on smear data?

SITE WORK DAY

Lab 3: Simple Soil and Water Sampling Protocol

I. Objectives

At the end of this lab the student shall be able to:

A. Perform soil sampling.
B. Perform water sampling.
C. Set up radiological area when a contaminated sample is discovered.

II. Soil Sampling

A. Purpose

1. To determine whether the soil is radioactively contaminated.
2. To characterize the radioactive components of the soil by laboratory isotopic analysis.
3. To effectively control the radiological hazard.

B. Soil sampling preparation

1. Protective clothing
2. Minimum protective clothing requirements shall include rubber shoe covers and waterproof gloves
3. Monitoring and survey equipment
4. Portable alpha probe instrument
5. Portable beta-gamma probe instrument
6. Portable dose rate instrument
7. Smear paper (swipes,wipes)
8. Small plastic bags
9. Pen and data sheet for documentation

C. Sampling equipment and supplies

1. Sampling apparatus (i.e., core drill)
2. Sample container(s) (i.e., 1-liter polyethylene bottle with cap)

3. Metal tray
4. Medium mesh screen (sieve - about 1 ft. by 1 ft.)
5. Trowel or spoon
6. Plastic bags (medium and large)
7. Plastic sheeting
8. Absorbent materials (i.e., cotton rags or diapers)
9. Adhesive tape
10. Mild soap or detergent
11. Bucket of water
12. Barrier rope or tape, and stanchions
13. Appropriate work site posting (i.e., EPA work area)
14. Knife or scissors
15. Yellow and magenta radiation rope
16. Underground Radioactive Materials signs
17. Do Not Enter Without Approval signs
18. Surface contamination signs

D. Simple soil sampling procedure

1. Don protective clothing

   a. Put on minimum shoe covers and gloves

2. Set up work area

   a. Take area and surface readings to ensure no surface contamination or exposure dose rates are significant (Ref: US EPA SOSGs)

   b. Establish perimeter work area

c. Install barriers and posting (EPA work area)

d. Spread plastic sheeting over sample location, and cut hole in exact location where sample will be drawn

e. Set up staging area and place equipment near sample hole

f. Set up small cleaning area on plastic sheeting (about 2 ft. by 2 ft.) Surround with absorbent material

g. Place bucket of water, detergent, large plastic bag, and some absorbent material near cleaning area but not inside cleaning area

3. Prepare to obtain sample

a. Prepare sample apparatus to draw sample

b. Ensure monitoring instruments are near sample hole and operating

c. Have dampened absorbent material handy

4. Obtain sample

a. Draw sample and monitor with portable contamination instruments while sample is being obtained (Primarily beta-gamma, spot check with alpha)

b. If background levels increase, it is a good indication the sample is radioactive. Use dose rate instrument to monitor and continue to draw sample.

Note 1: If exposure rate increases to 3-5 times above background, work can continue, but a health physicist should be consulted.

Note 2: If exposure rate reaches 1 mR/hr or above, stop work and consult with a health physicist. If not, continue as follows.

c. Continue to draw sample while carefully wiping sampling apparatus with dampened absorbent material. Place absorbent material in large plastic bag as waste.

d. Place sample on metal tray and spread out into very thin layer. If sample is too chunky, break up with trowel or use medium mesh screen to sift sample onto metal tray.

e. Use beta-gamma and alpha contamination instruments to monitor soil sample, and document results.

Note 3: If there is no indication of detectable contamination, work can continue as normal (non-contaminated).

5. Treatment of contaminated sample

a. If contamination is detected, carefully transfer soil sample on tray into sample container using trowel and cap container.

b. Transfer sample to cleaning area. Carefully change gloves. Dip absorbent material in bucket of water, slightly wring but leave wet and decontaminate outer surfaces of sample container inside cleaning area. Dry outer surface of container using dry absorbent material.

Note 4: Place wet and dry absorbent material into large plastic waste bag after each single use.

c. Survey outer surface of container for loose surface contamination using smear paper and checking smear paper with portable beta-gamma and alpha instruments. If outer surfaces remain contaminated, repeat step b., and resurvey. Document results.

d. If outer surfaces are contamination free, place sample in medium plastic bag, tie off top, and tape seal. If outer surfaces remain contaminated after decontamination, place sample in medium plastic bag, tie off top, tape seal, and repeat using second medium plastic bag (provides double containment).

e. Ensure outer surface of plastic bag containment is contamination free, and prepare sample for shipment to analytical laboratory using prescribed radioactive materials shipping methods.

6. Termination of soil sampling work

a. Monitor unused materials to verify they are contamination free, and remove from work area. Document results.

b. Monitor remaining materials, and decontaminate as necessary. Those that can be verified as contamination free shall be removed from work area. Those that remain contaminated shall be disposed of in large plastic waste bag, or sealed in large plastic bag for subsequent use. Document results.

c. Carefully roll or fold up plastic sheeting and dispose of in large plastic waste bag

d. Perform surface contamination monitoring of entire work area surface. Contaminated dirt can be placed in large plastic waste bag. Document results.

E. Securing the work area/Setting up radiological area

1. Setting up perimeter boundaries

a. Remove the work site perimeter barriers and postings. Monitor to ensure they are contamination free

b. Replace perimeter barriers with yellow and magenta radiation rope

2. Classify area based on survey results

Note 5: The remaining contained contaminated items can be secured and left inside the area for subsequent site use or appropriately shipped for proper disposition. In any case, the outer surfaces of bags shall be contamination free.

3. If nothing is left inside the boundaries and the ground surface is contamination free, the area can be posted as 1-UNDERGROUND RADIOACTIVE MATERIALS and 2-DO NOT ENTER WITHOUT APPROVAL.

4. If contained plastic bags are left inside and the ground surface is contamination free, the area can be posted as 1-RADIOACTIVE MATERIALS AREA, 2-UNDERGROUND RADIOACTIVE MATERIALS and 3-DO NOT ENTER WITHOUT APPROVAL.

5. In addition to a. and b. above, if the ground surface remains contaminated, it will be classified as a surface contamination area and appropriate posting will be required (ie. CONTROLLED SURFACE CONTAMINATION AREA).

Note 6: All postings shall be installed about waist high. All postings shall be visible from all accessible sides to the site.

F. Final monitoring

1. Remove protective clothing, place in plastic waste bag, and seal

2. Perform whole body personnel monitoring prior to leaving work site

G. Considerations

1. Be conscientious of cross contamination at all times

2. Change gloves regularly, especially when performing different tasks (consider wearing two pair of gloves)

3. Work carefully to prevent the spread of contamination

4. Monitor yourself whenever you suspect you may have become contaminated

5. Bring extra protective clothing, such as rubber shoe covers, in the event they get ripped, torn, or otherwise rendered useless

6. Dispose of all used smear paper as contaminated waste, or place in small plastic bags to go to laboratory for further analysis

7. Ensure no free standing water is noticeable in contaminated waste bag(s)

III. Water Sampling

A. Purpose

1. To determine whether the water is radioactively contaminated

2. To characterize the radioactive components of the water by laboratory isotopic analysis

3. To effectively control the radiological hazard

B. Water sampling preparation

1. Protective clothing

a. Minimum protective clothing requirements shall include waterproof shoe covers (preferably boots) and waterproof gloves (preferably mid-forearm length)

b. Waterproof apron

2. Monitoring and survey equipment

a. Portable alpha probe instrument

b. Portable beta-gamma probe instrument

c. Portable dose rate instrument (water may be suspected of being infested with debris)

d. Smear paper (swipes,wipes)

e. Small plastic bags

f. Pen and data sheet for documentation

3. Sampling equipment and supplies

a. Sampling apparatus (optional depending on type and depth of desired sample, i.e., extension pole equipped with sample bottle stopper)

b. Sample container(s) (i.e., 1-liter polyethylene bottle with cap)

c. Plastic bags (medium and large)

d. Plastic sheeting

e. Absorbent materials (i.e., cotton rags or diapers)

f. Adhesive tape

g. Mild soap or detergent

h. Bucket of water

i. Appropriate work site posting (i.e., EPA work area)

j. Yellow and magenta radiation rope, and stanchions to hold rope

k. Do Not Enter Without Approval signs

l. Radiological Control Area signs (e.g., radiologically contaminated water, surface contamination)

C. Simple water sampling procedure

1. Don protective clothing

a. Put on minimum shoe covers, gloves, and apron

2. Set up work area

   a. Take area and surface readings to ensure no surface contamination or exposure dose rates are significant. (Ref: US EPA SOSGs)

   b. Establish perimeter work area, and install posting (EPA work area)

   c. Spread plastic sheeting near sampling location

   d. Set up small cleaning area on plastic sheeting (about 2 ft. by 2 ft.). Surround with absorbent material

   e. Place bucket of water, detergent, large plastic bag, and some absorbent material near cleaning area but not inside cleaning area

   f. Set up staging area near sampling location and place remainder of equipment

3. Prepare to obtain sample

   a. Ensure monitoring instruments are near sampling location and operating

   b. Have dry absorbent material handy

   c. Have open sample bottle and cap handy

4. Obtain sample

   a. (1) For surface sample: skim top of water surface using open bottle, collect sample, and cap bottle

      (2) For underwater sample: turn bottle upside down, submerge below water surface (being careful not to let water level reach top of glove), turn bottle right side up and collect sample, bring out of water and cap bottle

   b. Use dry absorbent material to dry outer surfaces of sample bottle. Place absorbent material and bottle on plastic sheeting, change gloves

   c. Survey sample bottle for contamination

      (1) If no contamination is detected by dry smears or direct readings on sample or any used materials, you can assume materials to be

clean. Occasionally spot check for contamination, if none is detected, continue as normal.

(2) If any contamination at all is detected on outer surfaces of bottle, dispose of smears and used absorbents in large plastic bag as contaminated waste. A direct reading increase with beta-gamma probe may indicate sample itself is contaminated. Document results.

d. If sample container is found to be contaminated on the outer surfaces, it must be decontaminated. Transfer sample to cleaning area, change gloves, and prepare to decontaminate.

e. Use a little detergent in the bucket of water and dip some absorbent in it. Hand wring over bucket, then wipe outer surfaces of container. Dry and resurvey for contamination. Dispose of smears and absorbents as contaminated.

f. After outer surfaces are found to be contamination free using dry smears, decontamination is complete. Change gloves. Increase in radiation level from a direct beta-gamma reading on the side of the sample would indicate sample itself is contaminated. Place sample in medium plastic bag and seal bag using adhesive tape. Document results.

g. Ensure outer surfaces of plastic bag containment is contamination free, and prepare sample for shipment to analytical laboratory using prescribed radioactive materials shipping methods.

5. Termination of water sampling work

a. Monitor unused materials to verify they are contamination free, and remove from work area. Document results.

b. Monitor remaining materials, and decontaminate as necessary. Those that can be verified as contamination free shall be removed from work area. Those that remain contaminated shall be disposed of in large plastic waste bag, or sealed in large plastic bag for subsequent use. Document results

c. Blot wet areas on plastic sheeting using dry absorbent material Carefully roll or fold up plastic sheeting and dispose of in large plastic waste bag

Note 7: If any free standing water is noticeable in contaminated waste bag, place some extra dry absorbent material in bag to absorb water.

d. Perform surface contamination monitoring of entire work area surface to ensure no residual contamination is left on the ground
Document results

6. Securing the work area/Setting up radiological area

a. Install yellow and magenta radiation rope around entire water body being sampled

b. Post appropriate radiological control area signs
Post Do Not Enter Without Approval signs. Signs should be about waist high, and seen from all accessible approaches.

c. Secure contaminated waste inside posted area, or properly transport for disposal as contaminated waste

7. Final monitoring

a. Monitor protective clothing, remove and properly dispose

b. Perform whole body personnel monitoring prior to leaving work site

8. Considerations

a. Be conscientious of cross contamination at all times

b. Change gloves regularly, especially when performing different tasks, consider wearing two pair of gloves.

c. Work carefully to prevent the spread of contamination and be conscience of where potentially contaminated water is dripping

d. Monitor yourself whenever you suspect you may have become contaminated

e. Bring extra protective clothing, it might come in handy

f. Do not leave any free-standing water in contaminated waste bag

U.S. Environmental Protection Agency
Region 5, Library (PL-12J)
77 West Jackson Boulevard, 12th Floor
Chicago, IL 60604-3590