MANUAL OF PROTECTIVE ACTION GUIDES AND PROTECTIVE ACTIONS FOR NUCLEAR INCIDENTS

Presented By

The Environmental Protection Agency

at

NASA HEADQUARTERS
date

JUNE 10 - 11, 1998

SESSION 1

WELCOME AND INTRODUCTIONS

EPA 400-R-92-001
MANUAL OF PROTECTIVE ACTIONS AND PROTECTIVE ACTIONS FOR NUCLEAR INCIDENTS WORKSHOP

NASA HEADQUARTERS
300 E STREET, S.W.
WASINGTON D.C.
JUNE 10 - 11, 1998

Wednesday, June 10, 1998

8:30 - 9:00 am	Welcome and Introductions
9:00 - 10:00 am	Overview (How the PAG manual is laid out)
10:00 - 11:00 am	Rationale for PAG values (PAG Principles)
11:00 - 12:00 pm	Application and Interpretation of PAGs (When to use them and how)
12:00 - 1:00 pm	Lunch
1:00 - 2:30 pm	Introduction to Dose Projection (Discussion of Terminology and EPA assumptions used)
2:30 - 4:30 pm	Implementation of Emergency Worker Dose Limits (Who are Emergency Workers and What limits apply)
4:30	End of Day One

Thursday, June 11, 1998

8:30 - 10:00 am	Development of DCFs and DRLs (What are they and how do you apply them)
10:00 - 11:00 pm	Dose Projection for Early Phase (Problem solving)
11:00 - 12:00 pm	PAGs for Relocation (Assumptions made and rationale for use)
12:00 - 1:00 pm	Lunch
1:00 - 3:30 pm	Dose Projection for Relocation (Problem solving)
3:30 - 4:00 pm	Review and Wrap-up

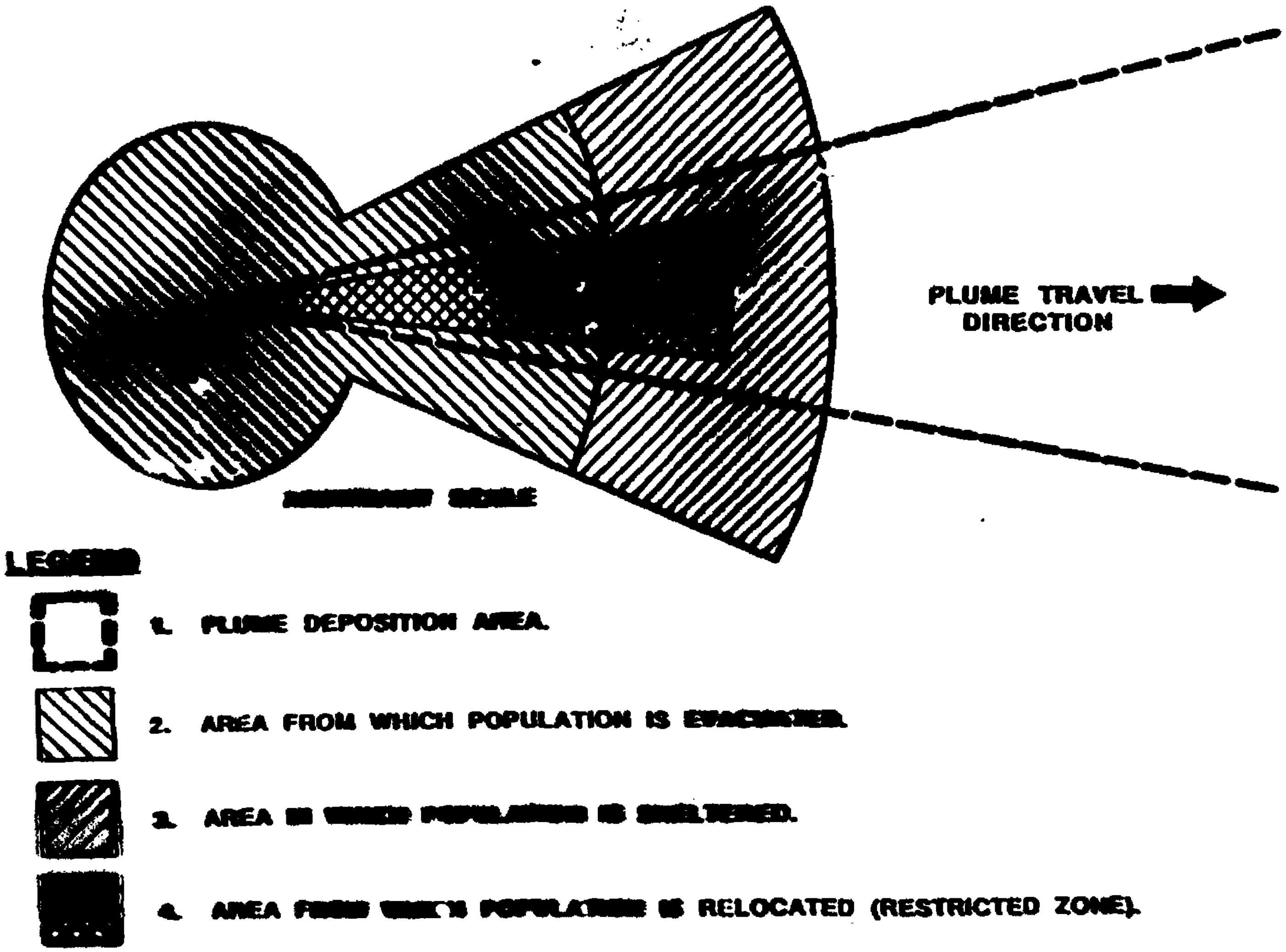
SESSION 2

OVERVIEW OF BACKGROUND MATERIALS

SUPPORTING THE WORKSHOP

TOPICS

- Response areas
- Organization and content of the PAG Manual and its major support documents
- Exposure pathways
- Incident phases


PLUME TRAVEL DIRECTION
1. PLUME DEPOSITION AREA.
2. AREA FROM WHICH POPULATION IS
3. AREA
4. AREA RELOCATED (RESTRICTED ZONE).

CONTENTS OF THE PAG MANUAL

CHAPTERS	SUBJECTS
1	Background information
2, 3, & 4	PAGs for plume, ingestion, and relocation
5, 6, & 7	Implementation guidance for the 3 PAG categories
8	Reserved for recovery guidance

CONTENTS OF THE PAG MANUAL
(cont'd)

APPENDICES	SUBJECTS
A	Definitions of terms
B	Risk of health effects from radiation
C	Rationale for selecting the early phase PAG values
D	Rationale for food PAGs
E	Rationale for Relocation PAGs

DOSES N EXCESS OF THE L M TS FOR EMERGENCY WORKERS

- Old limits of 75 and 100 rem present unacceptably high risk for <u>assignment</u>.

- No limit is needed for persons who volunteer for higher doses if:
  - they are fully aware of the risks involved, and
  - they are lifesaving or preventing dose to a large population.

- Chart of risks is provided (see page 2-12).

BAS S FOR EMERGENCY WORKER DOSE L M TS
(cont'd)

- 25 rem limit is justified for:
  - life saving
  - preventing substantial risks to populations
- ICRP-26 recognizes 25 rem as a lifetime limit for specially justified circumstances.
- Acute effects to adults will be avoided.

BAS S FOR EMERGENCY WORKER DOSE L M TS
(cont'd)

- 10 rem limit for protecting <u>valuable</u> property
  - Some emergency situations justify dose limits higher than 5 rem.
  - ICRP-26 recognizes 10 rem as an annual limit for any single event for workers.
- Higher limits are conditional.

BAS S FOR EMERGENCY WORKER DOSE L M TS
(pp. C-22 to 24)

- 5 rem limit unless higher limit is justified
  - Occupational guidance should normally govern.
  - Limit emergency workers to nonpregnant adults.
  - Occupational limits for organs, extremities and lens of the eye should also apply.

MAJOR CONCLUSIONS LEADING TO THE SELECTION OF 1 REM AS THE PAG FOR EVACUATION (p. C-19)

- If sheltering is implemented to 0.5 rem at centerline, and evacuation to 1 rem, the avoided dose from evacuation will be about 0.5 rem.

- Therefore, the PAG recommended for evacuation is 1 rem.

MAJOR CONCLUSIONS LEADING TO THE SELECTION OF THE PAG FOR EVACUATION (pp. C-18 & C-19)

- 0.5 rem is the selected dose to be avoided.
  - This satisfies Principles 1 and 2.
  - Cost of going lower is not justified. (Principle 3)
  - Net reduction in average risk will occur (Principle 4).
  - Meets acceptable risk to the fetus established for occupational exposure.

AVERAGE VERSUS CENTERLINE DOSE
(p. C-12)

Centerline Dose (rem)	Average Dose Avoided by Stability Class (mrem per individual)		
	A	C	F
0.5 to 1	340	190	70
1 to 2	670	380	150
2 to 5		870	330
5 to 10			750

CALCULATION OF RADIATION RISK VERSUS EVACUATION RISK (p. C-10)

- Estimated risk of death from transportation = 9E-8/person mile.
- Assume 100 mile round trip for evacuation.
- Estimated risk of death from radiation = 3E-4/person rem.
- Calculate the equivalent risk (rem/100 miles).

UPPER BOUNDS ON DOSE FOR EVACUATION BASED ON COST OF AVOIDING FATALITIES
(p. C-11 and E-2)

Accident Category	Atmospheric Stability Class	Dose Upper Bounds[a]	
		Maximum (rem)	Minimum (rem)
SST-1[b]	A	5	0.4
	C	5	0.4
	F	10	0.8
SST-2	A	1	0.15
	C	3.5	0.25
	F	10	0.7

[a] Based on an assumed range of $400,000 to $7,000,000 per life saved.
[b] SST means Siting Source Term. See page E-2 of PAG Manual.

AVERAGE RISK OF DELAYED HEALTH EFFECTS IN THE U.S. POPULATION

(pp. B-19 to 25)

Health Effect	Effects per Person-rem		
	Whole Body	Thyroid	Skin
Fatal cancers	2.8E-4[a]	3.6E-5[b]	3.0E-6
Nonfatal cancers	2.4E-4	3.2E-4	3.0E-4
Genetic disorders (all generations)	1.0E-4		

[a] Risk to the fetus is estimated to be 5 to 10 times greater.

[b] Risk to young children is estimated to be about 1.7 times greater. Their dose is also about 2 times greater.

ACUTE HEALTH EFFECTS: CONCLUSIONS
(cont'd)

Dose	Acute Health Effect
10 rad	The dose level below which a fetus would not be expected to suffer teratogenesis.
5 rad	The approximate minimum level of detectability for acute cellular effects using the most sensitive methods.

ACUTE HEALTH EFFECTS: CONCLUSIONS

(p. B-17)

Dose	Acute Health Effect
50 rad	Less than 2 % of the exposed expected to show forewarning symptoms.
25 rad	Forewarning symptoms are not expected.

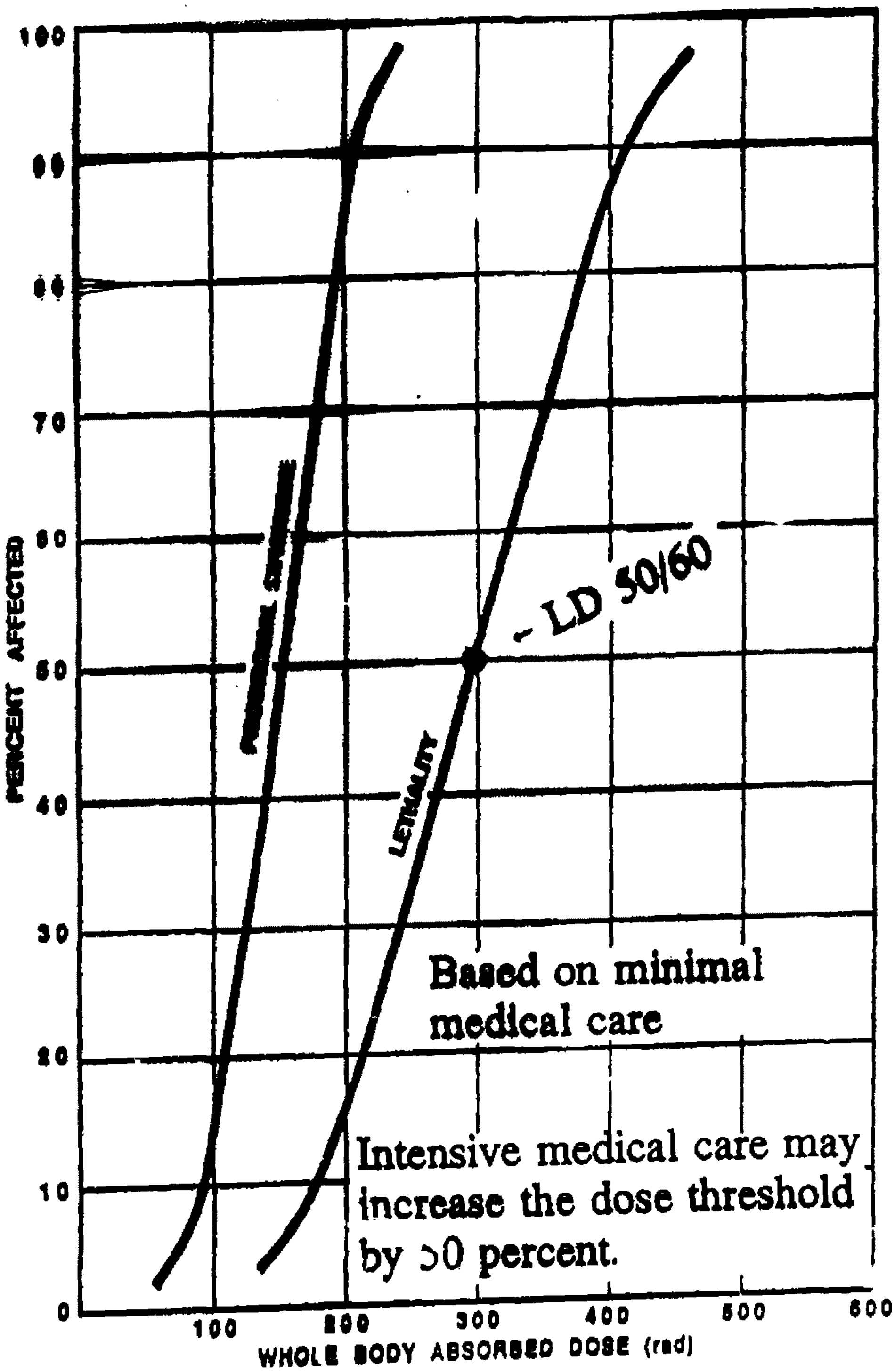


FIGURE B-1. ACUTE HEALTH EFFECTS AS A FUNCTION OF WHOLE BODY DOSE.

RADIATION HEALTH EFFECTS
(Appendix B)

- Acute (deterministic) health effects
- Mental retardation
- Radiogenic cancers
- Thyroid disorders and cancers
- Genetic disorders

BASIS FOR SETTING PAG LEVELS
(p. 1-5)

	<u>PRINCIPLE</u>	<u>STRATEGY</u>
(1)	Avoid acute health effects.	Stay below threshold dose.
(2)	Adequately protect against cancer and genetic effects under emergency conditions.	Set PAG at this level unless driven <u>down</u> by cost/risk considerations (3), or <u>up</u> by risk/risk considerations (4).
(3)	Optimize cost of protective action versus avoided dose.	Use this principle only if the the PAG value is driven down.
(4)	Regardless of the above principles, the risk from a protective action should not itself exceed the risk from the dos th t would be voided.	Use this principle only if the PAG value is driven up.

SHELTERING CONSTRAINTS
(pp. 5-19 to 21 and C-14 to 16)

- Sheltering provides only partial protection.
  - Protection factor decreases with time.
  - Ventilation rates vary.
  - Protection varies with building type.
  - Risk of shelter failure is significant.

BASIS FOR PROTECTIVE ACTION DECISIONS DURING THE EARLY PHASE
(p. 5-2)

- Plant conditions and utility PARs
- Dose projections
- Field monitoring results

PROTECTIVE ACTIONS FOR THE EARLY PHASE (p. 1-4)

- **Evacuation**
- **Sheltering**
- **Access control**
- **KI administration**
- **Control of surface contamination**

TOPICS

- Protective action effectiveness
- PAG Principles
- Basis for PAG values and Emergency worker dose limits

SESSION 3

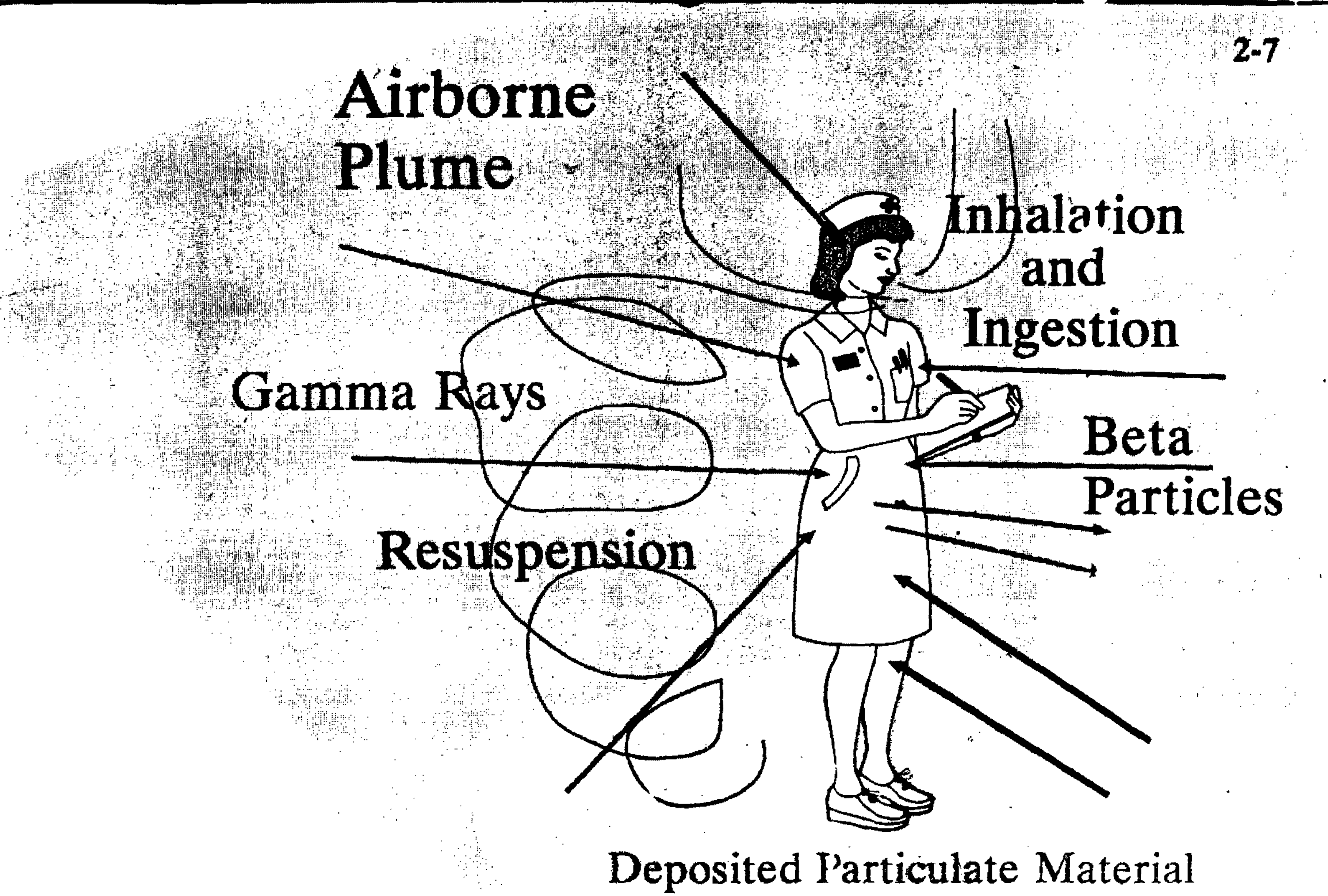
RATIONALE FOR PAG VALUES
AND
EMERGENCY WORKER DOSE LIMITS

INCIDENT PHASES
(pp. 1-2 to 1-4)

- Three phases of a radiological incident
  - Early
  - Intermediate
  - Late

- In all phases, the PAGs are independent.

- Refer to PAG Manual Page 1-4.



Exposure Pathways for the Early Phase

MAJOR SUPPORT DOCUMENTS (cont'd)

- Evaluation of Skin and Ingestion Exposure Pathways (EPA 520/1-89-016)

- Evacuation Risks--An Evaluation (EPA-520/6/74-002)

- An Analysis of Evacuation Options for Nuclear Accidents (EPA 520/1-87-023)

- Economic Criteria for Relocation (EPA 520/1-89-015)

MAJOR SUPPORT DOCUMENTS

- Externa Dose-Rate Conversion Factors for Ca cu ation of Dose to the Public (DOE/EH 0070)
- EPA Federal Guidance Report No. 11 (EPA 520/1-88-020)
- EPA Federal Guidance Report No. 12 (EPA 402-R-93-081)

SESSION 4

APPLICATION AND INTERPRETATION
OF
PROTECTIVE ACTION GUIDES
AND
EMERGENCY WORKER DOSE LIMITS
FOR
THE EARLY PHASE

MAIN TOPICS

- Definitions and interpretations
- Special dose quantities and concepts
- PAG values and their application
- The use of KI for emergency workers
- The impact of the changes to the guidance

APPLICABILITY OF PAGs
(p. 2-1 & 2-2)

- PAGs apply to all nuclear incidents or accidents except nuclear war.
  - Developed based on nuclear power plant accidents
  - Dose limits also apply to all - - -

- The <u>implementation guidance</u> applies primarily to nuclear power plants.

DEFINITIONS
(pp. 1-2 & A-3)

- Protective Action Guide (PAG):

  The projected dose to individuals in the general population that warrants protective action.

- Projected Dose:

  The calculated future dose that would be received by individuals if no protective actions were taken.

PAG INTERPRETATIONS
(pp. 1-1, & 1-7)

PAGs are:

- Decision levels for public officials

- Used to minimize risk from an event which is occurring or has already occurred

PAG INTERPRETATIONS
(pp. 2-1, 4-1, 2-2, & 1-6)
(cont'd)

PAGs are:

- Mandatory for planning
  - but, professional judgment is required for their application

- Independent of the type or magnitude of the release

PAG NTERPRETAT ONS
(pp. -6, & 2-2)
(cont'd)

PAGs are:

- A supplement to design safety of nuclear facilities

- Designed to protect all individuals in the population

PAG INTERPRETATIONS
(pp. 1-6, 2-1, 2-4, & 2-10)
(cont'd)

PAGs are not:

- The basis for the size of the EPZ
- Dose limits
- Additive to other doses

PAG INTERPRETATIONS
(pp. 1-7, & 2-1)
(cont'd)

PAGs do not:

- Imply an acceptable level of dose for nonemergency situations.

- Represent the boundary between safe and unsafe conditions.

- Supersede Federal Radiation Council (FRC) Guidance.

PAG INTERPRETATIONS
(pp. A-2 & A-3)
(cont'd)

PAGs do not include:

- Previous radiation doses.

- Safety factors to account for uncertainties in dose projection procedures.

DOSE QUANTITIES USED FOR EMERGENCY RESPONSE (pp. B-1 & B-2)

- Absorbed dose
- Projected dose
- Committed dose

SPECIAL DOSE QUANTITIES
(p. B-1 & B-2)

- Dose equivalent (DE)
  - Organ dose
  - Risk of cancer

- Committed dose equivalent (CDE)
  - 50 years

- Effective dose equivalent (EDE)

- Committed effective dose equivalent (CEDE)

TOTAL EFFECTIVE DOSE EQUIVALENT (TEDE)

- TEDE (an NRC term) means the <u>sum</u> of the deep dose equivalent from external gamma radiations (EDE) and the committed effective dose equivalent (CEDE) from internal exposures.

- Plume PAGs are expressed as this sum.
  "TEDE" is not used in the PAG Manual

- EDE from external sources is the same as NRC's term "deep dose equivalent."

EARLY PHASE PAGs
(pp. 2 5 to 2 8 & C 20)
(cont'd)

Projected dose (rem)	Action
1 to 5 TEDE 5 to 25 CDE thyroid 50 to 250 DE skin	Evacuation (or, for some situations, sheltering) should normally be initiated at the lower end of the range.
25 CDE thyroid from radioiodine	Administer stable iodine (KI) to the public in accordance with State medical procedures.

OTHER EARLY PHASE GUIDANCE
NOT PAGS
(pp. 2-4 to 2-9)

Projected dose (rem)	Action
<0.1 TEDE <0.5 CDE thyroid <5 DE skin	No action based on risk from radiation dose.
0.1 to <1 TEDE 0.5 to <5 CDE thyroid 5 to <50 DE skin	Sheltering should be considered, but this is not a PAG for sheltering.

DIFFERENCES IN EMERGENCY WORKER LIMITS AND PROTECTIVE ACTION GUIDES

- Difference in justification
- Difference in time period of exposure
- Limits vs threshold for decisions

EMERGENCY WORKER PROTECTION
(pp. 2-9 to 13 and C-22 to 24)

- Period of application of emergency worker limits

- Emergency worker dose and occupational dose are not additive unless required by license.

- No guidance for keeping records of dose to emergency workers

-

- Protection of minors and fetuses

EMERGENCY WORKER CATEGORIES
(p. C-22)

- Designated by State and local authorities

- Example categories:

  - Law enforcement and traffic control officials
  - Medical and public health personnel
  - Environmental monitors
  - Emergency vehicle operators
  - Utility, industrial, and institutional emergency workers

PERSPECTIVES FOR EMERGENCY WORKER LIMITS (pp. C-22 to 24)

- Apply the same dose limits as for occupationally exposed workers wherever practicable.

- Permit higher dose limits when required to prevent substantial risks to populations or protect <u>valuable</u> property.

- Provide guidance for extreme emergencies.
  - Volunteers fully informed of risks

DOSE L M TS FOR EMERGENCY WORKERS (p. 2- 0)

DOSE LIMIT	ACTIVITY	CONDITION
5 rem	all	
10 rem	protecting valuable property	lower dose not practical
25 rem	life saving or protecting large populations	lower dose not practical
>25 rem	life saving or protecting large populations	only on a voluntary basis to persons fully aware of the risks.

KI FOR EMERGENCY WORKERS
(pp. 2-11 and 2-13)

- KI is recommended if atmospheric releases include radioiodine (no dose threshold).

- State medical procedures determine its availability and proper use.

SESSION 5

INTRODUCTION TO DOSE PROJECTION

FOR

PROTECTION OF THE PUBLIC

AND

EMERGENCY WORKERS

GENERAL APPROACH TO DOSE PROJECTION

- Determine or estimate source term (Q) and projected release duration (T_p).
- Use atmospheric dispersion model to calculate time integrated air concentration (X_{in}).
- Use dose models to calculate projected dose (D) by means of dose conversion factors (DCF).

GENERAL APPROACH FOR CALCULATING PROJECTED DOSE

Measure or calculate environmental concentrations.	Concentrations may be for individual nuclides or may be grouped by iodines and noble gases.
Multiply by duration of exposure to get time integrated concentration (X_{in}) for each nuclide or group of nuclides.	True X_{in} can be calculated if the total release is used. Not used with measured concentrations.
Multiply each X_{in} by the appropriate DCF to get TEDE or thyroid dose from each nuclide or group of nuclides.	Use DCFs from PAG Manual Table 5.1 for TEDE and 5.2 dose for CDE to thyroid from single nuclides. For groups of nuclides, DCFs must be calculated. A DCF for particulates, as a group, is not practical.
Sum TEDEs over all nuclides or groups of nuclides and su thyroid doses to get projected doses co parable to PAGs.	

NEEDED SOURCE TERM INFORMATION

- Gross noble gas, radioiodine, and particulate release rates

  or

  curies per second of each radionuclide

- Release height (release point information)
- Estimated release duration

NEEDED METEOROLOGY

- Wind speed,
- Wind direction
- Stability Classes
- Mixing depth
- Predicted changes
- Precipitation

GAUSSIAN DISPERS ON EQUAT ON

$$\frac{\chi \bar{u}}{Q} = \frac{e^{-\left(\frac{y^2}{2\sigma_y^2} + \frac{h^2}{2\sigma_z^2}\right)}}{\pi \sigma_y \sigma_z}$$

For a ground level release, release height (h) = 0.
At the centerline, the lateral distance (y) = 0.

$$\frac{\chi \bar{u}}{Q} = \frac{1}{\pi \sigma_y \sigma_z}$$

BASIC DOSE EQUATION

Th b sic dose equ tion is:

$$D = X_{in} \cdot DCF$$

D = Dose (rem)

X_{in} = Time integrated concentration in air ($uCi \cdot cm^{-3} \cdot h$)

h = duration of exposure (hours)

DCF = Dose conversion factor (r m p r $uCi \cdot cm^{-3} \cdot h$)

NEEDED INFORMATION FOR DOSE CALCULATIONS

- Radionuclide air concentration (X)
- Expected duration of exposure (T_p)
- Dose conversion factors (DCF)
- Dose projection procedures
  - computer programs
  - RASCAL

INFORMATION NEEDED TO SUPPORT PROTECTIVE ACTION DECISIONS

- Total effective dose equivalent (TEDE).
- Committed thyroid dose (CDE).
- Measurements of plume gamma rate.
- Measurements of gross radioiodine concentrations.

TIME INTEGRATED AIR CONCENTRATION, X_{in}

- Air concentration times projected exposure time.

$$X(uCi/cm^3) \cdot T_p(hour) = X_{in}$$

- Permits addition of the dose conversion factors over the three exposure pathways.

TIME INTEGRATED AIR CONCENTRATION, X_{in}

(cont'd)

- High concentration for short time
- Low concentration for long time.
- Symbol: X_{in}
- Matches units of EPA's dose conversion factors.

TIME INTEGRATED AIR CONCENTRATION, X_{in}

(cont'd)

PROBLEM ONE

- Xe-133 air concentration is 1.0E-4 uCi/cm^3.
- Expected duration of air concentration is 2 hours.
- X_{in} equals ?????? ($uCi \cdot cm^{-3} \cdot h$).

T ME INTEGRATED A R CONCENTRAT ON, X_{in}

(cont'd)

PROBLEM TWO

- Xe-133 air concentration is 5.0E-5 uCi/cm^3.
- Expected duration of this air concentration is 240 minutes.
- X_{in} equals ?????? (uCi · cm^{-3} · h).

TIME INTEGRATED AIR CONCENTRATION, X_{in}
(cont'd)

SOLUTIONS TO PROBLEMS 1 AND 2

- X_{in} = (air concentration) (expected exposure time)

- X_{in} = (1.0E-04 uCi/cm^3) (2 h)
  = 2.0E-04 uCi · cm^{-3} · h

- X_{in} = (5.0E-05 uCi/cm^3) (240m/60m/h)
  = 2.0E-04 uCi · cm^{-3} · h

DCF DEFINITION
(p. A-1)

- Dose Conversion Factors (DCF) change environmental concentrations (or time integrated concentrations) to dose.

- Dose units (rad = rem)

- EPA DCF unit: rem per $uCi \cdot cm^{-3} \cdot h$

PARAMETERS THAT AFFECT DCFs

- Physical characteristics
- Chemical characteristics
- Breathing rates
- Assumed deposition velocities
- Biological system clearances

ASSUMED VALUES FOR CALCULATIONS

- Breathing rate = 1.2 m^3/h

- Deposition velocity

	EPA	RASCAL
- Iodine	1 cm/s	0.3 cm/s
- Particulates	0.1 cm/s	0.3 cm/s

- Gamma shielding factor due to ground roughness
  EPA = 1 RASCAL default = 0.7

- Public exposure to deposited materials before relocation is 4 days (96 h)

DOSE CONVERSION FACTOR TABLES (TABLE 5-1 AND TABLE 5-2)

- Table 5-1: Dose Conversion Factors and Derived Response Levels for Combined Exposure Pathways During the Early Phase of a Nuclear Incident.

- Table 5-2: Dose Conversion Factors and Derived Response Levels - Inhalation of Radioiodine.

- Refer to EPA Manual

SKIN DOSE

- DCFs for skin are not provided for early phase.
- Skin dose is not expected to be controlling.
- Skin dose is controlled by bathing and changing clothing.

USING DCFs FOR COMBINED PATHWAYS (TABLE 5-1)

- GIVEN:
  - The concentration of tritium (H-3) in a plume is 5E-3 Ci/m^3.
  - Exposure to plume expected for 3 hours.
- PROBLEM:
  - What is the time integrated air concentration?
  - What is the dose conversion factor?
  - What is the projected dose?
  - What kind of dose is it?

US NG DCFs FOR COMB NED PATHWAYS (TABLE 5-)
(cont'd)

SOLUTION: Calculate X_{in} and look up the DCF.

- X_{in} = (air concentration) (expected exposure time)
  = (5E-3 uCi/cm^3) (3 hours)

- X_{in} = 1.5E-02 uCi $\cdot$ cm^{-3} $\cdot$ h

- DCF for tritium from Table 5-1 is
  7.7E+01 rem per uCi $\cdot$ cm^{-3} $\cdot$ h

USING DCFs FOR COMBINED PATHWAYS (TABLE 5-1)

(cont'd)

- Projected dose = X_{in} times DCF

or

$(1.5E\text{-}2 \text{ uCi} \cdot \text{cm}^{-3} \cdot \text{h})(7.7E\text{+}1 \text{ rem per uCi} \cdot \text{cm}^{-3} \cdot \text{h})$

- Projected dose = 1.2 rem

- This projected dose is considered to be total effective dose equivalent (TEDE). Why?

US NG DCFs FOR COMB NED PATHWAYS (TABLE 5-)

(cont'd)

THE PROJECTED DOSE IS THE TEDE BECAUSE:

- DCF is based on committed effective dose equivalents.
- All significant early phase exposure pathways are included.
- All significant radionuclides are included.

SUMMARY

$$D = \sum_{1}^{n} DCF_{i} \cdot X_{in,\,i}$$

DCF_i = DCF for radionuclide (i)

n = Number of radionuclides present

$X_{in,\,i}$ = The time integrated concentration of radionuclide (i)

SESSION 6

IMPLEMENTATION OF

EMERGENCY WORKER DOSE LIMITS

MAIN TOPICS

- Emergency workers
- Relative importance of exposure pathways
- Inhalation dose control methods
- PAG Subcommittee guidance
- Dose for the record

EMERGENCY WORKERS
(p. 2-9)

- State responsibility for defining emergency workers
- Example assignments
  - Law enforcement/traffic control
  - Radiation protection
  - Transportation services

EXPOSURE PATHWAYS FOR EMERGENCY WORKERS

- External gamma radiation
  - Plume
  - Groundshine

- Inhalation from the plume and resuspended materials
  - Plume inhalation may be the major pathway

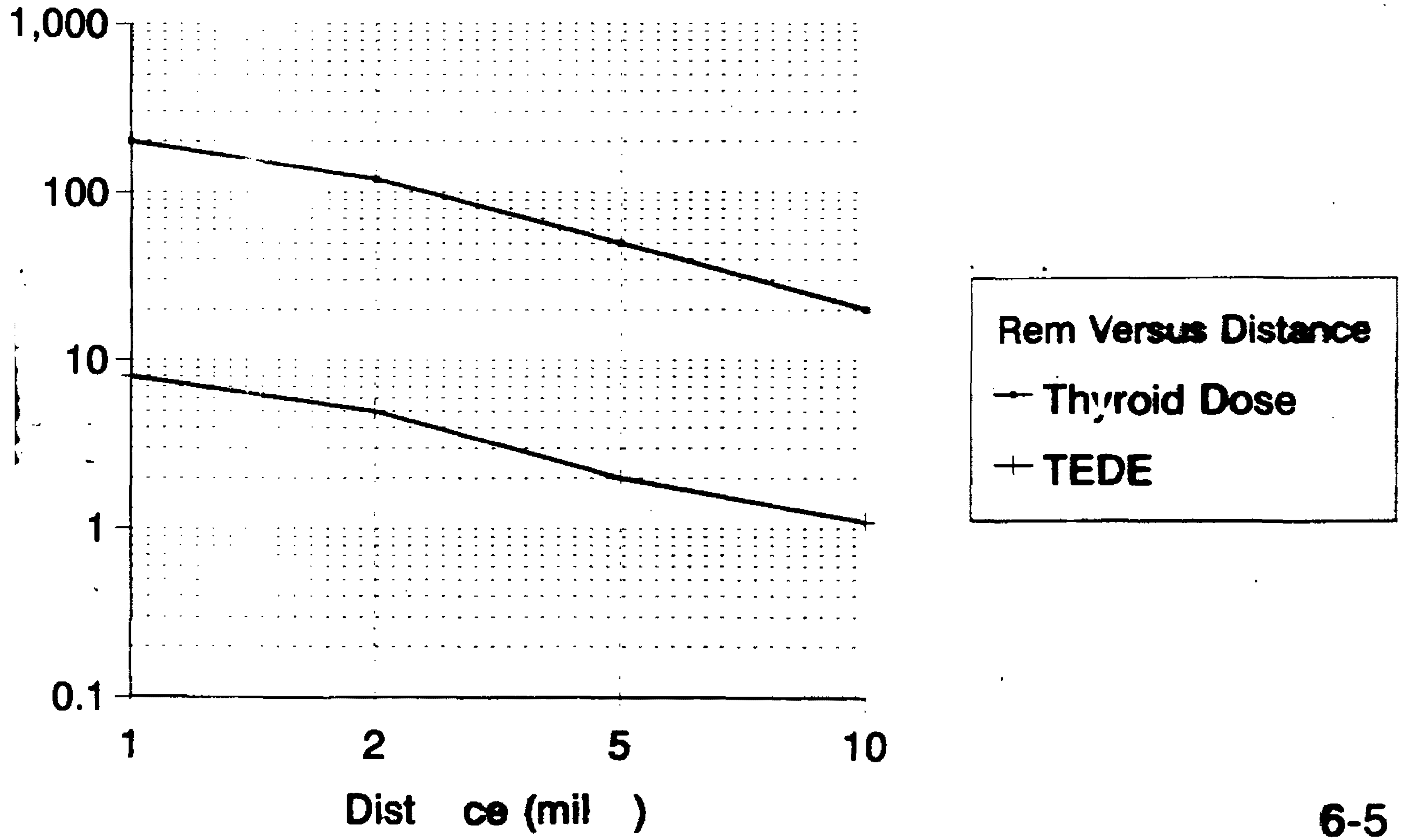
External beta radiation
  - Plume
  - Groundshine
  - Deposited materials on skin and clothing

NHALAT ON OF RESUSPENDED MATER AL

- R susp sion rat s
  - Empirical values range from 10^{-5} to 10^{-9} m^{-1}
- Importance of pathway
  - Plume phase
  - Post plume phase
  - For example, at 10^{-5} m^{-1}, 1 mR/h yields about 0.05 mrem CEDE from inhalation

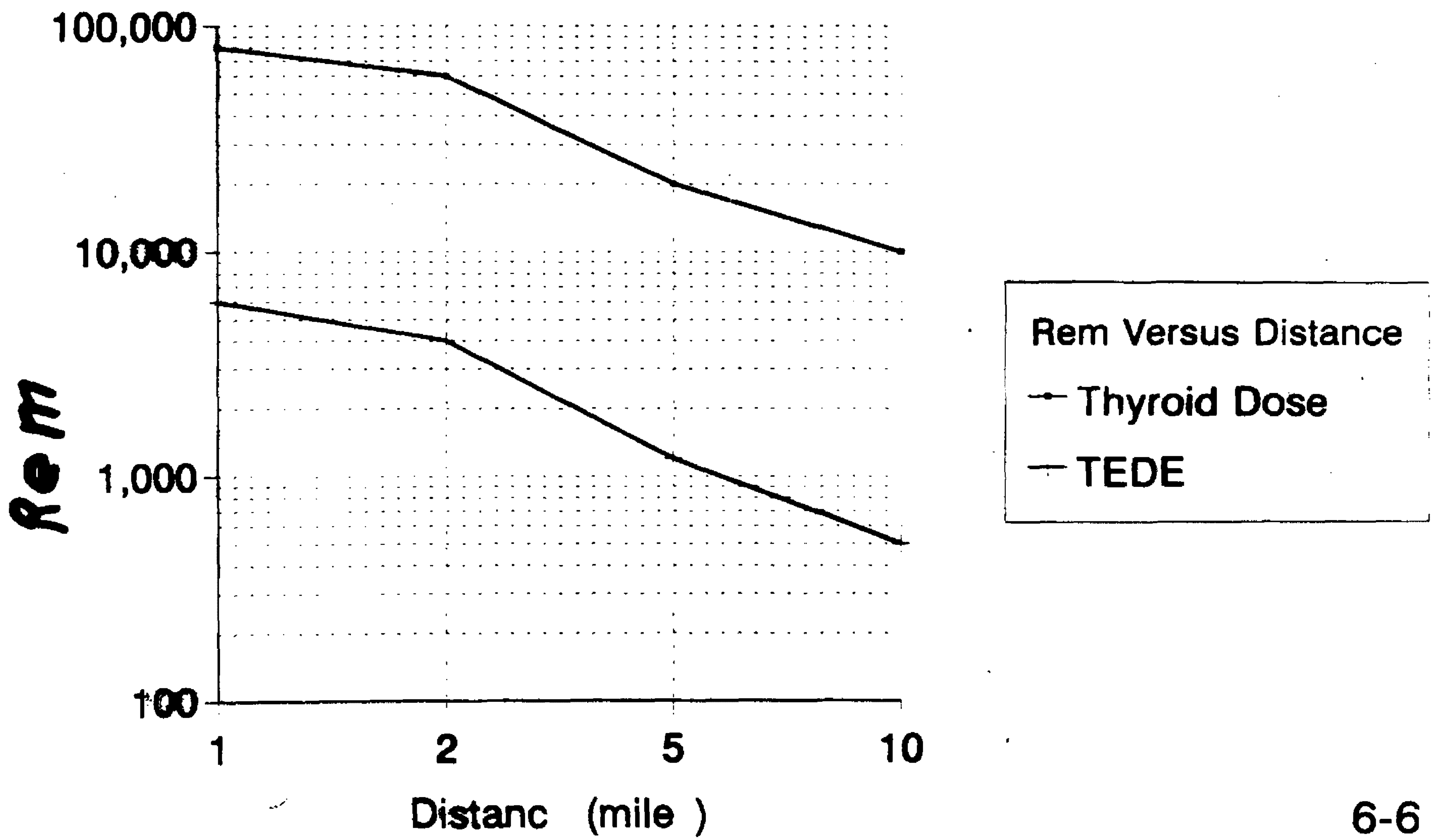
EXAMPLE DOSES FROM A REACTOR ACCIDENT

RTM-93 CASE 5; Gap release for one hour; Late release @ 100 % per day
No Spray; No protective action; o rain; Met cond. was not Specified



EXA PLE DOSES FRO A REACTOR ACCIDENT

RT -93 CASE 16, Severe core damage; 100% per hour leak rate; No spray; o ra'n; No protective action; et Cond. was not Spec'f'ed.



INHALATION DOSE CONTROL USING RESPIRATORS

- Mentioned, but not promoted by EPA or FEMA
- Effectiveness
  - Filter type
  - Air supplied type
- Advantages
  - Protects workers from inhalation dose.
  - Dose control by dosimeter is simple.

NHALATION DOSE CONTROL
US NG RESP RATORS
(cont'd)

- Disadvantages
  - OSHA requirements
    - Fitting and testing
    - Training
    - Medical examinations
  - No beards
  - Reduced vision, communication, and efficiency
  - Discomfort
  - Logistics

PAG SUBCOMMITTEE GUIDANCE
DATED JULY 1994

ISSUE: How should the dose to emergency workers, especially those exposed to a radioactive plume, be monitored and controlled to meet the EPA dose limits in terms of total effective dose equivalent (TEDE)

- Guidance:
  - Relates to accidents at nuclear power plants
  - Based on current practices
  - Other approaches may be acceptable

PAG SUBCOMMITTEE GUIDANCE
(CONTINUED)

- Maintain 5 rem TEDE limit where practicable.

- The primary activities for emergency workers within an airborne plume will be:
  - Protection of valuable property,
  - Protection of large populations, and
  - Monitoring.

- States should maintain flexibility in dose limits

PAG SUBCOMMITTEE GUIDANCE
(cont'd)

- Doses up to 10 and 25 rem (and above) should be accepted and planned for.
- DRDs may be used to estimate inhalation dose.
- Use of KI is recommended.
- Flexibility in control procedures is granted.
- Three acceptable options are presented.

OPTIONS FOR ADJUSTING EMERGENCY WORKER GAMMA DOSE LIMITS TO ACCOUNT FOR SIGNIFICANT PARTICULATE RELEASES

Options[a]	Evacuation Phase	Post-Evacuation Phase
1	No adjustments	Adjust, if necessary
2	Fixed admin. limit set prior to Emrg.	Adjust, if necessary
3	Contextual adjustment based on plant data	Contextual adjustment based on plant and environmental data

[a]Oth r options may be co sid r d

OPTION ONE

- Control only whole body gamma and thyroid dose during evacuation.

- Rationale
  - Not practical to rotate workers
  - Inhalation dose is controlled for tasks after evacuation.
  - Evacuation may be completed before plume arrives.

- Disadvantages
  - Higher risk of over-exposure compared to other options

OPTION TWO

- Pre-established administrative limits

- Rationale
  - Easy to implement
  - Will meet limits for most probable accidents

- Disadvantages
  - May not provide adequate control for the most severe accidents
  - Possible discontinuity between States

DOSIMETER ADJUSTMENT FACTORS

Accid nt Category	Adjustme t Factors[a]	
	With KI	Without KI
BWR-1	13 to 29	16 to 37
PWR-1	8 to 16	11 to 26
BWR-3	3 to 7	5 to 12
PWR-3	4 to 8	6 to 14
PWR-5	1.4 to 2	3 to 6
PWR-7	1 to 2	1 to 2

[a] Calculated for distances ranging from 1 to 25 miles, stability classes ranging from A to F, and for 13 hours of exposure.

OPTION THREE

- Calculate contextual mission limits applicable to the accident in progress.

- Rationale
  - Can use same data as for dose projection
  - Mission limits would be more defendable.

- Disadvantages
  - Variable limits may be confusing to implement.
  - Necessary data may not be available.

RETROSPECTIVE EVALUATION OF DOSE FOR THE RECORD

- Applicable to emergency workers who are exposed to an airborne plume containing iodines and/or particulate materials

- KI administration affects the evaluation.

RETROSPECTIVE EVALUATION OF DOSE FOR THE RECORD
(cont'd)

- Based on dosimeter readings (primarily TLD) <u>and</u>
  - Release composition
  - Environmental data (importance of air samples)

- Or based on dosimeter readings <u>and</u>
  - Release composition
  - Whole body counts
  - Bioassay

RETROSPECTIVE ANALYSIS USING RELEASE AND ENVIRONMENTAL DATA

- Need measured dose rates and air sample data.
- Dose rate measurements by air sampling teams relate air concentrations to dosimeter readings.
- Calculations of ratio of exposure rate to air concentration allows worker dosimeter readings to be related to TEDE - becomes official record.

RETROSPECTIVE - PROBLEM

- Monitoring data at location A:
  GM counter (closed beta shield, 1 m) - 950 mR/h
  GM counter (open beta shield, 1 m - open window pointing up) - significantly higher

- Air sample is collected at location A and sent to the laboratory for analysis. The laboratory reports the following results:

Ce-141	1.0e-05	uCi/cm^3
Ba-140	1.0e-04	uCi/cm^3
Cs-134	1.0e-05	uCi/cm^3

- WHAT CONCLUSIONS CAN BE REACHED IMMEDIATELY FOR LOCATION A?

- WHAT ARE THE FOLLOWING FROM A 1 HR EXPOSURE?

  IMMERSION PLUS DEPOSITION DOSE (EDE)?
  INHALATION DOSE (CEDE)? (See WORK SHEET on VG 6-22.)
  TOTAL DOSE (TEDE)?

- WHAT IS THE DOSE TO EMERGENCY WORKERS EXPRESSED AS TEDE PER ROENTGEN AS READ ON A DOSIMETER?

RETROSPECT VE - PROBLEM SOLUT ON

- Immediate conclusions:
  - There had been a release of radioactive material .
  - The plume was present.
  - Particulates were present.
  - Actual risk could be much higher than implied by dosimeter readings.
- Compare DCFs from plume shine versus ground shine for Cs-134. (The DCF for deposited materials assumes persons remain 96 hours (4 days) at this location - correct for this).
  - The deposition dose is not significant because the 1 hr DCF is small compared to the immersion DCF.
- Assuming "mR" is approximately equal to "mrem", the whole body dose rate from gamma radiations (EDE/h) is:

  950 mrem/h

- Gamma dose (EDE) due to a 1 hour external exposure to the plume and groundshine

  $950 \text{ mrem/h} \cdot 1 \text{ h} = 950 \text{ mrem} = 0.95 \text{ rem}$

PROBLEM SOLUTION WORK SHEET

Problem Emergency worker : Projected Dose at Location A from inhalation

Nuclide(s)	Air Concentration (X) (uCi/cm^3)	Projected Exposure Time (h)	Integrated Air Concentration (X_{in}) (uCi · cm^{-3} · h)	DCF from Table 5-4 (rem per uCi · cm^{-3} · h)	Inhalation Committed Effective Dose Equivalent (CEDE) (rem)
Ce-141	1.0E-05				
Ba-140	1.0E-04				
Cs-134	1.0E-05				
				Totals >	

PROBLEM SOLUTION
(cont'd)

- Total projected dose (TEDE) to worker for nominal 1 hour exposure to plume:
  0.95 rem (EDE) + 1.12 rem (CEDE) + 0.00 (EDE) =
  2.07 rem (TEDE)

- Nominal expected increase in dosimeter reading after 1 hour is:

  0.95 rem (EDE) due to gamma from the plume +

  approximately 0.00 rem (EDE) due to gamma from ground shine

  total is 0.95 "R" recorded on dosimeter

- 0.95 "R" Dosimeter reading is equatable to a total dose for the record:
  2.07 rem (TEDE)

- Retrospective dose for the nominal worker record:

  ach 1.0 "R" on dosimeter is quivalent to 2.2 rem (TEDE)

FACTORS THAT MAY AFFECT DOSE CALCULATIONS

- Insufficient air sample and exposure rate data
- Ground shine becomes important.
- Emergency workers get significant doses outside the plume.
- Emergency workers do not take KI.
- Emergency workers use respirators.

PLAN CHANGES NEEDED TO SUPPORT OPTIONS 1 OR 2

- Specify the administrative dose limits for evacuation support.
- Specify procedures for dose control after evacuation is complete.

PLAN CHANGES NEEDED TO SUPPORT OPTION 3

- Specify procedures for contextual determination of administrative dose limits.
  - Calculation models to be used
  - Data needs
  - Sources of data

- Identify communication procedures and equipment.

- Procedures for changing the administrative limits if applicable

GU DANCE APPLICABLE TO ALL OPT ONS

- Other options may be se ected.
  - FEMA will review written proposals.
- FEMA recommends admin. limits of 2 R or more.
- Need procedures for:
  - Retrospective dose determinations
  - Training
- Existing dosimetry systems are acceptable.
- KI use is recommended.

SESSION 7

DEVELOPMENT

OF

DCFs AND DRLs

IMPLEMENTATION OF PAGS

- Must compare a projected TEDE or CDE to the applicable PAG

- BASIC DOSE EQUATION

  - Dose (TEDE or CDE) = Dose Rate x Time

  - Dose Rate = Concentration x Conversion Factor

  - Dose = Time Integrated Concentration x DCF

DEFINITIONS

- Dose Conversion Factor (DCF): A value that converts an environmental level to dose.
    - Tabulated in units of: rem per uCi · cm^{-3} · h
- Derived Response Level (DRL): Calculated environmental level that corresponds to a particular PAG.
    - Tabulated in units of: uCi · cm^{-3} · h

PATHWAYS
(PAG Manual - Section 5.6)

- Three exposure pathways are included:
  - Gammas from the plume (immersion)
  - Inhalation from plume
  - Gammas from ground shine (deposited radionuclides)

- Pathways considered, but not included:
  - Beta due to skin deposition
  - Inhalation of resuspended materials
  - Beta from the plume

SUPPORTING DOCUMENTS FOR DCFS

- "External Dose-Rate Conversion Factors for Calculation of Dose to the Public" (DOE/EH 0070)
  - Needed for plume and ground shine

- "Limiting Values of Radionuclide Intake and Air Concentration and, Dose Conversion Factors for Inhalation, Submersion and Ingestion" (FGR-11) EPA 520/1-88-020 (September 1988).
  - Needed only to modify EPA DCFs for inhalation

TIME INTEGRATED AIR CONCENTRATION, X_{in}

- Air concentration times projected exposure time.

$$X(uCi/cm^3) \cdot T_p(hour) = X_{in}$$

- Permits addition of the dose conversion factors over the three exposure pathways.

EXTERNAL EXPOSURE TO GAMMA RADIATION FROM THE PLUME
(Section 5.6.1)

- Table 5-3 (PAG manual, beginning on P. 5-25)
- Gamma radiation due to immersion.
- Conservative if plume is overhead.
- Semi-infinite source assumption.

EXTERNAL EXPOSURE TO GAMMA RADIATION FROM THE PLUME
(cont'd)

- DCFs yield effective dose equivalent (EDE).
- Based on DOE/EH-0070; EPA FGR #12.
- Short-lived daughters are accounted for.

Table 5-3: Dose Conver ion Factor (DCF) and Derived Re ponse Leve s (DRL) for Externa Exposure Due to mmer ion in Contaminated Air

Radionuclide	DCF rem per $uCi \cdot cm^{-3} \cdot h$	DRL $uCi \cdot cm^{-3} \cdot h$
H-3	0.0E+00	0.0E+00
C-14	0.0E+00	0.0E+00
Na-22	1.3E+03	7.8E-04
Na-24	2.7E+03	3.7E-04
P-32	0.0E+00	0.0E+00

PAG M nu l - beginning on p g 5-25

INHALATION FROM THE PLUME
(Section 5 6 2)

- Table 5-4 (PAG manual, beginning on 5-31)
- Inhalation of radioactive particulate material
- Alpha, beta and gamma emitters
- Chemical and physical form that yields the highest dose

INHALATION FROM THE PLUME
(Section 5.6.2)
(cont'd)

- Committed effective dose equivalent (CEDE)
- Radionuclides may remain in the body.
- 50 year time frame for dose
- Federal Guidance Report No. 11
- Standard Person

Table 5-4: Dose Conversion Factors (DCF) and Derived Response levels (DRL) for Doses Due to Inhalation

Radionuclide	Lung Class	DCF rem per $uCi \cdot cm^{-3} \cdot h$	DRL $uCi \cdot cm^{-3} \cdot h$
H-3	V	7.7E+01	1.3E-02
C-14	L ORG C[a]	2.5E+03	4.0E-04
Na-22	D	9.2E+03	1.1E-04
Na-24	D	1.5E+03	6.9E-04
P-32	W	1.9E+04	5.4E-05

[a]L ORG C denotes labelled organic compounds

PAG Manu l - b ginning on pag 5-31

Table 5-4: Dose Conversion Factors (DCF) and Derived Response levels (DRL) for Doses to the Thyroid Due to Inhalation

Radionuclide	Lung Class	DCF rem per $uCi \cdot cm^{-3} \cdot h$	DRL $uCi \cdot cm^{-3} \cdot h$
Te/I-132	W/D	2.9E+05	1.8E-05
I-125	D	9.6E+05	5.2E-06
I-129	D	6.9E+06	7.2E-07
I-131	D	1.3E+06	3.9E-06

PAG Manual - beginning on page 5-35
Also see Table 5-2 on page 5-15

EXTERNAL DOSE FROM DEPOSITED MATERIALS
(Section 5.6.3)

- Table 5-5 (PAG manual, beginning on 5-37)
- Gamma radiation following deposition
- Radioiodine and particulates from a plume
- Assumes 4-day exposure
- Dry deposition

EXTERNAL DOSE FROM DEPOSITED MATERIALS
(cont'd)

- Deposition velocity
  - 0.1 cm/s for particulate materials
  - 1 cm/s for radioiodine
  - Much higher if there is rain

EXTERNAL DOSE FROM DEPOSITED MATERIALS
(cont'd)

- DCF for deposited materials is the effective dose equivalent (EDE) in rem per:
  - 1 uCi/cm^3 concentration of a radionuclide
  - 1 hour of deposition
  - 96 hours of exposure to decaying radionuclides

TABLE 5-5: DCF EQUATION FOR GROUND SHINE
(pp. 5-34 and 5-37)

$$DCF = V_g \cdot DRCF \cdot 1.14E\text{-}3 \left[\frac{1 - e^{-\lambda t}}{\lambda} \right]$$

DCF = the dose per unit air concentration
(rem per uCi · cm^{-3} · h)

TABLE 5-5: DCF EQUATION
(cont'd)

- V_g = deposition velocity (cm/h)
- DRCF = the dose rate conversion factor from DOE/EH 0070 (mrem/y per uCi/m^2)
- 1.14E-3 = conversion factor from mrem/y per uCi/m^2 to rem/h per uCi/cm^2
- λ = decay constant (h^{-1})
- t = duration (h), assumed to be 96 hours

Table 5-5: Dose Conversion Factors (DCF) and Derived Response levels (DRL) for a 4-Day Exposure to Gamma Radiation from Deposited Radionuclides

Radionuclide	DCF rem per $uCi \cdot cm^{-3} \cdot h$	DRL $uCi \cdot cm^{-3} \cdot h$
H-3	0.0E+00	- -
C-14	0.0E+00	- -
Na-22	8.3E+03	1.2E-04
Na-24	3.1E+03	3.2E-04
P-32	0.0E+00	- -

PAG Manual - beginning on page 5-37.

MOD FY NG DOSE CONVERS ON FACTORS

- Changes in physical characteristics
- Changes in chemical characteristics
- Changes in breathing rates
- Changes in assumed deposition velocities

COMBINED PATHWAYS

(PAG Manual, Table 5-1)

- The DCF and DRL for each pathway is related to the time integrated air concentration (X_{in}). They may be combined for a particular radionuclide

- $\text{Dose}_{Total} = \text{Dose}_{Ext} + \text{Dose}_{Inh} + \text{Dose}_{Ground\ Shine}$

$$\text{Dose}_{Total} = DCF_{Ext} \cdot X_{in} + DCF_{Inh} \cdot X_{in} + DCF_{GS} \cdot X_{in}$$

$$\text{Dose}_{Total} = X_{in} \cdot (DCF_{Ext} + DCF_{inh} + DCF_{GS}) = X_{in} \cdot DCF_{combined}$$

Table 5-1: Dose Conversion Factors (DCF) and Derived Response levels (DRL) for Combined Exposure Pathways During the Early Phase of a Nuclear Incident

Radionuclide	DCF rem per $uCi \cdot cm^{-3} \cdot h$	DRL $uCi \cdot cm^{-3} \cdot h$
H-3	7.7E+01	1.3E-02
C-14	2.5E+03	4.0E-04
Na-22	1.9E+04	5.3E-05
Na-24	7.3E+03	1.4E-04
P-32	1.9E+04	5.4E-05

PAG M nual - b ginning on p g 5-9.

EXAMPLE OF COMBINED PATHWAYS

Nuclide selected__________

		DCF	X_{in}	Dose
Pathway	Table	(rem per $uCi \cdot cm^{-3} \cdot h$)	($uCi \cdot cm^{-3} \cdot h$)	(rem)
External	5-3		1	
Inhalation	5-4		1	
Ground Shine	5-5		1	
Summation				
Combined	5-1		1	

SESSION 8

DOSE PROJECTION PROBLEMS

FOR THE EARLY PHASE

INTRODUCTION

- Two student problems

1. Use of combined pathways DCFs
   1a-1 Thyroid dose at 1 mile
   1b-1 TEDE at 1 mile
   1a-2 Thyroid dose at 2 miles
   1b-2 TEDE at 2 miles

2. Use of separate pathway DCFs

STEPS TO DETERMINE THE REQUESTED PROJECTED DOSES

- Determine diffusion coefficients ($X\bar{u}/Q$) at the distances required.
- Determine the wind speed in m/s ($\bar{u}$).
- Determine the source term in Ci/s (Q).
- Solve for X.

STEPS TO DETERMINE THE REQUESTED PROJECTED DOSES
(cont'd)

- Determine the projected exposure time (T_p).
- Calculate the time integrated concentration (X_{in}).
- Select the specific DCF (rem per $\mu Ci \cdot cm^{-3} \cdot h$).
- Calculate the projected dose (rem).

PROBLEM : PROJECTED DOSE
US NG COMB NED PATHWAY DCFs

Problem 1a: Determine the Committed Dose Equivalent (CDE) to the thyroid from a plume containing I-131, and

Problem 1b: Determine the Total Effective Dose Equivalent (TEDE) for a plume with a mix of three isotopes (Xe-133, I-131, and Cs-134).

And: Determine the above doses at 1 mile and 2 miles from the release point.

PROBLEM 1

- Calculate at 1 mile
  - Concentrations (X)
  - Time Integrated Concentration (X_{in})
  - Dose (CDE to Thyroid and TEDE)
- Use Worksheet (VG 8-6)

RAD AT ON ACC DENT ASSESSMENT COURSE
WORK SHEET

Problem 1a -1 & 1b-1 : Projected Dose at 1 Mile(s): From thyroid & combined pathway

Nuclide(s) & Prblm. # 1a-1	$X\bar{u}/Q$ @ 1 mi (m^{-2})	Q (Ci/s)	$\bar{u}$ (m/s)	X @ 1 mi ($\mu Ci/cm^3$)	Exp. time (h)	X_{in} @ 1 mi ($\mu Ci \cdot cm^{-3} \cdot h$)	DCF Table No.	DCF_{th} $\frac{rem}{\mu Ci \cdot cm^{-3} \cdot h}$	Dose (CDE) (rem)
I-131									
Nuclide # 1b-1									TEDE (rem)
								DCF_{cp}	
Xe-133									
I-131									
Cs-134									
								TOTAL →	

PROBLEM 1 INITIAL CONDITIONS

- Time from shutdown to release. 2 hours
- Estimated release time: 3 hours
- Release height: Ground level
- Stability is class D.
- Wind speed is 2 m/s (4.5 mph).
- Forecast is for no change.

Xu/Q AS A FUNCTION OF DOWNWIND DISTANCE AND STABILITY CLASS

Values of $X\bar{u}/Q$ (m^{-2})

Di tance (M'le)	Class A	Class B	Class C	Class D	Class E	Ciass F
0.5	6.6E-6	3.0E-5	7.6E-5	2.1E-4	4.2E-4	9.6E-4
1	1.0E-6	7.4E-6	2.1E-5	7.0E-5	1.4E-4	3.3E-4
2	5.5E-7	1.9E-6	6.1E-6	2.4E-5	5.0E-5	1.2 -4
3	3.9E-7	8.4E-7	2.9E-6	1.3E-5	2.8E-5	6.8E-5
4	3.0E-7	4.8E-7	1.7E-6	8.5E-6	1.9E-5	4.6 -5
5	2.5E-7	3.3E-7	1.2E-6	6.1E-6	1.4E-5	3.3 -5
7	1.9E-7	2.5E-7	6.3E-7	3.7E-6	8.4E-6	2.2E-5
10	1.4E-7	1.8E-7	3.3E-7	2.3E-6	5.1E-6	1.4E-5
15	9.9E-8	1.3E-7	1.8E-7	1.2E-6	3.1E-6	8.4E-6

A 1250 meter lid is used.
This a ground level release.

PROBLEM 1: SOURCE TERM

SOURCE TERM (Q):

- Xe-133	1,700 Ci/s
- I-131	0.17 Ci/s
- Cs-134	0.05 Ci/s

PROBLEM 1a-1
CALCULATE AIR CONCENTRATION (X)

- At 1 mile and for I-131:

$$X\bar{u}/Q = 7.0E\text{-}05 \quad \text{(from VG 8-8)}$$

- WHERE:
  - X = air concentration ($\mu Ci/cm^3$)
  - $\bar{u}$ = average wind speed (m/s)
  - Q = source term (Ci/s)

- SOLVE FOR X AT 1 MILE:

PROBLEM 1a-1: CALCULATE INTEGRATED AIR CONCENTRATION (X_{in}) FOR I-131

Using values recorded on the Work Sheet

Solve for X_{in}:

$$X_{in} = X \cdot t$$

PROBLEM 1a-1
COMMITTED DOSE EQUIVALENT (CDE) TO THE THYROID

- The committed dose equivalent (CDE) to the thyroid is:

______________________ $(X_{in} \cdot DCF_{th})$

- The dose model is:

$$CDE_{th} = DCF_{th} \cdot X_{in} = DCF_{th} \cdot \left[\frac{Q}{\bar{u}} \cdot \frac{X\bar{u}}{Q} \cdot h \right]$$

PROBLEM 1b-1: PROJECTED DOSE

- Calculate the TEDE for three nuclides: Xe-133, I-131, and Cs-134.

- Assumptions: Same as for problem 1a-1

- Dose Model:

$$TEDE = DCF_{cp} \cdot X_{in} = DCF_{cp} \left[\frac{Q}{\bar{u}} \cdot \frac{X\bar{u}}{Q} \cdot h \right]$$

PROBLEM 1b-1
SOLVE FOR X AT 1 MILE FOR THREE NUCLIDES

- Model:

$$X = \frac{X\bar{u}}{Q} \cdot \frac{Q}{\bar{u}}$$

Calculate concentrations (X)

$$\left.\begin{array}{ll} Xe-133, & Q = 1.7E+3 \\ I-131, & Q = 1.7E-1 \\ Cs-134, & Q = 5.0E-2 \end{array}\right\} \cdot \quad 7.0E-5 \; =$$

$\bar{u} = 2$ m/s

PROBLEM Ib-I
INTEGRATED AIR CONCENTRATION (X_{in})

- Using the results from VG 8-14

- Solve for X_{in} for the three nuclides.

$$X_{in} = X \cdot t$$

- Exposure duration = 3 hours

PROBLEM 1a-2
SOLVE FOR (CDE) TO THE THYROID FROM I-131 AT 2 MILES

$$CDE_{th} = DCF_{th} \cdot X_{in}$$

- Step 1. Obtain $X\bar{u}/Q$ for 2 mi = 2.4E-5. (VG 8-8)

- Step 2.

$$X = \left[\frac{2.5E-5 \ m^{-2} \cdot 1.7E-1 \ Ci/s}{1 \ m/s} \right]$$

PROBLEM 1a-2
SOLVE FOR THE (CDE) TO THE THYROID FROM I-131 AT 2 MILES

- Step 3. $X_{in} = X \cdot h =$

- Step 4. Obtain DCF_{th}. The Table is ________

  - The value is ________________

- Step 5. Dose = $X_{in} \cdot DCF_{th}$ = ____________
  Use the Worksheet on VG 8-18

RAD AT ON ACC DENT ASSESSMENT COURSE
WORK SHEET

Problem 1a-2 & 1b-2 : Projected Dose at 2 Mile(s): From thyroid & combined pathway

Nuclide(s) & Prblm. # 1a-2	$X\bar{u}/Q$ @ 2 mi (m^{-2})	Q (Ci/s)	$\bar{u}$ (m/s)	X @ 2 mi ($\mu Ci/cm^3$)	Exp. time (h)	X_{in} @ 2 mi ($\mu Ci \cdot cm^{-3} \cdot h$)	DCF Table No.	DCF_{th} $\frac{rem}{\mu Ci \cdot cm^{-3} \cdot h}$	Dose (CDE) (rem)
I-131									
Nuclides # 1b-2									TEDE (rem)
								DCF_{cp}	
Xe-133									
I-131									
Cs-134									
								TOTAL →	

PROBLEM b-2: DOSE PROJECT ON TEDE AT 2 M LES

- Using the same assumptions for the three radionuclides, calculate the TEDE at 2 miles.

  - Exposure duration = 3 hours

  - Stability class = D

  - Wind speed = 2 m/s

- $CDE_{cp} = DCF_{cp} \cdot X_{in} = DCF_{cp} \cdot (Q/\bar{u} \cdot X\bar{u}/Q \cdot h)$

PROBLEM 1b-2: FIND TEDE AT 2 MILES FOR Xe-133, I-131, AND Cs-134

- Step 1

$$X_{2mi} = \frac{X\bar{u}}{Q} \cdot \frac{Q}{\bar{u}} = 2.4E{-5} \cdot \begin{Bmatrix} 1.7E{+3} \\ 1.7E{-1} \\ 5.0E{-2} \end{Bmatrix} \div 2$$

- Step 2 → $X \cdot h = X_{in}$ ($h = 3$)
- Step 3 → $X_{in} \cdot DCF_{cp} = TEDE$
- DCF_{cp} comes from Table ____________

PROBLEM 2: DOSE PROJECTION USING SEPARATE PATHWAY DCFs

- Assumptions:

  - Time from shutdown to release: 2 hours

  - Estimated release time: 3 hours

  - Release height: Ground level

- Stability is class D

  - Wind speed is 2 m/s (4.5 mph).

PROBLEM 2: PROJECTED DOSE AS A FUNCTION OF PATHWAY

- Same source terms, meteorology, and exposure time as for problem 1.

- Same integrated air concentrations.

- Three separate exposure pathways.

PROBLEM 2: PROJECTED DOSE AS A FUNCTION OF PATHWAY (cont'd)

- External dose (EDE) from the plume (Table 5-3)
- Plume inhalation dose (CEDE) (Table 5-4)
- External dose (EDE) from deposited radionuclides (Table 5-5)

PROBLEM 2: DOSE MODELS

$$Dose_p = DCF_p \cdot X_{in} = DCF_p \cdot \left[\frac{Q}{\bar{u}} \cdot \frac{X\bar{u}}{Q} \cdot h \right]$$

- $(X\bar{u}/Q \cdot Q/\bar{u}) \cdot h = X \cdot h = X_{in}$
- For I-131: (2.4E-5) · (1.7E-1)/2 = 2.0E-6 Ci/m^3
- 2.0E-6 Ci/m^3 · 3h = 6.0E-6 (μCi · cm^{-3} · h)
- Calculate X_{in} and dose for each nuclide.
- Fill in matrixes (VG 8-25, 26, and 27).

RADIOLOGICAL ACCIDENT ASSESSMENT COURSE
WORK SHEET

Problem 2a : Projected Dose at 2 Mile(s): From immersion pathway

Nuclide(s) & Prblm. # 2a	$X\bar{u}/Q$ @ 2 mi (m^{-2})	Q (Ci/s)	$\bar{u}$ (m/s)	X @ 2 mi ($\mu Ci/cm^3$)	Exp. time (h)	X_{in} @ 2 mi ($\mu Ci \cdot cm^{-3} \cdot h$)	DCF Table No.	DCF_{im} $\frac{rem}{\mu Ci \cdot cm^{-3} \cdot h}$	Dose (___) (rem)
Xe-133									
I-131									
Cs-134									
								TOTAL →	

RAD OLOG CAL ACC DENT ASSESSMENT COURSE
WORK SHEET

Problem__2b__: Projected Dose at__2__Mile(s): From inhalation__ pathway

Nuclide(s) & Prblm. # 2b	$X\bar{u}/Q$ @ 2 mi (m^{-2})	Q (Ci/s)	$\bar{u}$ (m/s)	X @ 2 mi ($\mu Ci/cm^3$)	Exp. time (h)	X_{in} @ 2 mi ($\mu Ci \cdot cm^{-3} \cdot h$)	DCF Table No.	DCF_{inh} $\frac{rem}{\mu Ci \cdot cm^{-3} \cdot h}$	Dose (__) (rem)
Xe-133									
I-131									
Cs-134									
								TOTAL →	

RAD OLOG CAL ACC DENT ASSESSMENT COURSE
WORK SHEET

Problem 2c : Projected Dose at 2 Mile(s): From deposition pathway

Nuclide(s) & Prblm. # 2c	$X\bar{u}/Q$ @ 2 mi (m^{-2})	Q (Ci/s)	$\bar{u}$ (m/s)	X @ 2 mi ($\mu Ci/cm^3$)	Exp. time (h)	X_{in} @ 2 mi ($\mu Ci \cdot cm^{-3} \cdot h$)	DCF Table No.	DCF_{dep} $\frac{rem}{\mu Ci \cdot cm^{-3} \cdot h}$	Dose (___) (rem)
Xe-133									
I-131									
Cs-134									
								TOTAL →	

RADIOLOGICAL ACCIDENT ASSESSMENT COURSE
WORK SHEET

Problem # 2

The dose model is: Dose = DCF · X_{in} = DCF · (Q/ū · Xū/Q · h)

DOSE PROJECTION AT 2 MILES FOR INDIVIDUAL PATHWAYS				
Nuclide	Pathway	DCF rem / ($\mu Ci \cdot cm^{-3} \cdot h$)	X_{in} ($\mu Ci \cdot cm^{-3} \cdot h$)	Dose (rem)
I-131	immersion	2.2E+2	6.0E-6	1.3E-3
	inhalation	3.9E+4	6.0E-6	2.4E-1
	deposition	1.3E+4	6.0E-6	8.0E-2
	TEDE for I-131			3.2E-1
Cs-134	immersion	9.1E+2	1.8E-6	1.7E-3
	inhalation	5.6E+4	1.8E-6	1.0E-1
	deposition	6.2E+3	1.8E-6	1.1E-2
	TEDE for Cs-134			1.1E-1
Xe-133	immersion	20	6.0E-2	1.2
	inhalation	0	6.0E-2	0
	deposition	0	6.0E-2	0
	TEDE for Xe-133			1.2
TEDE for all radionuclides combined				1.5

SESSION 9

PROTECTIVE ACTION GUIDES FOR RELOCATION AND RETURN

AND

DOSE LIMITS FOR RECOVERY WORKERS

THE "R" WORDS
(p. A-3)

- Relocation: The removal or continued exclusion of people (households) from contaminated areas to avoid <u>chronic</u> radiation exposure.

- Return: The reoccupation of areas cleared for <u>unrestricted</u> residence or use.

- Restricted zone: An area with controlled access from which the population has been relocated.

THE "R" WORDS
(p. A-3)
(cont'd)

- Reentry: Temporary entry into a restricted zone under controlled conditions.

- Recovery: The process of reducing radiation exposure rates and concentrations in the environment to acceptable levels for unconditional occupancy or use.

POTENTIAL TIME FRAME OF RESPONSE TO A NUCLEAR INCIDENT

- Refer to PAG Manual Page 7-5.
- Times are estimates only.
- Sequences may vary some.

EXPOSURE PATHWAYS
(p. 4-2)

- Pathways to be evaluated as basis for relocation
  - Whole body exposure to gamma radiation
  - Inhalation of resuspended materials

- Minor pathways (no evaluation needed for reactor accidents)
  - Beta skin exposure
  - Inadvertent ingestion of dirt
  - Refer to EPA 520/1-89-016

ESTIMATED DOSE FROM MINOR EXPOSURE PATHWAYS

Individual[a]	Exposure Pathway	First Year Dose (rem)	
		Soil	Pavement
adult	skin[b]	2.4	8.4
	ingestion[c]	0.01	0.1
child	skin[b]	8.1	14
	ingestion[c]	0.05	0.5
adult or child	groundshine	1.0	1.0

[a]Maximum exposed individuals. Average exposure is about 1/3 to 1/6 lower.

[b]Includes beta dose from nearby surfaces and from material on the skin.

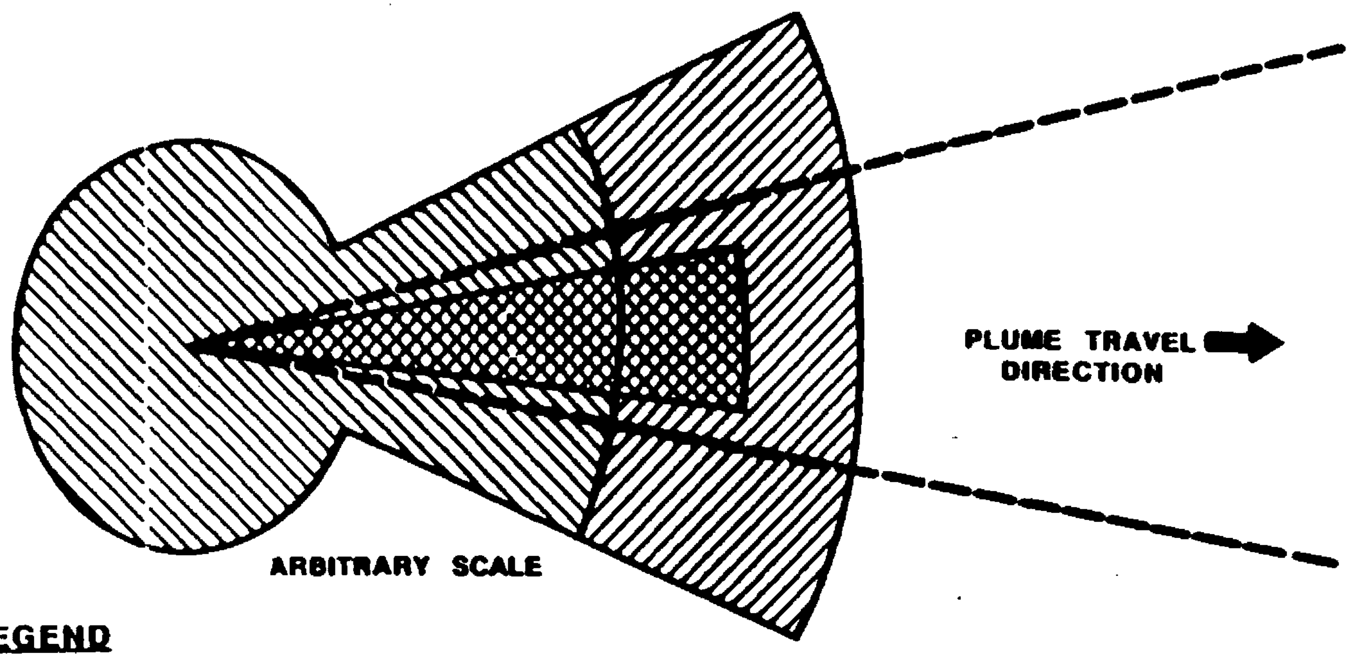
[c]Inadvertent ing stion of cont mi at d dirt.

RELOCATION AND RETURN PAGS
(p. 4-4)

Projected Dose From First Year Exposure	Protective Action
≥2 rem TEDE ≥100 rem DE skin	Establish restricted zone and relocate the general population.
<2 rem TEDE <100 rem DE	Apply simple dose reduction techniques to skin.

RELOCATION AND RETURN PAGS
(p. 4-4, 4-5, E-13, & E-20)
(cont'd)

- Additional guidance
  - 0.5 rem in any year after the first
  - 5 rem in 50 years
- Actual dose should be less than projected dose
  - Shielding
  - Mobility
  - Special dose reduction efforts
  - Refer to tabl s on p ges E-13 and E-20



LEGEND

1. PLUME DEPOSITION AREA.
2. AREA FROM WHICH POPULATION IS EVACUATED.
3. AREA IN WHICH POPULATION IS SHELTERED.
4 FROM WHICH LATION IS RELOCATED (RESTRICTED ZONE).

GRADUAL RETURN
(p. 4-5 & 7-4)

- Establishment of buffer zone

- Gradual return

- FEMA option to combine temporary relocation and gradual return boundaries

    - Advantage - no early dose calculations

    - Disadvantage - large relocation area
      - major public disruption

DOSE REDUCTION FOR RETURNEES
(p. 4-3)

- Areas for priority
    - Dose in excess of 0.5 rem in 1st year
    - Residences of pregnant women
- Responsibility for actions

EXAMPLES OF
S MPLE DOSE REDUCT ON TECHN QUES
(pp. 4-3, 7-6, E-13, & E-19)

- Scrub/flush/wipe hard surfaces.
- Soak or plow soil.
- Cut and remove grass clippings and other foliage.
- Remove spots of soil where radioactivity has concentrated.
- Disposal of contaminated materials

SIMPLE DOSE REDUCTION TECHNIQUES
(pp. 4-3, 7-6, E-13, & E-19)
(cont'd)

- Remove debris.
- Spend more time in areas with lower contamination levels (e.g., indoors).
- Replace sandbox sand.
- Pay special attention to child hygiene.

RAT ONALE - FOUR PR NC PLES

- Acute health effects
- Delayed health effects
- Cost of avoiding risk
- Risk - risk comparison

FACTORS <u>NOT</u> NCLUDED N THE RELOCAT ON PAGs

- Physical and mental stress
- Past exposures
- Dose from ingestion
- Dose from occupational exposure

COST ANALYSIS
(pp. E-8, E-9, & E-10)

- Assumptions:

  - Value of avoiding a statistical death is $400,000 to $7,000,000.

  - Average daily cost of relocation is $27 - Refer to EPA 520/1-89-015.

- Where does the daily cost of relocation equal the monetary value of average daily risk avoided?

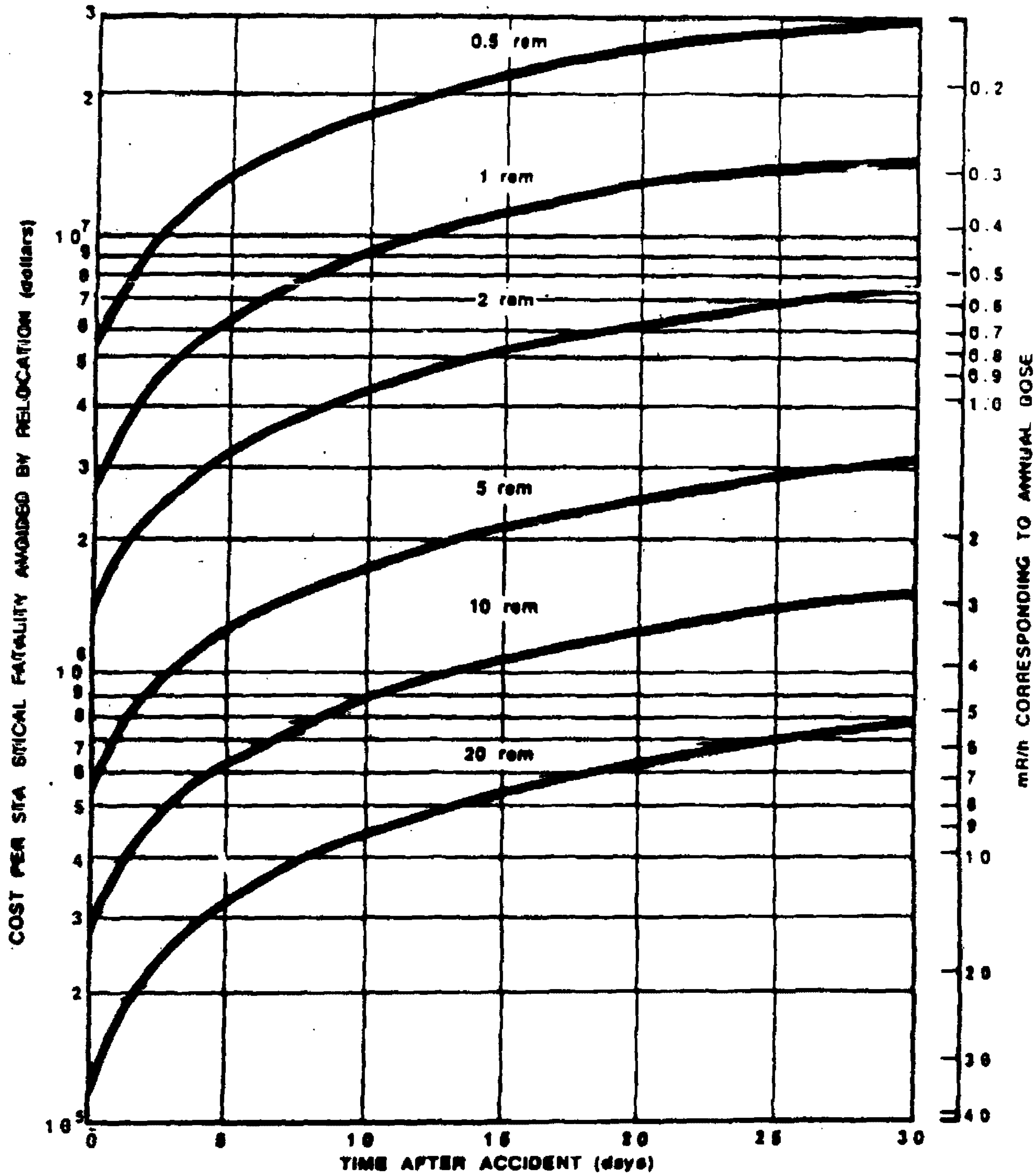


FIGURE E-3. COST OF AVOIDING STATISTICAL FATALITIES AND EXPOSURE RATES CORRESPONDING TO VARIOUS TOTAL FIRST YEAR DOSES (ASSUMES AN SST-2 ACCIDENT AND A $27 PER PERSON-DAY COST OF RELOCATION).

BASIS FOR SETTING PAG LEVELS
(p.1-5)

PRINCIPLE	STRATEGY
(1) Avoid acute health effects.	Stay below threshold dose.
(2) Adequately protect against cancer and genetic effects under emergency conditions.	Set PAG at this level unless driven down by cost/risk considerations (3), or up by risk/risk considerations (4).
(3) Optimize cost of protective action versus avoided dose.	Use this principle only if the the PAG value is driven down.
(4) Regardless of the above principles, the risk from a protective action should not itself exceed the risk from the dose that would be avoided.	Use this principle only if the PAG value is driven up.

CONCLUSIONS ON APPROPRIATE VALUE FOR RELOCATION PAG
(p. E-18)

- Principle on acute effects is not applicable.

- Judgment of acceptable level of risk of delayed health effects:
  - 5 rem in 50 years
  - 0.5 rem in any single year after the first

- 2 rem in the first year will meet the above criteria for nuclear power plant accidents.

CONCLUSIONS ON APPROPRIATE VALUE FOR RELOCATION PAG
(p. E-18)
(cont'd)

- Cost will not drive the first year dose below 2 rem.

- Risk from relocation is assumed to be the same as for evacuation (i.e., equivalent to the risk from about 30 mrem).

DOSE LIMITS FOR RECOVERY WORKERS
(pp. 4 6, 7 17, & E 19)

- Same as for occupationally exposed workers

- TEDE	5 rem/y
- CDE to any organ	50 rem/y

- One tenth these values to persons under age 18

- TEDE to declared pregnant women	0.5 rem/9mo

SESSION 10

DATA COLLECTION AND DOSE PROJECTION

FOR

RELOCATION AND RETURN DECISIONS

IMPLEMENTING PAGS FOR THE INTERMEDIATE PHASE

- Relocation
- Reentry
- Return
- Early Decontamination
- Ingestion of Food and Water
  - Independent decision

OVERV EW OF
MPLEMENTAT ON PROCESS

- Collect environmental samples.

- Analyze samples.

- Calculate
  - Exposure rates and projected dose.
  - Accident specific DCFs.
  - Derived response level.

- Make gamma exposure rate measurements.

OVERV EW OF
MPLEMENTAT ON PROCESS
(cont'd)

- Take air samples and calculate projected dose from inhalation of resuspended materials.
- Identify the boundary of the restricted zone.
- Relocate the population.
- Identify the buffer zones.
- Implement gradual return.

SAMPLE COLLECT ON AND ANALYS S

- Purpose of samp es
  - Dose projection
  - Evaluation of variation in mix by area

- Nature of samples

- Locations of samples
  - Based on exposure rate
  - Priorities
  - Terrain

- Types of analyses

ALTERNATIVE METHODS FOR DOSE PROJECTION

- METHOD ONE - Sample from each area of interest
  - Known size of area in each sample
  - Use data from each sample analysis to project dose.
  - Plot projected doses on map to identify location of boundary to the restricted zone.

ALTERNATIVE METHODS FOR DOSE PROJECTION
(cont'd)

- METHOD TWO - Take a few samples from several areas.

- Determine whether the radionuclide mix is reasonably constant or predictable. If so:

  - Calculate a time-dependent derived response level (DRL_{td}) corresponding to the PAG.

  - Use the DRL_{td} to identify the restricted zone.

CONS DERAT ON OF METHOD ONE

- Requires a arge number of
  - samples
  - laboratory analyses
  - dose projections
- May yield wrong result for other than flat terrain
- Only method available if radionuclide mix is neither constant nor predictable

CONSIDERATION OF METHOD TWO

- Not useful for an inconsistent mix of radionuclides.
- Greatly reduces the sampling and laboratory effort.
- Results are independent of terrain type or presence of contaminated foliage.
- Inaccuracies due to non-representative samples cancel.

EXAMPLE CALCULATION OF EXPOSURE RATE
- Method One -

Radionuclide	Concentration pCi/m^2	Initial exposure Rate @ 1m (mR/h per pCi/m^2) (table 7-1 or 7-2)	Exposure Rate @ 1m (mR/h)
Cs-134	2E+7		
I-131	3E+7		
		Total:	

EXAMPLE CALCULATION OF PROJECTED DOSE
- Method One -

Integrated Dose - Year One					
		Weathering		No Weathering	
Radionuclide	Concentration (pCi/m^2)	DCF ($mrem/pCi/m^2$) (Table 7-1)	Projected Dose (mrem)	DCF ($mrem/pCi/m^2$) (Table 7-2)	Projected Dose (mrem)
Cs-134	2E+7				
I-131	3E+7				
		TOTAL		TOTAL	

EXAMPLE CALCULATION OF PROJECTED DOSE
- Method One -

Integrated Dose - Year Two					
		Weathering		No Weathering	
Radionuclide	Concentration(pCi/m^2)	DCF ($mrem/pCi/m^2$) (Table 7-1)	Projected Dose (mrem)	DCF ($mrem/pCi/m^2$) (Table 7-2)	Projected Dose (mrem)
Cs-134	2E+7				
I-131	3E+7				
		TOTAL		TOTAL	

EXAMPLE CALCULATION OF PROJECTED DOSE
- Method One -

Integrated Dose - Zero to 50 Years					
Radionuclide	Concentration (pCi/m^2)	Weathering		No Weathering	
		DCF ($mrem/pCi/m^2$) (Table 7-1)	Projected Dose (mrem)	DCF ($mrem/pCi/m^2$) (Table 7-2)	Projected Dose (mrem)
Cs-134	2E+7				
I-131	3E+7				
		TOTAL		TOTAL	

METHOD 2

- Calculate an accident-specific dose conversion factor (DCF_{as}).
  - This factor is time dependent.

- Use DCF_{as} to calculate a time-dependent derived response level (DRL_{td}) in mR/h corresponding to the PAG.

CALCULAT ON OF ACCIDENT SPEC F C DCF
Method 2

$$DCF_{as} = \frac{mrem\ per\ yr{-}1,\ yr{-}2,\ or\ 0\ to\ 50\ yr}{Exposure\ Rate\ @\ 1\ m\ (mR/h)}$$

- Assume weathering and results from VGs 9, 10, 11, and 12, and calculate:
  - Year one DCF_{as} = ____________________
  - Year two DCF_{as} = ____________________
  - Zero to 50 year DCF_{as} = ____________________

CALCULATION OF ACCIDENT SPECIFIC DRL
Method 2

$$DRL_{td} = \frac{PAG}{DCF_{as}}$$

- For the previous example (weathering included):
  - Year one DRL_{as} = ______________
  - Year two DRL_{as} = ______________
  - Zero to 50 year DRL_{as} = __________________

DCF FOR PROJECTED EXTERNAL GAMMA DOSE

$$DCF = DS_f \int_0^t e^{-(\lambda_R + \lambda_2 + \lambda_3)t}\, dt$$

$$DCF = DS_f \left\{ \frac{.63\left\{1 - e^{-(\lambda_R + \lambda_2)t}\right\}}{\lambda_R + \lambda_2} + \frac{.37\left\{1 - e^{-(\lambda_R + \lambda_3)t}\right\}}{\lambda_R + \lambda_3} \right\}$$

D = dose rate per unit deposit (mrem/yr per pCi/m^2) (data in DOE EH 0070)

S_f = protection factor for shielding and partial occupancy (assumed to be unity)

λ_R = radioactive decay constant (yr^{-1})

λ_2 = assumed weathering decay constant for 63% of the radionuclide = 1.13 yr^{-1}

λ_3 = assumed weathering decay constant for 37% of the radionuclide = 7.48E-3 yr^{-1}

t = time of exposure (yr)

CALCULATION OF DOSE FROM INHALATION OF RESUSPENDED MATERIALS (CEDE)

(Table 7-4, p. 7-16)

$$H_{50} = I \times DCF$$

WHERE:

H_{50} = CEDE for 50 y from intake of nuclides

I = total intake (pCi)

DCF = dose per unit intake for the radionuclide (rem per pCi)

- Data are from EPA FGR No. 11
- Convert to appropriate units

TOTAL INTAKE FROM INHALATION OF RESUSPENDED MATERIAL

$$I = BC_0 \left\{ \frac{.63\left\{1 - e^{-(\lambda_R + \lambda_2)t}\right\}}{\lambda_R + \lambda_2} + \frac{.37\left\{1 - e^{-(\lambda_R + \lambda_3)t}\right\}}{\lambda_R + \lambda_3} \right\}$$

WHERE:

I	=	total intake in 1 year (pCi)
B	=	breathing rate, assumed to be 1.05E+4 m^3/yr
C_o	=	initial air concentration of the resuspended radionuclide (pCi/m^3)
λ_R	=	radioactive decay constant (yr^{-1})
λ_2	=	assumed weathering decay constant for 63% of the radionuclide = 1.13 yr^{-1}
λ_3	=	assumed weathering decay constant for 37% of the radionuclide = 7.48E-3 yr^{-1}
t	=	time of exposure (yr)

WEATHERING OF THE RESUSPENSION FACTOR

- EPA assumes gamma weathering for resuspension.
- Empirical data for alpha emitters shows much faster reduction.
- Refer to:
  - WASH-1400 Appendix VI page E-13 for a time dependent model.
  - IAEA Safety Series 81, 1986, page 62 for plot of the resuspension factor as a function of time and of the integral.

CALCULATION OF INHALATION DOSE (CEDE) FROM RESUSPENDED MATERIALS					
Includes weathering? [ ] yes [ ] no					
Sample location ____________________ Analysis date ____________					
Radio-Nuclide	**Air Concentration (pCi/m^3)**	**Yr. 1 DCF (mrem per pCi/m^3)**	**Dose From Yr. 1 Exp. (mrem)**	**Yr. 2 DCF (mrem per pCi/m^3)**	**Dose From Yr. 2 Exp. (mrem)**
Cs-134	1200				
I-131	420				
		TOTAL→		TOTAL→	

SESS ON

DOSE PROJECTION PROBLEMS

FOR

RELOCATION AND RETURN DECISIONS

PROBLEM 1 - A: DERIVATION OF AN ACCIDENT-SPECIFIC DOSE CONVERSION FACTOR (1)

- Method ONE -

GIVEN:

- A surface soil sample is analyzed and is found to contain the following concentrations (pCi / m^2):

Zr-95	7.4 E+6	Cs-134	12.0 E+6
Ru-103	3.1 E+6	Cs-137	1.2 E+6
I-131	4.1 E+6	Ba-140	6.2 E+6

- Radioactive decay and weathering will occur.

CALCULATION OF ACCIDENT-SPECIFIC DCF (DCF_{as})					
For? [x] Year 1 [ ] Year 2 [ ] 50 Years					
Sample location________________ Weathering? [ ] yes [ ] no					
Radio-Nuclide	Measured Ground Concentration (pCi/m^2)	Initial Exp. Rate @ 1m (mR/h per pCi/m^2)	Calculated Exp. Rate (mR/h @1m)	Integrated Dose (mrem per pCi/m^2)	Calculated DOSE (mrem)
Zr-95	7.4E+06				
Ru-103	3.1E+06				
I-131	4.1E+06				
Cs-134	1.2E+07				
Cs-137	1.2E+06				
Ba-140	6.2E+06				
		TOTAL→		TOTAL→	

Combined DCF_{as} _______________mrem per mR/h (date_______________)

CALCULATION OF ACCIDENT-SPECIFIC DCF (DCF_{as})					
For? [ ] Year 1 [X] Year 2 [ ] 50 Years					
Sample location______________ Weathering? [ ] yes [ ] no					
Radio-Nuclide	Measured Ground Concentration (pCi/m^2)	Initial Exp. Rate @ 1m (mR/h per pCi/m^2)	Calculated Exp. Rate (mR/h @1m)	Integrated Dose (mrem per pCi/m^2)	Calculated DOSE (mrem)
Zr-95	7.4E+06				
Ru-103	3.1E+06				
I-131	4.1E+06				
Cs-134	1.2E+07				
Cs-137	1.2E+06				
Ba-140	6.2E+06				
		TOTAL→		TOTAL→	

Combin d DCF_{as} ______________mr m per mR/h (d t ______________)

CALCULATION OF ACCIDENT-SPECIFIC DCF (DCF_{as})					
For? [ ] Year 1 [ ] Year 2 [X] 50 Years					
Sample location_______________ Weathering? [ ] yes [ ] no					
Radio-Nuclide	Measured Ground Concentration (pCi/m^2)	Initial Exp. Rate @ 1m (mR/h per pCi/m^2)	Calculated Exp. Rate (mR/h @1m)	Integrated Dose (mrem per pCi/m^2)	Calculated DOSE (mrem)
Zr-95	7.4E+06				
Ru-103	3.1E+06				
I-131	4.1E+06				
Cs-134	1.2E+07				
Cs-137	1.2E+06				
Ba-140	6.2E+06				
		TOTAL→		TOTAL→	

Combin d DCF_{as} _______________mr m p r mR/h (dat _______________)

PROBLEM I - B: DERIVATION OF AN ACCIDENT-SPECIFIC DOSE CONVERSION FACTOR (I)

- Method TWO -

GIVEN:

- A surface soil sample is analyzed and is found to contain the following activities (uCi / sample):

Zr-95	7.4	Cs-134	12
Ru-103	3.1	Cs-137	1.2
I-131	4.1	Ba-140	6.2

- Radioactive decay and weathering will occur.

CALCULATION OF ACCIDENT-SPECIFIC DCF (DCF_{as})					
For? [x] Year 1 [ ] Year 2 [ ] 50 Years					
Sample location______________ Weathering? [ ] yes [ ] no					
Radio-Nuclide	Measured Ground Concentration (pCi/sample)	Initial Exp. Rate @ 1m (mR/h per pCi/m^2)	Nominal Calculated Exp. Rate (mR/h @1m)	Integrated Dose (mrem per pCi/m^2)	Nominal Calculated DOSE (mrem @1m)
Zr-95	7.4E+06				
Ru-103	3.1E+06				
I-131	4.1E+06				
Cs-134	1.2E+07				
Cs-137	1.2E+06				
Ba-140	6.2E+06				
		TOTAL→		TOTAL→	

Combined DCF_{as} ______________mrem per mR/h (date______________)

CALCULATION OF ACCIDENT-SPECIFIC DCF (DCF_{as})					
For? [ ] Year 1 [X] Year 2 [ ] 50 Years					
Sample location_______________ Weathering? [ ] yes [ ] no					
Radio-Nuclide	Measured Ground Concentration (pCi/sample)	Initial Exp. Rate @ 1m (mR/h per pCi/m^2)	Nominal Calculated Exp. Rate (mR/h @1m)	Integrated Dose (mrem per pCi/m^2)	Nominal Calculated DOSE (mrem @1m)
Zr-95	7.4E+06				
Ru-103	3.1E+06				
I-131	4.1E+06				
Cs-134	1.2E+07				
Cs-137	1.2E+06				
Ba-140	6.2E+06				
		TOTAL→		TOTAL→	

Combined DCF_{as} _______________ mrem per mR/h (date_______________)

CALCULATION OF ACCIDENT-SPECIFIC DCF (DCF_{as})					
For? [ ] Year 1 [ ] Year 2 [X] 50 Years					
Sample location________________ Weathering? [ ] yes [ ] no					
Radio-Nuclide	Measured Ground Concentration (pCi/sample)	Initial Exp. Rate @ 1m (mR/h per pCi/m²)	Nominal Calculated Exp. Rate (mR/h @1m)	Integrated Dose (mrem per pCi/m²)	Nominal Calculated DOSE (mrem @1m)
Zr-95	7.4E+06				
Ru-103	3.1E+06				
I-131	4.1E+06				
Cs-134	1.2E+07				
Cs-137	1.2E+06				
Ba-140	6.2E+06				
		TOTAL→		TOTAL→	

Combined DCF_{as} ________________mrem per mR/h (date________________)

PROBLEM 2: DERIVED RESPONSE LEVELS

- Using results from Problem 1, calculate time-dependent derived response levels (DRL_{td}) corresponding to:
  - year 1
  - year 2
  - 50 years

- Interpret the results.

PROBLEM 3
PROJECTED DOSE

- Field teams report the following exposure rates:

Location A	3 mR/h
Location B	10 mR/h
Location C	30 mR/h

- Assume the radionuclide mix from Problem 1.

- What is the projected dose from gamma radiation at each location for each of the three time periods?

SESSION 12

COURSE REVIEW AND WRAP-UP

Ritchey C. Lyman
Office of Radiation and Indoor Air
Phone (202) 564-9363
Fax: (202) 565-2037
lyman.ritchey@epa.gov

CALCULATION OF INHALATION DOSE (CEDE) FROM RESUSPENDED MATERIALS					
Includes weathering? [x] yes [ ] no					
Sample location A			Analysis date		
Radio-Nuclide	Air Concentration (pCi/m^3)	Yr. 1 DCF (mrem per pCi/m^3)	Dose From Yr. 1 Exp. (mrem)	Yr. 2 DCF (mrem per pCi/m^3)	Dose From Yr. 2 Exp. (mrem)
Zr-95	760				
Ru-103	320				
I-131	420				
Cs-134	1200				
Cs-137	120				
Ba-140	630				
		TOTAL→		TOTAL→	

- PROBLEM SOLUTIONS -

PROBLEM SOLUTION

Problem Emergency worker : Projected Dose at Location A from inhalation

Nuclide(s)	Air Concentration (X) (uCi/cm^3)	Projected. Exposure Time (h)	Integrated Air Concentration (uCi · cm^{-3} · h)	DCF from Table 5-4 (rem per uCi · cm^{-3} · h)	Inhalation Committed Effective Dose Equivalent (CEDE) (rem)
Ce-141	1.0E-05	1	0.00001	1.1E+04	0.11
Ba-140	1.0E-04	1	0.0001	4.5E+03	0.45
Cs-134	1.0E-05	1	0.00001	5.6E+04	0.56
				Totals >	1.12

EXAMPLE OF COMBINED PATHWAYS SOLUTION

Nuclide selected_Co-60__

		DCF	X_{in}	Dose
Pathway	Table	(rem per uCi · cm^{-3} · h)	(uCi · cm^{-3} · h)	(rem)
External	5-3	1.5E+3	1	1.5E+3
Inhalation	5-4	2.6E+5	1	2.6E+5
Ground Shine	5-5	8.9E+3	1	8.9E+3
Summation				2.6E+5
Combined	5-1	2.7E+5	1	2.7E+5

RAD AT ON ACC DENT ASSESSMENT COURSE
WORK SHEET

Problem 1a-1 & 1b-1 : Projected Dose at 1 Mile(s): From thyroid & combined pathway

Nuclide(s) & Prblm. # 1a-1	Xū/Q @ 1 mi (m^{-2})	Q (Ci/s)	ū (m/s)	X @ 1 mi (µCi/cm^3)	Exp. time (h)	X_{in} @ 1 mi (µCi · cm^{-3} · h)	DCF Table No.	DCF_{th} rem / µCi · cm^{-3} · h	Dose (CDE) (rem)
I-131	7.0E-5	0.17	2	6.0E-6	3	1.8E-5	5-2	1.3E+6	23
Nuclide # 1b-1								DCF_{cp}	TEDE (rem)
Xe-133	7.0E-5	1700	2	6.0E-2	3	1.8E-1	5-1	2.0E+1	3.6
I-131	7.0E-5	0.17	2	6.0E-6	3	1.8E-5	5-1	5.3E+4	0.95
Cs-134	7.0E-5	0.05	2	1.8E-6	3	5.25E-5	5-1	6.3E+4	0.33
								TOTAL →	4.9

RAD AT ON ACC DENT ASSESSMENT COURSE
WORK SHEET

Problem 1a-2 & 1b-2 : Projected Dose at 2 Mile(s): From thyroid & combined pathway

Nuclide(s) & Prblm. # 1a-2	$X\bar{u}/Q$ @ 2 mi (m^{-2})	Q (Ci/s)	$\bar{u}$ (m/s)	X @ 2 mi ($\mu Ci/cm^3$)	Exp time (h)	X_{in} @ 2 mi ($\mu Ci \cdot cm^{-3} \cdot h$)	DCF Table No.	DCF_{th} $\frac{rem}{\mu Ci \cdot cm^{-3} \cdot h}$	Dose (CDE) (rem)
I-131	2.4E-5	0.17	2	2.0E-6	3	6.0E-6	5-2	1.3E+6	8
Nuclides # 1b-2									TEDE (rem)
								DCF_{cp}	
Xe-133	2.4E-5	1700	2	2.0E-2	3	6.0E-2	5-1	2.0E+1	1.2
I-131	2.4E-5	0.17	2	2.0E-6	3	6.0E-6	5-1	5.3E+4	0.32
Cs-134	2.4E-5	0.05	2	6.0E-7	3	1.8E-6	5-1	6.3E+4	0.12
								TOTAL →	1.6

RAD OLOG CAL ACC DENT ASSESSMENT COURSE
WORK SHEET

Problem 2a Projected Dose at 2 Mile(s): From immersion pathway

Nuclide(s) & Prblm. # 2	$X\bar{u}/Q$ @2 mi (m^{-2})	Q (Ci/s)	$\bar{u}$ (m/s)	X @ 2 mi ($\mu Ci/cm^3$)	Exp. time (h)	X_{in} @ 2 mi ($\mu Ci \cdot cm^{-3} \cdot h$)	DCF Table No.	DCF_{im} $\frac{rem}{\mu Ci \cdot cm^{-3} \cdot h}$	Dose (EDE) (rem)
Xe-133	2.4E-5	1700	2	2.0E-2	3	6.0E-2	5-3	20	1.2
I-131	2.4E-5	0.17	2	2.0E-6	3	6.0E-6	5-3	2.2E+2	1.3E-3
Cs-134	2.4E-5	0.05	2	6.0E-7	3	1.8E-6	5-3	9.1E+2	1.7E-3
								TOTAL→	1.2

RAD OLOG CAL ACC DENT ASSESSMENT COURSE
WORK SHEET

Problem 2b : Projected Dose at 2 Mile(s): From inhalation pathway

Nuclide(s) & Prblm. # 2b	$X\bar{u}/Q$ @ 2 mi (m^{-2})	Q (Ci/s)	$\bar{u}$ (m/s)	X @ 2 mi ($\mu Ci/cm^3$)	Exp. time (h)	X_{in} @ 2 mi ($\mu Ci \cdot cm^{-3} \cdot h$)	DCF Table No.	DCF_{inh} $\frac{rem}{\mu Ci \cdot cm^{-3} \cdot h}$	Dose (CEDE) (rem)
Xe-133	2.4E-5	1700	2	2.0E-2	3	6.0E-2	5-4	0	0
I-131	2.4E-5	0.17	2	2.0E-6	3	6.0E-6	5-4	3.9E+4	2.4E-1
Cs-134	2.4E-5	0.05	2	6.0E-7	3	1.8E-6	5-4	5.6E+4	1.0E-1
								TOTAL→	3.4E-1

RADIOLOGICAL ACCIDENT ASSESSMENT COURSE
WORK SHEET

Problem_2c_: Projected Dose at_2_Mile(s): From ground shine pathway

Nuclide(s) & Prblm. #_2c_	$X\bar{u}/Q$ @ 2 mi (m^{-2})	Q (Ci/s)	$\bar{u}$ (m/s)	X @ 2 mi ($\mu Ci/cm^3$)	Exp. time (h)	X_{in} @ 2 mi ($\mu Ci \cdot cm^{-3} \cdot h$)	DCF Table No.	DCF_{dep} $\frac{rem}{\mu Ci \cdot cm^{-3} \cdot h}$	Dose (EDE) (rem)
Xe-133	2.4E-5	1700	2	2.0E-2	3	6.0E-2	5.5	0	0
I-131	2.4E-5	0.17	2	2.0E-6	3	6.0E-6	5.5	1.3E+4	8.0E-2
Cs-134	2.4E-5	0.05	2	6.0E-7	3	1.8E-6	5.5	6.2E+3	1.1E-2
								TOTAL →	0.09

EXAMPLE CALCULATION OF EXPOSURE RATE
- Method One -

SOLUTION

Radionuclide	Concentration pCi/m^2	Initial exposure Rate @ 1m (mR/h per pCi/m^2) (table 7-1 or 7-2)	Exposure Rate @ 1m (mR/h)
Cs-134	2E+7	2.6E-8	0.52
I-131	3E+7	6.6E-9	0.20
		Total:	0.72

EXAMPLE CALCULATION OF PROJECTED DOSE
- M thod On -

SOLUTION

Integrated Dose - Year One					
		Weathering		No Weathering	
Radionuclide	Concentration (pCi/m^2)	DCF ($mrem/pCi/m^2$) (Table 7-1)	Projected Dose (mrem)	DCF ($mrem/pCi/m^2$) (Table 7-2)	Projected Dose (mrem)
Cs-134	2E+7	1.0E-4	2000	1.3E-4	2600
I-131	3E+7	1.3E-6	39	1.3E-6	39
		TOTAL	2039	TOTAL	2639

EXAMPLE CALCULATION OF PROJECTED DOSE
- Method One -

SOLUTION

Integrated Dose - Year Two					
Radionuclide	Concentration (pCi/m^2)	Weathering		No Weathering	
		DCF ($mrem/pCi/m^2$) (Table 7-1)	Projected Dose (mrem)	DCF ($mrem/pCi/m^2$) (Table 7-2)	Projected Dose (mrem)
Cs-134	2E+7	4.7E-5	940	9.6E-5	1900
I-131	3E+7	0	0	0	0
		TOTAL	940	TOTAL	1900

EXAMPLE CALCULATION OF PROJECTED DOSE
- Method One -

SOLUTION

Integrated Dose - Zero to 50 Years					
Radionuclide	Concentration (pCi/m^2)	Weathering		No Weathering	
		DCF ($mrem/pCi/m^2$) (Table 7-1)	Projected Dose (mrem)	DCF ($mrem/pCi/m^2$) (Table 7-2)	Projected Dose (mrem)
Cs-134	2E+7	2.4E-4	4800	4.7E-4	9400
I-131	3E+7	1.3E-6	39	1.3E-6	39
		TOTAL	4839	TOTAL	9439

CALCULATION OF ACCIDENT-SPECIFIC DCF
- Method 2 -

SOLUTION

$$DCF_{as} = \frac{mrem\ per\ yr\text{-}1,\ yr\text{-}2,\ or\ 0\ to\ 50\ yr}{Exposure\ Rate\ @\ 1\ m\ (mR/h)}$$

- **Assume weathering and results from VGs 9, 10, 11, and 12, and calculate:**
  - **Year one DCF_{as} = 2039 mrem/0.72 mR/h = 2832 mrem/mR/h**
  - **Year two DCF_{as} = 940 mrem/0.72 mR/h = 1305 mrem/mR/h**
  - **0 to 50 y ar DCF_{as} = 4839 mr m/0.72 mR/h = 6720**

CALCULATION OF ACCIDENT SPECIFIC DRL
- Method 2 -

SOLUTION

$$DRL_{td} = \frac{PAG}{DCF_{as}}$$

- **For the previous example (weathering included):**
  - **Year one DRL_{as} = 2000 mrem ÷ 2832 mrem/mR/h = 0.71 mR/h**
  - **Year two DRL_{as} = 500 mrem ÷ 1305 mrem/mR/h = 0.38 mR/h**
  - **Zero to 50 year DRL_{as} = 5000 ÷ 6720 = 0.74 mR/h**

CALCULATION OF INHALATION DOSE (CEDE) FROM RESUSPENDED MATERIALS

Includes weathering? [x] yes [ ] no

Sample location ______________________ Analysis date______________

Radio-Nuclide	Air Concentration (pCi/m^3)	Yr. 1 DCF (mrem per pCi/m^3)	Dose From Yr. 1 Exp. (mrem)	Yr. 2 DCF (mrem per pCi/m^3)	Dose From Yr. 2 Exp. (mrem)
Cs-134	1200	3.1E-1	370	1.5E-1	180
I-131	420	1.1E-2	4.6	0	0
		TOTAL→	375	TOTAL→	180

Problem 1: Derivation of an Accid nt-Sp cific Dose Conv rsion Factor

SOLUTION

- Refer to Table 7-1 and, as example, Table 7-3.
- Unit of the DCF for the projected external gamma dose is:
  xx mrem for each mR/h measured at the beginning of the period
- For year one:
  1.6E+03 mrem per 4.9E-01 mR/h yields
  3.3e+3 mrem per mR/h or 3.3 rem per mR/h
- For 0-50 years:
  4.0E-03 mrem per 4.9E-01 mR/h
  8.2E+3 mrem per mR/h or 8.2 rem per mR/h

CALCULATION OF ACCIDENT-SPECIFIC DCF (DCF_{as})					
For? [x] Year 1 [ ] Year 2 [ ] 50 Years					
Sample location_A__________ Weathering? [x] yes [ ] no					
Radio-Nuclide	Measured Ground Concentration (pCi/m^2)	Initial Exp. Rate @ 1m (mR/h per pCi/m^2)	Calculated Exp. Rate (mR/h@1m)	Integrated Dose (mrem per pCi/m^2)	Calculated DOSE (mrem)
Zr-95	7.4e+06	1.2e-08	8.9e-02	3.3e-05	2.4e+02
Ru-103	3.1e+06	8.2e-09	2.5e-02	7.1e-06	2.2e+01
I-131	4.1e+06	6.6e-09	2.7e-02	1.3e-06	5.3e+00
Cs-134	1.2e+07	2.6e-08	3.1e-01	1.0e-04	1.2e+03
Cs-137	1.2e+06	1.0e-08	1.2e-02	4.5e-05	5.4e+01
Ba-140	6.2e+06	3.2e-09	2.0e-02	1.1e-05	6.8e+01
		TOTAL→	4.9e-01	TOTAL→	1.6e+03

Co bined DCF_{as} __3.3 e+03__ re per R/h (date______________)

CALCULATION OF ACCIDENT-SPECIFIC DCF (DCF_{as})					
For? [ ] Year 1 [x] Year 2 [ ] 50 Years					
Sample locat'on_A__________ Weather ng? [x] yes [ ] no					
Radio-Nuclide	Measured Ground Concentration (pCi/m²)	Initial Exp. Rate @ 1m (mR/h per pCi/m²)	Calculated Exp. Rate (mR/h@1m)	Integrated Dose (mrem per pCi/m²)	Calculated DOSE (mrem)
Zr-95	7.4e+06	1.2e-08	8.9e-02	4.0e-07	3.0e+00
Ru-103	3.1e+06	8.2e-09	2.5e-02	0.0e+00	0.0e+00
I-131	4.1e+06	6.6e-09	2.7e-02	0.0e+00	0.0e+00
Cs-134	1.2e+07	2.6e-08	3.1e-01	4.7e-05	5.6e+02
Cs-137	1.2e+06	1.0e-08	1.2e-02	2.9e-05	3.5e+01
Ba-140	6.2e+06	3.2e-09	2.0e-02	0.0e+00	0.0e+00
		TOTAL→	4.9e-01	TOTAL→	6.0e+02

Co bined DCF_{as} __1.2 e+03__ re per mR/h (date_______________)

CALCULATION OF ACCIDENT-SPECIFIC DCF (DCF_{as})					
For? [ ] Year 1 [ ] Year 2 [x] 50 Years					
Sample location_A__________ Weathering? [x] yes [ ] no					
Radio-Nuclide	Measured Ground Concentration (pCi/m^2)	Initial Exp. Rate @ 1m (mR/h per pCi/m^2)	Calculated Exp. Rate (mR/h@1m)	Integrated Dose (mrem per pCi/m^2)	Calculated DOSE (mrem)
Zr-95	7.4e+06	1.2e-08	8.9e-02	3.4e-05	2.5e+02
Ru-103	3.1e+06	8.2e-09	2.5e-02	7.1e-06	2.2e+01
I-131	4.1e+06	6.6e-09	2.7e-02	1.3e-06	5.3e+00
Cs-134	1.2e+07	2.6e-08	3.1e-01	2.4e-04	2.9e+03
Cs-137	1.2e+06	1.0e-08	1.2e-02	6.1e-04	7.3e+02
Ba-140	6.2e+06	3.2e-09	2.0e-02	1.1e-05	6.8e+01
		TOTAL→	4.9e-01	TOTAL→	4.0e+03

Co bined DCF_{as} __8.2 e+03__mre per R/h (date_____________)

CALCULATION OF ACCIDENT-SPECIFIC DCF (DCF_{as})					
For? [x] Year 1 [ ] Year 2 [ ] 50 Years					
Sample location_A__________ Weathering? [x] yes [ ] no					
Radio-Nuclide	Measured Ground Concentration (pCi/m²)	Initial Exp. Rate @ 1m (mR/h per pCi/m²)	Nominal Calculated Exp. Rate (mR/h@1m)	Integrated Dose (mrem per pCi/m²)	Nominal Calculated DOSE (mrem)
Zr-95	7.4e+06	1.2e-08	8.9e-02	3.3e-05	2.4e+02
Ru-103	3.1e+06	8.2e-09	2.5e-02	7.1e-06	2.2e+01
I-131	4.1e+06	6.6e-09	2.7e-02	1.3e-06	5.3e+00
Cs-134	1.2e+07	2.6e-08	3.1e-01	1.0e-04	1.2e+03
Cs-137	1.2e+06	1.0e-08	1.2e-02	4.5e-05	5.4e+01
Ba-140	6.2e+06	3.2e-09	2.0e-02	1.1e-05	6.8e+01
		TOTAL→	4.9e-01	TOTAL→	1.6e+03

Co bined DCF_{as} __3.3 e+03__ re per R/h (date_____________)

CALCULATION OF ACCIDENT-SPECIFIC DCF (DCF_{as})					
For? [ ] Year 1 [x] Year 2 [ ] 50 Years					
Sample location_A__________ Weathering? [x] yes [ ] no					
Radio-Nuclide	Measured Ground Concentration (pCi/m^2)	Initial Exp. Rate @ 1m (mR/h per pCi/m^2)	Nominal Calculated Exp. Rate (mR/h@1m)	Integrated Dose (mrem per pCi/m^2)	Nominal Calculated DOSE (mrem)
Zr-95	7.4e+06	1.2e-08	8.9e-02	4.0e-07	3.0e+00
Ru-103	3.1e+06	8.2e-09	2.5e-02	0.0e+00	0.0e+00
I-131	4.1e+06	6.6e-09	2.7e-02	0.0e+00	0.0e+00
Cs-134	1.2e+07	2.6e-08	3.1e-01	4.7e-05	5.6e+02
Cs-137	1.2e+06	1.0e-08	1.2e-02	2.9e-05	3.5e+01
Ba-140	6.2e+06	3.2e-09	2.0e-02	0.0e+00	0.0e+00
		TOTAL→	4.9e-01	TOTAL→	6.0e+02

Combin d DCF_{as} __1.2 e+03__ mrem p r mR/h (d t ______________)

CALCULATION OF ACCIDENT-SPECIFIC DCF (DCF_{as})					
For? [ ] Year 1 [ ] Year 2 [x] 50 Years					
Sample location_A__________ Weathering? [x] yes [ ] no					
Radio-Nuclide	Measured Ground Concentration (pCi/m²)	Initial Exp. Rate @ 1m (mR/h per pCi/m²)	Nominal Calculated Exp. Rate (mR/h@1m)	Integrated Dose (mrem per pCi/m²)	Nominal Calculated DOSE (mrem)
Zr-95	7.4e+06	1.2e-08	8.9e-02	3.4e-05	2.5e+02
Ru-103	3.1e+06	8.2e-09	2.5e-02	7.1e-06	2.2e+01
I-131	4.1e+06	6.6e-09	2.7e-02	1.3e-06	5.3e+00
Cs-134	1.2e+07	2.6e-08	3.1e-01	2.4e-04	2.9e+03
Cs-137	1.2e+06	1.0e-08	1.2e-02	6.1e-04	7.3e+02
Ba-140	6.2e+06	3.2e-09	2.0e-02	1.1e-05	6.8e+01
		TOTAL→	4.9e-01	TOTAL→	4.0e+03

Co bined DCF_{as} __8.2 e+03__ re per R/h (date_____________)

Problem 2: Derived Respons L v ls

SOLUTION

- A time-dependent derived response level (DRL_{td}) is the meter reading (mR/h @ 1m) which, at the time of measurement, corresponds to either the year 1, year 2, or 0-50 year dose.

- For year one, a meter reading of 1 mR/h at 1 meter above the ground indicates an external gamma radiation dose of 3.3 rem during the first year. Therefore, the DCF (rem per mR/h) is 3.3 rem per mR/h.

- A meter reading of 2.0/3.3 or about 0.6 mR/h, would indicate that the first year dose would be 2 rem or greater.

- The DRL_{td} for year 1 is 0.6 mR/h.

- The DRL_{td} for year 2 is 0.5/1.2 or about 0.4 mR/h.

- The DRL for ye r 0-50 is 5.0/8.2 or bout 0.61 mR/h.

Problem 2 Derived Response Levels
SOLUTION
(cont'd)

- **Table 4-1: Protective Action Guides for Exposure to Deposited Radioactivity During the Intermediate Phase of a Nuclear Incident**

  Relocate if projected dose is greater than 2 rem.

  Projected dose includes external gamma radiation dose and the committed effective dose equivalent from inhalation during the first year.

  Beta skin dose may be up to 50 times higher.

- **Persons in areas with meter readings above 0.6 mR/h should be relocated.**

Problem 3 Projected Dose
SOLUTION

Location	Meter Reading (mR/hr)	Projected Dose year one (rem)	Projected Dose year two (rem)	Projected Dose 0 to 50 y (rem)
A	3	9.9	3.6	24.6
B	10	33	12	82
C	30	99	36	246
DCF for year 1 (rem per mR/h)			3.3	
DCF for year 2 (rem per mR/h)			1.2	
DCF for 0 to 50 y (rem per mR/h)			8.2	

Prob em 4: Inha ation Do e (CEDE)
SOLUTION

CALCULATION OF INHALATION DOSE (CEDE) FROM RESUSPENDED MATERIALS					
Includes weathering? [x] yes [ ] no					
Sample location ____A________________ Analysis date________________					
Radio-Nuclide	Air Concentration (pCi/m^3)	Yr. 1 DCF (mrem per pCi/m^3)	Dose From Yr. 1 Exp. (mrem)	Yr. 2 DCF (mrem per pCi/m^3)	Dose From Yr. 2 Exp. (mrem)
Zr-95	760	6.5e-02	4.9e+01		0.0e+00
Ru-103	320	1.3e-02	4.2e+00		0.0e+00
I-131	420	1.1e-02	4.6e+00		0.0e+00
Cs-134	1200	3.1e-01	3.7e+02	1.5e-01	1.8e+02
Cs-137	120	2.5e-01	3.0e+01	1.4e-01	1.7e+01
Ba-140	630	4.4e-03	2.8e+00		0.0e+00
		TOTAL→	4.6e+02	TOTAL→	2.0e+02

Problem 4: I h latio Dose (CEDE)
SOLUTION
(co t'd)

- **Year one CEDE - 4.6E+02 mrem or 0.46 rem**
- **Year two CEDE - 2.0E+02 mrem or 0.20 rem**
- **Year one EDE - 9.9 rem (see problem 3)**
- **Year one TEDE - 9.9 + 0.5 = 10.4 rem**
- **Year two EDE - 3.6 rem (see problem 3)**
- **Year two TEDE - 3.6 + 0.20 = 3.8 rem**
- **Normally the lung clearance class and the particle size are not known. Assume the most conservative condition.**

MANUAL OF PROTECTIVE ACTION GUIDES AND PROTECTIVE ACTIONS FOR NUCLEAR INCIDENTS

Presented By

The Environmental Protection Agency

at

NASA HEADQUARTERS
date

JUNE 10 - 11, 1998

SESSION 1

WELCOME AND INTRODUCTIONS

EPA 400-R-92-001
MANUAL OF PROTECTIVE ACTIONS AND PROTECTIVE ACTIONS FOR NUCLEAR INCIDENTS WORKSHOP

NASA HEADQUARTERS
300 E STREET, S.W.
WASINGTON D.C.
JUNE 10 - 11, 1998

Wednesday, June 10, 1998

8:30 - 9:00 am	Welcome and Introductions
9:00 - 10:00 am	Overview (How the PAG manual is laid out)
10:00 - 11:00 am	Rationale for PAG values (PAG Principles)
11:00 - 12:00 pm	Application and Interpretation of PAGs (When to use them and how)
12:00 - 1:00 pm	Lunch
1:00 - 2:30 pm	Introduction to Dose Projection (Discussion of Terminology and EPA assumptions used)
2:30 - 4:30 pm	Implementation of Emergency Worker Dose Limits (Who are Emergency Workers and What limits apply)
4:30	End of Day One

Thursday, June 11, 1998

8:30 - 10:00 am	Development of DCFs and DRLs (What are they and how do you apply them)
10:00 - 11:00 pm	Dose Projection for Early Phase (Problem solving)
11:00 - 12:00 pm	PAGs for Relocation (Assumptions made and rationale for use)
12:00 - 1:00 pm	Lunch
1:00 - 3:30 pm	Dose Projection for Relocation (Problem solving)
3:30 - 4:00 pm	Review and Wrap-up

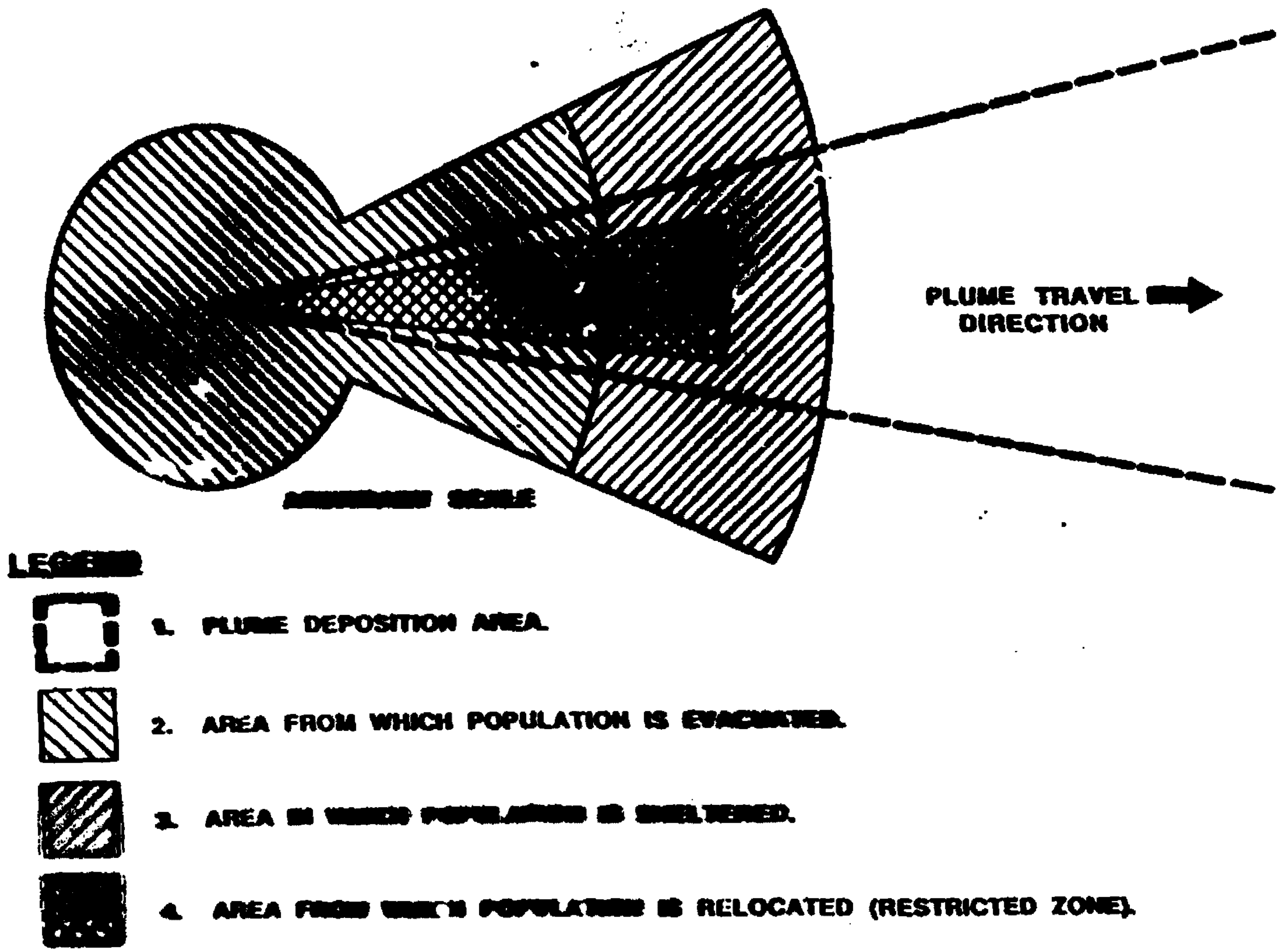
SESSION 2

OVERVIEW OF BACKGROUND MATERIALS

SUPPORTING THE WORKSHOP

TOPICS

- Response areas
- Organization and content of the PAG Manual and its major support documents
- Exposure pathways
- Incident phases


PLUME TRAVEL DIRECTION
1. PLUME DEPOSITION AREA.
2. AREA FROM WHICH POPULATION IS
3. AREA
4. AREA RELOCATED (RESTRICTED ZONE).

CONTENTS OF THE PAG MANUAL

CHAPTERS	SUBJECTS
1	Background information
2, 3, & 4	PAGs for plume, ingestion, and relocation
5, 6, & 7	Implementation guidance for the 3 PAG categories
8	Reserved for recovery guidance

CONTENTS OF THE PAG MANUAL
(cont'd)

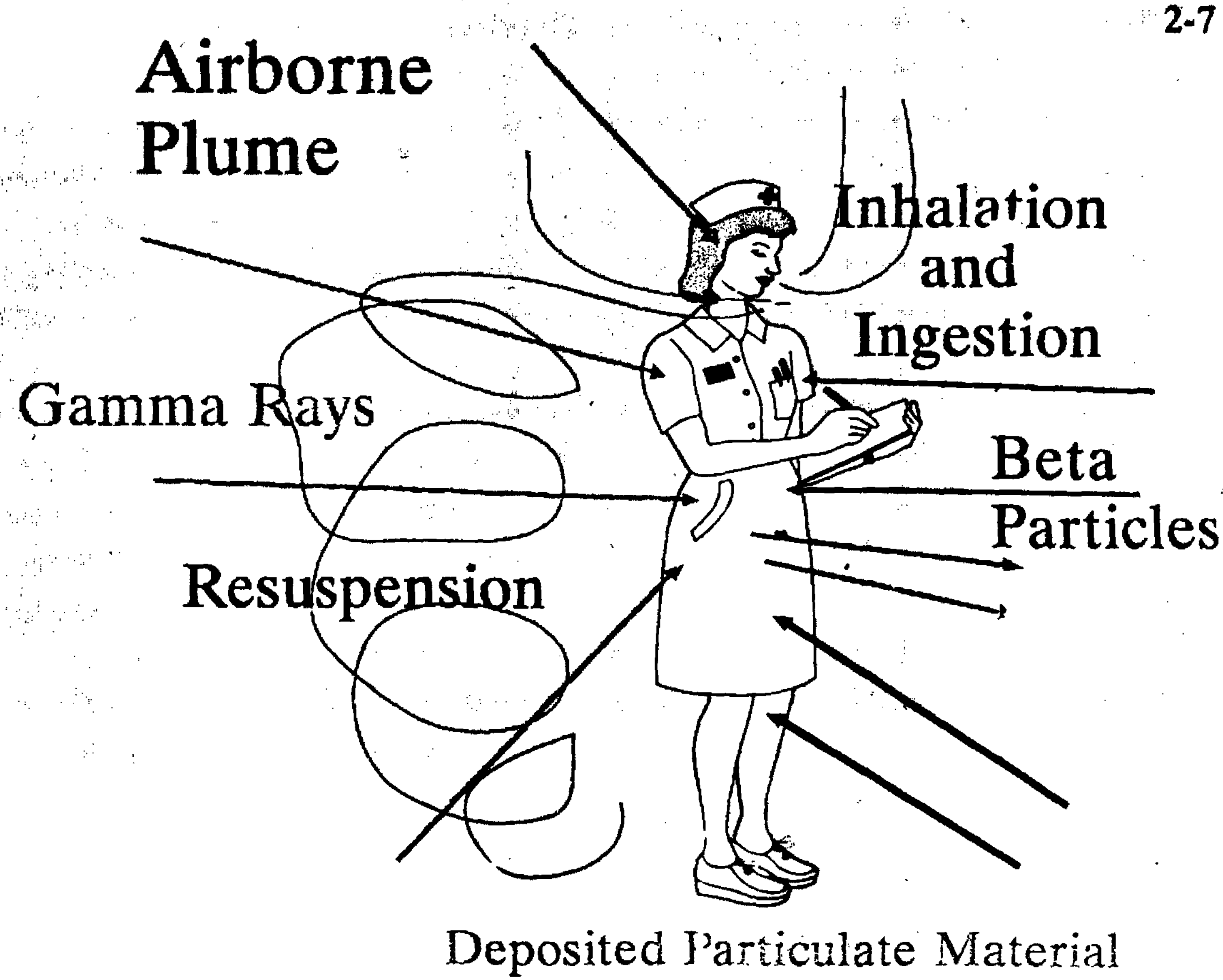
APPENDICES	SUBJECTS
A	Definitions of terms
B	Risk of health effects from radiation
C	Rationale for selecting the early phase PAG values
D	Rationale for food PAGs
E	Rationale for Relocation PAGs

MAJOR SUPPORT DOCUMENTS

- Externa Dose-Rate Conversion Factors for Ca cu ation of Dose to the Public (DOE/EH 0070)
- EPA Federal Guidance Report No. 11 (EPA 520/1-88-020)
- EPA Federal Guidance Report No. 12 (EPA 402-R-93-081)

MAJOR SUPPORT DOCUMENTS (cont'd)

- Evaluat'on of Sk'n and Ingest'on Exposur P thw ys (EPA 520/1-89-016)
- Evacuation Risks--An Evaluation (EPA-520/6/74-002)
- An Analysis of Evacuation Options for Nuclear Accidents (EPA 520/1-87-023)
- Economic Criteria for Relocation (EPA 520/1-89-015)



Exposure Pathways for the Early Phase

INCIDENT PHASES
(pp. 1-2 to 1-4)

- Three phases of a radiological incident
  - Early
  - Intermediate
  - Late

- In all phases, the PAGs are independent.

- Refer to PAG Manual Page 1-4.

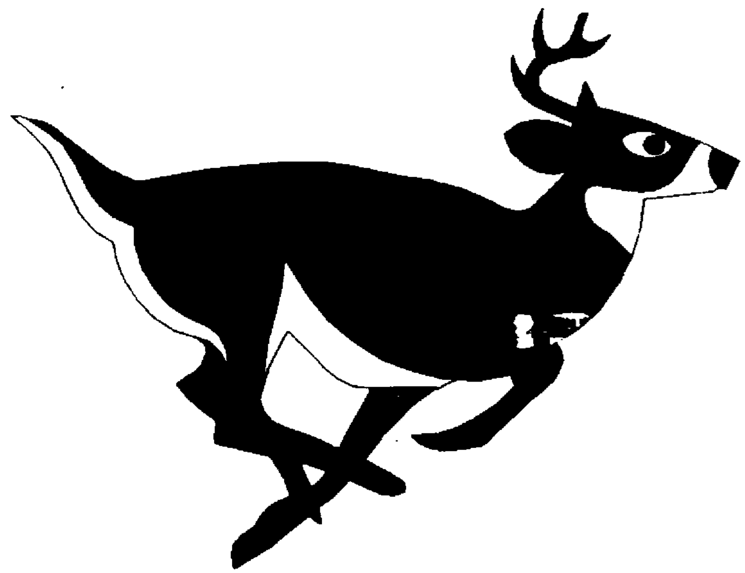
SESSION 3

RATIONALE FOR PAG VALUES
AND
EMERGENCY WORKER DOSE LIMITS

TOPICS

- Protective action effectiveness
- PAG Principles
- Basis for PAG values and Emergency worker dose limits

PROTECTIVE ACTIONS FOR THE EARLY PHASE (p. 1-4)



- **Evacuation**
- **Sheltering**
- **Access control**
- **KI administration**

Control of surface contam'nation

BASIS FOR PROTECTIVE ACTION DECISIONS DURING THE EARLY PHASE
(p. 5-2)

- Plant conditions and utility PARs

- Dose projections

- Field monitoring results

SHELTERING CONSTRAINTS
(pp. 5-19 to 21 and C-14 to 16)

- Sheltering provides only partial protection.
  - Protection factor decreases with time.
  - Ventilation rates vary.
  - Protection varies with building type.
  - Risk of shelter failure is significant.

BASIS FOR SETTING PAG LEVELS
(p. 1-5)

	PRINCIPLE	STRATEGY
(1)	Avoid acute health effects.	Stay below threshold dose.
(2)	Adequately protect against cancer and genetic effects under emergency conditions.	Set PAG at this level unless driven <u>down</u> by cost/risk considerations (3), or <u>up</u> by risk/risk considerations (4).
(3)	Optimize cost of protective action versus avoided dose.	Use this principle only if the the PAG value is driven down.
(4)	Regardless of the above principles, the risk from a protective action should not itself exceed the risk from the dose that would be avoided.	Use this principle only if the PAG value is driven up.

RADIATION HEALTH EFFECTS
(Appendix B)

- Acute (deterministic) health effects
- Mental retardation
- Radiogenic cancers
- Thyroid disorders and cancers
- Genetic disorders

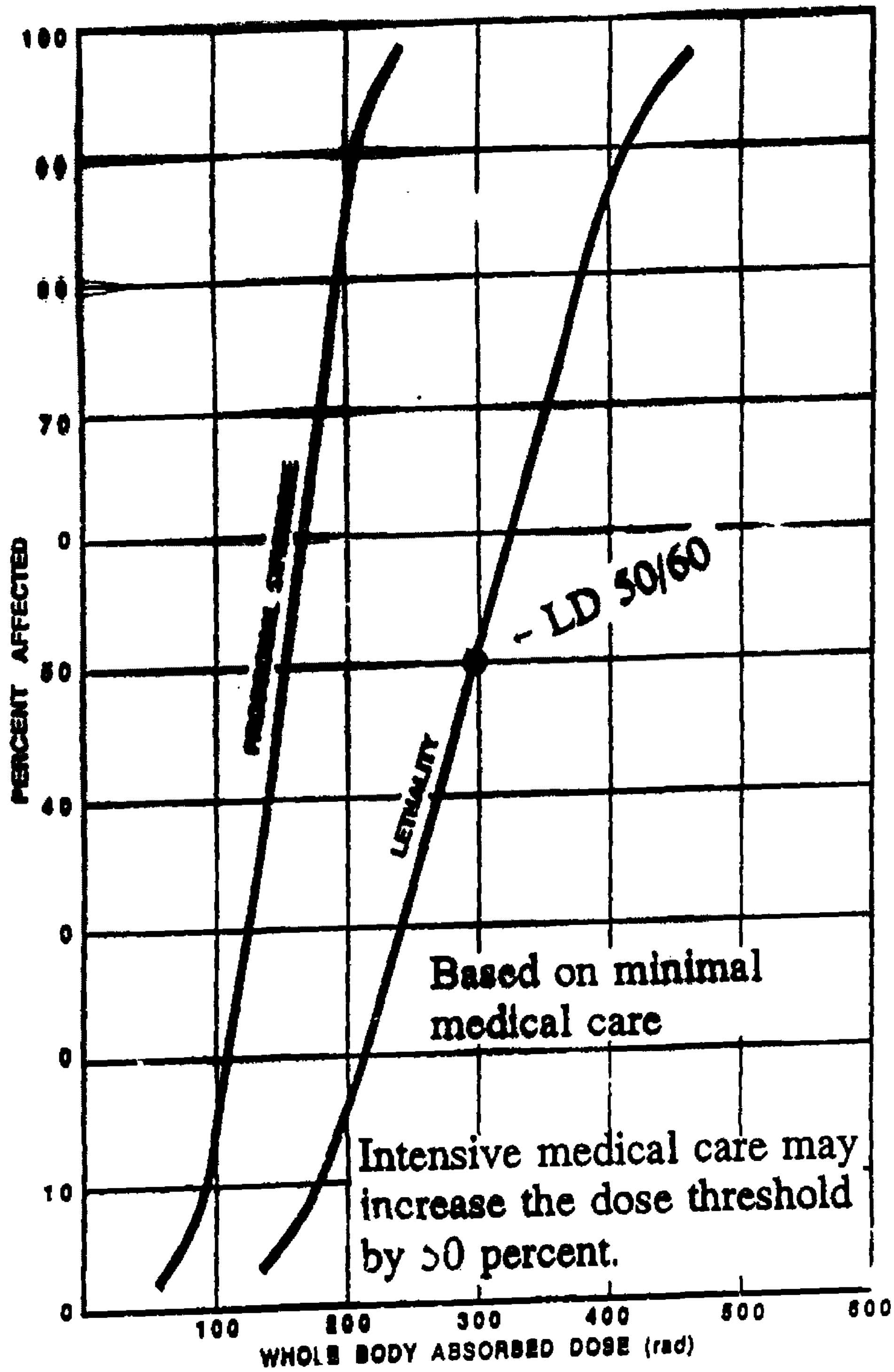


FIGURE B-1. ACUTE HEALTH EFFECTS AS A FUNCTION OF WHOLE BODY DOSE.

ACUTE HEALTH EFFECTS: CONCLUSIONS

(p. B-17)

Dose	Acute Health Effect
50 rad	Less than 2 % of the exposed expected to show forewarning symptoms.
25 rad	Forewarning symptoms are not expected.

ACUTE HEALTH EFFECTS: CONCLUSIONS
(cont'd)

Dose	Acute Health Effect
10 rad	The dose level below which a fetus would not be expected to suffer teratogenesis.
5 rad	The approximate minimum level of detectability for acute cellular effects using the most sensitive methods.

AVERAGE RISK OF DELAYED HEALTH EFFECTS IN THE U.S. POPULATION

(pp. B-19 to 25)

Health Effect	Effects per Person-rem		
	Whole Body	Thyroid	Skin
Fatal cancers	2.8E-4[a]	3.6E-5[b]	3.0E-6
Nonfatal cancers	2.4E-4	3.2E-4	3.0E-4
Genetic disorders (all generations)	1.0E-4		

[a] Risk to the fetus is estimated to be 5 to 10 times greater.

[b] Risk to young children is estimated to be about 1.7 times greater. Their dose is also about 2 times greater.

UPPER BOUNDS ON DOSE FOR EVACUATION BASED ON COST OF AVOIDING FATALITIES

(p. C-11 and E-2)

Accident Category	Atmospheric Stability Class	Dose Upper Bounds[a]	
		Maximum (rem)	Minimum (rem)
SST-1[b]	A	5	0.4
	C	5	0.4
	F	10	0.8
SST-2	A	1	0.15
	C	3.5	0.25
	F	10	0.7

[a] Based on an assumed range of $400,000 to $7,000,000 per life saved.
[b] SST m ans Siting Sourc Term. See page E-2 of PAG Manual.

CALCULATION OF RADIATION RISK VERSUS EVACUATION RISK
(p. C-10)

- Estimated risk of death from transportation = 9E-8/person mile.
- Assume 100 mile round trip for evacuation.
- Estimated risk of death from radiation = 3E-4/person rem.
- Calculate the equivalent risk (rem/100 miles).

AVERAGE VERSUS CENTERLINE DOSE
(p. C-12)

Centerline Dose (rem)	Average Dose Avoided by Stability Class (mrem per individual)		
	A	C	F
0.5 to 1	340	190	70
1 to 2	670	380	150
2 to 5		870	330
5 to 10			750

MAJOR CONCLUSIONS LEADING TO THE SELECTION OF THE PAG FOR EVACUATION
(pp. C-18 & C-19)

- 0.5 rem is the selected dose to be avoided.
  - This satisfies Principles 1 and 2.
  - Cost of going lower is not justified. (Principle 3)
  - Net reduction in average risk will occur (Principle 4).
  - Meets acceptable risk to the fetus established for occupational exposure.

MAJOR CONCLUSIONS LEADING TO THE SELECTION OF 1 REM AS THE PAG FOR EVACUATION

(p. C-19)

- If sheltering is implemented to 0.5 rem at centerline, and evacuation to 1 rem, the avoided dose from evacuation will be about 0.5 rem.

- Therefore, the PAG recommended for evacuation is 1 rem.

BAS S FOR EMERGENCY WORKER DOSE L M TS
(pp. C-22 to 24)

- 5 rem limit unless higher limit is justified
  - Occupational guidance should normally govern.
  - Limit emergency workers to nonpregnant adults.
  - Occupational limits for organs, extremities and lens of the eye should also apply.

BAS S FOR EMERGENCY WORKER DOSE L M TS
(cont'd)

- 10 rem limit for protecting <u>valuable</u> property
  - Some emergency situations justify dose limits higher than 5 rem.
  - ICRP-26 recognizes 10 rem as an annual limit for any single event for workers.
- Higher limits are conditional.

BASIS FOR EMERGENCY WORKER DOSE LIMITS
(cont'd)

- 25 rem limit is justified for:
    - life saving
    - preventing substantial risks to populations
- ICRP-26 recognizes 25 rem as a lifetime limit for specially justified circumstances.
- Acute effects to adults will be avoided.

DOSES N EXCESS OF THE L M TS
FOR EMERGENCY WORKERS

- Old limits of 75 and 100 rem present unacceptably high risk for <u>assignment</u>.

- No limit is needed for persons who volunteer for higher doses if:
  - they are fully aware of the risks involved, and
  - they are lifesaving or preventing dose to a large population.

- Chart of risks is provided (see page 2-12).

SESSION 4

APPLICATION AND INTERPRETATION
OF
PROTECTIVE ACTION GUIDES
AND
EMERGENCY WORKER DOSE LIMITS
FOR
THE EARLY PHASE

MAIN TOPICS

- Definitions and interpretations
- Special dose quantities and concepts
- PAG values and their application
- The use of KI for emergency workers
- The impact of the changes to the guidance

APPLICABILITY OF PAGs
(p. 2-1 & 2-2)

- PAGs apply to all nuclear incidents or accidents except nuclear war.
  - Developed based on nuclear power plant accidents
  - Dose limits also apply to all - - -

- The implementation guidance applies primarily to nuclear power plants.

DEF NIT ONS
(pp.   -2 & A-3)

- Protective Action Guide (PAG):

  The projected dose to individuals in the general population that warrants protective action.

- Projected Dose:

  The calculated future dose that would be received by individuals if no protective actions were taken.

PAG INTERPRETATIONS
(pp. 1-1, & 1-7)

PAGs are:

- Decision levels for public officials

- Used to minimize risk from an event which is occurring or has already occurred

PAG INTERPRETATIONS
(pp. 2-1, 4-1, 2-2, & 1-6)
(cont'd)

PAGs are:

- Mandatory for planning
  - but, professional judgment is required for their application
- Independent of the type or magnitude of the release

PAG NTERPRETAT ONS
(pp. -6, & 2-2)
(cont'd)

PAGs are:

- A supplement to design safety of nuclear facilities

- Designed to protect all individuals in the population

PAG INTERPRETATIONS
(pp. 1-6 2-1 2-4 & 2-10)
(cont'd)

PAGs are not:

- The basis for the size of the EPZ
- Dose limits
- Additive to other doses

PAG INTERPRETATIONS
(pp. 1 7 & 2 1)
(cont'd)

PAGs do not:

- Imply an acceptable level of dose for nonemergency situations.
- Represent the boundary between safe and unsafe conditions.
- Supersede Federal Radiation Council (FRC) Guidance.

PAG INTERPRETATIONS
(pp. A-2 & A-3)
(cont'd)

PAGs do not include:

- Previous radiation doses.

- Safety factors to account for uncertainties in dose projection procedures.

DOSE QUANTITIES USED FOR EMERGENCY RESPONSE
(pp. B-1 & B-2)

- Absorbed dose

- Projected dose

- Committed dose

SPECIAL DOSE QUANT T ES
(p. B-   & B-2)

- Dose equivalent (DE)
  - Organ dose
  - Risk of cancer
- Committed dose equivalent (CDE)
  - 50 years
- Effective dose equivalent (EDE)
- Committed effective dose equivalent (CEDE)

TOTAL EFFECTIVE DOSE EQUIVALENT (TEDE)

- TEDE (an NRC term) means the <u>sum</u> of the deep dose equivalent from external gamma radiations (EDE) and the committed effective dose equivalent (CEDE) from internal exposures.

- Plume PAGs are expressed as this sum.
  "TEDE" is not used in the PAG Manual

- EDE from external sources is the same as NRC's term "deep dose equivalent."

EARLY PHASE PAGs
(pp. 2 5 to 2 8 & C 20)
(cont'd)

Projected dose (rem)	Action
1 to 5 TEDE 5 to 25 CDE thyroid 50 to 250 DE skin	Evacuation (or, for some situations, sheltering) should normally be initiated at the lower end of the range.
25 CDE thyroid from radioiodine	Administer stable iodine (KI) to the public in accordance with State medical procedures.

OTHER EARLY PHASE GUIDANCE
NOT PAGS
(pp. 2-4 to 2-9)

Projected dose (rem)	Action
<0.1 TEDE <0.5 CDE thyroid <5 DE skin	No action based on risk from radiation dose.
0.1 to <1 TEDE 0.5 to <5 CDE thyroid 5 to <50 DE skin	Sheltering should be considered, <u>but</u> this is <u>not</u> a PAG for sh lt ring.

DIFFERENCES IN EMERGENCY WORKER LIMITS AND PROTECTIVE ACTION GUIDES

- Difference in justification
- Difference in time period of exposure
- Limits vs threshold for decisions

EMERGENCY WORKER PROTECTION
(pp. 2-9 to 13 and C-22 to 24)

- Period of application of emergency worker limits
- Emergency worker dose and occupational dose are not additive unless required by license.
- No guidance for keeping records of dose to emergency workers

-

- Protection of minors and fetuses

EMERGENCY WORKER CATEGORIES
(p. C-22)

- Designated by State and local authorities

- Example categories:

  - Law enforcement and traffic control officials
  - Medical and public health personnel
  - Environmental monitors
  - Emergency vehicle operators
  - Utility, industrial, and institutional emergency workers

PERSPECT VES FOR
EMERGENCY WORKER L M TS
(pp. C-22 to 24)

- Apply the same dose limits as for occupationally exposed workers wherever practicable.

- Permit higher dose limits when required to prevent substantial risks to populations or protect valuable property.

- Provide guidance for extreme emergencies.
  - Volunteers fully informed of risks

DOSE LIMITS FOR EMERGENCY WORKERS (p. 2-10)

DOSE LIMIT	ACTIVITY	CONDITION
5 rem	all	
10 rem	protecting valuable property	lower dose not practical
25 rem	life saving or protecting large populations	lower dose not practical
>25 rem	life saving or protecting large populations	only on a voluntary basis to persons fully aware of the risks.

KI FOR EMERGENCY WORKERS
(pp. 2-11 and 2-13)

- KI is recommended if atmospheric releases include radioiodine (no dose threshold).

- State medical procedures determine its availability and proper use.

SESSION 5

INTRODUCTION TO DOSE PROJECTION

FOR

PROTECTION OF THE PUBLIC

AND

EMERGENCY WORKERS

GENERAL APPROACH TO DOSE PROJECTION

- Determine or estimate source term (Q) and projected release duration (T_p).
- Use atmospheric dispersion model to calculate time integrated air concentration (X_{in}).
- Use dose models to calculate projected dose (D) by means of dose conversion factors (DCF).

GENERAL APPROACH FOR CALCULATING PROJECTED DOSE

Measure or calculate environmental concentrations.

Concentrations may be for individual nuclides or may be grouped by iodines and noble gases.

Multiply by duration of exposure to get time integrated concentration (X_{in}) for each nuclide or group of nuclides.

True X_{in} can be calculated if the total release is used. Not used with measured concentrations.

Multiply each X_{in} by the appropriate DCF to get TEDE or thyroid dose from each nuclide or group of nuclides.

Use DCFs from PAG Manual Table 5.1 for TEDE and 5.2 dose for CDE to thyroid from single nuclides. For groups of nuclides, DCFs must be calculated. A DCF for particulates, as a group, is not practical.

Sum TEDEs over all nuclides or groups of nuclides and su thyroid doses to get projected doses co parable to PAGs.

NEEDED SOURCE TERM INFORMATION

- Gross noble gas, radioiodine, and particulate release rates

  or

  curies per second of each radionuclide

- Release height (release point information)

- Estimated release duration

NEEDED METEOROLOGY

- Wind speed,
- Wind direction
- Stability Classes
- Mixing depth
- Predicted changes
- Precipitation

GAUSSIAN DISPERSION EQUATION

$$\frac{X\bar{u}}{Q} = \frac{e^{-\left(\frac{y^2}{2\sigma_y^2} + \frac{h^2}{2\sigma_z^2}\right)}}{\pi \sigma_y \sigma_z}$$

For a ground level release, release height (h) = 0.
At the centerline, the lateral distance (y) = 0.

$$\frac{X\bar{u}}{Q} = \frac{1}{\pi \sigma_y \sigma_z}$$

BASIC DOSE EQUATION

The basic dose equation is:

$$D = X_{in} \cdot DCF$$

D = Dose (rem)

X_{in} = Time integrated concentration in air ($uCi \cdot cm^{-3} \cdot h$)

h = duration of exposure (hours)

DCF = Dose conversion factor (r m p r $uCi \cdot cm^{-3} \cdot h$)

NEEDED NFORMAT ON FOR DOSE CALCULAT ONS

- Radionuclide air concentration (X)
- Expected duration of exposure (T_p)
- Dose conversion factors (DCF)
- Dose projection procedures
  - computer programs
  - RASCAL

INFORMATION NEEDED TO SUPPORT PROTECTIVE ACTION DECISIONS

- Total effective dose equivalent (TEDE).
- Committed thyroid dose (CDE).
- Measurements of plume gamma rate.
- Measurements of gross radioiodine concentrations.

TIME INTEGRATED AIR CONCENTRATION, X_{in}

- Air concentration times projected exposure time.

$$X(uCi/cm^3) \cdot T_p(hour) = X_{in}$$

- Permits addition of the dose conversion factors over the three exposure pathways.

TIME INTEGRATED AIR CONCENTRATION, X_{in}

(cont'd)

- High concentration for short time
- Low concentration for long time.
- Symbol: X_{in}
- Matches units of EPA's dose conversion factors.

TIME INTEGRATED AIR CONCENTRATION, X_{in}

(cont'd)

PROBLEM ONE

- Xe-133 air concentration is 1.0E-4 uCi/cm^3.
- Expected duration of air concentration is 2 hours.
- X_{in} equals ?????? $(uCi \cdot cm^{-3} \cdot h)$.

TIME INTEGRATED AIR CONCENTRATION, X_{in}
(cont'd)

PROBLEM TWO

- Xe-133 air concentration is 5.0E-5 uCi/cm^3.
- Expected duration of this air concentration is 240 minutes.
- X_{in} equals ?????? $(uCi \cdot cm^{-3} \cdot h)$.

TIME INTEGRATED AIR CONCENTRATION, X_{in}
(cont'd)

SOLUTIONS TO PROBLEMS 1 AND 2

- X_{in} = (air concentration) (expected exposure time)

- $X_{in} = (1.0E\text{-}04\ uCi/cm^3)\ (2\ h)$
  $= 2.0E\text{-}04\ uCi \cdot cm^{-3} \cdot h$

- $X_{in} = (5.0E\text{-}05\ uCi/cm^3)\ (240m/60m/h)$
  $= 2.0E\text{-}04\ uCi \cdot cm^{-3} \cdot h$

DCF DEFINITION
(p. A-1)

- Dose Conversion Factors (DCF) change environmental concentrations (or time integrated concentrations) to dose.

- Dose units (rad = rem)

- EPA DCF unit: rem per uCi $\cdot$ cm^{-3} $\cdot$ h

PARAMETERS THAT AFFECT DCFs

- Physical characteristics
- Chemical characteristics
- Breathing rates
- Assumed deposition velocities
- Biological system clearances

ASSUMED VALUES FOR CALCULATIONS

- Breathing rate = 1.2 m^3/h

- Deposition velocity

	EPA	RASCAL
- Iodine	1 cm/s	0.3 cm/s
- Particulates	0.1 cm/s	0.3 cm/s

- Gamma shielding factor due to ground roughness
EPA = 1 RASCAL default = 0.7

- Public exposure to deposited materials before relocation is 4 days (96 h)

DOSE CONVERSION FACTOR TABLES
(TABLE 5-1 AND TABLE 5-2)

- Table 5-1: Dose Conversion Factors and Derived Response Levels for Combined Exposure Pathways During the Early Phase of a Nuclear Incident.

- Table 5-2: Dose Conversion Factors and Derived Response Levels - Inhalation of Radioiodine.

- Refer to EPA Manual

SKIN DOSE

- DCFs for skin are not provided for early phase.
- Skin dose is not expected to be controlling.
- Skin dose is controlled by bathing and changing clothing.

US NG DCFs FOR COMB NED PATHWAYS (TABLE 5-)

- GIVEN:
  - The concentration of tritium (H-3) in a plume is 5E-3 Ci/m^3.
  - Exposure to plume expected for 3 hours.
- PROBLEM:
  - What is the time integrated air concentration?
  - What is the dose conversion factor?
  - What is the projected dose?
  - What kind of dose is it?

USING DCFs FOR COMBINED PATHWAYS (TABLE 5-1)

(cont'd)

SOLUTION: Calculate X_{in} and look up the DCF.

- X_{in} = (air concentration) (expected exposure time)
  = (5E-3 uCi/cm^3) (3 hours)

- X_{in} = 1.5E-02 uCi · cm^{-3} · h

- DCF for tritium from Table 5-1 is
  7.7E+01 rem per uCi · cm^{-3} · h

US NG DCFs FOR COMB NED PATHWAYS
(TABLE 5-)
(cont'd)

- Projected dose = X_{in} times DCF

or

$(1.5E\text{-}2\ uCi \cdot cm^{-3} \cdot h)(7.7E{+}1\ rem\ per\ uCi \cdot cm^{-3} \cdot h)$

- Projected dose = 1.2 rem

- This projected dose is considered to be total effective dose equivalent (TEDE). Why?

USING DCFs FOR COMBINED PATHWAYS (TABLE 5-1)
(cont'd)

THE PROJECTED DOSE IS THE TEDE BECAUSE:

- DCF is based on committed effective dose equivalents.

- All significant early phase exposure pathways are included.

- All significant radionuclides are included.

SUMMARY

$$D = \sum_{1}^{n} DCF_i \cdot X_{in,\, i}$$

DCF_i = DCF for radionuclide (i)

n = Number of radionuclides present

$X_{in,\, i}$ = The time integrated concentration of radionuclide (i)

SESSION 6

IMPLEMENTATION OF EMERGENCY WORKER DOSE LIMITS

MAIN TOPICS

- Emergency workers
- Relative importance of exposure pathways
- Inhalation dose control methods
- PAG Subcommittee guidance
- Dose for the record

EMERGENCY WORKERS
(p. 2-9)

- State responsibility for defining emergency workers
- Example assignments
  - Law enforcement/traffic control
  - Radiation protection
  - Transportation services

EXPOSURE PATHWAYS FOR EMERGENCY WORKERS

- External gamma radiation
  - Plume
  - Groundshine

- Inhalation from the plume and resuspended materials
  - Plume inhalation may be the major pathway

External beta radiation
  - Plume
  - Groundshine
  - Deposited materi ls on skin nd clothing

INHALATION OF RESUSPENDED MATERIAL

- R suspension r t s
  - Empirical values range from 10^{-5} to 10^{-9} m^{-1}

- Importance of pathway

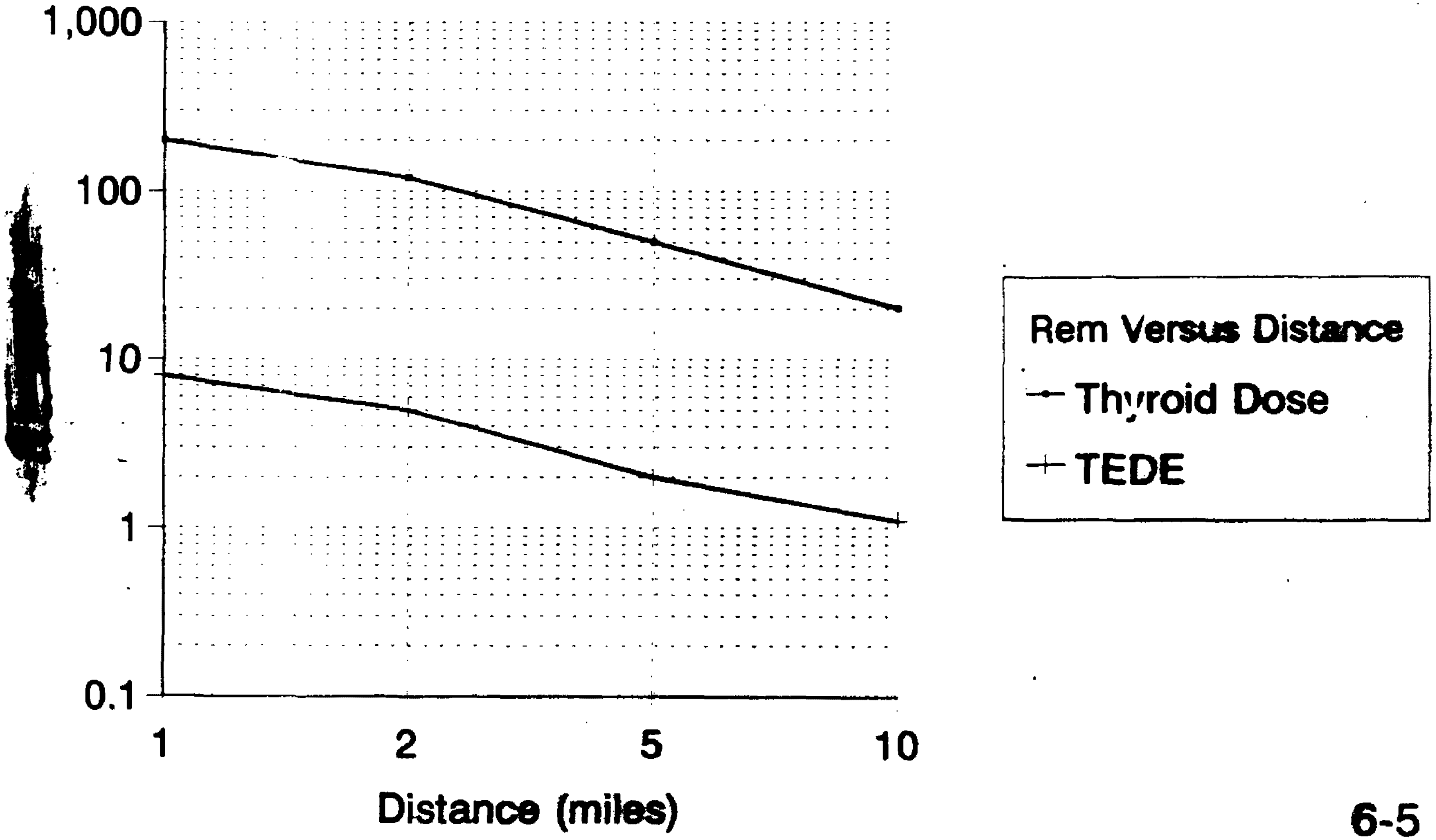
  - Plume phase

  - Post plume phase

  - For example, at 10^{-5} m^{-1}, 1 mR/h yields about 0.05 mrem CEDE from inhalation

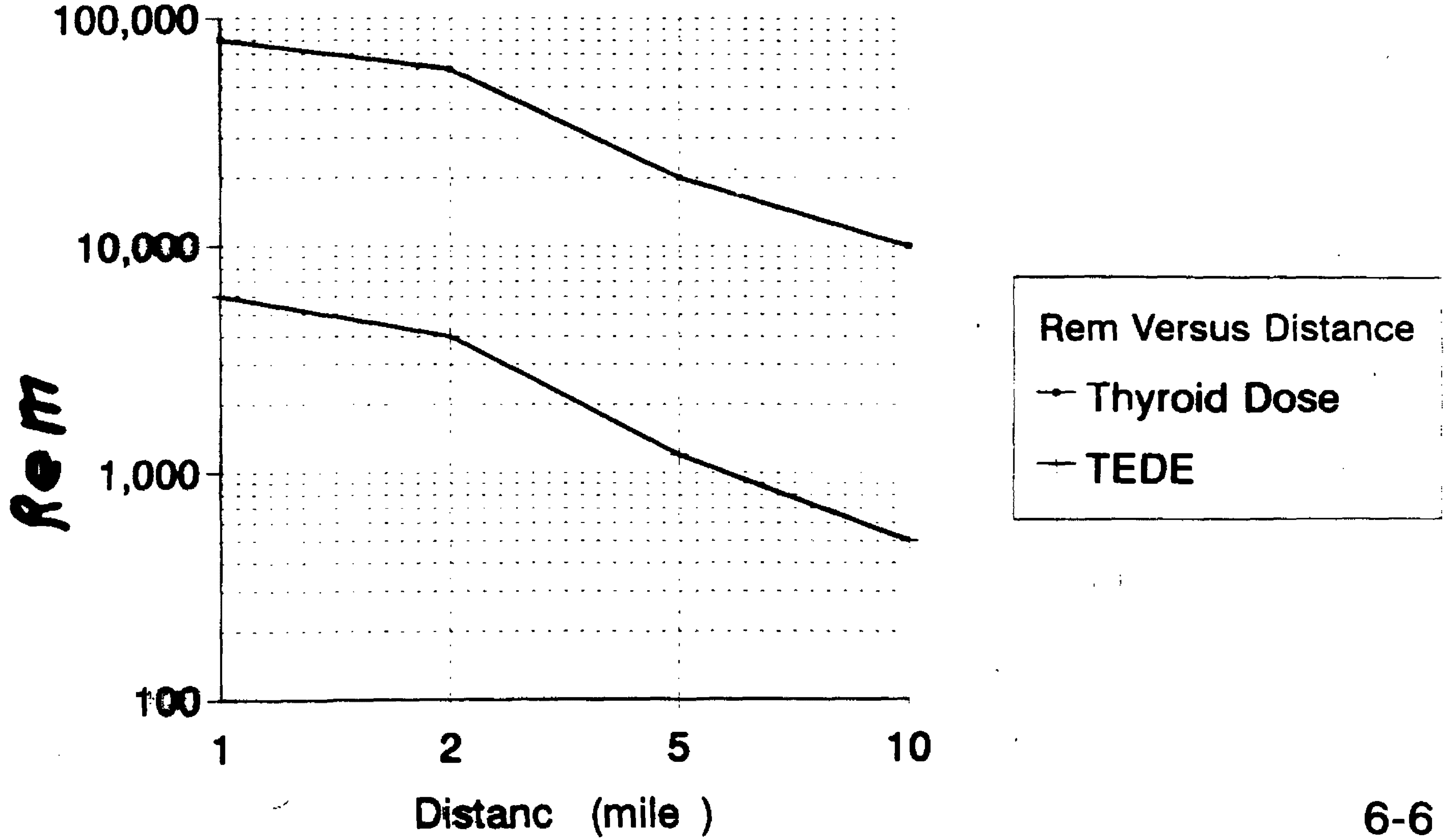
EXAMPLE DOSES FROM A REACTOR ACCIDENT

RTM-93 CASE 5; Gap release for one hour; Late release @ 100 % per day
No Spray; No protective action; No rain; Met cond. was not Specified



EXAMPLE DOSES FROM A REACTOR ACCIDENT

RT -93 CASE 16 Severe core damage· 100% per hour leak rate·
No spray; o rain; No protective action; et Cond. was not Specified.



INHALATION DOSE CONTROL USING RESPIRATORS

- Mentioned, but not promoted by EPA or FEMA

- Effectiveness
  - Filter type
  - Air supplied type

- Advantages
  - Protects workers from inhalation dose.
  - Dose control by dosimeter is simple.

INHALATION DOSE CONTROL USING RESPIRATORS
(cont'd)

- Disadvantages
  - OSHA requirements
    - Fitting and testing
    - Training
    - Medical examinations
  - No beards
  - Reduced vision, communication, and efficiency
  - Discomfort
  - Logistics

PAG SUBCOMMITTEE GUIDANCE DATED JULY 1994

ISSUE: How should the dose to emergency workers, especially those exposed to a radioactive plume, be monitored and controlled to meet the EPA dose limits in terms of total effective dose equivalent (TEDE)

- Guidance:
  - Relates to accidents at nuclear power plants
  - Based on current practices
  - Other approaches may be acceptable

PAG SUBCOMMITTEE GUIDANCE
(CONTINUED)

- Maintain 5 rem TEDE limit where practicable.

- The primary activities for emergency workers within an airborne plume will be:
  - Protection of valuable property,
  - Protection of large populations, and
  - Monitoring.

- States should maintain flexibility in dose limits

PAG SUBCOMMITTEE GUIDANCE
(cont'd)

- Doses up to 10 and 25 rem (and above) should be accepted and planned for.
- DRDs may be used to estimate inhalation dose.
- Use of KI is recommended.
- Flexibility in control procedures is granted.
- Three acceptable options are presented.

OPTIONS FOR ADJUSTING EMERGENCY WORKER GAMMA DOSE LIMITS TO ACCOUNT FOR SIGNIFICANT PARTICULATE RELEASES

Options[a]	Evacuation Phase	Post-Evacuation Phase
1	No adjustments	Adjust, if necessary
2	Fixed admin. limit set prior to Emrg.	Adjust, if necessary
3	Contextual adjustment based on plant data	Contextual adjustment based on plant and environmental data

[a]Oth r options may be consid r d

OPTION ONE

- Control only whole body g mma nd thyroid dose during evacuation.

- Rationale
  - Not practical to rotate workers
  - Inhalation dose is controlled for tasks after evacuation.
  - Evacuation may be completed before plume arrives.

- Disadvantages
  - Higher risk of over-exposure compared to other options

OPTION TWO

- Pre-established administrative limits

- Rationale
  - Easy to implement
  - Will meet limits for most probable accidents

- Disadvantages
  - May not provide adequate control for the most severe accidents
  - Possible discontinuity between States

DOSIMETER ADJUSTMENT FACTORS

Accident Category	Adjustm nt F ctors[a]	
	With KI	Without KI
BWR-1	13 to 29	16 to 37
PWR-1	8 to 16	11 to 26
BWR-3	3 to 7	5 to 12
PWR-3	4 to 8	6 to 14
PWR-5	1.4 to 2	3 to 6
PWR-7	1 to 2	1 to 2

[a] Calculated for distances ranging from 1 to 25 miles, stability classes ranging from A to F, and for 13 hours of exposure.

OPTION THREE

- Calculate contextual mission limits applicable to the accident in progress.

- Rationale
  - Can use same data as for dose projection
  - Mission limits would be more defendable.

- Disadvantages
  - Variable limits may be confusing to implement.
  - Necessary data may not be available.

RETROSPECTIVE EVALUATION OF DOSE FOR THE RECORD

- Applicable to emergency workers who are exposed to an airborne plume containing iodines and/or particulate materials

- KI administration affects the evaluation.

RETROSPECTIVE EVALUATION OF DOSE FOR THE RECORD
(cont'd)

- Based on dosimeter readings (primarily TLD) <u>and</u>
  - Release composition
  - Environmental data (importance of air samples)

- Or based on dosimeter readings <u>and</u>
  - Release composition
  - Whole body counts
  - Bioassay

RETROSPECTIVE ANALYSIS USING RELEASE AND ENVIRONMENTAL DATA

- Need measured dose rates and air sample data.
- Dose rate measurements by air sampling teams relate air concentrations to dosimeter readings.
- Calculations of ratio of exposure rate to air concentration allows worker dosimeter readings to be related to TEDE - becomes official record.

RETROSPECTIVE - PROBLEM

- Monitoring data at location A:
  GM counter (closed beta shield, 1 m) - 950 mR/h
  GM counter (open beta shield, 1 m - open window pointing up) - significantly higher

- Air sample is collected at location A and sent to the laboratory for analysis. The laboratory reports the following results:

Ce-141	1.0e-05	uCi/cm^3
Ba-140	1.0e-04	uCi/cm^3
Cs-134	1.0e-05	uCi/cm^3

- WHAT CONCLUSIONS CAN BE REACHED IMMEDIATELY FOR LOCATION A?

- WHAT ARE THE FOLLOWING FROM A 1 HR EXPOSURE?

  IMMERSION PLUS DEPOSITION DOSE (EDE)?
  INHALATION DOSE (CEDE)? (See WORK SHEET on VG 6-22.)
  TOTAL DOSE (TEDE)?

- WHAT IS THE DOSE TO EMERGENCY WORKERS EXPRESSED AS TEDE PER ROENTGEN AS READ ON A DOSIMETER?

RETROSPECTIVE - PROBLEM SOLUTION

- Immediate conclusions:
  - There had been a release of radioactive materials.
  - The plume was present.
  - Particulates were present.
  - Actual risk could be much higher than implied by dosimeter readings.
- Compare DCFs from plume shine versus ground shine for Cs-134. (The DCF for deposited materials assumes persons remain 96 hours (4 days) at this location - correct for this).
  - The deposition dose is not significant because the 1 hr DCF is small compared to the immersion DCF.
- Assuming "mR" is approximately equal to "mrem", the whole body dose rate from gamma radiations (EDE/h) is:

  950 mrem/h

- Gamma dose (EDE) due to a 1 hour external exposure to the plume and groundshine

  950 mrem/h · 1 h = 950 mrem = 0.95 rem

PROBLEM SOLUTION WORK SHEET

Problem_ Emergency worker __: Projected Dose at_Location A_ from_inhalation_

Nuclide(s)	Air Concentration (X) (uCi/cm^3)	Projected Exposure Time (h)	Integrated Air Concentration (X_{in}) (uCi · cm^{-3} · h)	DCF from Table 5-4 (rem per uCi · cm^{-3} · h)	Inhalation Committed Effective Dose Equivalent (CEDE) (rem)
Ce-141	1.0E-05				
Ba-140	1.0E-04				
Cs-134	1.0E-05				
				Totals >	

PROBLEM SOLUTION
(cont'd)

- Total projected dose (TEDE) to worker for nominal 1 hour exposure to plume:
  0.95 rem (EDE) + 1.12 rem (CEDE) + 0.00 (EDE) =
  2.07 rem (TEDE)

- Nominal expected increase in dosimeter reading after 1 hour is:

  0.95 rem (EDE) due to gamma from the plume +

  approximately 0.00 rem (EDE) due to gamma from ground shine

  total is 0.95 "R" recorded on dosimeter

- 0.95 "R" Dosimeter reading is equatable to a total dose for the record:
  2.07 rem (TEDE)

- Retrospective dose for the nominal worker record:

  each 1.0 "R" on dosimeter is equivalent to 2.2 rem (TEDE)

FACTORS THAT MAY AFFECT DOSE CALCULATIONS

- Insufficient air sample and exposure rate data
- Ground shine becomes important.
- Emergency workers get significant doses outside the plume.
- Emergency workers do not take KI.
- Emergency workers use respirators.

PLAN CHANGES NEEDED TO SUPPORT OPTIONS 1 OR 2

- Specify the administrative dose limits for evacuation support.
- Specify procedures for dose control after evacuation is complete.

PLAN CHANGES NEEDED TO SUPPORT OPTION 3

- Specify procedures for contextual determination of administrative dose limits.
  - Calculation models to be used
  - Data needs
  - Sources of data

- Identify communication procedures and equipment.

- Procedures for changing the administrative limits if applicable

GU DANCE APPL CABLE TO ALL OPT ONS

- Other options may be selected.
  - FEMA will review written proposals.

- FEMA recommends admin. limits of 2 R or more.

- Need procedures for:
  - Retrospective dose determinations
  - Training

- Existing dosimetry systems are acceptable.

- KI use is recommended.

SESSION 7

DEVELOPMENT

OF

DCFs AND DRLs

IMPLEMENTATION OF PAGS

- Must compare a projected TEDE or CDE to the applicable PAG

- BASIC DOSE EQUATION

  - Dose (TEDE or CDE) = Dose Rate x Time

  - Dose Rate = Concentration x Conversion Factor

  - Dose = Time Integrated Concentration x DCF

DEF N T ONS

- Dose Conversion Factor (DCF): A value that converts an environmental level to dose.

  - Tabulated in units of: rem per $uCi \cdot cm^{-3} \cdot h$

- Derived Response Level (DRL): Calculated environmental level that corresponds to a particular PAG.

  - Tabulated in units of: $uCi \cdot cm^{-3} \cdot h$

PATHWAYS
(PAG Manual - Section 5.6)

- Three exposure pathways are included:
  - Gammas from the plume (immersion)
  - Inhalation from plume
  - Gammas from ground shine (deposited radionuclides)

- Pathways considered, but not included:
  - Beta due to skin deposition
  - Inhalation of resuspended materials
  - Beta from the plume

SUPPORTING DOCUMENTS FOR DCFS

- "External Dose-Rate Conversion Factors for Calculation of Dose to the Public" (DOE/EH 0070)
  - Needed for plume and ground shine

- "Limiting Values of Radionuclide Intake and Air Concentration and, Dose Conversion Factors for Inhalation, Submersion and Ingestion" (FGR-11) EPA 520/1-88-020 (September 1988).
  - Needed only to modify EPA DCFs for inhalation

TIME INTEGRATED AIR CONCENTRATION, X_{in}

- Air concentration times projected exposure time.

$$X(uCi/cm^3) \cdot T_p(hour) = X_{in}$$

- Permits addition of the dose conversion factors over the three exposure pathways.

EXTERNAL EXPOSURE TO GAMMA RADIATION FROM THE PLUME
(Section 5.6.1)

- Table 5-3 (PAG manual, beginning on P. 5-25)
- Gamma radiation due to immersion.
- Conservative if plume is overhead.
- Semi-infinite source assumption.

EXTERNAL EXPOSURE TO GAMMA RADIATION FROM THE PLUME
(cont'd)

- DCFs yield effective dose equivalent (EDE).
- Based on DOE/EH-0070; EPA FGR #12.
- Short-lived daughters are accounted for.

Table 5-3: Dose Conversion Factors (DCF) and Derived Response Levels (DRL) for External Exposure Due to Immersion in Contaminated Air

Radionuclide	DCF rem per $uCi \cdot cm^{-3} \cdot h$	DRL $uCi \cdot cm^{-3} \cdot h$
H-3	0.0E+00	0.0E+00
C-14	0.0E+00	0.0E+00
Na-22	1.3E+03	7.8E-04
Na-24	2.7E+03	3.7E-04
P-32	0.0E+00	0.0E+00

PAG Manual - beginning on page 5-25

INHALATION FROM THE PLUME
(Section 5.6.2)

- Table 5-4 (PAG manual, beginning on 5-31)
- Inhalation of radioactive particulate material
- Alpha, beta and gamma emitters
- Chemical and physical form that yields the highest dose

INHALATION FROM THE PLUME
(Section 5.6.2)
(cont'd)

- Committed effective dose equivalent (CEDE)
- Radionuclides may remain in the body.
- 50 year time frame for dose
- Federal Guidance Report No. 11
- Standard Person

Table 5-4: Dose Conversion Factors (DCF) and Derived Response levels (DRL) for Doses Due to Inhalation

Radionuclide	Lung Class	DCF rem per $uCi \cdot cm^{-3} \cdot h$	DRL $uCi \cdot cm^{-3} \cdot h$
H-3	V	7.7E+01	1.3E-02
C-14	L ORG C[a]	2.5E+03	4.0E-04
Na-22	D	9.2E+03	1.1E-04
Na-24	D	1.5E+03	6.9E-04
P-32	W	1.9E+04	5.4E-05

[a]L ORG C denotes labelled organic compounds

PAG M nual - beginning on pag 5-31

Table 5-4: Dose Conversion Factors (DCF) and Derived Response levels (DRL) for Doses to the Thyroid Due to Inhalation

Radionuclide	Lung Class	DCF rem per $uCi \cdot cm^{-3} \cdot h$	DRL $uCi \cdot cm^{-3} \cdot h$
Te/I-132	W/D	2.9E+05	1.8E-05
I-125	D	9.6E+05	5.2E-06
I-129	D	6.9E+06	7.2E-07
I-131	D	1.3E+06	3.9E-06

PAG Manual - beginning on page 5-35
Also see Table 5-2 on page 5-15

EXTERNAL DOSE FROM DEPOSITED MATERIALS
(Section 5.6.3)

- Table 5-5 (PAG manual, beginning on 5-37)
- Gamma radiation following deposition
- Radioiodine and particulates from a plume
- Assumes 4-day exposure
- Dry deposition

EXTERNAL DOSE FROM DEPOSITED MATERIALS
(cont'd)

- Deposition velocity
  - 0.1 cm/s for particulate materials
  - 1 cm/s for radioiodine
  - Much higher if there is rain

EXTERNAL DOSE FROM DEPOSITED MATERIALS
(cont'd)

- DCF for deposited materials is the effective dose equivalent (EDE) in rem per:
  - 1 uCi/cm^3 concentration of a radionuclide
  - 1 hour of deposition
  - 96 hours of exposure to decaying radionuclides

TABLE 5-5: DCF EQUATION FOR GROUND SHINE (pp. 5-34 and 5-37)

$$DCF = V_g \cdot DRCF \cdot 1.14E\text{-}3 \left[\frac{1 - e^{-\lambda t}}{\lambda} \right]$$

DCF = the dose per unit air concentration
(rem per uCi · cm^{-3} · h)

TABLE 5-5 DCF EQUATION

(cont d)

- V_g = deposition velocity (cm/h)
- DRCF = the dose rate conversion factor from DOE/EH 0070 (mrem/y per uCi/m^2)
- 1.14E-3 = conversion factor from mrem/y per uCi/m^2 to rem/h per uCi/cm^2
- λ = decay constant (h^{-1})
- t = duration (h), assumed to be 96 hours

Table 5-5: Dose Conversion Factors (DCF) and Derived Response levels (DRL) for a 4-Day Exposure to Gamma Radiation from Deposited Radionuclides

Radionuclide	DCF rem per $uCi \cdot cm^{-3} \cdot h$	DRL $uCi \cdot cm^{-3} \cdot h$
H-3	0.0E+00	- -
C-14	0.0E+00	- -
Na-22	8.3E+03	1.2E-04
Na-24	3.1E+03	3.2E-04
P-32	0.0E+00	- -

PAG Manual - beginning on page 5-37.

MOD FY NG DOSE CONVERS ON FACTORS

- Changes in physical characteristics
- Changes in chemical characteristics
- Changes in breathing rates
- Changes in assumed deposition velocities

COMBINED PATHWAYS

(PAG M nua , T b 5-)

- The DCF and DRL for each pathway is related to the time integrated air concentration (X_{in}). They may be combined for a particular radionuclide

- $$Dose_{Total} = Dose_{Ext} + Dose_{Inh} + Dose_{Ground\ Shine}$$

$$Dose_{Total} = DCF_{Ext} \cdot X_{in} + DCF_{Inh} \cdot X_{in} + DCF_{GS} \cdot X_{in}$$

$$Dose_{Total} = X_{in} \cdot (DCF_{Ext} + DCF_{inh} + DCF_{GS}) = X_{in} \cdot DCF_{combined}$$

Table 5-1: Dose Convers on Factors (DCF) and Derived Response levels (DRL) for Comb ned Exposure Pathways Dur ng the Early Phase of a Nuclear Incident

Radionuclide	DCF rem per uCi · cm^{-3} · h	DRL uCi · cm^{-3} · h
H-3	7.7E+01	1.3E-02
C-14	2.5E+03	4.0E-04
Na-22	1.9E+04	5.3E-05
Na-24	7.3E+03	1.4E-04
P-32	1.9E+04	5.4E-05

PAG M nual - begin ing on p g 5-9.

EXAMPLE OF COMBINED PATHWAYS

Nuclide selected__________

		DCF	X_{in}	Dose
Pathway	Table	(rem per uCi · cm^{-3} · h)	(uCi · cm^{-3} · h)	(rem)
External	5-3		1	
Inhalation	5-4		1	
Ground Shine	5-5		1	
Summation				
Combined	5-1		1	

SESSION 8

DOSE PROJECTION PROBLEMS

FOR THE EARLY PHASE

INTRODUCTION

- Two student problems

1. Use of combined pathways DCFs
   1a-1 Thyroid dose at 1 mile
   1b-1 TEDE at 1 mile
   1a-2 Thyroid dose at 2 miles
   1b-2 TEDE at 2 miles

2. Use of separate pathway DCFs

STEPS TO DETERMINE THE REQUESTED PROJECTED DOSES

- Determine diffusion coefficients ($X\bar{u}/Q$) at the distances required.
- Determine the wind speed in m/s ($\bar{u}$).
- Determine the source term in Ci/s (Q).
- Solve for X.

STEPS TO DETERMINE THE REQUESTED PROJECTED DOSES
(cont'd)

- Determine the projected exposure time (T_p).
- Calculate the time integrated concentration (X_{in}).
- Select the specific DCF (rem per $\mu Ci \cdot cm^{-3} \cdot h$).
- Calculate the projected dose (rem).

PROBLEM : PROJECTED DOSE
US NG COMB NED PATHWAY DCFs

Problem 1a: Determine the Committed Dose Equivalent (CDE) to the thyroid from a plume containing I-131, and

Problem 1b: Determine the Total Effective Dose Equivalent (TEDE) for a plume with a mix of three isotopes (Xe-133, I-131, and Cs-134).

And: Determine the above doses at 1 mile and 2 miles from the release point.

PROBLEM 1

- Calculate at 1 mile
  - Concentrations (X)
  - Time Integrated Concentration (X_{in})
  - Dose (CDE to Thyroid and TEDE)
- Use Worksheet (VG 8-6)

RAD AT ON ACC DENT ASSESSMENT COURSE
WORK SHEET

Problem 1a -1 & 1b-1 : Projected Dose at 1 Mile(s): From thyroid & combined pathway

Nuclide(s) & Prblm. # 1a-1	$X\bar{u}/Q$ @ 1 mi (m^{-2})	Q (Ci/s)	$\bar{u}$ (m/s)	X @ 1 mi ($\mu Ci/cm^3$)	Exp. time (h)	X_{in} @ 1 mi ($\mu Ci \cdot cm^{-3} \cdot h$)	DCF Table No.	DCF_{th} $\frac{rem}{\mu Ci \cdot cm^{-3} \cdot h}$	Dose (CDE) (rem)
I-131									
Nuclide # 1b-1									TEDE (rem)
								DCF_{cp}	
Xe-133									
I-131									
Cs-134									
								TOTAL →	

PROBLEM 1: INITIAL CONDITIONS

- Time from shutdown to release: 2 hours
- Estimated release time: 3 hours
- Release height: Ground level
- Stability is class D.
- Wind speed is 2 m/s (4.5 mph).
- Forecast is for no change.

$X\bar{u}/Q$ AS A FUNCTION OF DOWNWIND DISTANCE AND STABILITY CLASS

Values of $X\bar{u}/Q$ (m^{-2})

Distance (Miles)	Class A	Class B	Class C	Class D	Class E	Class F
0.5	6.6E-6	3.0E-5	7.6E-5	2.1E-4	4.2E-4	9.6E-4
1	1.0E-6	7.4E-6	2.1E-5	7.0E-5	1.4E-4	3.3E-4
2	5.5E-7	1.9E-6	6.1E-6	2.4E-5	5.0E-5	1.2E-4
3	3.9E-7	8.4E-7	2.9E-6	1.3E-5	2.8E-5	6.8E-5
4	3.0E-7	4.8E-7	1.7E-6	8.5E-6	1.9E-5	4.6E-5
5	2.5E-7	3.3E-7	1.2E-6	6.1E-6	1.4E-5	3.3E-5
7	1.9E-7	2.5E-7	6.3E-7	3.7E-6	8.4E-6	2.2E-5
10	1.4E-7	1.8E-7	3.3E-7	2.3E-6	5.1E-6	1.4E-5
15	9.9E-8	1.3E-7	1.8E-7	1.2E-6	3.1E-6	8.4E-6

A 1250 meter lid is used.
This is a ground level release.

PROBLEM 1: SOURCE TERM

SOURCE TERM (Q):

- Xe-133 1,700 Ci/s
- I-131 0.17 Ci/s
- Cs-134 0.05 Ci/s

PROBLEM 1a-1
CALCULATE AIR CONCENTRATION (X)

- At 1 mile and for I-131:

$$X\bar{u}/Q = 7.0E\text{-}05 \quad \text{(from VG 8-8)}$$

- WHERE:
  - X = air concentration ($\mu Ci/cm^3$)
  - $\bar{u}$ = average wind speed (m/s)
  - Q = source term (Ci/s)

- SOLVE FOR X AT 1 MILE:

PROBLEM 1a-1: CALCULATE INTEGRATED AIR CONCENTRATION (X_{in}) FOR I-131

Using values recorded on the Work Sheet

Solve for X_{in}:

$$X_{in} = X \cdot t$$

PROBLEM 1a-1
COMMITTED DOSE EQUIVALENT (CDE) TO THE THYROID

- The committed dose equivalent (CDE) to the thyroid is:

________________________ $(X_{in} \cdot DCF_{th})$

- The dose model is:

$$CDE_{th} = DCF_{th} \cdot X_{in} = DCF_{th} \cdot \left[\frac{Q}{\bar{u}} \cdot \frac{X\bar{u}}{Q} \cdot h \right]$$

PROBLEM 1b-1: PROJECTED DOSE

- Calculate the TEDE for three nuclides:
  Xe-133, I-131, and Cs-134.

- Assumptions: Same as for problem 1a-1

- Dose Model:

$$TEDE = DCF_{cp} \cdot X_{in} = DCF_{cp} \left[\frac{Q}{\bar{u}} \cdot \frac{X\bar{u}}{Q} \cdot h \right]$$

PROBLEM 1b-1
SOLVE FOR X AT 1 MILE
FOR THREE NUCLIDES

- Model:

$$X = \frac{X\bar{u}}{Q} \cdot \frac{Q}{\bar{u}}$$

Calculate concentrations (X)

$$\left.\begin{array}{rl} Xe-133, & Q = 1.7E+3 \\ I-131, & Q = 1.7E-1 \\ Cs-134, & Q = 5.0E-2 \end{array}\right\} \cdot \ 7.0E-5 =$$

$\bar{u} = 2$ m/s

PROBLEM 1b-1
INTEGRATED AIR CONCENTRATION (X_{in})

- Using the results from VG 8-14

- Solve for X_{in} for the three nuclides.

$$X_{in} = X \cdot t$$

- Exposure duration = 3 hours

PROBLEM 1a-2
SOLVE FOR (CDE) TO THE THYROID FROM I-131 AT 2 MILES

$$CDE_{th} = DCF_{th} \cdot X_{in}$$

- Step 1. Obtain X$\bar{u}$/Q for 2 mi = 2.4E-5. (VG 8-8)

- Step 2.

$$X = \left[\frac{2.5E-5\ m^{-2} \cdot 1.7E-1\ Ci/s}{1\ m/s} \right]$$

PROBLEM 1a-2
SOLVE FOR THE (CDE) TO THE THYROID FROM I-131 AT 2 MILES

- Step 3. $X_{in} = X \cdot h$ =

- Step 4. Obtain DCF_{th}. The Table is _______

  - The value is _______________

- Step 5. Dose = $X_{in} \cdot DCF_{th}$ = ___________
  Use the Worksheet on VG 8-18

RAD AT ON ACC DENT ASSESSMENT COURSE
WORK SHEET

Problem 1a-2 & 1b-2 : Projected Dose at 2 Mile(s): From thyroid & combined pathway

Nuclide(s) & Prblm. # 1a-2	$X\bar{u}/Q$ @ 2 mi (m^{-2})	Q (Ci/s)	$\bar{u}$ (m/s)	X @ 2 mi ($\mu Ci/cm^3$)	Exp. time (h)	X_{in} @ 2 mi ($\mu Ci \cdot cm^{-3} \cdot h$)	DCF Table No.	DCF_{th} $\frac{rem}{\mu Ci \cdot cm^{-3} \cdot h}$	Dose (CDE) (rem)
I-131									
Nuclides # 1b-2									TEDE (rem)
								DCF_{cp}	
Xe-133									
I-131									
Cs-134									
								TOTAL →	

PROBLEM 1b-2: DOSE PROJECTION TEDE AT 2 MILES

- Using the same assumptions for the three radionuclides, calculate the TEDE at 2 miles.

  - Exposure duration = 3 hours

  - Stability class = D

  - Wind speed = 2 m/s

- $CDE_{cp} = DCF_{cp} \cdot X_{in} = DCF_{cp} \cdot (Q/\bar{u} \cdot X\bar{u}/Q \cdot h)$

PROBLEM 1b 2: FIND TEDE AT 2 MILES FOR Xe 133 I 131 AND Cs 134

- Step 1

$$X_{2mi} = \frac{X\bar{u}}{Q} \cdot \frac{Q}{\bar{u}} = 2.4E{-5} \cdot \begin{Bmatrix} 1.7E+3 \\ 1.7E-1 \\ 5.0E-2 \end{Bmatrix} \div 2$$

- Step 2 → $X \cdot h = X_{in}$ $(h = 3)$
- Step 3 → $X_{in} \cdot DCF_{cp} = TEDE$
- DCF_{cp} comes from Table ______________

PROBLEM 2: DOSE PROJECTION USING SEPARATE PATHWAY DCFs

- Assumptions:

  - Time from shutdown to release: 2 hours

  - Estimated release time: 3 hours

  - Release height: Ground level

- Stability is class D

  - Wind speed is 2 m/s (4.5 mph).

PROBLEM 2: PROJECTED DOSE AS A FUNCTION OF PATHWAY

- Same source terms, meteorology, and exposure time as for problem 1.

- Same integrated air concentrations.

- Three separate exposure pathways.

PROBLEM 2: PROJECTED DOSE AS A FUNCTION OF PATHWAY (cont'd)

- External dose (EDE) from the plume (Table 5-3)
- Plume inhalation dose (CEDE) (Table 5-4)
- External dose (EDE) from deposited radionuclides (Table 5-5)

PROBLEM 2: DOSE MODELS

$$Dose_p = DCF_p \cdot X_{in} = DCF_p \cdot \left[\frac{Q}{\bar{u}} \cdot \frac{X\bar{u}}{Q} \cdot h \right]$$

- $(X\bar{u}/Q \cdot Q/\bar{u}) \cdot h = X \cdot h = X_{in}$
- For I-131: (2.4E-5) · (1.7E-1)/2 = 2.0E-6 Ci/m^3
- 2.0E-6 Ci/m^3 · 3h = 6.0E-6 ($\mu Ci \cdot cm^{-3} \cdot h$)
- Calculate X_{in} and dose for each nuclide.
- Fill in matrixes (VG 8-25, 26, and 27).

RAD OLOG CAL ACC DENT ASSESSMENT COURSE
WORK SHEET

Problem 2a : Projected Dose at 2 Mile(s): From immersion pathway

Nuclide(s) & Prblm. # 2a	$X\bar{u}/Q$ @ 2 mi (m^{-2})	Q (Ci/s)	$\bar{u}$ (m/s)	X @ 2 mi ($\mu Ci/cm^3$)	Exp. time (h)	X_{in} @ 2 mi ($\mu Ci \cdot cm^{-3} \cdot h$)	DCF Table No.	DCF_{im} $\frac{rem}{\mu Ci \cdot cm^{-3} \cdot h}$	Dose (___) (rem)
Xe-133									
I-131									
Cs-134									
								TOTAL →	

RAD OLOG CAL ACC DENT ASSESSMENT COURSE
WORK SHEET

Problem 2b : Projected Dose at 2 Mile(s): From inhalation pathway

Nuclide(s) & Prblm. # 2b	$X\bar{u}/Q$ @ 2 mi (m^{-2})	Q (Ci/s)	$\bar{u}$ (m/s)	X @ 2 mi ($\mu Ci/cm^3$)	Exp. time (h)	X_{in} @ 2 mi ($\mu Ci \cdot cm^{-3} \cdot h$)	DCF Table No.	DCF_{inh} $\frac{rem}{\mu Ci \cdot cm^{-3} \cdot h}$	Dose (__) (rem)
Xe-133									
I-131									
Cs-134									
								TOTAL →	

RADIOLOGICAL ACCIDENT ASSESSMENT COURSE
WORK SHEET

Problem 2c : Projected Dose at 2 Mile(s): From deposition pathway

Nuclide(s) & Prblm. # 2c	Xū/Q @ 2 mi (m^{-2})	Q (Ci/s)	ū (m/s)	X @ 2 mi ($\mu Ci/cm^3$)	Exp. time (h)	X_{in} @ 2 mi ($\mu Ci \cdot cm^{-3} \cdot h$)	DCF Table No.	DCF_{dep} $\frac{rem}{\mu Ci \cdot cm^{-3} \cdot h}$	Dose (__) (rem)
Xe-133									
I-131									
Cs-134									
								TOTAL →	

RADIOLOGICAL ACCIDENT ASSESSMENT COURSE
WORK SHEET

Problem #___2____

The dose model is: Dose = DCF · X_{in} = DCF · (Q/ū · Xū/Q · h)

DOSE PROJECTION AT 2 MILES FOR INDIVIDUAL PATHWAYS				
Nuclide	Pathway	DCF rem / (µCi · cm^{-3} · h)	X_{in} (µCi · cm^{-3} · h)	Dose (rem)
I-131	immersion	2.2E+2	6.0E-6	1.3E-3
	inhalation	3.9E+4	6.0E-6	2.4E-1
	deposition	1.3E+4	6.0E-6	8.0E-2
	TEDE for I-131			3.2E-1
Cs-134	immersion	9.1E+2	1.8E-6	1.7E-3
	inhalation	5.6E+4	1.8E-6	1.0E-1
	deposition	6.2E+3	1.8E-6	1.1E-2
	TEDE for Cs-134			1.1E-1
Xe-133	immersion	20	6.0E-2	1.2
	inhalation	0	6.0E-2	0
	deposition	0	6.0E-2	0
	TEDE for Xe-133			1.2
TEDE for all radionuclides combined				1.5

SESSION 9

PROTECTIVE ACTION GUIDES FOR RELOCATION AND RETURN

AND

DOSE LIMITS FOR RECOVERY WORKERS

THE "R" WORDS
(p. A-3)

- Relocation: The removal or continued exclusion of people (households) from contaminated areas to avoid chronic radiation exposure.

- Return: The reoccupation of areas cleared for unrestricted residence or use.

- Restricted zone: An area with controlled access from which the population has been relocated.

THE "R" WORDS
(p. A-3)
(cont'd)

- Reentry: Temporary entry into a restricted zone under controlled conditions.

- Recovery: The process of reducing radiation exposure rates and concentrations in the environment to acceptable levels for unconditional occupancy or use.

POTENTIAL TIME FRAME OF RESPONSE TO A NUCLEAR INCIDENT

- Refer to PAG Manual Page 7-5.

- Times are estimates only.

- Sequences may vary some.

EXPOSURE PATHWAYS
(p. 4-2)

- Pathways to be evaluated as basis for relocation
  - Whole body exposure to gamma radiation
  - Inhalation of resuspended materials

- Minor pathways (no evaluation needed for reactor accidents)
  - Beta skin exposure
  - Inadvertent ingestion of dirt
  - Refer to EPA 520/1-89-016

ESTIMATED DOSE FROM MINOR EXPOSURE PATHWAYS

Individual[a]	Exposure Pathway	First Year Dose (rem)	
		Soil	Pavement
adult	skin[b]	2.4	8.4
	ingestion[c]	0.01	0.1
child	skin[b]	8.1	14
	ingestion[c]	0.05	0.5
adult or child	groundshine	1.0	1.0

[a]Maximum exposed individuals. Average exposure is about 1/3 to 1/6 lower.

[b]Includes beta dose from nearby surfaces and from material on the skin.

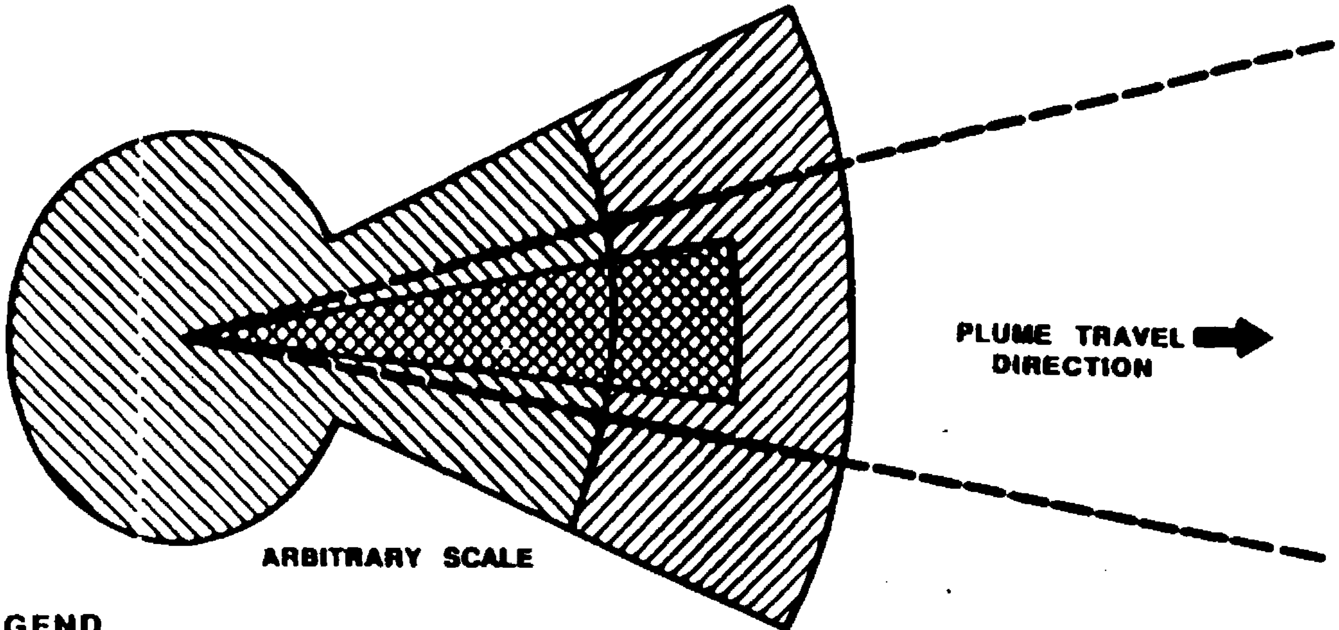
[c]Inadvertent ing stion of contaminat d dirt.

RELOCATION AND RETURN PAGS
(p. 4-4)

Projected Dose From First Year Exposure	Protective Action
≥2 rem TEDE ≥100 rem DE skin	Establish restricted zone and relocate the general population.
<2 rem TEDE <100 rem DE	Apply simple dose reduction techniques to skin.

RELOCATION AND RETURN PAGS
(p. 4-4 4-5 E-13 & E-20)
(cont'd)

- Additional guidance
  - 0.5 rem in any year after the first
  - 5 rem in 50 years
- Actual dose should be less than projected dose
  - Shielding
  - Mobility
  - Special dose reduction efforts
  - Refer to tables on pages E-13 and E-20



LEGEND

1. PLUME DEPOSITION AREA.

2. AREA FROM WHICH POPULATION IS EVACUATED.

3. AREA IN WHICH POPULATION IS SHELTERED.

4 AREA FROM WHICH POPULATION IS RELOCATED (RESTRICTED ZONE).

GRADUAL RETURN
(p. 4-5 & 7-4)

- Establishment of buffer zone
- Gradual return
- FEMA option to combine temporary relocation and gradual return boundaries
  - Advantage - no early dose calculations
  - Disadvantage - large relocation area
    - major public disruption

DOSE REDUCTION FOR RETURNEES
(p. 4-3)

- Areas for priority
  - Dose in excess of 0.5 rem in 1st year
  - Residences of pregnant women
- Responsibility for actions

EXAMPLES OF
S MPLE DOSE REDUCT ON TECHN QUES
(pp. 4-3, 7-6, E-13, & E-19)

- Scrub/flush/wipe hard surfaces.
- Soak or plow soil.
- Cut and remove grass clippings and other foliage.
- Remove spots of soil where radioactivity has concentrated.
- Disposal of contaminated materials

SIMPLE DOSE REDUCTION TECHNIQUES
(pp. 4 3, 7 6, E-13, & E 19)
(cont'd)

- Remove debris.

- Spend more time in areas with lower contamination levels (e.g., indoors).

- Replace sandbox sand.

- Pay special attention to child hygiene.

RAT ONALE - FOUR PR NC PLES

- Acute health effects
- Delayed health effects
- Cost of avoiding risk
- Risk - risk comparison

FACTORS NOT NCLUDED N THE RELOCAT ON PAGs

- Physical and mental stress
- Past exposures
- Dose from ingestion
- Dose from occupational exposure

COST ANALYSIS
(pp. E-8, E-9, & E-10)

- Assumptions:

  - Value of avoiding a statistical death is $400,000 to $7,000,000.

  - Average daily cost of relocation is $27 - Refer to EPA 520/1-89-015.

- Where does the daily cost of relocation equal the monetary value of average daily risk avoided?

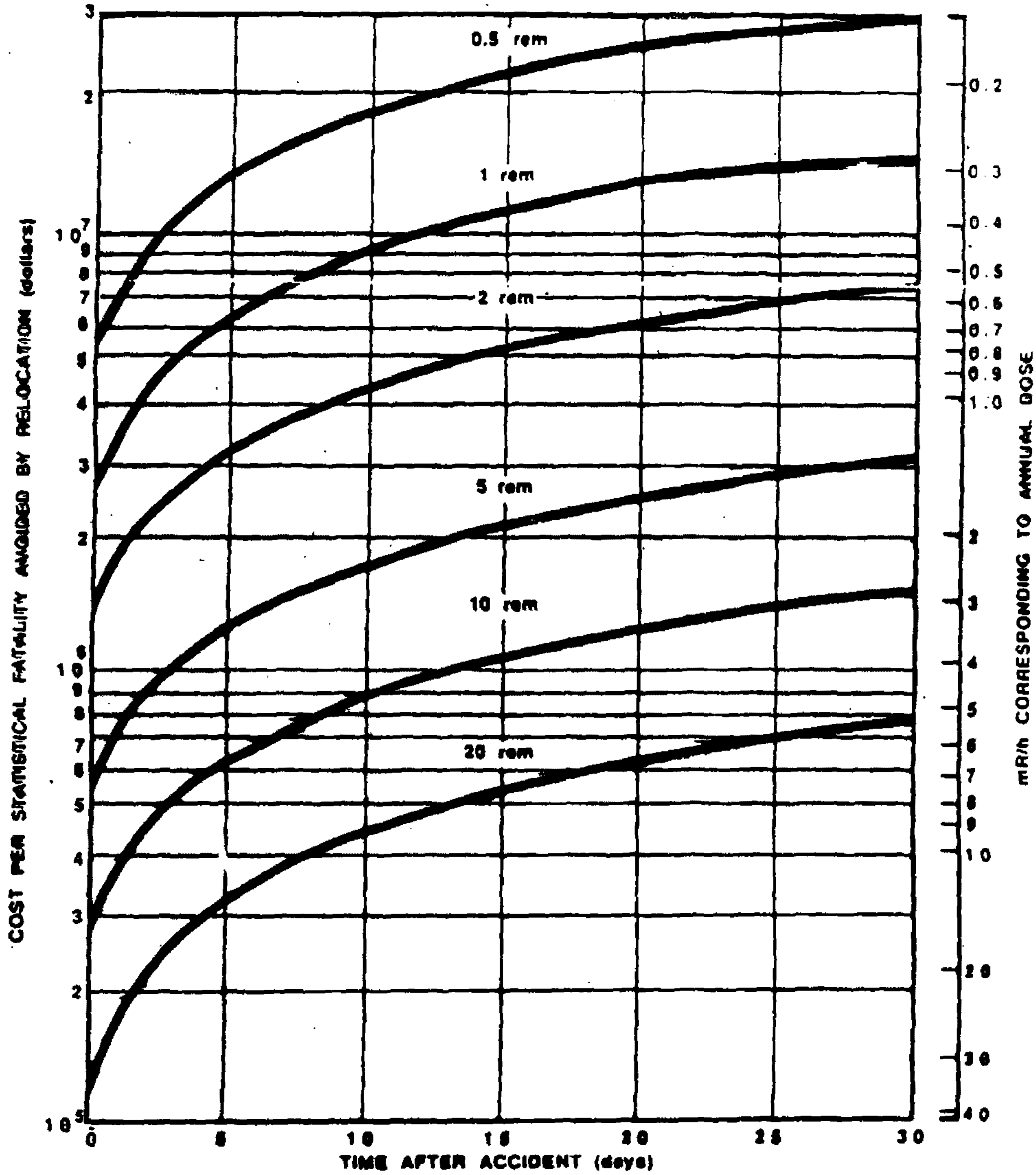


FIGURE E-3. COST OF AVOIDING STATISTICAL FATALITIES AND EXPOSURE RATES CORRESPONDING TO VARIOUS TOTAL FIRST YEAR DOSES (ASSUMES AN SST-2 ACCIDENT AND A $27 PER PERSON-DAY COST OF RELOCATION).

BASIS FOR SETTING PAG LEVELS
(p.1-5)

PRINCIPLE	STRATEGY
(1) Avoid acute health effects.	Stay below threshold dose.
(2) Adequately protect against cancer and genetic effects under emergency conditions.	Set PAG at this level unless driven down by cost/risk considerations (3), or up by risk/risk considerations (4).
(3) Optimize cost of protective action versus avoided dose.	Use this principle only if the the PAG value is driven down.
(4) Regardless of the above principles, the risk from a protective action should not itself exceed the risk from the dos th t would be void d.	Use this principle only if the PAG value is driven up.

CONCLUSIONS ON APPROPRIATE VALUE FOR RELOCATION PAG
(p. E-18)

- Principle on acute effects is not applicable.

- Judgment of acceptable level of risk of delayed health effects:
  - 5 rem in 50 years
  - 0.5 rem in any single year after the first

- 2 rem in the first year will meet the above criteria for nuclear power plant accidents.

CONCLUS ONS ON APPROPR ATE VALUE FOR RELOCAT ON PAG (p. E-18)

(cont'd)

- Cost will not drive the first year dose below 2 rem.

- Risk from relocation is assumed to be the same as for evacuation (i.e., equivalent to the risk from about 30 mrem).

DOSE LIMITS FOR RECOVERY WORKERS
(pp. 4 6, 7 17, & E 19)

- Same as for occupationally exposed workers

  - TEDE 5 rem/y
  - CDE to any organ 50 rem/y

  - One tenth these values to persons under age 18

  - TEDE to declared pregnant women 0.5 rem/9mo

SESSION 10

DATA COLLECTION AND DOSE PROJECTION

FOR

RELOCATION AND RETURN DECISIONS

IMPLEMENTING PAGS FOR THE INTERMEDIATE PHASE

- Relocation
- Reentry
- Return
- Early Decontamination
- Ingestion of Food and Water
  - Independent decision

OVERV EW OF
MPLEMENTAT ON PROCESS

- Collect environmental samples.

- Analyze samples.

- Calculate
  - Exposure rates and projected dose.
  - Accident specific DCFs.
  - Derived response level.

- Make gamma exposure rate measurements.

OVERV EW OF
MPLEMENTAT ON PROCESS
(cont'd)

- Take air samples and calculate projected dose from inhalation of resuspended materials.
- Identify the boundary of the restricted zone.
- Relocate the population.
- Identify the buffer zones.
- Implement gradual return.

SAMPLE COLLECTION AND ANALYSIS

- Purpose of samples
  - Dose projection
  - Evaluation of variation in mix by area
- Nature of samples
- Locations of samples
  - Based on exposure rate
  - Priorities
  - Terrain
- Types of analyses

ALTERNATIVE METHODS FOR DOSE PROJECTION

- METHOD ONE - Sample from each area of interest
  - Known size of area in each sample
  - Use data from each sample analysis to project dose.
  - Plot projected doses on map to identify location of boundary to the restricted zone.

ALTERNATIVE METHODS FOR DOSE PROJECTION
(cont'd)

- METHOD TWO - Take a few samples from several areas.

- Determine whether the radionuclide mix is reasonably constant or predictable. If so:

  - Calculate a time-dependent derived response level (DRL_{td}) corresponding to the PAG.

  - Use the DRL_{td} to identify the restricted zone.

CONS DERAT ON OF METHOD ONE

- Requires a arge number of
  - samples
  - laboratory analyses
  - dose projections

- May yield wrong result for other than flat terrain

- Only method available if radionuclide mix is neither constant nor predictable

CONSIDERATION OF METHOD TWO

- Not useful for an inconsistent mix of radionuclides.
- Greatly reduces the sampling and laboratory effort.
- Results are independent of terrain type or presence of contaminated foliage.
- Inaccuracies due to non-representative samples cancel.

EXAMPLE CALCULATION OF EXPOSURE RATE
- Method One -

Radionuclide	Concentration pCi/m^2	Initial exposure Rate @ 1m (mR/h per pCi/m^2) (table 7-1 or 7-2)	Exposure Rate @ 1m (mR/h)
Cs-134	2E+7		
I-131	3E+7		
		Total:	

EXAMPLE CALCULATION OF PROJECTED DOSE
- Method One -

Integrated Dose - Year One					
Radionuclide	Concentration (pCi/m^2)	Weathering		No Weathering	
		DCF ($mrem/pCi/m^2$) (Table 7-1)	Projected Dose (mrem)	DCF ($mrem/pCi/m^2$) (Table 7-2)	Projected Dose (mrem)
Cs-134	2E+7				
I-131	3E+7				
		TOTAL		TOTAL	

EXAMPLE CALCULATION OF PROJECTED DOSE
- Method One -

Integrated Dose - Year Two					
		Weathering		No Weathering	
Radionuclide	Concentration(pCi/m^2)	DCF (mrem/pCi/m^2) (Table 7-1)	Projected Dose (mrem)	DCF (mrem/pCi/m^2) (Table 7-2)	Projected Dose (mrem)
Cs-134	2E+7				
I-131	3E+7				
		TOTAL		TOTAL	

EXAMPLE CALCULATION OF PROJECTED DOSE
- Method One -

Integrated Dose - Zero to 50 Years					
Radionuclide	Concentration (pCi/m^2)	Weathering		No Weathering	
		DCF ($mrem/pCi/m^2$) (Table 7-1)	Projected Dose (mrem)	DCF ($mrem/pCi/m^2$) (Table 7-2)	Projected Dose (mrem)
Cs-134	2E+7				
I-131	3E+7				
		TOTAL		TOTAL	

METHOD 2

- Calculate an accident-specific dose conversion factor (DCF_{as}).
  - This factor is time dependent.

- Use DCF_{as} to calculate a time-dependent derived response level (DRL_{td}) in mR/h corresponding to the PAG.

CALCULATION OF ACCIDENT SPECIFIC DCF
Method 2

$$DCF_{as} = \frac{mrem\ per\ yr{-}1,\ yr{-}2,\ or\ 0\ to\ 50\ yr}{Exposure\ Rate\ @\ 1\ m\ (mR/h)}$$

- Assume weathering and results from VGs 9, 10, 11, and 12, and calculate:
  - Year one DCF_{as} = ____________________
  - Year two DCF_{as} = ____________________
  - Zero to 50 year DCF_{as} = ____________________

CALCULATION OF ACCIDENT SPECIFIC DRL
Method 2

$$DRL_{td} = \frac{PAG}{DCF_{as}}$$

- For the previous example (weathering included):
  - Year one DRL_{as} = ______________
  - Year two DRL_{as} = ______________
  - Zero to 50 year DRL_{as} = ________________

DCF FOR PROJECTED EXTERNAL GAMMA DOSE

$$DCF = DS_f \int_0^t e^{-(\lambda_R + \lambda_2 + \lambda_3)t}\, dt$$

$$DCF = DS_f \left\{ \frac{.63\left\{1 - e^{-(\lambda_R + \lambda_2)t}\right\}}{\lambda_R + \lambda_2} + \frac{.37\left\{1 - e^{-(\lambda_R + \lambda_3)t}\right\}}{\lambda_R + \lambda_3} \right\}$$

D

= dose rate per unit deposit (mrem/yr per pCi/m^2) (data in DOE EH 0070)

S_f = protection factor for shielding and partial occupancy (assumed to be unity)

λ_R = radioactive decay constant (yr^{-1})

λ_2 = assumed weathering decay constant for 63% of the radionuclide = 1.13 yr^{-1}

λ_3 = assumed weathering decay constant for 37% of the radionuclide = 7.48E-3 yr^{-1}

t = time of exposure (yr)

CALCULATION OF DOSE FROM INHALATION OF RESUSPENDED MATERIALS (CEDE)

(Table 7-4, p. 7-16)

$$H_{50} = I \times DCF$$

WHERE:

H_{50} = CEDE for 50 y from intake of nuclides

I = total intake (pCi)

DCF = dose per unit intake for the radionuclide (rem per pCi)

- Data are from EPA FGR No. 11
- Convert to appropriate units

TOTAL NTAKE FROM NHALAT ON OF RESUSPENDED MATERIAL

$$I = BC_0 \left\{ \frac{.63\left\{1 - e^{-(\lambda_R + \lambda_2)t}\right\}}{\lambda_R + \lambda_2} + \frac{.37\left\{1 - e^{-(\lambda_R + \lambda_3)t}\right\}}{\lambda_R + \lambda_3} \right\}$$

WHERE:

I	=	total intake in 1 year (pCi)
B	=	breathing rate, assumed to be 1.05E+4 m^3/yr
C_o	=	initial air concentration of the resuspended radionuclide (pCi/m^3)
λ_R	=	radioactive decay constant (yr^{-1})
λ_2	=	assumed weathering decay constant for 63% of the radionuclide = 1.13 yr^{-1}
λ_3	=	assumed weathering decay constant for 37% of the radionuclide = 7.48E-3 yr^{-1}
t	=	time of exposure (yr)

WEATHERING OF THE RESUSPENSION FACTOR

- EPA assumes gamma weathering for resuspension.

- Empirical data for alpha emitters shows much faster reduction.

- Refer to:
  - WASH-1400 Appendix VI page E-13 for a time dependent model.

  - IAEA Safety Series 81, 1986, page 62 for plot of the resuspension factor as a function of time and of the integral.

CALCULATION OF INHALATION DOSE (CEDE) FROM RESUSPENDED MATERIALS

Includes weathering? [ ] yes [ ] no

Sample location ____________________ Analysis date ______________

Radio-Nuclide	Air Concentration (pCi/m^3)	Yr. 1 DCF (mrem per pCi/m^3)	Dose From Yr. 1 Exp. (mrem)	Yr. 2 DCF (mrem per pCi/m^3)	Dose From Yr. 2 Exp. (mrem)
Cs-134	1200				
I-131	420				
		TOTAL→		TOTAL→	

SESS ON

DOSE PROJECTION PROBLEMS

FOR

RELOCATION AND RETURN DECISIONS

PROBLEM 1 - A: DERIVATION OF AN ACCIDENT-SPECIFIC DOSE CONVERSION FACTOR (1)

- Method ONE -

GIVEN:

- A surface soil sample is analyzed and is found to contain the following concentrations (pCi / m^2):

Zr-95	7.4 E+6	Cs-134	12.0 E+6
Ru-103	3.1 E+6	Cs-137	1.2 E+6
I-131	4.1 E+6	Ba-140	6.2 E+6

- Radioactive decay and weathering will occur.

CALCULATION OF ACCIDENT-SPECIFIC DCF (DCF_{as})					
For? [x] Y ar 1 [ ] Ye r 2 [ ] 50 Y rs					
Sample location________ Weathering? [ ] yes [ ] no					
Radio-Nuclide	Measured Ground Concentration (pCi/m^2)	Initial Exp. Rate @ 1m (mR/h per pCi/m^2)	Calculated Exp. Rate (mR/h @1m)	Integrated Dose (mrem per pCi/m^2)	Calculated DOSE (mrem)
Zr-95	7.4E+06				
Ru-103	3.1E+06				
I-131	4.1E+06				
Cs-134	1.2E+07				
Cs-137	1.2E+06				
Ba-140	6.2E+06				
		TOTAL→		TOTAL→	

Combined DCF_{as} ____________mrem per mR/h (date____________)

CALCULATION OF ACCIDENT-SPECIFIC DCF (DCF_{as})					
For? [ ] Year 1 [X] Year 2 [ ] 50 Years					
Sample location_______________ Weathering? [ ] yes [ ] no					
Radio-Nuclide	Measured Ground Concentration (pCi/m^2)	Initial Exp. Rate @ 1m (mR/h per pCi/m^2)	Calculated Exp. Rate (mR/h @1m)	Integrated Dose (mrem per pCi/m^2)	Calculated DOSE (mrem)
Zr-95	7.4E+06				
Ru-103	3.1E+06				
I-131	4.1E+06				
Cs-134	1.2E+07				
Cs-137	1.2E+06				
Ba-140	6.2E+06				
		TOTAL→		TOTAL→	

Combin d DCF_{as} _______________mrem p r mR/h (d t _______________)

CALCULATION OF ACCIDENT-SPECIFIC DCF (DCF_{as})					
For? [ ] Year 1 [ ] Year 2 [X] 50 Years					
Sample location__________ Weathering? [ ] yes [ ] no					
Radio-Nuclide	Measured Ground Concentration (pCi/m^2)	Initial Exp. Rate @ 1m (mR/h per pCi/m^2)	Calculated Exp. Rate (mR/h @1m)	Integrated Dose (mrem per pCi/m^2)	Calculated DOSE (mrem)
Zr-95	7.4E+06				
Ru-103	3.1E+06				
I-131	4.1E+06				
Cs-134	1.2E+07				
Cs-137	1.2E+06				
Ba-140	6.2E+06				
		TOTAL→		TOTAL→	

Combined DCF_{as} ____________mrem per mR/h (date____________)

PROBLEM 1 - B: DERIVATION OF AN ACCIDENT-SPECIFIC DOSE CONVERSION FACTOR (1)

- Method TWO -

GIVEN:

- A surface soil sample is analyzed and is found to contain the following activities (uCi / sample):

Zr-95	7.4	Cs-134	12
Ru-103	3.1	Cs-137	1.2
I-131	4.1	Ba-140	6.2

- Radioactive decay and weathering will occur.

CALCULATION OF ACCIDENT-SPECIFIC DCF (DCF_{as})					
For? [x] Y r l [ ] Ye r 2 [ ] 50 Y ars					
Sample location________________ Weathering? [ ] yes [ ] no					
Radio-Nuclide	Measured Ground Concentration (pCi/sample)	Initial Exp. Rate @ 1m (mR/h per pCi/m^2)	Nominal Calculated Exp. Rate (mR/h @1m)	Integrated Dose (mrem per pCi/m^2)	Nominal Calculated DOSE (mrem @1m)
Zr-95	7.4E+06				
Ru-103	3.1E+06				
I-131	4.1E+06				
Cs-134	1.2E+07				
Cs-137	1.2E+06				
Ba-140	6.2E+06				
		TOTAL→		TOTAL→	

Combin d DCF_{as} ________________mr m p r mR/h (dat ______________)

CALCULATION OF ACCIDENT-SPECIFIC DCF (DCF_{as})					
For? [ ] Year 1 [X] Y ar 2 [ ] 50 Y rs					
Sample location______________ Weathering? [ ] yes [ ] no					
Radio-Nuclide	Measured Ground Concentration (pCi/sample)	Initial Exp. Rate @ 1m (mR/h per pCi/m^2)	Nominal Calculated Exp. Rate (mR/h @1m)	Integrated Dose (mrem per pCi/m^2)	Nominal Calculated DOSE (mrem @1m)
Zr-95	7.4E+06				
Ru-103	3.1E+06				
I-131	4.1E+06				
Cs-134	1.2E+07				
Cs-137	1.2E+06				
Ba-140	6.2E+06				
		TOTAL→		TOTAL→	

Combin d DCF_{as} ______________mr m p r mR/h (d te______________)

CALCULATION OF ACCIDENT-SPECIFIC DCF (DCF_{as})					
For? [ ] Year 1 [ ] Year 2 [X] 50 Years					
Sample location____________ Weathering? [ ] yes [ ] no					
Radio-Nuclide	Measured Ground Concentration (pCi/sample)	Initial Exp. Rate @ 1m (mR/h per pCi/m²)	Nominal Calculated Exp. Rate (mR/h @1m)	Integrated Dose (mrem per pCi/m²)	Nominal Calculated DOSE (mrem @1m)
Zr-95	7.4E+06				
Ru-103	3.1E+06				
I-131	4.1E+06				
Cs-134	1.2E+07				
Cs-137	1.2E+06				
Ba-140	6.2E+06				
		TOTAL→		TOTAL→	

Combin d DCF_{as} ____________mr m p r mR/h (dat ____________)

PROBLEM 2: DERIVED RESPONSE LEVELS

- Using results from Problem 1, calculate time-dependent derived response levels (DRL_{td}) corresponding to:

  - year 1

  - year 2

  - 50 years

- Interpret the results.

PROBLEM 3
PROJECTED DOSE

- Field teams report the following exposure rates:

Location A	3 mR/h
Location B	10 mR/h
Location C	30 mR/h

- Assume the radionuclide mix from Problem 1.

- What is the projected dose from gamma radiation at each location for each of the three time periods?

PROBLEM 3: PROJECTED DOSE
(cont'd)

Location	Meter Reading (mR/hr)	Projected dose year one (rem)	Projected dose year two (rem)	Projected dose 0 to 50 y (rem)
A	3			
B	10			
C	30			
DCF for year one (rem per mR/h)			3.3	
DCF for year two (rem per mR/h)			1.2	
DCF for 0 to 50 y (r m p r mR/h)			8.2	

PROBLEM 4: INHALATION DOSE DUE TO RESUSPENDED MATERIALS (1)

- Analysis of an air sample collected at location "A" where the exposure rate is 3 mR/h yields activities as follows (pCi/m^3):

Zr-95	760	Cs-134	1200
Ru-103	320	Cs-137	120
I-131	420	Ba-140	630

- Weathering is assumed.

CALCULATION OF INHALATION DOSE (CEDE) FROM RESUSPENDED MATERIALS					
Includes weathering? [x] yes [ ] no					
Sample location A			Analysis date		
Radio-Nuclide	Air Concentration (pCi/m^3)	Yr. 1 DCF (mrem per pCi/m^3)	Dose From Yr. 1 Exp. (mrem)	Yr. 2 DCF (mrem per pCi/m^3)	Dose From Yr. 2 Exp. (mrem)
Zr-95	760				
Ru-103	320				
I-131	420				
Cs-134	1200				
Cs-137	120				
Ba-140	630				
		TOTAL→		TOTAL→	

SESSION 12

COURSE REVIEW AND WRAP-UP

Ritchey C. Lyman
Office of Radiation and Indoor Air
Phone (202) 564-9363
Fax: (202) 565-2037
lyman.ritchey@epa.gov

- PROBLEM SOLUTIONS -

PROBLEM SOLUTION

Problem Emergency worker : Projected Dose at Location A from inhalation

Nuclide(s)	Air Concentration (X) (uCi/cm^3)	Projected. Exposure Time (h)	Integrated Air Concentration (uCi · cm^{-3} · h)	DCF from Table 5-4 (rem per uCi · cm^{-3} · h)	Inhalation Committed Effective Dose Equivalent (CEDE) (rem)
Ce-141	1.0E-05	1	0.00001	1.1E+04	0.11
Ba-140	1.0E-04	1	0.0001	4.5E+03	0.45
Cs-134	1.0E-05	1	0.00001	5.6E+04	0.56
				Totals >	1.12

EXAMPLE OF COMBINED PATHWAYS SOLUTION

Nuclide selected_Co-60__

		DCF	X_{in}	Dose
Pathway	Table	(rem per uCi · cm $^{-3}$ · h)	(uCi · cm^{-3} · h)	(rem)
External	5-3	1.5E+3	1	1.5E+3
Inhalation	5-4	2.6E+5	1	2.6E+5
Ground Shine	5-5	8.9E+3	1	8.9E+3
Summation				2.6E+5
Combined	5-1	2.7E+5	1	2.7E+5

RAD AT ON ACC DENT ASSESSMENT COURSE
WORK SHEET

Problem_1a-1 & 1b-1_: Projected Dose at_1__Mile(s): From_thyroid & combined_ pathway

Nuclide(s) & Prblm. # 1a-1	$X\bar{u}/Q$ @ 1 mi (m^{-2})	Q (Ci/s)	$\bar{u}$ (m/s)	X @ 1 mi ($\mu Ci/cm^3$)	Exp. time (h)	X_{in} @ 1 mi ($\mu Ci \cdot cm^{-3} \cdot h$)	DCF Table No.	DCF_{th} rem / $\mu Ci \cdot cm^{-3} \cdot h$	Dose (CDE) (rem)
I-131	7.0E-5	0.17	2	6.0E-6	3	1.8E-5	5-2	1.3E+6	23
Nuclide # 1b-1								DCF_{cp}	TEDE (rem)
Xe-133	7.0E-5	1700	2	6.0E-2	3	1.8E-1	5-1	2.0E+1	3.6
I-131	7.0E-5	0.17	2	6.0E-6	3	1.8E-5	5-1	5.3E+4	0.95
Cs-134	7.0E-5	0.05	2	1.8E-6	3	5.25E-5	5-1	6.3E+4	0.33
								TOTAL →	4.9

RAD AT ON ACC DENT ASSESSMENT COURSE
WORK SHEET

Problem 1a-2 & 1b-2 : Projected Dose at 2 Mile(s): From thyroid & combined pathway

Nuclide(s) & Prblm. # 1a-2	$X\bar{u}/Q$ @ 2 mi (m^{-2})	Q (Ci/s)	$\bar{u}$ (m/s)	X @ 2 mi ($\mu Ci/cm^3$)	Exp time (h)	X_{in} @ 2 mi ($\mu Ci \cdot cm^{-3} \cdot h$)	DCF Table No.	DCF_{th} $\frac{rem}{\mu Ci \cdot cm^{-3} \cdot h}$	Dose (CDE) (rem)
I-131	2.4E-5	0.17	2	2.0E-6	3	6.0E-6	5-2	1.3E+6	8
Nuclides # 1b-2								DCF_{cp}	TEDE (rem)
Xe-133	2.4E-5	1700	2	2.0E-2	3	6.0E-2	5-1	2.0E+1	1.2
I-131	2.4E-5	0.17	2	2.0E-6	3	6.0E-6	5-1	5.3E+4	0.32
Cs-134	2.4E-5	0.05	2	6.0E-7	3	1.8E-6	5-1	6.3E+4	0.12
								TOTAL →	1.6

RAD OLOG CAL ACC DENT ASSESSMENT COURSE
WORK SHEET

Problem 2a Projected Dose at 2 Mile(s): From immersion pathway

Nuclide(s) & Prblm. # 2	Xū/Q @2 mi (m^{-2})	Q (Ci/s)	ū (m/s)	X @ 2 mi (μCi/cm^3)	Exp. time (h)	X_{in} @ 2 mi (μCi · cm^{-3} · h)	DCF Table No.	DCF_{im} rem / μCi · cm^{-3} · h	Dose (EDE) (rem)
Xe-133	2.4E-5	1700	2	2.0E-2	3	6.0E-2	5-3	20	1.2
I-131	2.4E-5	0.17	2	2.0E-6	3	6.0E-6	5-3	2.2E+2	1.3E-3
Cs-134	2.4E-5	0.05	2	6.0E-7	3	1.8E-6	5-3	9.1E+2	1.7E-3
								TOTAL→	1.2

RADIOLOGICAL ACCIDENT ASSESSMENT COURSE
WORK SHEET

Problem 2b : Projected Dose at 2 Mile(s): From inhalation pathway

Nuclide(s) & Prblm. # 2b	$X\bar{u}/Q$ @ 2 mi (m^{-2})	Q (Ci/s)	$\bar{u}$ (m/s)	X @ 2 mi ($\mu Ci/cm^3$)	Exp. time (h)	X_{in} @ 2 mi ($\mu Ci \cdot cm^{-3} \cdot h$)	DCF Table No.	DCF_{inh} $\frac{rem}{\mu Ci \cdot cm^{-3} \cdot h}$	Dose (CEDE) (rem)
Xe-133	2.4E-5	1700	2	2.0E-2	3	6.0E-2	5-4	0	0
I-131	2.4E-5	0.17	2	2.0E-6	3	6.0E-6	5-4	3.9E+4	2.4E-1
Cs-134	2.4E-5	0.05	2	6.0E-7	3	1.8E-6	5-4	5.6E+4	1.0E-1
								TOTAL→	3.4E-1

RADIOLOGICAL ACCIDENT ASSESSMENT COURSE
WORK SHEET

Problem 2c : Projected Dose at 2 Mile(s): From ground shine pathway

Nuclide(s) & Prblm. # 2c	$X\bar{u}/Q$ @ 2 mi (m^{-2})	Q (Ci/s)	$\bar{u}$ (m/s)	X @ 2 mi ($\mu Ci/cm^3$)	Exp. time (h)	X_{in} @ 2 mi ($\mu Ci \cdot cm^{-3} \cdot h$)	DCF Table No.	DCF_{dep} $\frac{rem}{\mu Ci \cdot cm^{-3} \cdot h}$	Dose (EDE) (rem)
Xe-133	2.4E-5	1700	2	2.0E-2	3	6.0E-2	5.5	0	0
I-131	2.4E-5	0.17	2	2.0E-6	3	6.0E-6	5.5	1.3E+4	8.0E-2
Cs-134	2.4E-5	0.05	2	6.0E-7	3	1.8E-6	5.5	6.2E+3	1.1E-2
								TOTAL →	0.09

EXAMPLE CALCULAT ON OF EXPOSURE RATE
- M thod On -

SOLUTION

Radionuclide	Concentration pCi/m^2	Initial exposure Rate @ 1m (mR/h per pCi/m^2) (table 7-1 or 7-2)	Exposure Rate @ 1m (mR/h)
Cs-134	2E+7	2.6E-8	0.52
I-131	3E+7	6.6E-9	0.20
		Total:	0.72

EXAMPLE CALCULATION OF PROJECTED DOSE
- Method One -

SOLUTION

Integrated Dose - Year One					
		Weathering		No Weathering	
Radionuclide	Concentration (pCi/m^2)	DCF ($mrem/pCi/m^2$) (Table 7-1)	Projected Dose (mrem)	DCF ($mrem/pCi/m^2$) (Table 7-2)	Projected Dose (mrem)
Cs-134	2E+7	1.0E-4	2000	1.3E-4	2600
I-131	3E+7	1.3E-6	39	1.3E-6	39
TOTAL			2039	TOTAL	2639

EXAMPLE CALCULATION OF PROJECTED DOSE
- Method One -

SOLUTION

Integrated Dose - Year Two					
Radionuclide	Concentration (pCi/m^2)	Weathering		No Weathering	
		DCF ($mrem/pCi/m^2$) (Table 7-1)	Projected Dose (mrem)	DCF ($mrem/pCi/m^2$) (Table 7-2)	Projected Dose (mrem)
Cs-134	2E+7	4.7E-5	940	9.6E-5	1900
I-131	3E+7	0	0	0	0
		TOTAL	940	TOTAL	1900

EXAMPLE CALCULATION OF PROJECTED DOSE
- Method One -

SOLUTION

Integrated Dose - Zero to 50 Years					
Radionuclide	Concentration (pCi/m^2)	Weathering		No Weathering	
		DCF ($mrem/pCi/m^2$) (Table 7-1)	Projected Dose (mrem)	DCF ($mrem/pCi/m^2$) (Table 7-2)	Projected Dose (mrem)
Cs-134	2E+7	2.4E-4	4800	4.7E-4	9400
I-131	3E+7	1.3E-6	39	1.3E-6	39
		TOTAL	4839	TOTAL	9439

CALCULATION OF ACCIDENT SPECIFIC DCF
Method 2

SOLUTION

$$DCF_{as} = \frac{mrem\ per\ yr\text{-}1,\ yr\text{-}2,\ or\ 0\ to\ 50\ yr}{Exposure\ Rate\ @\ 1\ m\ (mR/h)}$$

- **Assume weathering and results from VGs 9, 10, 11, and 12, and calculate:**
  - **Year one DCF_{as} = 2039 mrem/0.72 mR/h = 2832 mrem/mR/h**
  - **Year two DCF_{as} = 940 mrem/0.72 mR/h = 1305 mrem/mR/h**
  - **0 to 50 year DCF_{as} = 4839 rem/0.72 R/h = 6720**

CALCULATION OF ACCIDENT SPECIFIC DRL
- Method 2 -

SOLUTION

$$DRL_{td} = \frac{PAG}{DCF_{as}}$$

- **For the previous example (weathering included):**

  - **Year one DRL_{as} = 2000 mrem ÷ 2832 mrem/mR/h = 0.71 mR/h**

  - **Year two DRL_{as} = 500 mrem ÷ 1305 mrem/mR/h = 0.38 mR/h**

  - **Z ro to 50 y r DRL_{as} = 5000 ÷ 6720 = 0.74 mR/h**

CALCULATION OF INHALATION DOSE (CEDE) FROM RESUSPENDED MATERIALS					
Includes weathering? [x] yes [ ] no					
Sample location ______________			Analysis date______________		
Radio-Nuclide	Air Concentration (pCi/m^3)	Yr. 1 DCF (mrem per pCi/m^3)	Dose From Yr. 1 Exp. (mrem)	Yr. 2 DCF (mrem per pCi/m^3)	Dose From Yr. 2 Exp. (mrem)
Cs-134	1200	3.1E-1	370	1.5E-1	180
I-131	420	1.1E-2	4.6	0	0
		TOTAL→	375	TOTAL→	180

Problem 1: Derivation of an Accident-Specific Dose Conversion Factor

SOLUTION

- Refer to Table 7-1 and, as example, Table 7-3.
- Unit of the DCF for the projected external gamma dose is:
  xx mrem for each mR/h measured at the beginning of the period
- For year one:
  1.6E+03 mrem per 4.9E-01 mR/h yields
  3.3e+3 mrem per mR/h or 3.3 rem per mR/h
- For 0-50 years:
  4.0E-03 mrem per 4.9E-01 mR/h
  8.2E+3 mrem per mR/h or 8.2 rem per mR/h

CALCULATION OF ACCIDENT-SPECIFIC DCF (DCF_{as})					
For? [x] Year 1 [ ] Year 2 [ ] 50 Years					
Sample location_A__________ Weathering? [x] yes [ ] no					
Radio-Nuclide	Measured Ground Concentration (pCi/m^2)	Initial Exp. Rate @ 1m (mR/h per pCi/m^2)	Calculated Exp. Rate (mR/h@1m)	Integrated Dose (mrem per pCi/m^2)	Calculated DOSE (mrem)
Zr-95	7.4e+06	1.2e-08	8.9e-02	3.3e-05	2.4e+02
Ru-103	3.1e+06	8.2e-09	2.5e-02	7.1e-06	2.2e+01
I-131	4.1e+06	6.6e-09	2.7e-02	1.3e-06	5.3e+00
Cs-134	1.2e+07	2.6e-08	3.1e-01	1.0e-04	1.2e+03
Cs-137	1.2e+06	1.0e-08	1.2e-02	4.5e-05	5.4e+01
Ba-140	6.2e+06	3.2e-09	2.0e-02	1.1e-05	6.8e+01
		TOTAL→	4.9e-01	TOTAL→	1.6e+03

Co bined DCF_{as} __3.3 e+03__ re per R/h (date______________)

CALCULATION OF ACCIDENT-SPECIFIC DCF (DCF_{as})					
For? [ ] Year 1 [x] Year 2 [ ] 50 Years					
Sample location_A__________ Weathering? [x] yes [ ] no					
Radio-Nuclide	Measured Ground Concentration (pCi/m^2)	Initial Exp. Rate @ 1m (mR/h per pCi/m^2)	Calculated Exp. Rate (mR/h@1m)	Integrated Dose (mrem per pCi/m^2)	Calculated DOSE (mrem)
Zr-95	7.4e+06	1.2e-08	8.9e-02	4.0e-07	3.0e+00
Ru-103	3.1e+06	8.2e-09	2.5e-02	0.0e+00	0.0e+00
I-131	4.1e+06	6.6e-09	2.7e-02	0.0e+00	0.0e+00
Cs-134	1.2e+07	2.6e-08	3.1e-01	4.7e-05	5.6e+02
Cs-137	1.2e+06	1.0e-08	1.2e-02	2.9e-05	3.5e+01
Ba-140	6.2e+06	3.2e-09	2.0e-02	0.0e+00	0.0e+00
		TOTAL→	4.9e-01	TOTAL→	6.0e+02

Co bined DCF_{as} __1.2 e+03__ re per R/h (date______________)

CALCULATION OF ACCIDENT-SPECIFIC DCF (DCF_{as})					
For? [ ] Year 1 [ ] Year 2 [x] 50 Years					
Sample location_A__________ Weathering? [x] yes [ ] no					
Radio-Nuclide	Measured Ground Concentration (pCi/m^2)	Initial Exp. Rate @ 1m (mR/h per pCi/m^2)	Calculated Exp. Rate (mR/h@1m)	Integrated Dose (mrem per pCi/m^2)	Calculated DOSE (mrem)
Zr-95	7.4e+06	1.2e-08	8.9e-02	3.4e-05	2.5e+02
Ru-103	3.1e+06	8.2e-09	2.5e-02	7.1e-06	2.2e+01
I-131	4.1e+06	6.6e-09	2.7e-02	1.3e-06	5.3e+00
Cs-134	1.2e+07	2.6e-08	3.1e-01	2.4e-04	2.9e+03
Cs-137	1.2e+06	1.0e-08	1.2e-02	6.1e-04	7.3e+02
Ba-140	6.2e+06	3.2e-09	2.0e-02	1.1e-05	6.8e+01
		TOTAL→	4.9e-01	TOTAL→	4.0e+03

Co bined DCF_{as} __8.2 e+03__ re per R/h (date____________)

CALCULATION OF ACCIDENT-SPECIFIC DCF (DCF_{as})					
For? [x] Year 1 [ ] Year 2 [ ] 50 Years					
Sample location_A__________ Weathering? [x] yes [ ] no					
Radio-Nuclide	Measured Ground Concentration (pCi/m^2)	Initial Exp. Rate @ 1m (mR/h per pCi/m^2)	Nominal Calculated Exp. Rate (mR/h@1m)	Integrated Dose (mrem per pCi/m^2)	Nominal Calculated DOSE (mrem)
Zr-95	7.4e+06	1.2e-08	8.9e-02	3.3e-05	2.4e+02
Ru-103	3.1e+06	8.2e-09	2.5e-02	7.1e-06	2.2e+01
I-131	4.1e+06	6.6e-09	2.7e-02	1.3e-06	5.3e+00
Cs-134	1.2e+07	2.6e-08	3.1e-01	1.0e-04	1.2e+03
Cs-137	1.2e+06	1.0e-08	1.2e-02	4.5e-05	5.4e+01
Ba-140	6.2e+06	3.2e-09	2.0e-02	1.1e-05	6.8e+01
		TOTAL→	4.9e-01	TOTAL→	1.6e+03

Co bined DCF_{as} __3.3 e+03__ re per R/h (date____________)

CALCULATION OF ACCIDENT-SPECIFIC DCF (DCF_{as})					
For? [ ] Year 1 [x] Year 2 [ ] 50 Years					
Sample location_A__________ Weathering? [x] yes [ ] no					
Radio-Nuclide	Measured Ground Concentration (pCi/m^2)	Initial Exp. Rate @ 1m (mR/h per pCi/m^2)	Nominal Calculated Exp. Rate (mR/h@1m)	Integrated Dose (mrem per pCi/m^2)	Nominal Calculated DOSE (mrem)
Zr-95	7.4e+06	1.2e-08	8.9e-02	4.0e-07	3.0e+00
Ru-103	3.1e+06	8.2e-09	2.5e-02	0.0e+00	0.0e+00
I-131	4.1e+06	6.6e-09	2.7e-02	0.0e+00	0.0e+00
Cs-134	1.2e+07	2.6e-08	3.1e-01	4.7e-05	5.6e+02
Cs-137	1.2e+06	1.0e-08	1.2e-02	2.9e-05	3.5e+01
Ba-140	6.2e+06	3.2e-09	2.0e-02	0.0e+00	0.0e+00
		TOTAL→	4.9e-01	TOTAL→	6.0e+02

Combined DCF_{as} __1.2 e+03__ re per R/h (date______________)

CALCULATION OF ACCIDENT-SPECIFIC DCF (DCF_{as})					
For? [ ] Year 1 [ ] Year 2 [x] 50 Years					
Sample location_A__________ Weathering? [x] yes [ ] no					
Radio-Nuclide	Measured Ground Concentration (pCi/m^2)	Initial Exp. Rate @ 1m (mR/h per pCi/m^2)	Nominal Calculated Exp. Rate (mR/h@1m)	Integrated Dose (mrem per pCi/m^2)	Nominal Calculated DOSE (mrem)
Zr-95	7.4e+06	1.2e-08	8.9e-02	3.4e-05	2.5e+02
Ru-103	3.1e+06	8.2e-09	2.5e-02	7.1e-06	2.2e+01
I-131	4.1e+06	6.6e-09	2.7e-02	1.3e-06	5.3e+00
Cs-134	1.2e+07	2.6e-08	3.1e-01	2.4e-04	2.9e+03
Cs-137	1.2e+06	1.0e-08	1.2e-02	6.1e-04	7.3e+02
Ba-140	6.2e+06	3.2e-09	2.0e-02	1.1e-05	6.8e+01
		TOTAL→	4.9e-01	TOTAL→	4.0e+03

Co bined DCF_{as} __8.2 e+03__ re per R/h (date______________)

Problem 2: Derived Response Levels

SOLUTION

- A time-dependent derived response level (DRL_{td}) is the meter reading (mR/h @ 1m) which, at the time of measurement, corresponds to either the year 1, year 2, or 0-50 year dose.

- For year one, a meter reading of 1 mR/h at 1 meter above the ground indicates an external gamma radiation dose of 3.3 rem during the first year. Therefore, the DCF (rem per mR/h) is 3.3 rem per mR/h.

- A meter reading of 2.0/3.3 or about 0.6 mR/h, would indicate that the first year dose would be 2 rem or greater.

- The DRL_{td} for year 1 is 0.6 mR/h.

- The DRL_{td} for year 2 is 0.5/1.2 or about 0.4 mR/h.

- The DRL for year 0-50 is 5.0/8.2 or about 0.61 mR/h.

Proble 2: Derived Response Levels
SOLUTION
(co t'd)

- Table 4-1: Protective Action Guides for Exposure to Deposited Radioactivity During the Intermediate Phase of a Nuclear Incident

  Relocate if projected dose is greater than 2 rem.

  Projected dose includes external gamma radiation dose and the committed effective dose equivalent from inhalation during the first year.

  Beta skin dose may be up to 50 times higher.

- Persons in areas with meter readings above 0.6 mR/h should be r locat d.

Probl m 3 Projected Dos
SOLUTION

Location	Meter Reading (mR/hr)	Projected Dose year one (rem)	Projected Dose year two (rem)	Projected Dose 0 to 50 y (rem)
A	3	9.9	3.6	24.6
B	10	33	12	82
C	30	99	36	246
DCF for year 1 (rem per mR/h)			3.3	
DCF for year 2 (rem per mR/h)			1.2	
DCF for 0 to 50 y (rem per mR/h)			8.2	

PROBLEM 3: PROJECTED DOSE
(cont'd)

Location	Meter Reading (mR/hr)	Projected dose year one (rem)	Projected dose year two (rem)	Projected dose 0 to 50 y (rem)
A	3			
B	10			
C	30			
DCF for year one (rem per mR/h)			3.3	
DCF for year two (rem per mR/h)			1.2	
DCF for 0 to 50 y (rem per mR/h)			8.2	

PROBLEM 4: NHALAT ON DOSE DUE TO RESUSPENDED MATERIALS ( )

- Analysis of an air sample collected at location "A" where the exposure rate is 3 mR/h yields activities as follows (pCi/m^3):

Zr-95	760	Cs-134	1200
Ru-103	320	Cs-137	120
I-131	420	Ba-140	630

- Weathering is assumed.

Problem 4: Inhalation Dose (CEDE)
SOLUTION

CALCULATION OF INHALATION DOSE (CEDE) FROM RESUSPENDED MATERIALS

Includes weathering? [x] yes [ ] no

Sample location ____A________________ Analysis date________________

Radio-Nuclide	Air Concentration (pCi/m^3)	Yr. 1 DCF (mrem per pCi/m^3)	Dose From Yr. 1 Exp. (mrem)	Yr. 2 DCF (mrem per pCi/m^3)	Dose From Yr. 2 Exp. (mrem)
Zr-95	760	6.5e-02	4.9e+01		0.0e+00
Ru-103	320	1.3e-02	4.2e+00		0.0e+00
I-131	420	1.1e-02	4.6e+00		0.0e+00
Cs-134	1200	3.1e-01	3.7e+02	1.5e-01	1.8e+02
Cs-137	120	2.5e-01	3.0e+01	1.4e-01	1.7e+01
Ba-140	630	4.4e-03	2.8e+00		0.0e+00
		TOTAL→	4.6e+02	TOTAL→	2.0e+02

P blem 4: Inhalation Do (C D)
SOLUTION
(cont'd)

- Year one CEDE - 4.6E+02 mrem or 0.46 rem
- Year two CEDE - 2.0E+02 mrem or 0.20 rem
- Year one EDE - 9.9 rem (see problem 3)
- Year one TEDE - 9.9 + 0.5 = 10.4 rem
- Year two EDE - 3.6 rem (see problem 3)
- Year two TEDE - 3.6 + 0.20 = 3.8 rem
- Normally the lung clearance class and the particle size are not known. Ass me the most co servative co ditio .