United States
Environmental Protection
Agency

Air and Radiation
(ANR-459)

EPA 520/1-90-016
June 1990

EPA

Transuranium Elements

Volume 2
Technical Basis For Remedial Actions

TRANSURANIUM ELEMENTS

VOLUME II

TECHNICAL BASIS FOR REMEDIAL ACTIONS

BY

GORDON BURLEY

OFFICE OF RADIATION PROGRAMS
U.S. ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, DC 20460

CONTENTS

CHAPTER

1 INTRODUCTION

2 IMPLEMENTATION OF RECOMMENDATIONS

3 ECONOMIC ANALYSIS OF REMEDIAL ACTIONS

4 INCIDENTS OF NEW CONTAMINATION

5 "SCREENING LEVEL" FOR STABILIZED CONTAMINATION AND AN "ACTION LEVEL" FOR NEW SOIL CONTAMINATION

6 RADIOLOGICAL ASSESSMENT - ROCKY FLATS PLANT

7 PLANNING AND CONDUCT OF CLEANUP OF ENEWETAK ATOLL

1. INTRODUCTION

1.1 BACKGROUND

The transuranium elements have an atomic number greater than 92 and are radioactive. The principal transuranium element of concern is plutonium, which is produced in nuclear reactors and used in nuclear weapons and as fuel for fast-breeder reactors. Plutonium-239 is a very long-lived material with a radiological half-life of about 24,000 years. Other transuranium elements of importance include neptunium, americium, curium, and californium.

The transuranium elements, especially plutonium, have been recognized as potentially hazardous even in very small amounts. Mathematical models, based on an extensive data base, have been developed to predict the movement of the transuranium nuclides through the environment to man. The principal modes of intake are inhalation of resuspended materials previously deposited on soil surfaces and ingestion through drinking water and other parts of the food chain. Most of these radionuclides are alpha emitters and may cause lung, bone, or liver cancer when inhaled or ingested.

Present levels of the transuranium elements in the environment have resulted from several sources - regional and worldwide fallout from the testing of nuclear weapons in the atmosphere, accidents involving military and related operations, and local releases from nuclear facilities. The major portion of the transuranium elements in the environment is the result of surface and atmospheric nuclear weapons tests during the period 1945-1963. Atmospheric tests injected radioactivity into the stratosphere which has since then been slowly deposited more or less uniformly over the lands and oceans of the earth. As a result of these earlier weapons tests, the existing level of

FIGURE 1-1

PERIODIC CHART OF THE ELEMENTS

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57-71 La* Series	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89-103 Act† Series	(104)	(105)	(106)	(107)	(108)										

*Lanthanide Series	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
†Actinide Series	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102	(103) Lw

TABLE 1-1

INVENTORY OF PLUTONIUM FOR SELECTED SITES IN THE UNITED STATES

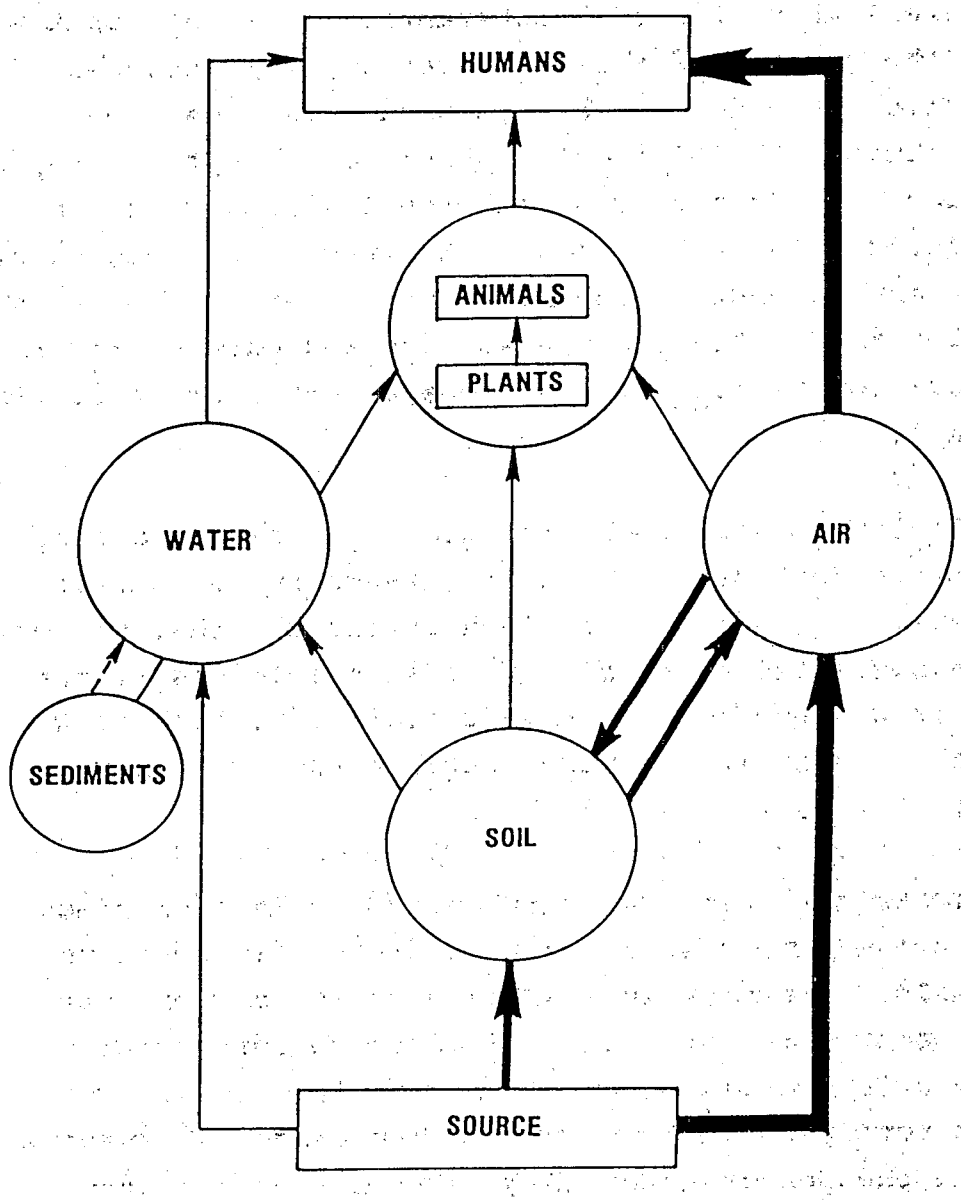
LOCATION	APPROX INVENTORY	REMARKS
U.S. (Fallout)	20,000 Ci	Worldwide Pu-238 = 17,000 Ci Pu-239 = 440,000 Ci U.S. Average = 1.5 mCi/km^2
Nevada Test Site (near Las Vegas, NV)	>155 Ci	Nuclear Test Site Surface and Subsurface Tests
Rocky Flats Plant (near Denver, CO)	8-10 Ci	Weapons Fabrication Facility
Mound Laboratory (Miamisburg, OH)	5-6 Ci	Pu-238 Processing Facility
Savannah River Plant (SW area of SC)	3-5 Ci	Pu Production Facility (Pu and higher isotopes)
Hanford Site (central WA)	*	Pu Production-Research Facility (high levels of Pu on site)
Los Alamos Laboratory (NW of Santa Fe, MM)	*	Weapons Development (Pu-239 in remote canyons)
Oak Ridge Laboratory (east TN near Knoxville)	*	Research and Development Facility
Idaho National Engineering Lab (central ID)	*	Separation, Test, and Research Facility (Pu-239 in soil/groundwater)
Trinity Site (near Alamogordo, NM)	>45 Ci	Site of first atomic bomb test

transuranium element contamination in soils of the United States is about 0.002 uCi/m^2. More recent weapon tests have not added significant amounts to this level.

Areas where there is substantial localized contamination above the general background level are well documented and extensive environmental analyses have been carried out at all these sites. The sites of highest contamination are, for the most part, on Federally owned property and access may be restricted. Table 1-1 shows estimates of the amount of plutonium in the environment at the major United States locations. More detailed information on the sources and current levels of the transuranium elements in the general environment is given in Volume I.

Plutonium and other transuranium elements can move through the environment by a variety of transport mechanisms and pathways. These are determined by the chemical and physical form of the deposited material, the characteristics of the surface, local land use patterns, and other factors such as wind or rainfall. Principal environmental pathways to humans are shown in Fig. 1-1.

Transuranium elements released to the environment may exist as discrete particles or they may become attached to other materials. The principal modes of transport of these elements from a source to man are by direct airborne movement from the source or by resuspension of previously deposited small particles by the action of wind or other disturbance. Resuspension is a complex phenomenon affected by a number of factors, including the characteristics of the surface, type of vegetative cover, meteorological conditions, and age of the deposit. In general, resuspension will be relatively high immediately after initial deposition, gradually decrease with time, and approach a long-term constant within about one year after deposition.



PRINCIPAL PATHWAYS OF THE TRANSURANIUM ELEMENTS THROUGH THE ENVIRONMENT TO MAN

FIGURE 1-2

Transport of plutonium and other transuranium elements through the food chain and subsequent ingestion is generally of lesser importance than the air pathway. Transuranium elements may be deposited on plant surfaces or assimilated through the plant root system. The uptake by plants is relatively small and most animals, including humans, have a high discrimination factor against transfer of these elements into body tissues. The solubility of plutonium in water is very low and nearly all plutonium released into lakes and streams is ultimately deposited and sorbed onto sediments. Other possible routes of entry into humans include direct ingestion of contaminated soils and contamination of wounds, but are generally of minor importance relative to the inhalation and ingestion pathways.

Potential health effects caused by the transuranium elements are a function of several biological and physical parameters including the biological retention time in tissue, the type of radioactive emission, and the half-life of the nuclide. For the more important transuranium nuclides, such as Pu-238 or Pu-239, biological retention times are very long and radioactive decay occurs at such a slow rate that uptake of these materials in the human body will result in prolonged exposure of body organs. Many of the transuranium nuclides decay by emission of an alpha particle (ionized helium atom), in a manner similar to radium and other naturally occurring alpha emitting nuclides. Alpha particles are highly ionizing and damaging, but their penetration in tissue is very small (about 40 μm). Thus, biological damage is limited to tissue in the immediate vicinity of the radioactive material, and a potential health hazard from transuranium elements in the environment can only result when these materials are inhaled or ingested into the body.

Inhaled particles are initially deposited in various regions of the respiratory tract, where they remain until either cleared or translocated to other body organs. Much of the material deposited in the lung is cleared within a few days, but some of the smaller particles which diffuse into the pulmonary regions of the lung are removed much more slowly and have a biological half-life of a year or more. This may lead to an increase in the risk of lung cancer in exposed individuals. Inhaled transuranium elements may also transfer and be retained in other body organs, and cause cancers of the bone and liver. For the less soluble transuranium compounds, such as plutonium oxide, this will contribute only marginally to the total risk for the inhalation pathway.

Ingestion of transuranium elements generally represents a smaller environmental risk to humans than inhalation. A relatively small fraction of any ingested transuranium element may be transferred to the bloodstream from the digestive tract and deposited in bone, liver, gonadal tissue, and other organs. In most cases, less than one part in ten thousand of the ingested material is absorbed by the body, with the remainder excreted. The risk to individuals as a result of ingestion of transuranium elements is mainly due to potential bone and liver cancers.

A potential risk of genetic damage to the progeny of exposed individuals exists because of possible accumulation of the transuranium elements in gonadal tissues. At the dose rates generally deemed acceptable for long-term exposure for persons in the general population, this risk is small compared to the natural incidence of genetic damage.

1.2 OTHER PUBLICATIONS

The Environmental Protection Agency published the basis and text of proposed Federal Radiation Protection Guidance in the Federal Register, Vol. 42, pp. 60956-9, on November 30, 1977. It also published a technical summary document explaining the proposed recommendations (EPA 520/4-77-016), and provided responses to comments (Technical Report, EPA 520/4-78-010).

The Environmental Protection Agency has also published additional related documents entitled "The Ecological Impact of Land Restoration and Cleanup" (Technical Report, EPA 520/3-78-006), "Selected Topics: Transuranium Elements in the General Environment" (EPA/ORP Technical Note CSD-78-1), "Plutonium Air Inhalation Dose (PAID)" (EPA/ORP Technical Note CSD-77-4), and "A Computer Code for Cohort Analysis of Increased Risk of Death (CAIRD)" (Technical Report EPA 520/4-78-012).

A summary of environmental research on transuranium elements, funded by the Department of Energy through calendar year 1979, was published recently as Transuranic Elements in the Environment, Wayne C. Hanson, Editor. It is available as Document DOE/TIC-22800 from the National Technical Information Service, U.S.Department of Commerce, Springfield, VA 22161. The book contains an extensive summary of available information, prepared by a number of technical experts, on all aspects of the inventory, distribution in terrestrial and aquatic ecosystems, environmental transport mechanisms and models, and biological effects of the transuranium elements.

Comprehensive reports on plutonium and other transuranium elements prepared by multinational groups of experts have recently been published by the World Health Organization in Nuclear Power--Health Implications of Transuranium Elements (1982), and by the Nuclear Energy Agency (NEA) of the

Organization for Economic Cooperation and Development in The Environmental and Biological Behavior of Plutonium and Some Other Transuranium Elements (1982). These reports are intended primarily for use by Government officials of member countries, and offer a useful summary of available information in language intended for a nontechnical audience.

1.3 RISK COMPARISONS

National and international radiation protection organizations have suggested that the annual average effective dose equivalent to persons in the general population not exceed 100 mrem per year for all sources except background radiation and medical exposures. This corresponds to an added risk of about 10^{-5} per year. Appropriate dose rate limits for specific body organs may be derived to correspond with these risk limits, and should consider both the different modes of intake into the body and the cumulative risks from translocation and retention in more than one organ. Further recommendations suggest that doses be kept as-low-as-reasonably-achievable and that there be a justification for the exposure.

A comparison with other risks is useful in providing a perspective understandable to most people. However, such a comparison can provide only a descriptive basis for individual judgments and does not provide an analytical decision method. The major categories of risks leading to premature death (in order of decreasing probability) include: disease, accidents, and natural catastrophes. A tabulation of commonly encountered risks and their probability of occurrence (averaged over the U.S. population) is shown in Table 1-2. It should be noted that the risk to a specified critical group (e.g., persons living in an area subject to hurricanes) may be much greater than that shown here.

TABLE 1-2

PROBABILITY OF DEATH BY VARIOUS CAUSES
(U.S. Population Average for 1978)

Cause	Total Number of Deaths	Individual Risk (Probability/yr)[a]
Accidents		
Motor Vehicle	52,411	2.4×10^{-4}
Air Transport	1,880	8.6×10^{-6}
Railway	602	2.8×10^{-6}
Falls	13,690	6.3×10^{-5}
Fire	6,163	2.8×10^{-5}
Drowning	5,784	2.7×10^{-5}
Industrial	5,168	2.4×10^{-6}
Electrocution	984	4.5×10^{-6}
Explosion	562	2.6×10^{-6}
Firearms	1,806	8.3×10^{-6}
Diseases		
Cardiovascular	964,000	4.4×10^{-3}
Malignancies	396,720	1.8×10^{-3}
Influenza/Pneumonia	58,230	2.7×10^{-4}
Diabetes	33,800	1.6×10^{-4}
Natural Events		
Lightning	160	7.3×10^{-7}
Tornadoes	118[b]	5.4×10^{-7}
Hurricanes	90[c]	4.1×10^{-7}

(a) Based on total U.S. Population
(b) 1953-75 average
(c) 1901-71 average

For the same reason, it is useful to view an objective for radiation protection by comparison with the unavoidable exposure received from natural background radiation. All persons are exposed to radiation which consists of cosmic rays and the radiation from naturally occurring radionuclides (such as uranium) which exist in the general environment. The annual dose from this background radiation varies by location, with an average of about 100 millirem per year to persons in the continental United States. The average risk from natural background radiation is of the order of 10^{-5} per year.

Implementation criteria may be provided to assure that the radiation protection recommendations will be applied conservatively. ICRP Publication 26 states (Paragraph 120) that "...due to the maximizing assumptions usually made in selecting critical groups, the doses actually received by the most highly exposed individual will in most cases be considerably lower than the doses postulated for the critical group." This assures that the average risk to all persons in the general population will be much lower than that for the critical segment.

Implementation criteria should include a cost-benefit analysis in optimizing the radiological protection of the public. While the primary emphasis of recommendations is on minimization of the dose to individuals, consideration of the collective dose, which gives a measure of the total detriment to the population, is useful in an assessment of the costs which society may be willing to bear for remedial actions intended to provide a reduction of risks. Such an evaluation is part of the system of dose limitation recommended by the International Commission on Radiological Protection, which includes justification, limitation, and optimization, and is given in ICRP Publication 26. To determine whether a further reduction of exposure from a given level is desirable, the ICRP suggests that the value of any increased benefit achieved by such a reduction in exposure should be weighed against the cost of obtaining this reduction.

The long radioactive half-lives of some of the transuranium elements make the evaluation of the total detriment over the entire time of persistence in the environment, to the extent practicable, a question of considerable importance. While such a procedure is useful in decisions on risk management, it is not the only consideration and risk management must involve a balanced judgment of all appropriate factors.

1.4 COSTS OF REMEDIAL ACTIONS

Dispersion of plutonium and other transuranium elements in the environment may result in a number of different types of problems, ranging from contamination of soils and other surfaces to the contamination of structures and persons. The objectives of remedial actions should be protection of persons and limitation of long-term environmental contamination. Each situation will need to be evaluated on a site-specific basis, and different remedial action options chosen as applicable.

The costs of remedial actions are determined by a number of factors: (1) the size of the contaminated area, (2) the type of structures and/or surface(s) that are contaminated, (3) the population density and distribution, (4) the type of terrain and other ecological factors, the type of land use, and (5) the associated level of contamination. In general, a contaminated area may be divided into sectors, and appropriate cleanup actions developed for each sector. The total cost for remedial actions is the sum of costs for all sectors.

Two categories of situations must be addressed by a review of economic impacts: (1) existing plutonium and other transuranium element contamination at a few sites where the contamination is stabilized and the distribution and soil concentration are well characterized, and (2) possible future releases (from operating facilities, nuclear weapons accidents, and other possible sources), where neither the magnitude of

release nor its location can be known in advance of the occurrence.

A final consideration applicable to any remedial action program is the possibility that disturbance of the environment might do long-term harm. The Environmental Protection Agency has examined this aspect, and published an extensive analysis entitled "The Ecological Impact of Land Restoration and Cleanup," EPA Technical Report 520/3-78-006. This report examined in detail the consequences of disturbing some of the more significant ecosystems and their recovery rates. Such an evaluation is essential prior to the initiation of any major remedial action program. It can therefore be concluded that consideration of all factors involved in deciding on the feasibility, type, and extent of cleanup is needed prior to initiation of such actions, and that such decisions must be made in the context of an overall balancing of the costs and benefits.

1.5 IMPLEMENTATION

Implementation of criteria is the responsibility of the Federal or State authority under whose jurisdiction the facility which caused the environmental contamination operates, or which otherwise has jurisdiction and/or control of the materials which are released. Implementation includes determining both the actual or potential hazard to people and instituting remedial actions where required.

The principles of justification, limitation, and optimization recommended by the International Commission on Radiological Protection should be applied to the development of applicable criteria. The full range of options for remedial actions should be considered and both the effective risk reduction and incremental costs determined relative to a base case. An evaluation of the feasibility and costs for such a range of options should be included as part of the documentation

of the decision process. The determination of the appropriate risk limits for each incident of contamination should be carried out on a site-specific basis, and decisions on the focus and extent of remedial actions should be made on the basis of long-term public health protection.

Specific implementation directives for remedial actions, in a report entitled "Nuclear Weapon Accident Response Procedures (NARP) Manual," have previously been provided by the Defense Nuclear Agency of the Department of Defense (Report DNA 5100.1, January 1984). This manual provides valuable information on administrative procedures and technical data applicable to an emergency response situation. In addition, the United States undertook a large-scale remedial action operation on the Enewetak Atoll during the 1970's, with the objective of resettling the native population of a former weapons test site. Although the situation was unique, the operation provided valuable experience applicable to future remedial actions. The Department of Energy provided cleanup objectives for the transuranium elements, and applied these to islands categorized by use and occupancy. The Environmental Protection Agency has also published detailed general procedures for remedial actions in the "National Oil and Hazardous Substances Pollution Contingency Plan". Other criteria and recommendations developed for specific cleanup operations have been published elsewhere and should be reviewed prior to initiation of any remedial actions.

Implementation of criteria may be facilitated by direct measurement of ambient environmental concentrations. ICRP Publication 26 states (Paragraph 82) that "In many practical situations it will be convenient to make use of a derived limit, calculated with the aid of a model, which provides a quantitative link between a particular measurement and the recommended dose-equivalent limit or intake limit. In deriving such a limit the intention should be to establish a figure such that adherence to it will provide virtual certainty of compliance with the

[International] Commission [on Radiological Protection] recommended dose-equivalent limits. However, failure to adhere to the derived limit will not necessarily imply failure to achieve compliance with the Commission's recommendations and may require only a more careful study of the circumstances."

It can generally be expected that a variety of techniques could be used to achieve reductions in risk to exposed persons. An economic evaluation can be used to identify the technique or combination of techniques which will achieve a specified objective at least total cost. Monetary costs, environmental costs, and other non-quantifiable costs should all be considered in the evaluation of each alternative combination of possible remedial actions.

1.6 ENVIRONMENTAL ASSESSMENTS

Under the provisions of the National Environmental Policy Act of 1969, it is intended that every major Federal action be examined in terms of projected impacts and that all available alternatives be considered. The purpose of such an analysis is to compare the options in terms of the broad range of projected health, sociological, economic, and environmental impacts.

Under Section 102(2)D of the National Environmental Policy Act of 1969, agencies are required to study, develop, and describe appropriate alternatives to the proposed or recommended courses of action. The purpose is to analyze the environmental effects, benefits, costs, risks, and related issues, so as not to limit options which might better advance environmental quality or have less detrimental effect. Examples of such alternatives are those of taking no action, of postponing action pending further study, or of taking actions of significantly different nature which could provide similar benefits with less severe environmental impacts.

The possible impacts of a remedial action will vary according to the nature and scale of the method used for cleanup and restoration of a contaminated area, and may be particularly sensitive to the location. The primary impacts of most remedial actions will generally be some temporary disruption of normal activities on and near the site, temporary impairment of air and water quality, and possibly significant effects on flora and fauna.

2. IMPLEMENTATION OF RECOMMENDATIONS (REVISED)

(Reprinted with minor changes from "Response to Comments"

EPA Technical Report 520/4-78-010)

2.1 INTRODUCTION

Implementation of recommendations concerning transuranium element environmental contamination involves consideration of all the pathways that could result in radiation doses to persons in the general population. Such a consideration includes a determination of the levels and extent of existing contamination and the projections of actual or potential doses to a critical segment of the exposed population. This requires an evaluation of the site, a projection of the radiation dose rates via all applicable pathways to determine whether recommended dose rates are exceeded, and initiation of remedial actions where indicated.

A reasonable evaluation of a contaminated site should include a description of the site and environmental measurements of contamination levels in environmental media, in sufficient detail to convey adequate information to the general public. Environmental pathway and dosimetry models used to estimate radiation doses to persons should be described to permit evaluation of the procedures used.

The objective of environmental sampling and analysis is to derive information for the purpose of estimating dose rates to pulmonary lung and to bone of exposed individuals. These dose estimates are derived on the basis of models which consider the various pathways by which transuranium elements in the environment may interact with people and produce exposure to radiation. Such models describe the characteristics of transuranium elements in the environment, the manner in which

they may be transported through the air or through food pathways, modes of interaction with man (including inhalation or ingestion) and, finally, factors related to the radiation energy deposition in organs and tissues. In general, dose estimates are best derived from data acquired from measurements in the dose pathway as close as possible to the point where transuranium elements interact with people.

Three general procedures can be used to judge compliance with specific recommendations. These procedures, which are described in more detail in the following sections, may be used for the entire site or for portions of the site as appropriate:

a. dose rates can be calculated, using the appropriate dosimetry models, from measurements of the concentration of the transuranium elements in air, food, and water at the point of inhalation and/or ingestion by persons. This is the most direct method.

b. soil concentration levels of the transuranium elements can be compared to a "screening level" for soil, defined as that level below which the concentration of the transuranium elements is not likely to lead to dose rates in excess of the recommendations.

c. dose rates can be calculated from the soil contamination levels of the transuranium elements using site-specific parameters for transport models and the appropriate dosimetry models.

2.2 IMPLEMENTATION BY ESTIMATING DOSE RATES TO LUNG AND BONE

The objective of implementing actions is to demonstrate that dose rates to members of the critical segment of the exposed population are not exceeded. The most direct method of showing compliance for a specific site, or for subareas of a specific

site, is to measure transuranium element concentrations in environmental media such as air, food, and water at the point of interaction with people and then to calculate the potential radiation dose rates using the appropriate dose conversion factors and dose model parameters. When this procedure is used, adequate documentation should be provided to demonstrate how dose rates are calculated. It is most appropriate to use realistic environmental measurements and realistic model input parameters; conservative parameters should only be used to the extent necessary to compensate for uncertainties.

In certain cases, compliance may be achieved by restricted occupancy of a site, or portions of a site. Time restrictions for occupancy, or other use limitations, may be established to limit the exposure of a critical segment of the population. In general, such occupancy or use restrictions should be applied only if remedial actions sufficient to permit unrestricted access are either impossible or economically prohibitive.

2.2.1 DOSE RATE TO THE LUNG

Lung dose rates are calculated using appropriate dosimetry models, which require knowledge of the annual average transuranium element concentration in air, aerosol particle size distribution, and solubility class of the specific radionuclides present. Apparatus and procedures for the sampling and analysis of particulates in air are available, but the accuracy and precision of measurements must be verified prior to implementation of the recommendations.

Judgment should be exercised in the design of an air sampling program to ensure that air concentration levels are representative of actual exposure conditions. Environmental measurements of airborne particulates which bias the dose estimates by the collection of only certain particle size ranges should be avoided, or a suitable correction should be made.

It is preferable that the particle size distribution be experimentally measured for a specific site. Reasonable values can be assumed based on analogies with similar sites when projected lung dose rates are small compared to the guidance level. The solubility class of an aerosol can usually be determined from the history of the contaminating event and the subsequent environmental weathering mechanisms.

A derived air concentration "screening level", which indicates with high probability that a given dose rate will not be exceeded, may be substituted for a site-specific air concentration limit. Such a derived air concentration "screening level" should be based on an activity median aerodynamic particle diameter (AMAD) not to exceed 0.1 um, which is substantially smaller than observed values at all sites where transuranium element contamination presently exists. For an assumed objective of a committed effective dose equivalent of 10 millirem, the calculated limiting concentration for this procedure would be about 1 fCi/m^3 of alpha emitting transuranium nuclides, for air samples averaged over a period of one year or more. Air concentrations above this value do not necessarily mean that the objective would be exceeded, but rather indicate that a more thorough evaluation of existing conditions should be made.

Elevated levels of transuranium elements in air indicate that these elements may be found in nearby soils. When these levels approach some limiting value, implementation should include a characterization of the environmental source term to provide a means of judgment with respect to the potential for future exposure levels and the practicality of remedial measures.

2.2.2 DOSE RATE TO THE BONE

Bone dose rates are calculated with appropriate dosimetry models using a knowledge of the average amounts of transuranium

elements that are ingested in a year, their chemical state at the time of ingestion, and the proper dose conversion factor. Inhalation of transuranium elements, especially in soluble forms, can also lead to radiation doses to bone and should be considered where appropriate.

Sampling and measurements of transuranium elements in food and water at the point of human consumption is the most direct and preferred procedure for determining the annual average ingested amount of these elements. Alternatively, the amounts of ingested radionuclides may be estimated using environmental pathways models. The chemical state at the time of ingestion is inferred from the medium in which the transuranium elements are incorporated. In particular, transuranium elements which are incorporated into biological tissue should be considered as "organically complexed" and require a special dose conversion factor.

Suitable sampling and analytical procedures are available for the analysis of the transuranium elements in food and water. As with the inhalation pathway, elevated levels of plutonium and the transuranium elements in food or water indicate that these elements may be found in nearby soil or in sediments. Under such conditions, implementation should include a characterization of the environmental source term, to provide a means of judgment with respect to the potential for future exposure levels and the practicality of remedial measures.

2.3 IMPLEMENTATION BY USE OF A SOIL "SCREENING LEVEL"

Compliance with recommendations may be shown for the total area of a site, or for subareas of a site, by certifying that such areas have transuranium element soil concentration levels less than a derived "screening level". The "screening level" is a total transuranium element soil concentration level in the top 1 cm of soil such that dose rates will not exceed the

recommendations under the vast majority of land use conditions. When this implementation mechanism is used, all lands subject to unrestricted use must meet the screening level criteria. Because of present uncertainties in the amount of plant uptake for the more soluble transuranium nuclides, such as americium and curium, and the resultant possibility of larger doses via the ingestion pathway than calculated, the "screening level" concept may not be applicable when the soils of a contaminated area contain these nuclides in amounts greater than 20-25% of the total activity.

Lands with concentration levels less than the "screening level" may be judged to be suitable for all normal activities including residential and agricultural uses. The use of this "screening level" is intended to reduce the land areas requiring extensive evaluation and to minimize the number of measurements needed.

If land areas have transuranium element levels greater than the "screening level," it should not be presumed that recommended dose rates are necessarily exceeded, because conservative assumptions were used in the derivation. Additional site specific evaluations of potential dose rates to lung and bone should be made before remedial actions are initiated.

Inherent in the application of the screening level is the assumption that soil contamination by the transuranium elements will cause radiation exposure through pathways such as the inhalation of resuspended soil, the ingestion of foodstuffs grown on the soil, the ingestion of soil by children, and the ingestion of drinking water contaminated by soil runoff.

2.4 IMPLEMENTATION BY SITE-SPECIFIC PARAMETERS

Implementation may be shown for a specific site, or for sub-areas of a specific site, by means of soil measurements by using pathway and dosimetry models with parameters determined for the specific site, to certify that the resulting dose rates do not exceed recommended values. This approach differs from the use of a soil "screening level" because parameters such as the resuspension factor are determined for a specific site. It is expected that use of site-specific parameters will show that soil contamination levels higher than the suggested "screening level" may correspond to organ doses well below guidance levels. Implementation by site-specific parameters is appropriate where land areas have transuranium element levels greater than the "screening level" and further evaluation is necessary to determine whether or not the recommended dose limits are being exceeded.

The air concentration where people are located generally can be correlated with the adjacent soil concentration by use of a resuspension factor, and can be used to estimate the inhalation dose rate. The site-specific resuspension factor may be either measured directly or calculated from other data. Direct experimental determinations are often difficult to make and not always reproducible. Therefore, calculational techniques are sometimes preferred although their correlation with measured values is subject to considerable uncertainty. A method has been developed (described in Volume I), based on the concept of air mass loading, which may be useful for this purpose. An "effective" resuspension factor is derived, defined as the resuspension factor derived from the air mass loading for the given location and modified by a "distribution factor" which takes into account the generally observed nonuniform distribution of the activity with size of particles in calculating the amount of transuranium element activity in the inhalable fraction of the resuspended material. The "distribution factor" is a

theoretically derived parameter, and its correlation to actually observed situations has not yet been established. The resuspension factor derived in this manner is applicable only to extremely large area sources, and must be further corrected for the dilution by uncontaminated materials when used for small contaminated areas.

The ingestion pathway must be evaluated separately, using data applicable to the specific site in terms of type of crops, plant uptake parameters, and pathway to a critical segment of the population. The more unusual transfer mechanisms to people, such as the ingestion of soil by children and the contamination of drinking water sources, may also need to be examined if shown to be of importance.

2.5 SAMPLING AND ANALYSIS METHODS

2.5.1 CHOICE OF METHODS

The choice of suitable methods for sampling and analysis is the responsibility of the implementing organization. It should demonstrate that the proposed methods have the necessary sensitivity, accuracy, and precision. A description of the apparatus and techniques used to collect the samples, the procedures for preparing the samples for analysis, and the method used for radiochemical analysis should be included.

2.5.2 AIR SAMPLING

When air sampling is chosen as the principal method of implementing the Guidance, continuous monitoring should be performed at locations indicative of potential doses to persons in the general population. Aerosol collection efficiencies as a function of particle size and other appropriate parameters must be reported for the instruments and placements used. Results

must be given in terms of an annual average air concentration of transuranium elements at the specified site.

2.5.3 FOOD SAMPLING

When foods are grown in contaminated soils, and the ingestion pathway may represent a hazard to persons in a critical segment of the population, representative samples should be obtained for analysis and evaluation. Results should be reported in terms of activity per unit of wet or dry weight, as appropriate, for specific food products and for typical "market basket" averages for an individual.

2.5.4 DRINKING WATER SAMPLING

When soil or sediment analyses indicate the potential for the presence of transuranium element contamination in drinking water supplies, periodic monitoring should be performed. Results should be reported in terms of activity per unit volume for both raw and finished drinking water.

2.5.5 SOIL SAMPLING

When soil sampling is chosen as either the principal or ancillary method of complying with the criteria, statistically valid procedures appropriate to the objective should be used to characterize the entire area known or suspected to be contaminated. When soil measurements are made to evaluate the inhalation pathway, emphasis should be on obtaining representative samples of surface soils subject to resuspension and transport. In order to achieve a degree of uniformity in application, it is useful to define specific procedures. It is suggested that soil samples be taken to a depth of one centimeter and include all soil particles less than two millimeters in size. Several individual samples may be composited for a single measurement. At some sampling points it may not be possible to

collect samples to a depth of one centimeter e.g., very stony soil or a thick grassy area. In such cases, other means must be found to obtain representative samples.

For site-specific evaluations of resuspension parameters, it may be necessary to determine the fraction of the total activity associated with ranges of soil particle sizes (distribution factor). Standard liquid or air sedimentation and separation techniques may be used for this purpose. In general, soil characteristics should be altered as little as possible in the collection and preparation of the soil sample and care should be taken to choose a method which does not cause the breaking up of soil aggregates that were present when the sample was taken.

Radiochemical analysis techniques for the determination of transuranium elements in soils are available and have been published. These differ primarily in the method used to solubilize the plutonium in the sample. Acid leaching, acid dissolution, and fusion are most commonly used. The fusion method is considered to be applicable to a wider variety of soils than the other two methods.

Alternative collection, separation, and analysis methods may be used but must be adequately justified in terms of technical validity and relationship to results obtained by the recommended method.

2.6 STATISTICAL CRITERIA

The characterization of any large area in a cost-effective manner requires that the sample locations be carefully determined in order to optimize the information obtained. Statistical methods are available to permit design of sampling programs to obtain results with the accuracy and precision desired.

When planning a soil survey it is advisable to divide the total area under investigation into units at the very beginning of the survey rather than to collect samples more or less haphazardly. Then samples taken to determine the acceptability of the land by comparison of measured concentration levels to the screening level may be collected from sampling units in accordance with a sampling plan. If it is later decided that more sampling is necessary, no change in the sampling plan is necessary, and the location for additional samples will have already been determined.

The number of samples to take within a sampling unit may be estimated from the specific statistical approach used in the sampling plan. An important factor affecting the number of samples to be taken is the risk of making the wrong decision in deciding whether a sampling unit is acceptable or requires remedial action. To reduce the risk of making the wrong decision, larger numbers of samples must be taken. Judgment must be used to strike a balance between the desirability of making the right decision and the difficulties and expense involved in taking large numbers of samples. An additional factor affecting the number of samples in the variability of the transuranium element concentration within a sampling unit. If detailed information is not available on the variability, a simple approach is to take the same number of samples within each unit. These could be taken on a grid system to ensure that all subareas of the sampling unit are sampled. A disadvantage of this approach is that if the variability is substantially different in units, then the probability of detecting concentration levels requiring remedial action will vary from unit to unit. If estimates of variability are available from past studies, these can be used to help determine the number of samples required within each unit so that the probability of making a correct decision will be the same for all units.

After soil concentration levels have been determined, it must be decided if the area under consideration complies with the recommendations or whether further evaluation will be needed. The statistical methodology that is used must be such that few assumptions regarding the form of the soil concentration distribution will be necessary to ensure the validity of the statistical test. The methods should also ensure reasonably low bounds on the risk of making the wrong decision, and the probability of not accepting an area which meets the criteria, or of accepting one which does not, should be small. Acceptance criteria which allow a maximum chance of error of 5-10% are generally considered appropriate.

Considerable variation generally occurs in environmental samples taken even in closely adjacent locations. If one or more samples from any unit exceed the air or soil concentration limits corresponding to the recommendations, a decision must be made on whether the sampling unit is acceptable. Such a decision is best based on statistical tests which consider both the magnitude of the deviations from the average and the number of samples which are involved. A number of statistical methods are available for performing such an evaluation, and the choice must be made on the basis of the data available and the results desired.

3. ECONOMIC ANALYSIS OF REMEDIAL ACTIONS

3.1 INTRODUCTION

Dispersion of plutonium and other transuranium elements in the environment may result in a number of different types of problems, ranging from contamination of soils and other surfaces to the contamination of structures and persons. The objectives of remedial actions should be protection of persons and limitation of long-term environmental contamination. Each situation will need to be evaluated on a site-specific basis, and different remedial action options chosen as applicable.

The costs of remedial actions are determined by a number of factors: (1) the size of the contaminated area, (2) the type of structures and/or surface(s) that are contaminated, (3) the population density and distribution, (4) the type of terrain and other ecological factors, the type of land use, and (5) the associated level of contamination. In general, a contaminated area may be divided into sectors, and appropriate cleanup actions developed for each sector. The total cost for remedial actions is the sum of costs for all sectors.

Two categories of situations must be addressed by a review of economic impacts: (1) existing plutonium and other transuranium element contamination at a few sites where the contamination is stabilized and the distribution and soil concentration are well characterized, and (2) possible future releases (from operating facilities, nuclear weapons accidents, etc), where neither the magnitude of release nor its location can be known in advance of the occurrence.

An assessment of economic impacts of an incident of environmental contamination requires two considerations:

(1) development of general radiation protection criteria, and (2) an optimization of costs and benefits for each appropriate option in the range between the lower and upper bounds defined by the radiation protection criteria.

3.2 COST ESTIMATION

Most of the transuranium elements are alpha emitters and must be inhaled or ingested to cause harm. In general, only contamination on or near the surface is of importance in the transport to man. Remedial actions may require reduction of surface contamination for both soils and structures. Food may need to be embargoed and alternative supplies provided. The local residents may have to be relocated and temporary or permanent access restrictions imposed. The monetary or non-monetary costs of these detriments must be evaluated and balanced against the dose reduction achieved by different countermeasures.

There are two general techniques for lowering the level of contamination in surface soils: (1) plowing, which leaves the contamination in place, but lowers the concentration levels in the topmost layer of soil, or (2) removal of all surface soils to a defined depth and transportation to another location for final disposal. When the surface soils are removed, they may be stored on-site, or off-site in State or Federal repositories. On-site storage is an option that could be used under certain circumstances where a part of the site can be reserved for disposal, and defers or avoids the extremely high costs of off-site storage. The costs of these alternatives must be evaluated on a site-specific basis and decisions made on the basis of both feasibility and other factors.

The threshold of remedial action for residual soil contamination may be established by a derived soil "screening level", which gives a conservative approach to a corresponding dose rate to the critical segment of the exposed population.

Remedial action would generally not be considered for sites with soil contamination below this level. Cost-minimization is the appropriate criterion to identify the preferred set of remedial actions that will bring a site into compliance. The total cost of each possible set of options that can attain compliance should be evaluated to determine the least-cost method. Environmental costs and other nonmonetary costs not quantifiable in monetary terms should, if possible, be considered in the evaluation. Whenever feasible, it is desirable that costs be quantified monetarily, but if this is not feasible, they should be quantified in nonmonetary terms. Narrative descriptions should be used when no quantification is possible. A difficulty is that different combinations of decontamination procedures are expected to have somewhat different mixes of monetarily quantifiable, nonmonetarily quantifiable, and nonquantifiable costs.

Extensive data on available techniques and decontamination costs for various types of structural surfaces have been compiled. These serve as the basis for complex optimization computer programs which will aid in developing a rational basis for decisions on appropriate remedial actions. Optimization procedures must be carried out separately for each specified countermeasure, or combination of countermeasures, and may result in different dose constraints in each case.

Estimated costs of remedial actions were discussed in general terms in Chapter 4 of the "Response to Comments" document published by EPA. A detailed evaluation of costs entitled "Department of Energy Comments on Decontamination Costs" is reproduced as an annex to that publication. However, these are appropriate only for an assessment of cleanup of contaminated soils and do not include the added costs for contaminated structures, relocation, or alternative food supplies. In general, costs (in 1988 dollars) for most simple soil cleanup methods would range from less than $1,000 to $20,000 per acre if relocation and disposal of soils is not required.

Disposal in a near-surface regional facility is estimated to cost up to $190,000 per acre, and disposal in a geological repository $500,000 or more per acre. The added costs of cleanup of buildings and disposal of residual other materials must be added to obtain the total costs.

A schematic comparison of remedial action methods and costs appropriate to a range of soil contamination levels is shown in Table 3-1, and a summary of various applicable cleanup measures is shown in Table 3-2.

The Department of Energy (DOE) analyzed the cumulative costs (in 1977 dollars) of remedial action at three real (but unidentified) sites. Two area sizes of 1 km^2 and 10 km^2 were used at each site for a total of six sets of costs (Table 3-3). These sites are devoted to a number of uses, including crops, orchards, pasture, woodlots, forests, shoreline, and residential and commercial areas. The areas analyzed are so large that the derived decontamination costs may not represent realistic estimates of the probable cost of remedial actions. A comparable analysis in 1988 dollars may range up to double the above.

The Department of Energy analysis is shown here primarily to illustrate the effect of different assumptions on the cost estimates. Comparison of the four sets of remedial actions shows that for similar treatment strategies there is little difference in the average costs per unit area of treatment for the six sites. Off-site disposal at Federal repositories would account for 82 to 98% of the costs for remedial actions at the six sites when earth removal is the treatment strategy. However, it should be noted that these comparisons are limited to the costs of soil cleanup which may reflect only a portion of the total costs.

TABLE 3-1

POSSIBLE REMEDIAL ACTION METHODS AND COSTS
FOR A RANGE OF CONTAMINATION LEVELS

Maximum Soil Contamination Level (uCi/m^2)	Maximum Annual Risk to Individual	Possible Method(s)				Estimated Costs ($/acre)
		Stabilization	Restoration	Cleanup	Disposal	
0.1	10^{-6}/yr	x	x	Plowing		$1,600 (range $900-$4800)
1	10^{-5}/yr	x	x	Scaping/ Plowing	on-site	$3,600 (range $1600-$6800)
10	10^{-4}/yr	x	x	Soil Removal	on-site	$6,000 (range $2200-$8800)
100	10^{-3}/yr	x	x	Soil Removal/ Decontamination	on-site and/or non-retrievable	$25,000 (range $10,000-$100,000)
1000	10^{-2}/yr	x	x	soil removal	container storage	$100,000 (range $80,000-$200,000)
10,000	10^{-1}/yr	x	x	soil removal	geological repository (high-level waste)	$500,000 (range $150,000-$600,000)

TABLE 3-2

	IN-PLACE OPTIONS	REMOVAL/ON-SITE DISPOSAL	REMOVAL/OFF-SITE DISPOSAL
STABILIZATION	Optional	Optional	Optional
SITE ACTIONS	Plowing (shallow) (deep) Soil Cover (4-12")	Surface Removal (Scraping or Vacuuming)	Surface Removal (Scraping or Vacuuming)
REMOVAL	none	Soil Grass/Crops, etc Trees Selected Materials Decontamination Materials	Soil Grass, Crops, etc Trees Structures, etc Decontamination Materials
PACKAGING	none	Optional	Separation/Classification Transfer to Special Containers Storage
TRANSPORTATION	none	On-Site Moving	Long-Distance Hauling (Base Cost + Distance)
DISPOSAL	none	On-Site Burial	Disposal at Designated Site(s)
RESTORATION	Fertilizer/Seeding Shrubs, etc	Topsoil Replacement Fertilizer/Seeding Shrubs, etc	Topsoil Replacement Fertilizer/Seeding Shrubs, Trees, etc
ESTIMATED COSTS	$2-10K/acre	$10-50K/acre	$500K-1M/acre

TABLE 3-3

DEPARTMENT OF ENERGY ESTIMATES
OF REMEDIAL COSTS PER UNIT AREA FOR
ASSUMED REFERENCE SITES

Area	Treatment[a]	Total Cost ($ Million 1977)	Cost/km^2 ($ Million 1977)	Cost/acre ($ Thousand 1977)
1.0 km^2:				
Reference Site One	ER	115.6	115.6	468
	SR	95.2	95.2	385
	DP	12.9	12.9	52
	SP	11.4	11.4	46
Reference Site Two	ER	93.3	93.3	378
	SR	133.5	133.5	540
Reference Site Three	ER	121.2	121.2	490
	SR	95.4	95.4	386
	DP	21.2	21.2	86
	SP	19.5	19.5	79
10.0 km^2:				
Reference Site One	ER	1127.0	112.7	456
	SR	1062.4	106.2	430
	DP	159.5	16.0	65
	SP	145.2	14.5	59
Reference Site Two	ER	1103.1	110.3	446
	SR	1080.7	108.1	437
Reference Site Three	ER	1213.0	121.3	491
	SR	942.7	94.3	382
	DP	144.8	14.5	59
	SP	128.5	12.9	52

[a] ER = Earth removal to depth of 5 cm; DP = Deep (1-m) plowing; SP = Shallow (25-cm) plowing; SR = Site restriction, including construction of a biobarrier.

Average Cost - Earth Removal = $454,000/acre
Average Cost - Site Restriction = $427,000/acre
Average Cost - Shallow Plowing = $59,000/acre
Average Cost - Deep Plowing = $66,000/ acre

Source: Enclosure II, Department of Energy Comments on Decontamination Costs Discussed in the EPA Proposed Guidance on Dose Limits for Persons Exposed to Transuranium Elements in the General Environment, Table 13

3.3 COST OF IMPLEMENTATION

3.3.1 EXISTING SITES OF CONTAMINATION

A review of costs of implementation for existing sites of contamination is most useful when viewed in terms of a specific objective. The following discussion is intended to supply a perspective of applying recommendations to these sites in terms of a soil "screening level" which corresponds to an inhalation dose to an individual not to exceed a committed effective dose equivalent of 10 millirem. Alternative objectives in terms of different dose or soil contamination levels might be chosen. A brief description is given below for each site (Figures 1-4), indicating the general contamination pattern and population distribution.

There are four Federal sites in the United States that presently have transuranium element contamination above ambient levels beyond their boundaries. These include the Rocky Flats Plant in Jefferson County, Colorado, Mound Laboratory in Miamisburg, Ohio, Nevada Test Site in southern Nevada, and Trinity Test Site near Alamogordo, New Mexico. The majority of all contamination released is confined within areas under the direct control of the Federal government, which imposes restrictions on the access and use of these areas. Relatively small amounts of transuranium element contamination exist outside the boundaries of these sites on lands generally accessible to the public.

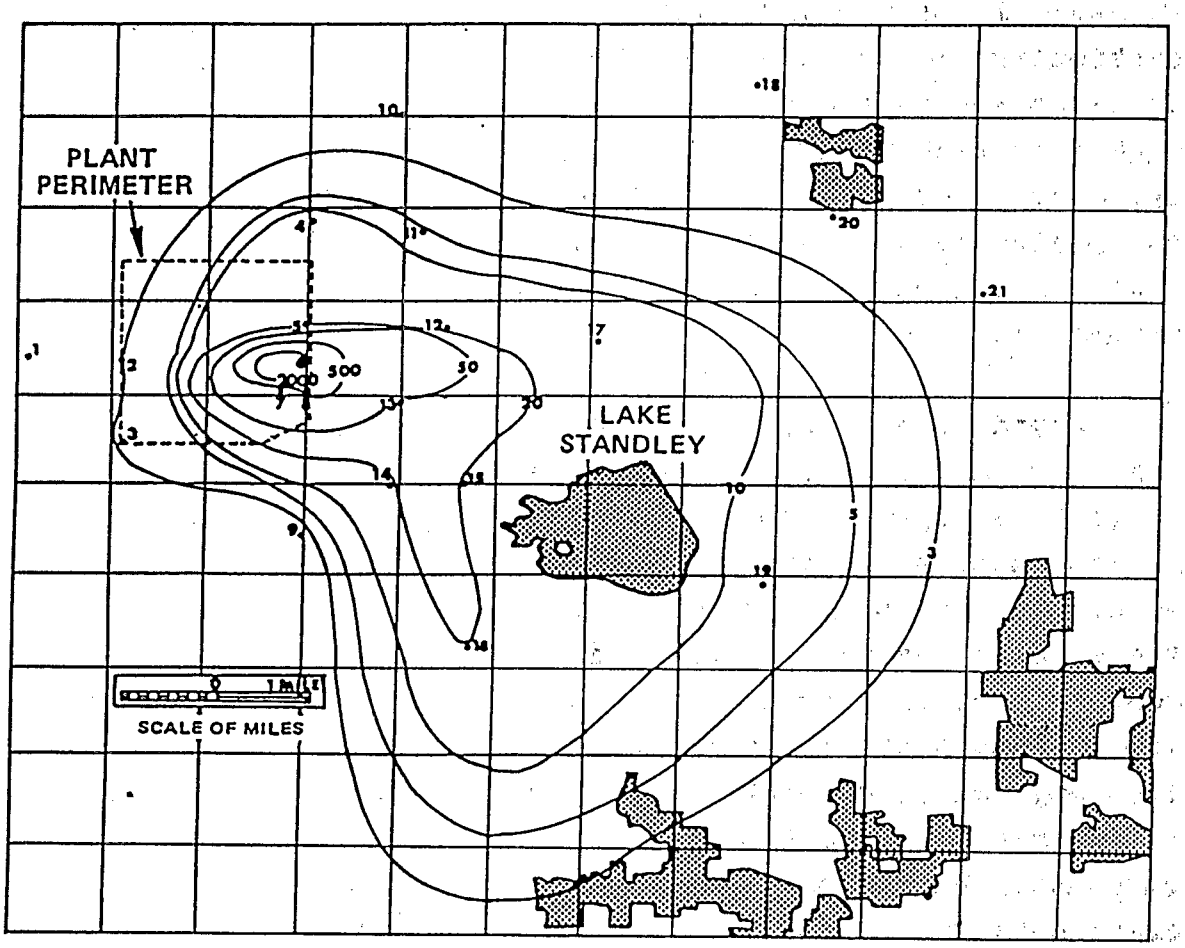
The Rocky Flats Plant (RFP) produces components for nuclear weapons. There have been two fires which released some plutonium to the environment. In addition, a number of barrels containing cutting oil and stored in an open unprotected area slowly corroded and some of the contents eventually leaked and were dispersed. On the basis of soil concentration data, all off-site areas at the Rocky Flats Plant probably would result in maximum dose rates well below current recommendations. However,

TABLE 3-4

Comparison of Areas Outside the Boundaries of Existing Sites
Above Various Soil Concentration Levels
Relative to the Screening Level*
(in square miles)

Site	Area above: 0.02 uCi/m^2	0.2 uCi/m^2	2.0 uCi/m^2
Rocky Flats	1.6	0	0
NTS	165	0	0
Trinity	300	small	0
Mound	0.01	0.01	0.01

*Screening level = 0.2 uCi/m^2 transuranium elements in top 1 cm of soil



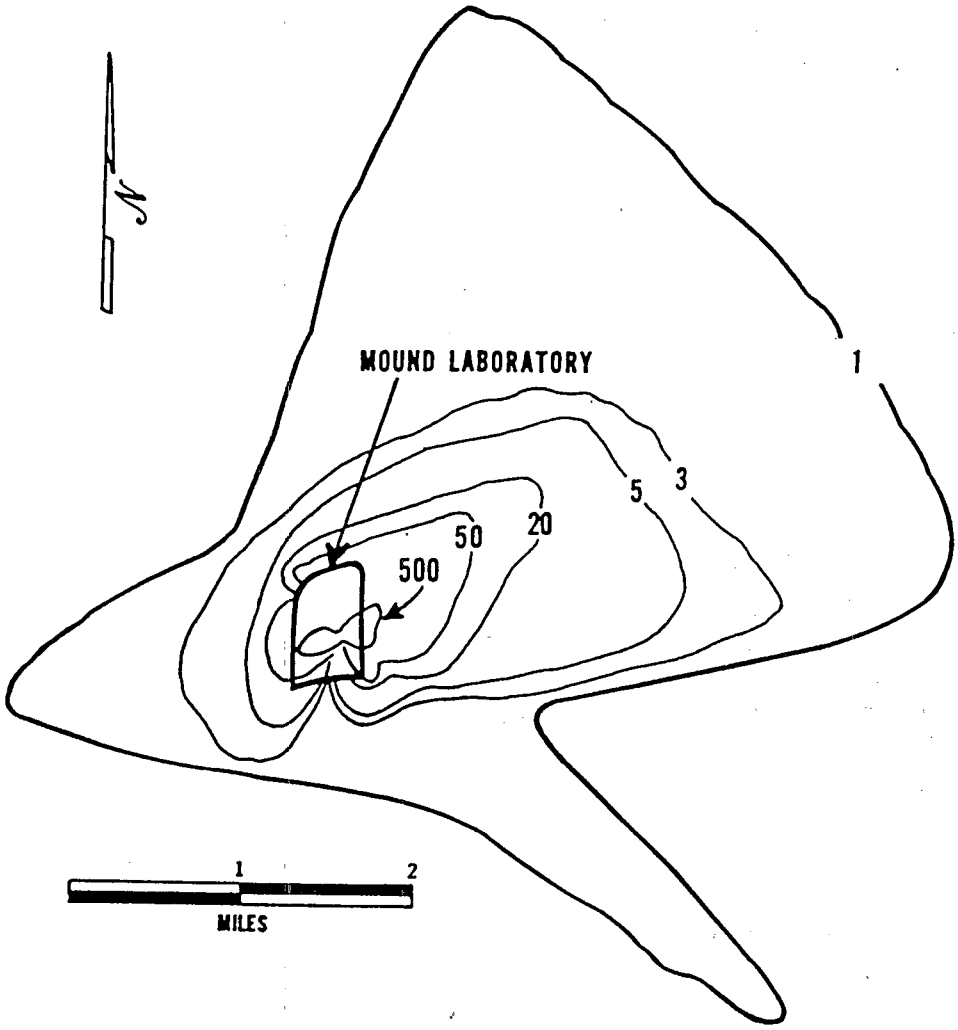
ROCKY FLATS
PLUTONIUM—239 CONTOURS mCi/km^2

FIGURE 3-1

confirmatory evaluations may be needed to determine the actual dose rates to the general population, particularly in the most highly contaminated areas east of the plant. The area is sparsely inhabited and there are few people living in the particular area of concern. The off-site area contaminated to a level one-tenth the "screening level" comprises about 1.6 mi^2, with a current population of less than 600. No uncontrolled areas are contaminated to a level greater than ten times the "screening level". All local water supplies are expected to yield ingestion dose rates well below the dose rate recommendations.

Mound Laboratory is a major research and development site for fabrication of radioisotopic heat sources used for space and terrestrial applications. In 1969 a pipeline transporting a Pu-238 waste solution ruptured, spilling the contaminated solution. The plutonium migrated slowly into nearby waterways. The majority of the plutonium is now sorbed and fixed on the sediments of the North and South Canals. Maximum concentrations are to 1 to 3 ft. below the sediment surface and currently do not pose any radiation problem, since very little of the plutonium is in soluble form and the canal water is not used for drinking purposes. Banks immediately adjacent to the canal and overflow creek subject to occasional flooding have maximum plutonium concentrations exceeding the "screening level." The amount of land in question is about 0.01 mi^2 and there are no people living on this land. There are no areas with transuranium element contamination greater than ten times the "screening level." The nature of the contaminating event limited the contamination to the waterways and adjacent banks. No immediate cleanup is indicated for this site, but continued surveillance will be required.

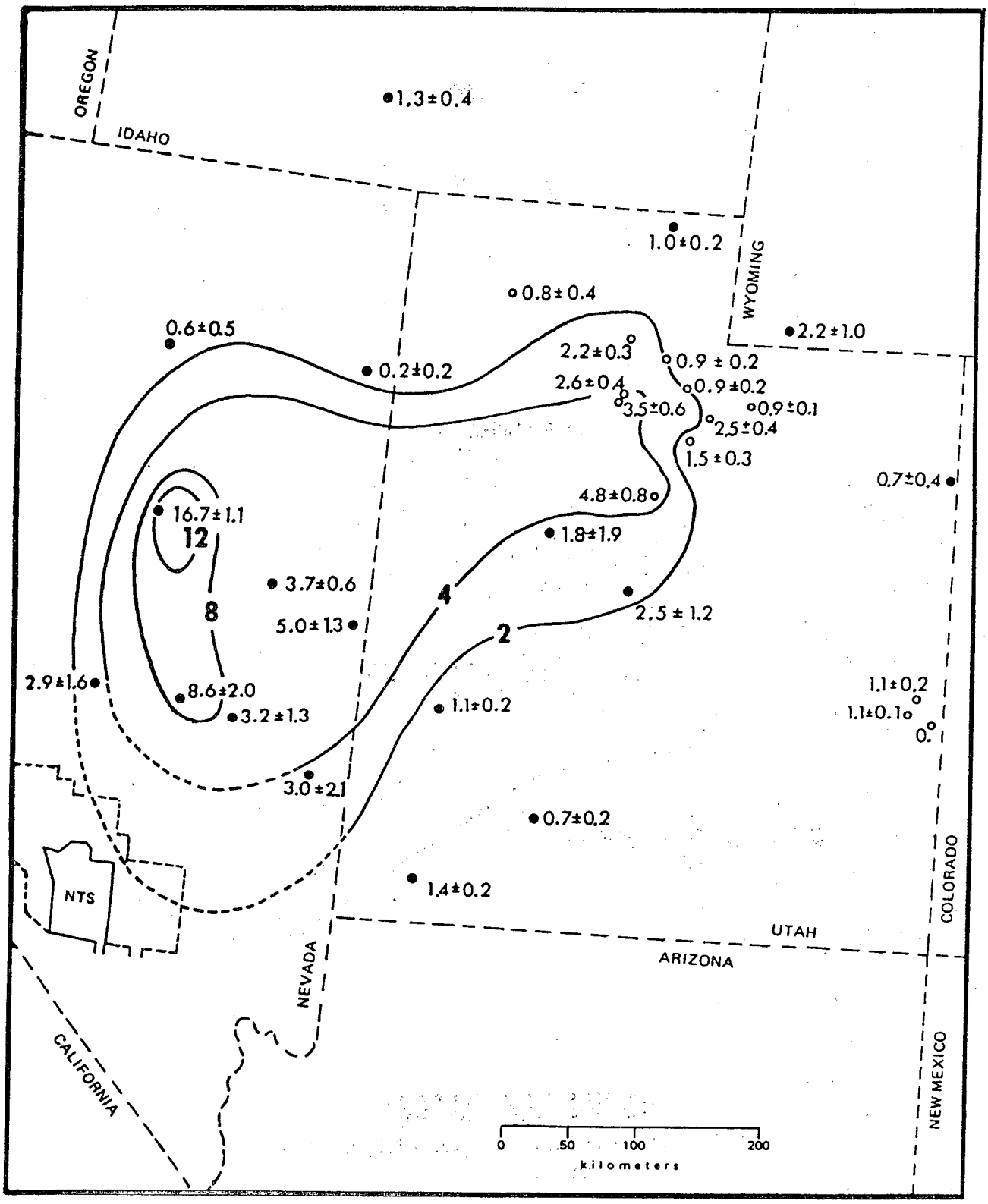
The Nevada Test Site (NTS) covers an area of 1400 mi^2 with an additional exclusion zone extending 16 to 48 miles. Major programs at NTS have included nuclear weapons tests, testing for



MOUND LABORATORY

PRELIMINARY ESTIMATE OF PLUTONIUM - 238 AIRBORNE DEPOSITION
(m Ci/km^2)

FIGURE 3-2



CUMULATIVE NTS DEPOSIT OF Pu-239,240
(mCi per km^2)

FIGURE 3-3

peaceful uses of nuclear explosives, and nuclear reactor engine development. These activities have resulted in plutonium contamination in certain areas of the test site and exclusion areas and slight contamination (above background levels) outside the exclusion areas. There are no known uncontrolled areas which have transuranium element contamination exceeding the " screening level." Land contaminated to one-tenth the "screening level" or less covers approximately 165 mi^2 with a resident population of less than 240 people.

The Trinity Test Site was the location of the first nuclear explosion. No other nuclear explosion tests were performed at Trinity. A site survey was performed by EPA during 1973-74 to determine residual plutonium concentration contours. The highest plutonium contamination levels in uncontrolled areas ranged from 0.2 to 0.9 uCi/m^2. The amount of land contaminated to a level one-tenth the "screening level" covers less than 300 mi^2, with fewer than 500 people living in the area in small towns, ranches, and farms. On the basis of the limited available data, no major remedial actions would appear to be indicated for this site.

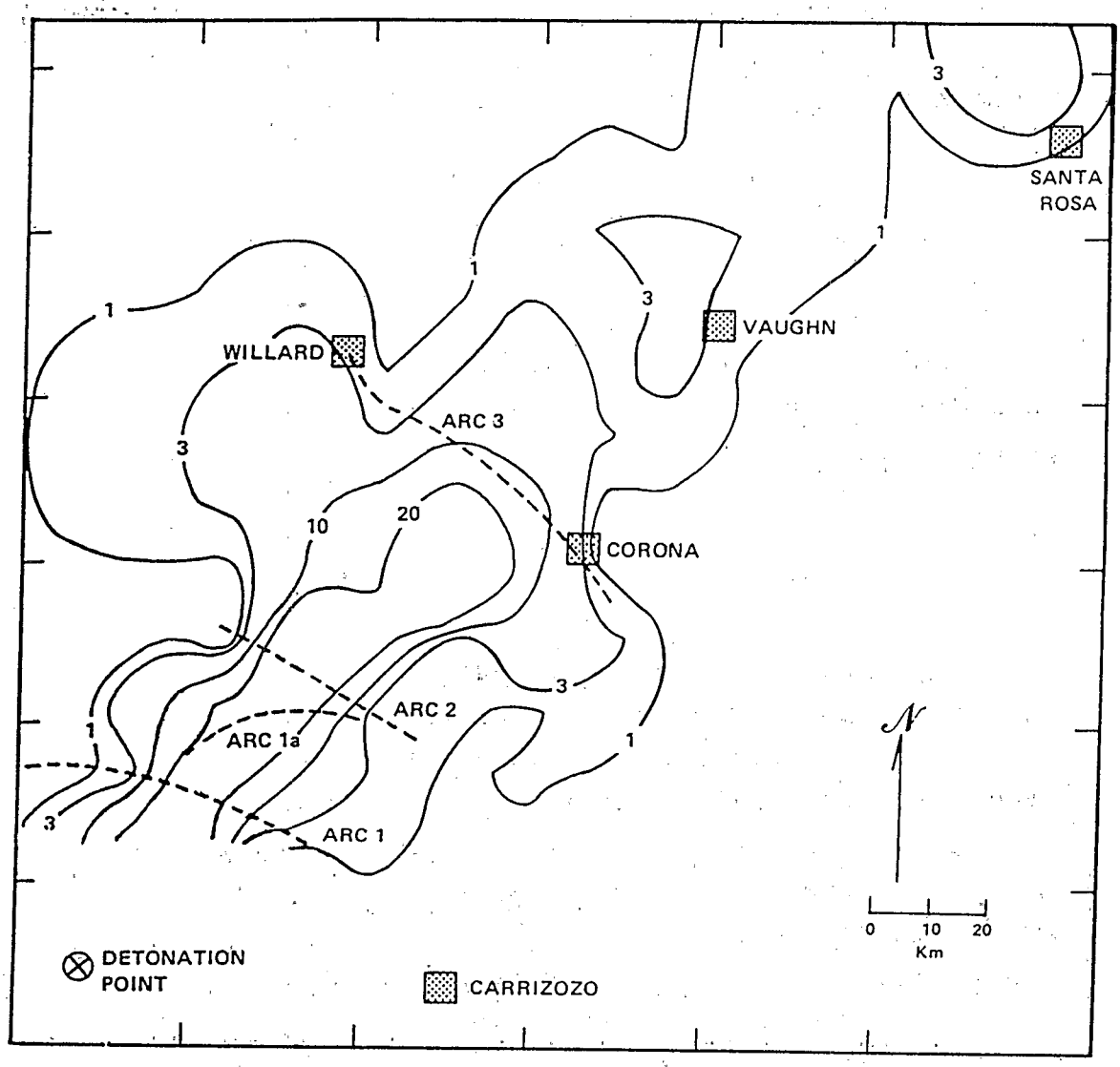
The above describes the method of evaluating the feasibility and cost of applying a reference recommendation to existing sites of contamination presently involving plutonium and other transuranium elements in the United States. On the basis of the available information, it can reasonably be expected that implementation of recommendations at a reference level of a committed effective dose equivalent of the order of 10 millirem would require only some confirmatory evaluations and probably no off-site cleanup actions. If that is the case, less restrictive recommendations would not change the situation. Monitoring activities are already in place at all these sites, and no appreciable augmentation of efforts should be anticipated. Therefore, application of such recommendation to the existing sites of transuranium element contamination should be possible at minimum cost.

3.4.2 FUTURE INCIDENTS

The remedial measures available for case of future incidents of contamination include stabilization, shallow or deep plowing, and soil removal with disposal in on-site or off-site repositories. In urban or industrial areas, houses, buildings, streets, and sidewalks may require decontamination. Protection of ground and/or surface water may be necessary. Temporary evacuation of the population may also be required.

The location, frequency, and magnitude of possible releases to the environment of transuranium elements that may occur in the future is indeterminate and cannot be predicted. Recommendations for cleanup must allow for sufficient flexibility for evaluation of feasible alternatives which would assure adequate long-term protection of the public health and safety. A detailed evaluation of possible scenarios for remedial actions would be both speculative and beyond the scope of this discussion.

There are few precedents for such prospective actions, there are literally an infinite number of possible scenarios, and a generalized benefit-cost analysis is not very useful. Therefore, criteria which recognize the range of existing radiation protection recommendations and implement these in a graduated system of levels of residual risk balanced by compensating protective actions to keep doses to people "as-low-as-reasonably-achievable" may be most appropriate. This would result in a system where increased risks are compensated for by increasingly stringent occupancy restrictions, environmental monitoring and/or medical surveillance. Optimization would be required for each site and the implementing agency would have to consider a range of options within the constraints of the recommendations.



TRINITY SITE
1973-1974 PLUTONIUM
SOIL SAMPLING RESULTS
(nCi/m^2)

FIGURE 3-4

4. INCIDENTS OF NEW CONTAMINATION

Incidents of new contamination require evaluation in terms of minimizing the impacts on potentially exposed persons and of restoration of the environment to as near normal as practicable. The considerations required include the development and implementation of emergency response criteria, the stabilization of the contamination as rapidly and effectively as possible, and the cleanup and restoration of the site.

Remedial action for newly created contamination must consider both the short-term and long-range objectives. Initial priority must be given to protective actions designed to minimize the impact on potentially exposed individuals and to localize contamination to the maximum extent practicable. Later actions can then be concerned with decontamination and restoration of the affected areas to minimize the total environmental impacts. Such a contamination incident requires consideration of two factors - the emergency response protective action criteria, and the guidance applicable to the maximum permissible residual concentration limit for the specific site.

An accident can be divided into three sequential events in terms of time and related actions (Figure 4-1). The initial phase is the period during the emergency, the second is the interim period when preventive actions are appropriate, and the final phase is the extended time period when the situation has stabilized and remedial actions commenced. The initial phase can be considered as a one-time event and protective action criteria formulated on that basis.

Newly created and deposited contamination of the environment by transuranium elements may represent a potential danger to the general public that must be dealt with as promptly as possible. The resuspension rate for newly deposited contamination has been

PLANNING	INCIDENT	EMERGENCY	PROTECTIVE ACTIONS	REMEDIAL ACTIONS
o Develop Emergency Plan o State-Local Review o Preparation - Equipment Training Testing		o Assess Emergency Status o Preliminary Accident Evaluation Project Doses to Persons o Activate Emergency Response Plan	o Start Field Monitoring - Update Dose Estimates o Implement Protective Actions o Terminate Protective Actions	o Evaluate Long-Term Doses and Public Health Impacts o Determine Acceptable Residual Contamination Level o Develop Remedial Action Plan - Consider Cleanup Options and Alternatives o Perform Remedial Actions o Certify Compliance

Diagram of Actions During the Emergency Response, Protective Action, and Remedial Action Phases of an Accidental Release of Radioactive Materials from a Facility

FIGURE 4-1

estimated to be higher by a factor of 1000 or more than for aged sources and therefore represents a proportionately greater hazard. The immediate objectives should, therefore, be to reduce the mobility of the new source by stabilization or removal and to temporarily evacuate those persons who might be subject to unacceptably high doses. Decisions on suitable protective actions must be made by responsible local officials. The primary consideration in such instances must be a minimization of the health and safety impacts on exposed members of the general population.

Analyses indicate that when a contaminating event occurs, most of the radiation dose associated with the event is committed within a short time (a period of a few weeks or months) unless protective measures are taken. This is because particulates from the initial release may be inhaled directly and the resuspension factor for newly deposited material is much higher before weathering and movement into soil surfaces occurs.

Intervention criteria are based on a projection of the ultimate consequence of the event and a judgment of how certain actions could reduce the impact. Initial remedial actions will, to some extent, depend on the information available and on the judgment of knowledgeable individuals. Initiation of countermeasures does not imply an acceptable dose, but rather is an ex-post-facto effort to minimize risk from an event in progress or from one that has already occurred.

Development of intervention criteria requires advance planning, so that emergency response plans can be implemented in a minimum period of time. Therefore, detailed emergency response plans should be prepared for all facilities, carriers, or organizations which handle plutonium in quantities sufficiently large so that a fractional or total release could present a hazard to man. Criteria should be developed for their use, local authorities should be involved in their development and

implementation, and possible alternatives should be considered. The underlying assumptions of any protective action plan is that some real or potential threshold risk must be exceeded before the plan is implemented. Therefore, a numerical value must be proposed as the limiting radiation dose to which people may be exposed before emergency actions are warranted.

For contaminating incidents involving plutonium or other transuranium nuclides, primary considerations in the development of intervention criteria should be given to airborne radioactivity resulting both from the initial plume and from material resuspended from the ground. The total integrated dose commitment from an environmental source is the summation of the exposures resulting from:

a. the initial cloud and its deposition,

b. the inhalation of resuspended material, where the resuspension factor decreases with time,

c. all other pathways, including food and drinking water.

Intervention criteria should provide a basis for the development of site-specific recovery criteria following an accidental release of transuranium elements to the general environment. Such criteria are necessary for the long-term protection of the public health. The recovery criteria must focus on minimizing the cumulative risks of prolonged exposure by persons in a critical group of the population, and have the objective of restoring an area for unrestricted occupancy.

5. "SCREENING LEVEL" FOR STABILIZED CONTAMINATION AND AN "ACTION LEVEL" FOR NEW SOIL CONTAMINATION

A general method for deriving a "screening level" for stabilized transuranium element contamination in soils and an "action level" for newly deposited contamination is presented, based on data from existing sites, current dosimetry, and models for environmental transport. These are intended to provide an adequate margin of safety below the designated radiation protection guidance for persons in the general population.

5.1 "SCREENING LEVEL" FOR STABILIZED CONTAMINATION

5.1.1 APPLICATION

A "screening level" can be defined as a conservative method of relating a dose limit for a critical group to a corresponding soil contamination level. It is intended primarily to define areas where residual contamination would lead to doses which are generally accepted to be of little concern and to allow unrestricted occupancy of an area. A method for deriving such a screening level for plutonium and other transuranium element concentration in soil is presented which is intended to provide a basis for minimizing both the area around a contaminated site which must be monitored and the number of soil samples which must be collected and analyzed. When the transuranium activity in soil is at or below the concentration derived by this method, it is highly unlikely that a given exposure level would be exceeded. Such a screening level is not intended to be interpreted as a derived intervention level or as a soil cleanup standard to which all sites of transuranium contamination must be decontaminated; instead, when properly applied, it would identify land areas where no additional monitoring is required. A screening level is

not a substitute for site-specific information, but may be useful in its absence.

The method for deriving a screening level was developed by careful consideration of all currently contaminated sites, placing particular emphasis on areas for which enough site-specific data are available for such factors as particle size and soil activity distributions. After examining these data, a hypothetical site was defined with a combination of parameters chosen to be conservative, i.e., to produce an acceptable level of transuranium activity more restrictive than that which would be derived for any of the existing sites. This conservative approach has been taken due to the uncertainties inherent in any calculational model, and because of the limited experience with contamination by the transuranium elements. Sites of future contamination are also likely to have characteristics similar to the existing sites.

Of the various models that have been suggested for relating soil contamination levels to airborne concentrations, the mass loading approach appears best suited for use in deriving a soil screening level. The mass loading approach has been shown to provide a good capability in predicting air concentrations on an annual basis at several sites with existing soil contamination and, since the screening level is intended as a generic value with application at all sites, it is generally not appropriate to use one of the more sophisticated resuspension models requiring detailed site-specific parameters such as wind speed, atmospheric stability class, soil erodibility index, etc. In applying the mass loading model to calculating a soil screening level, some modifications have been made, in an effort to overcome some of the shortcomings which are fundamental to the approach.

5.1.2 ENRICHMENT FACTOR

In an effort to take into consideration the non-uniform distribution of activity with soil particle size as well as the non-uniform resuspension of particle sizes, an "enrichment factor" has been derived which is included in the mass loading calculation. Potential exposure due to contaminated soil depends largely on the amount of activity associated with particles in the respirable size range (generally 10 μm). It has been suggested by several investigators that sampling of only those particles in a soil sample which are within the inhalable size range would give the best measure of risk to the public health. However, the weight fraction of particles in the less than 10 μm range is small in most soils, and sampling, separation, and analysis techniques are correspondingly more difficult and inaccurate. There is also considerable evidence that some of the larger particles really consist of aggregates and are relatively easily broken down into smaller ones, so that an instantaneous measurement of a single size range may not give a good picture of long-term trends. Another important objection to limited sampling is that larger particle sizes may make a substantial contribution to other possible pathways (e.g., ingestion), and hence should be measured. To evaluate the potential hazard of the inhalable fraction of soils, while retaining the advantages and conveniences of analyzing the entire soil sample, the mass loading approach has been modified by use of an "enrichment factor". The proposed method weights the fraction of the activity contained within the respirable range in terms of its deviation from the activity to mass ratio for the entire sample and, at the same time, addresses the problem of the nonuniform resuspension of particle sizes mentioned in the previous section. The inhalable fraction of the soil is weighted by considering the relative distribution of activity and soil mass as a function of particle size for representative samples of soil. To accomplish this, the sample of contaminated soil is segregated into size increments, and the activity and mass contained within each size

increment is determined. The factor g_i is then defined as the ratio of the fraction of the total activity contained within a size increment i to the fraction of the total mass contained within that increment. A value greater than 1 for g_i implies an enrichment of activity in relation to mass within that incremental fraction, while a value less than 1 indicates a dilution of the activity with respect to mass relative to the average for the sample.

In order to evaluate the inhalation of resuspended plutonium, the nonuniform resuspension of particle sizes in each size increment of the surface soil must also be considered. Accordingly, the mass loading can be derived as a function of the measured particle size spectrum. The fraction of the airborne mass contained within each size increment is calculated and designated as f_i. The factors of f_i and g_i can then be incorporated into the mass loading formulation as follows:

$$\text{Air Activity}_i = \text{Air Mass Loading} \times f_i \times \text{Soil Activity} \times g_i$$

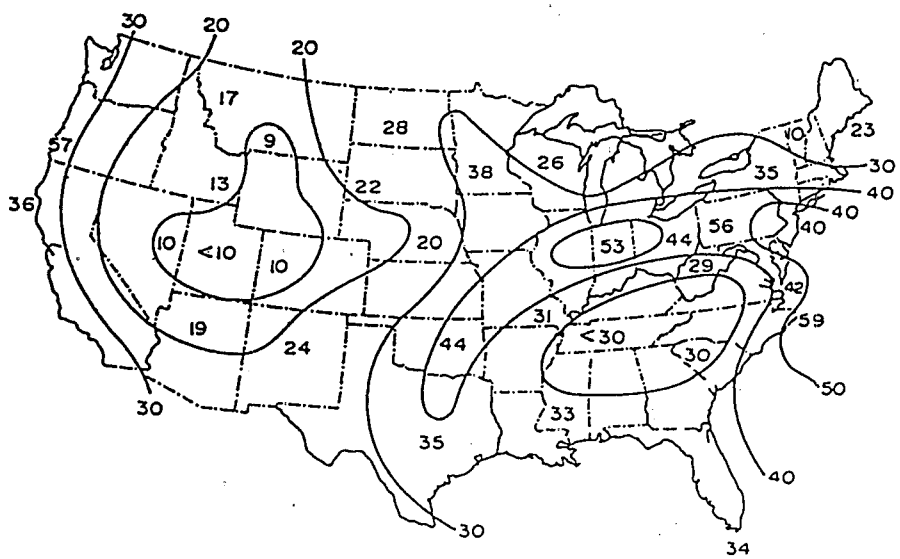
Summation over all the size increments results in the total air concentration:

$$\text{Air Activity} = \text{Air Mass Loading} \times \text{Soil Activity} \times \Sigma f_i g_i$$

The term $\Sigma f_i g_i$ gives the contribution of the plutonium from each soil size fraction to the total resuspended material, thereby taking into account both the nonuniform resuspension of particle sizes as well as the nonhomogeneous distribution of activity. The summation of $f_i g_i$ will be referred to as the "enrichment factor", where f_i accounts for the distribution of airborne mass as a function of particle size and g_i accounts for the variability of both soil activity and soil mass as a function of particle size.

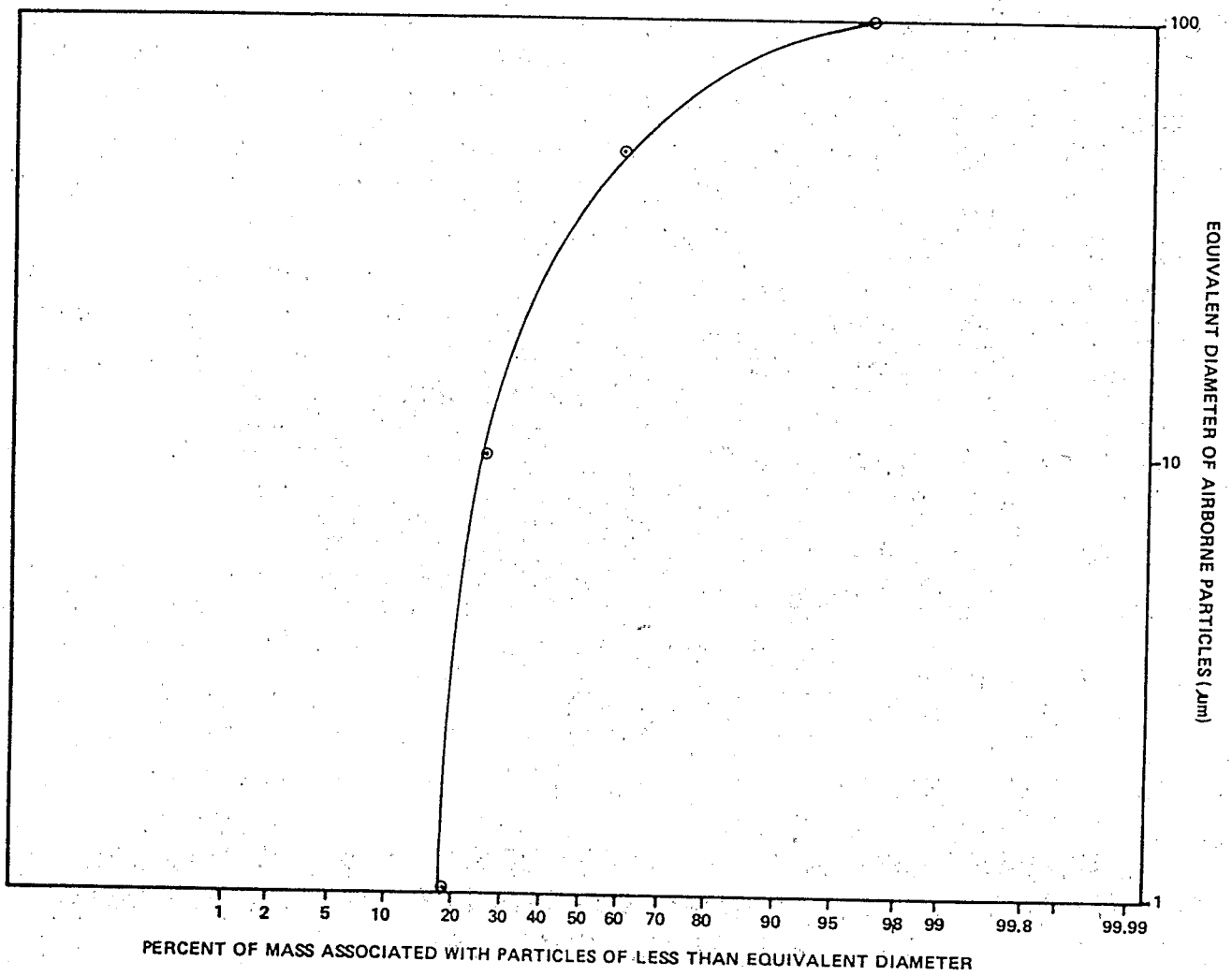
TABLE 5-1

SAMPLE	SIZE INCREMENT	WEIGHT FRACTION	ACTIVITY FRACTION	g_i	f_i	$f_i g_i$
RF 1A	105-2000	.62	.07	0.12	–	
	10-105	.18	.40	2.21	.7	
	<10	.20	.53	2.65	.3	2.34
RF 1B	105-2000	.63	.39	0.63	–	
	10-105	.17	.06	0.34	.7	
	<10	.20	.55	2.74	.3	1.06
RF 1C	105-2000	.64	.43	0.68	–	
	10-105	.16	.07	0.46	.7	
	<10	.20	.49	2.47	.3	1.06
RF 2A	105-2000	.46	.13	0.28	–	
	10-105	.43	.37	1.10	.7	
	<10	.20	.50	2.48	.3	1.51
						average = 1.49



ANNUAL MEAN MASS CONCENTRATIONS ($\mu g/m^3$) OF AIRBORNE PARTICLES FROM NON-URBAN STATIONS OF THE U.S. NATIONAL AIR SAMPLING NETWORK. 1964 - 1965

FIGURE 5-1



PARTICLE SIZE DISTRIBUTION OF RESUSPENDED SOIL

FIGURE 5-2

5.1.3 CORRECTION FOR AREA SIZE

Use of the mass loading approach implies that the air concentration is at equilibrium with the ground surface, i.e., a steady state situation exists in which the amount of material coming up from the surface is balanced by the amount of material depositing back onto the surface. In the strictest sense this limit can only be achieved for source areas approaching infinite dimensions. For source areas of finite dimensions, a fraction of the airborne mass loading can be derived from an uncontaminated area upwind which contributes no radioactive dust to the atmosphere. The smaller the size of the contaminated area, the less it will contribute to the mass loading level and the greater the uncertainties involved in applying the mass loading model.

Calculations have shown that, for a contaminated area which extends over 50 meters in one direction, the air concentration would be approximately a factor of one hundred smaller than from an area 5000 meters in length (based upon certain assumptions regarding meteorological conditions). Therefore, a correction for area size becomes necessary when applying the mass loading approach to small areas of contamination. In deriving the screening level for soil, the area contaminated has been assumed to be sufficiently large that a correction for area size is not necessary. It should be recognized that this is a conservative assumption and that areas of actual contamination may require a correction for area size; however, since one cannot predict a priori the extent of a contamination incident nor the prevalent meteorology, the conservative case has been assumed.

5.1.4 CALCULATION OF A SCREENING LEVEL FOR STABILIZED CONTAMINATION

The following assumptions were made in deriving the screening level: 1) the mass loading for the hypothetical site was taken to be 100 $\mu g/m^3$ and to have a particle size distribution similar to that reported for resuspended dust, 2) the soil is enriched with activity in the respirable size range relative to the soil as a whole, and 3) the contamination is widely dispersed and a correction for area size is not applied.

An annual average mass loading of 100 $\mu g/m^3$ is higher than the annual average for any non-urban site reported by the National Air Sampling Network (NASN) as shown in Figure 5-1 and is representative of an assumed very high resuspension rate for the hypothetical site. The particle size distribution of the resuspended soil, for use in calculating the screening level, is from data obtained from fields undergoing wind erosion in Colorado and Kansas and adapted as Figure 5-2. Comparison with other studies substantiates the applicability of these results to other areas. For example, it has been shown that 30% of the airborne mass is below 10 μm around the Hanford (WA) site and 33% of the measured airborne mass was below 10 μm (mass loading = 100 $\mu g/m^3$) in the area around Denver (CO).

Soil particle size and activity distribution data are available for five sites with plutonium contamination: Mound Laboratory (OH), Oak Ridge National Laboratory (TN), the Nevada Test Site (NV), the Trinity Site (NM) and the Rocky Flats Plant (CO). Of these sites, the greatest enrichment of activity within the fine particle size range is found in samples from the Rocky Flats area. For this reason, the Rocky Flats soil distribution (see Table 5-1) was used in calculating the screening level. Since the size of the contaminated area varies greatly from site to site, and because of the inability to predict the extent of

future contaminated areas, a reduction for area size is not incorporated into the model for a generally applicable screening level.

The following calculation applies the above general method to the derivation of a model soil contamination screening level. For an objective of limiting the annual dose rate to less than ten percent of the recommendations of national and international radiation protection organizations for a lifetime risk of $<10^{-4}$, the corresponding reference committed effective dose equivalent to the critical group would be 4 mrem/year (H_e = 0.04 mSv/yr). The derived screening level can be scaled to any alternative limit. For an assumption of a Class Y compound and inhalation of plutonium as the critical pathway to humans, the 4 mrem/year (0.04 mSv/yr) reference dose rate can be related to an air concentration of 2.0×10^{-15} Ci/m^3 of plutonium-239 with an assumed activity median aerodynamic diameter of 1 μm. The corresponding screening level is:

$$\text{Screening Level} = \frac{\text{Air Concentration}}{\text{Mass Loading} \times \Sigma f_i g_i \times \text{C.F.}}$$

$$\text{Screening Level} = \frac{2 \text{ fCi/m}^3}{100 \ \mu\text{g/m}^3 \times 1.5 \times 6.6 \times 10^{-11}}$$

$$\text{Screening Level} = 0.2 \ \mu\text{Ci/m}^2 \quad \text{for } H_e < 10 \text{ mrem}$$

$$= 8.0 \text{ KBq/m}^2 \quad \text{for } H_e < 0.1 \text{ mSv}$$

(C.F. is the units correction factor and is equal to 6.6×10^{-11} when a soil density of 1.5 g/cm^3 is assumed for a 1 cm depth dry soil sample. The soil sample should be limited to particles less than 1 mm diameter)

The resuspension factor for this hypothetical site is:

$$\text{Resuspension Factor} = \frac{2.0 \times 10^{-15} \text{ Ci/m}^3}{2.0 \times 10^{-7} \text{ Ci/m}^2}$$

$$= 1.0 \times 10^{-8} \text{ m}^{-1}$$

5.2 "ACTION LEVEL" FOR NEW PLUTONIUM CONTAMINATION IN SOILS

The protection of persons immediately following an accident requires implementation of actions which limit the dose rate to the critical segment of the population. Intervention criteria generally recommend that the dose be limited to 1 to 5 rem (10 to 50 mSv) during the initial post-accident phase. This can be achieved by limiting a combination of the exposure rate and occupancy time.

The principal difference between the initial phase and the long-term phase is that the newly deposited contamination is generally much more mobile and more easily resuspended. This would be even more enhanced by the movement of people and/or equipment in the contaminated zone. Resuspension also varies with the type and smoothness of the surface, wind velocity, and other factors. It has been estimated that resuspension from newly deposited materials may be as high as 10^{-4}/m, or a factor of 10,000 greater than for stabilized contamination.

It is possible to derive a soil concentration level for newly deposited transuranium element contamination which, to a first approximation, would give an indication of whether a dose of 1 rem to the exposed population will be exceeded (the current recommendation for maximum occupational exposure is an average of 2 rem/year (20 mSv/yr). For an exposure averaged over one year, the dose rate to the pulmonary lung is about one-third the equilibrium value. The corresponding relationship between the ambient air concentration and dose rate is given approximately by

3×40 fCi/m^3 = 100 mrem first year H_e, or
1.2 pCi/m^3 = 1 rem

For an objective of limiting the dose from new contamination to one rem for a continuing exposure of one year, the derived "Action Level" with the assumption of a constant resuspension factor of $R = 10^{-5}/m$ would be:

Action Level = 0.1 $\mu Ci/m^2$ < 1 rem (for one year exposure),

or

Action Level = 4.0 KBq/m^2 < 10 mSv

The above derivation is generally conservative and is derived for the current public health protection objectives for persons in the general population. The numerical value of the "Action Level" depends on the specific dose limit, the assumed reduction factor for various protective actions, and on site-specific environmental factors. A smaller resuspension factor would allow for a greater ambient level. The derived "Action Level" is most useful for short time periods immediately after initial deposition. An assumed exponential decrease of the resuspension factor with a one-year half-life to an asymptotic value of $10^{-8}/m$ represents a reasonably conservative approximation for longer time periods. The dose reduction factor for the first year is approximately 0.65, and the above calculation becomes progressively more conservative for increasing time increments after initial deposition.

The "Action Level" has been derived for an exposure of one full year, and represents only a single value in a continuum of functions. Smaller time increments lead to proportionally smaller doses. Alternatively, a larger soil concentration level may be allowed for a shorter exposure time. For example, for three days the ratio is 72 hours/8760 hours, or about 1/100. Therefore, the absorbed dose would be decreased by a factor of 100 for the given soil concentration or, conversely, a dose of one rem would be received in three days for a soil concentration 100 times greater than the above. The variations in radiation protection criteria can be related by the matrix shown in Figure 5-3.

TIME

SOIL CONC (uCi/m^2)	8 hrs	3 days	1 mo	1 year
10^{1}	1	10	100	1,000
10^{0}	0.1	1	10	100
10^{-1}	0.01	0.1	1	10
10^{-2}	0.001	0.01	0.1	1

DOSE (In REM)

"ACTION LEVELS" FOR PLUTONIUM-239

FIGURE 5-3

It should be noted that the above derivation assumes an allowable dose rate limit of 1 rem for the first year following a release and continuing occupancy, and must be modified in accord with both the appropriate radiation protection requirements and other factors. One can conclude that soil concentration levels of the order of 0.1 to 1 $\mu Ci/m^2$ (3 - 30 KBq/m^2) for newly deposited contamination, or the limit of detection for the FIDLER probe, represent a proper level for concern and initiation of protective actions and temporary access restrictions. A realistic assessment would be expected to lead to less restrictive conclusions. As such, a derived "action level" can only give preliminary guidance which must be evaluated by competent personnel on a site-specific basis.

6. RADIOLOGICAL ASSESSMENT - ROCKY FLATS PLANT

[Reprinted With Minor Changes from Response to Comments - EPA 520/4-78-010]

6.1 INTRODUCTION

This chapter presents an analysis of the potential hazards to individuals in the general population as a result of transuranium element contamination in the environs of the USDOE Rocky Flats Plant. It is intended primarily to serve as an illustrative example of how to carry out a comprehensive environmental assessment, and does not represent an evaluation of potential health hazards. Analysis is limited to data for the period 1970-77, when public concern about possible health hazards was greatest. The various pathways by which exposures might occur under present and projected land usages are examined and interpreted in terms of ambient levels of contamination.

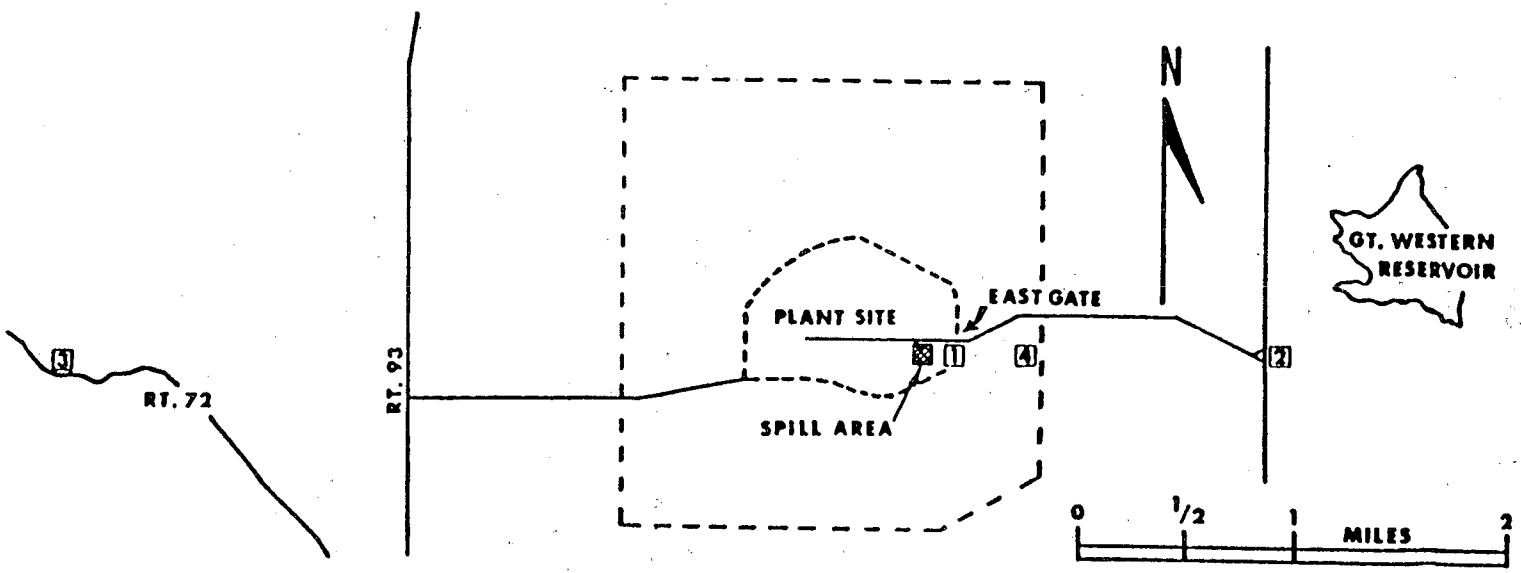
6.2 INHALATION PATHWAY

6.2.1 AMBIENT AIR CONCENTRATIONS

Under normal operating conditions, minute quantities of plutonium and other radionuclides have been released to the atmosphere from the Rocky Flats Plant. These releases originated from the plant's ventilation and filtration system. Measurements of airborne radioactivity in the vicinity of Rocky Flats and the neighboring communities are made on a continuous basis. In addition to monitoring the effluent air from production and research facilities, the Rocky Flats facility maintains a system of high-volume ambient air samplers within the plant boundary, at off-site locations in the immediate vicinity of the plant, and in several communities nearby. Altogether the system comprises 21 air samplers operating continuously within and on the perimeter of the Rocky Flats security area, and another

25 samplers located at various distances and directions from the plant. The data from this network are reported on a monthly basis to the Rocky Flats Area Office of the Department of Energy (DOE), the Division of Occupational and Radiological Health of the Colorado Department of Health, the Denver Regional Office of the EPA, the Health Departments of Boulder and Jefferson Counties, and city officials in several communities near the plant.

In addition to the surveillance network maintained by the Rocky Flats Plant, the Health and Safety Laboratory (HASL) of DOE conducted a program of continuous air sampling for plutonium at the Plant since June 1970 in response to the discovery of elevated levels of plutonium found in soils at location which were then off-site. The HASL network consisted of four sampling locations (Figure 6-1), three of which were downwind (east) from the original location of the oil drum storage site and the fourth air sampler was located off-site and upwind from the Rocky Flats Plant. Air concentration data in attocuries of Pu-239 per cubic meter of air (aCi/m^3), as reported by this network on a monthly basis from June 1970 to March 1976, are given in Table 6-1. A significant downward trend with time in the level of plutonium in air at the stations downwind from the plant can be seen. It has been suggested by HASL that this downward trend is attributable to the weathering of the contaminated soil in the on-site vicinity of the original oil drum storage site. This weathering may be due to the movement of the plutonium from the surface down into the soil, as well as changes in the characteristics of the plutonium remaining on the surface. In addition to showing a decrease with time the data indicate a decrease in concentration with increasing distance downwind from the site of the original spill area. Based upon air and soil sampling, as well as the direction of the prevailing winds around Rocky Flats, HASL concluded in 1972 (2) that the original spill area was the primary source of plutonium in the Rocky Flats environment.



MAP OF ROCKY FLATS PLANT AND VICINITY
INDICATING CONTINUOUS AIR SAMPLING SITES (1).

FIGURE 6-1

TABLE 6-1

MONTHLY AVERAGE AIR CONCENTRATIONS OF Pu-239 AT ROCKY FLATS PLANT (Attocuries /Cubic Meter)

		JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.	OCT.	NOV.	DEC.
SITE #1													
	1970	--	--	--	--	--	1990.00	1250.00	790.00	850.00	693.00	2260.00	962.00
	1971	1960.00	--	7140.00	9730.00	4920.00	3800.00	2980.00	3530.00	4040.00	5770.00	5770.00	3160.00
	1972	5430.00	1670.00	4610.00	1460.00	2080.00	6610.00	4720.00	1380.00	--	1620.00	498.00	1860.00
	1973	1160.00	3640.00	2520.00	612.00	1780.00	3040.00	2920.00	3320.00	1050.00	2010.00	1810.00	1690.00
	1974	402.00	802.00	891.00	1810.00	3060.00	5470.00	2670.00	3330.00	1120.00	407.00	580.00	643.00
	1975	1260.00	1360.00	1780.00	2180.00	2190.00	1160.00	567.00	426.00	179.00	--	1220.00	655.00
	1976	680.00	1240.00	864.00	--	--	--	--	--	--	--	--	--
SITE #2													
	1972	--	--	--	--	--	--	98.90	55.50	119.00	609.00	48.50	45.20
	1973	37.80	57.70	55.80	716.00[c]	51.80	57.70	92.10	65.00	152.00	31.50	25.20	76.30
	1974	16.80	23.20	462.00[c]	135.00	176.00	140.00	78.70	58.10	34.20	24.00	29.20	43.70
	1975	141.00	34.70	56.80	39.70	--	--	27.40	14.00	9.98	--	10.60	16.40
	1976	12.20	23.10	14.40	--	--	--	--	--	--	--	--	--
SITE #3													
	1972	--	--	--	--	--	--	--	--	--	21.90	18.50	25.60
	1973	18.40	41.70[a]	24.20	24.00	40.40	42.00	25.80	25.70	38.20	21.50	11.00	16.90
	1974	21.70	39.10	163.00[c]	283.00[c]	--	--	--	--	--	--	--	--
SITE #4													
	1974	--	--	--	--	1460.00	758.00	1430.00	222.00	199.00	395.00	1240.00	710.00
	1975	288.00	399.00	1850.00	254.00	139.00	684.00	118.00	146.00	72.20	189.00	188.00	128.00
	1976	184.00	303.00	72.60	236.00	109.00	319.00	98.20	63.10	--	--	--	--

-- NO DATA
Errors are less than 20% except:
a -error between 20% and 100%
b -error greater than 100%
c -suspect, omitted from average

The levels of airborne plutonium at the downwind edge of the buffer zone (Indiana Street) were approximately the same level as reported at the monitoring station upwind from the plant. Although these levels were about twice that expected from background radioactivity in the Rocky Flats area, the effect of the spill area upon the off-site environment has been much reduced from earlier levels.

Comparison of the HASL data for 1976 for the Indiana Street location (site 2) with the 1975 data reported by the Rocky Flats Plant (Table 6-2) for the same general area shows the two networks to agree within a factor of about 2. The values reported by HASL range between 12 to 23 aCi/m^3, while Rocky Flats reported an average of 37 aCi/m^3.

6.2.2 INHALATION DOSES DUE TO ON-SITE CONTAMINATION

An assessment can be made of the doses received through inhalation by individuals residing off-site at the time the measurements were made, based upon the considerable amount of air monitoring data available for the Rocky Flats Plant. In carrying out this assessment, a deliberate effort has been made to choose assumptions which are most likely to result in an overestimate of dose. These are:

1) Inhaled plutonium is considered to be in an insoluble form. (chemical solubility of an aerosol determines its residence time in the lung with insoluble compounds being retained the longest.)

2) The plutonium aerosol is assumed to have a lognormal distribution with an activity median aerodynamic diameter (AMAD) of 1 micrometer. (According to the ICRP (3) this implies that approximately 25% of the aerosol will be deposited in the pulmonary compartment of the lung. HASL (4) has reported 25% of

TABLE 6-2

PLUTONIUM IN AMBIENT AIR NEAR ROCKY FLATS PLANT (1976)
[Air Concentation in Attocuries/Cubic Meter]
Distances = 3 to 6 Kilometers

Station	Number of Samples Taken	Less Than Detectable	Volume (cubic meters)	Concentration $C_{maximum}$	Concentration $C_{average}$[a]
S-31	12	1	461,547.0	0.144	<0.032 ± 96%
S-32	12	1	543,346.0	0.134	<0.035 ± 96%
S-33	12	1	531,886.0	0.097	<0.034 ± 95%
S-34	3	1	118,243.0	0.176	<0.037 ± 550%
S-35	3	0	119,322.0	0.116	0.027 ± 538%
S-36	2	0	57,286.0	0.012	0.012 ± 1734%
S-37	12	0	525,181.0	0.198	0.056 ± 93%
S-38	10	0	460,089.0	0.097	0.027 ± 108%
S-39	12	1	502,129.0	0.102	<0.026 ± 97%
S-40	12	0	486,876.0	0.198	0.054 ± 92%
S-41	12	1	472,698.0	0.136	<0.033 ± 99%
S-42	12	1	416,244.0	0.137	<0.037 ± 96%
S-43	11	1	360,818.0	0.185	<0.056 ± 105%
S-44	12	1	429,709.0	0.094	<0.029 ± 103%
Summary	137	9	5,485,374.0	0.198	-
Volume-Weighted Average					<0.037 ± 29%

a. Volume-weighted average.

the airborne activity being in the respirable range around Rocky Flats, while Sehmel (5) has reported a 20% respirable fraction.

3) The individual is considered to be exposed continuously for 10 years at the currently observed air concentration. (No further reduction in airborne activity as a result of weathering or remedial actions is assumed)

4) All plutonium was assumed to contribute to the dose, with no correction being made for ambient background levels of plutonium.

The PAID code developed by EPA (6) was used to calculate the annual dose rate. Tables 6-3 and 6-4 have been generated by the PAID code and relate years of exposure to the resultant dose rate for various organs. Values in the tables are normalized to an aerosol concentration of 1.0 femtocurie per cubic meter of air (fCi/m^3) with a 1 μm AMAD.

6.2.3 INDIANA STREET LOCATION

Indiana Street is the nearest location to the Rocky Flats Plant where an individual in the general population could live and be exposed as a result of transuranium contamination originating from the Plant. This location is in the downwind direction of the prevailing winds that blow across the Rocky Flats Plant (7) and, therefore, it represents a worst case for offsite exposure.

From Figure 6-2 it can be seen that stations 5-35, 5-36, 5-37,5-38, and 5-39 are located along Indiana Street. The station reporting the highest annual average for 1975 was 5-37 with 0.056 fCi/m^3 (Table 6-2). Assuming this level to continue for the next 70 years, the 70th year dose rates to lung and bone can be calculated.

TABLE 6-3

ANNUAL DOSE RATE TO VARIOUS LUNG COMPARTMENTS FROM CHRONIC EXPOSURE TO PLUTONIUM-239 AEROSOLS

Concentration: 1.0 fCi/m^3 Particle AMAD: 0.05, 1.0 and 5.0 Microns

Duration of Exposure (Years)	Pulmonary mrad/yr. x 10^{-1}			Tracheobronchial mrad/yr. x 10^{-2}			Nasopharyngeal mrad/yr. x 10^{-6}		
	0.05u	1.0u	5.0u	0.05u	1.0u	5.0u	0.05u	1.0u	5.0u
1	3.9	1.5	.7	2.7	1.1	6.1	.04	11.	30.
5	9.1	3.5	1.7	3.7	1.5	7.9	.04	11.	30.
10	9.8	3.8	1.8	3.8	1.6	8.1	.04	11.	30.
70	9.9	3.8	1.8	3.8	1.6	8.1	.04	11.	30.

TABLE 6-4

ANNUAL DOSE RATES TO VARIOUS ORGANS FROM CHRONIC INHALATION OF TRANSURANIUM RADIONUCLIDES (In Millirad/Year)

Aerosol AMAD: 1 um Concentration: 1 fCi/m^3 $f_1=10^{-3}$

Nuclide: Pu-239

Duration of Exposure	Liver	Skeletal	Bone Red Marrow	Endosteal
1 year	1.0 E-3	5.0 E-4	4.8 E-4	6.6 E-3
5 years	1.8 E-2	6.5 E-3	6.2 E-3	8.6 E-2
10 years	5.2 E-2	1.9 E-2	1.8 E-2	2.5 E-1
15 years	8.9 E-2	3.4 E-2	3.2 E-2	4.5 E-1
20 years	1.3 E-1	4.9 E-2	4.7 E-2	6.5 E-1
30 years	1.9 E-1	7.8 E-2	7.4 E-2	1.0 E-0
40 years	2.4 E-1	1.1 E-1	1.1 E-1	1.5 E-0
50 years	2.9 E-1	1.3 E-1	1.2 E-1	1.7 E-0
70 years	3.6 E-1	1.7 E-1	1.6 E-1	2.3 E-0

Nuclide: Pu-241/Am-241*

Liver	Skeletal	Bone Red Marrow	Endosteal
1.4 E-6	5.0 E-7	4.6 E-7	5.8 E-6
8.7 E-5	3.2 E-5	3.0 E-5	3.7 E-4
4.6 E-4	1.7 E-4	1.6 E-4	2.0 E-3
1.1 E-3	4.1 E-4	1.6 E-4	2.0 E-3
1.8 E-3	7.1 E-4	6.6 E-4	4.8 E-3
3.4 E-3	1.4 E-3	1.3 E-3	1.6 E-2
5.0 E-3	2.2 E-3	2.0 E-3	2.6 E-2
6.4 E-3	3.0 E-3	2.8 E-3	3.5 E-2
8.0 E-3	4.4 E-3	4.1 E-3	5.1 E-2

Nuclide: Am-241

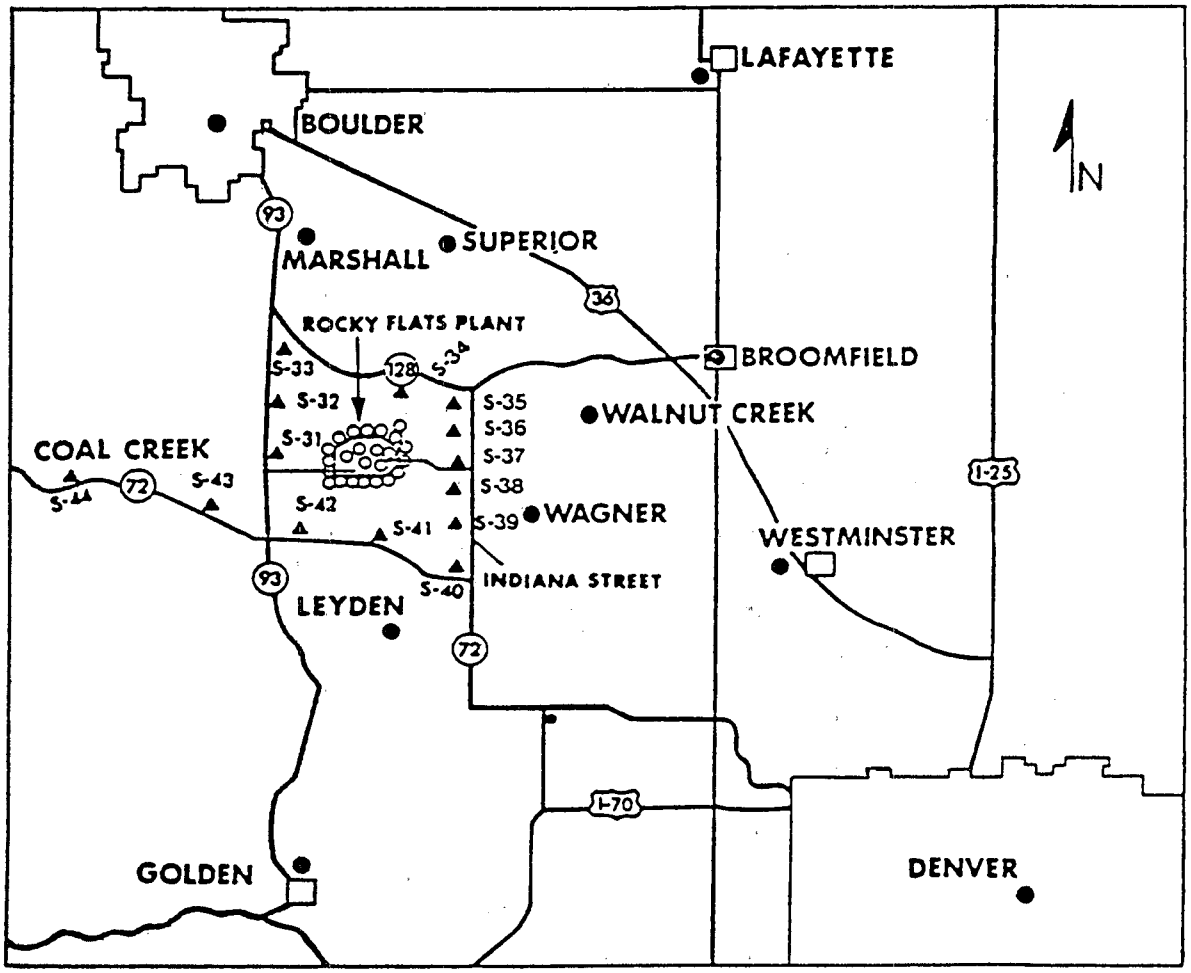
Duration of Exposure				
1 year	1.5 E-3	5.0 E-4	4.6 E-4	5.8 E-3
5 years	1.9 E-2	7.0 E-3	6.3 E-3	8.1 E-2
10 years	5.5 E-2	2.1 E-2	1.9 E-2	2.4 E-1
15 years	9.5 E-2	3.6 E-2	3.3 E-2	4.2 E-1
20 years	1.3 E-1	5.2 E-2	4.8 E-2	6.0 E-1
30 years	2.0 E-1	8.2 E-2	7.5 E-2	9.5 E-1
40 years	2.6 E-1	1.1 E-1	1.0 E-1	1.3 E-0
50 years	3.0 E-1	1.4 E-1	1.3 E-1	1.6 E-0
70 years	3.7 E-1	1.8 E-1	1.7 E-1	2.1 E-0

Nuclide: Cm-244/Pu-240

1.6 E-3	6.0 E-4	5.6 E-4	6.4 E-3
1.8 E-2	1.6 E-3	1.5 E-3	1.7 E-2
4.7 E-2	1.7 E-2	1.6 E-2	1.8 E-1
7.3 E-2	2.8 E-2	2.6 E-2	3.0 E-1
9.4 E-2	3.7 E-2	3.4 E-2	3.9 E-1
1.2 E-1	4.9 E-2	4.5 E-3	5.2 E-1
1.4 E-1	5.7 E-2	5.3 E-2	6.1 E-1
1.5 E-1	6.3 E-2	5.8 E-2	6.7 E-1
1.6 E-1	6.8 E-2	6.3 E-2	7.3 E-1

*Alpha dose only - 70th year beta dose rates: liver = 0.11 urad; bone = 0.049 urad.

LOCATION OF OFF-SITE AMBIENT AIR SAMPLERS (8).



LEGEND

- ○ ON-SITE AIR SAMPLERS
- ▲ AIR SAMPLERS, 3 TO 6 KILOMETERS (2 TO 4 MILES) DISTANCE
- ● COMMUNITY AIR SAMPLERS

FIGURE 6-2

As shown in Table 6-3, an air concentration of 1.0 fCi/m^3 for 1 μm AMAD aerosols of Pu-239 would produce a 70th year dose rate to the pulmonary compartment of 0.38 mrad/yr; therefore, proportionally, a concentration of 0.056 fCi/m^2 (5-37) will produce a 70th yr dose rate of 0.02 mrad/yr. The bone dose rate associated with this level of Pu-239 according to Table 6-4 will be 0.009 mrad/yr in the 70th year.

Data on the air concentration of Am-241 have been reported by HASL (7) for the years 1970 through 1974. These data show the americium levels, measured at the perimeter fence of the Plant, to be approximately 11% of the Pu-239 levels. HASL projected that the Am-241 activity level will reach its maximum value arising from the decay of Pu-241 in the year 2033 at which time it will amount to 18% of the Pu-239 activity. For the calculation of the dose rate from Am-241, it is assumed that Am-241 is at the maximum of 18% of the Pu-239. The 70th year dose rate corresponding to a concentration of 1 fCi/m^3 of Am-241 is 0.4 mrad/yr; proportionally, an air concentration of 0.18 x 0.056 fCi/m^3 would produce 0.004 mrad/yr to the pulmonary compartment. The associated bone dose would be approximately 0.002 mrad/yr.

Based upon these calculations, the total pulmonary dose rate after 70 years of exposure for an individual living along Indiana Street would be 0.024 mrad/yr, while the associated bone dose would be 0.01 mrad/yr. Individuals living further away from the Rocky Flats Plant should receive even lower doses than these due to the lower air concentrations reported for the nearby communities.

6.2.4 INHALATION DOSES DUE TO OFF-SITE CONTAMINATION

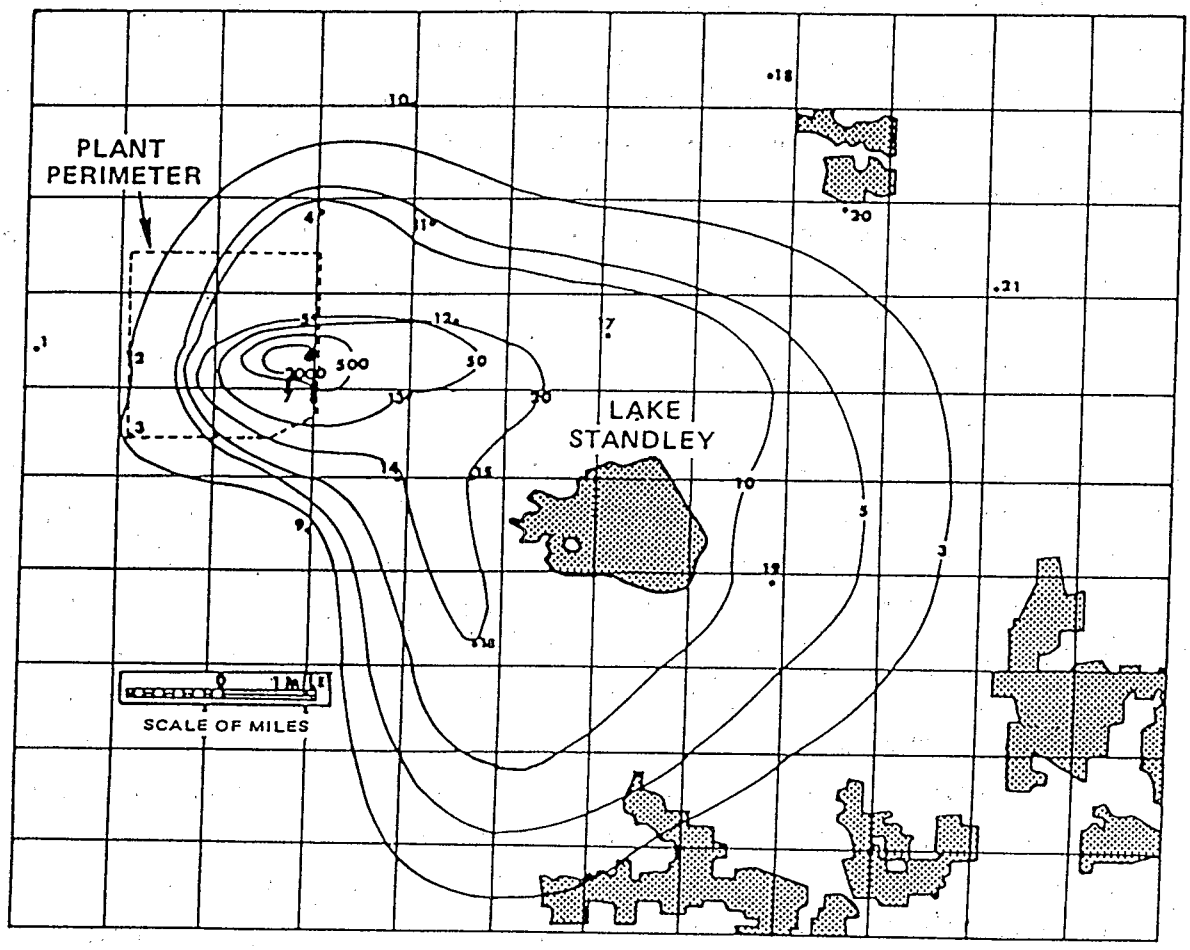
A complete assessment of the inhalation pathway for the Rocky Flats vicinity must consider the potential hazard from the low levels of contaminated soil which already exist off-site.

Questions have been raised as to the effect of this material in producing localized exposures which are not necessarily reflected in the data obtained through the air monitoring network around Rocky Flats. These inhalation exposures can arise through various mechanisms including: wind resuspension of contaminated soil, vehicular and mechanical disturbances of soil, accumulation and resuspension of dust within the home, as well as the resuspension of contaminated soil attached to clothing. The following analysis will attempt to investigate these exposure mechanisms and assess their potential impact.

6.2.5 WIND RESUSPENSION

Figure 6-3 shows the off-site soil contamination contours reported by HASL in 1970 (2). Soil sampling programs in 1975 (8) showed that these contours had not changed significantly from the 1970 report. The highest off-site contour shown by the HASL data was 0.05 uCi/m^2. These contours were developed based upon an inventory sample to a depth of 20 centimeters. What is important in assessing the resuspension of soil, however, is only the material existing near the surface. Based upon the HASL soil depth profiles, Anspaugh (9) stated that approximately 20% of the total activity is contained within the first centimeter. Therefore, the highest contour value of 0.05 uCi/m^2 would correspond to 0.01 uCi/m2 when corrected for a 1 cm. depth. On a mass basis, 0.01 uCi/m2 is equivalent to approximately 2 disintegrations per minute per gram of soil, i.e., 2 DPM/gm. The offsite area bounded by this contour is approximately two square kilometers and soil within that area would be projected to be at or above 2 DPM/gm. Beyond this area, off-site soil will generally be below this value.

This review uses the mass loading approach as an indicator of the general resuspension by wind over large land areas. Because of technical shortcomings identified with the mass



ROCKY FLATS
PLUTONIUM—239 CONTOURS mCi/km^2

FIGURE 6-3

loading approach (10), the concept has been modified by an area correction factor to correct for small areas of contamination and with an enrichment factor to reflect a nonuniform distribution of radioactivity with soil particle size. This latter modification is particularly important because transuranium activity associated with soil particles within the respirable range is a greater hazard than it would be if associated with the larger particle sizes.

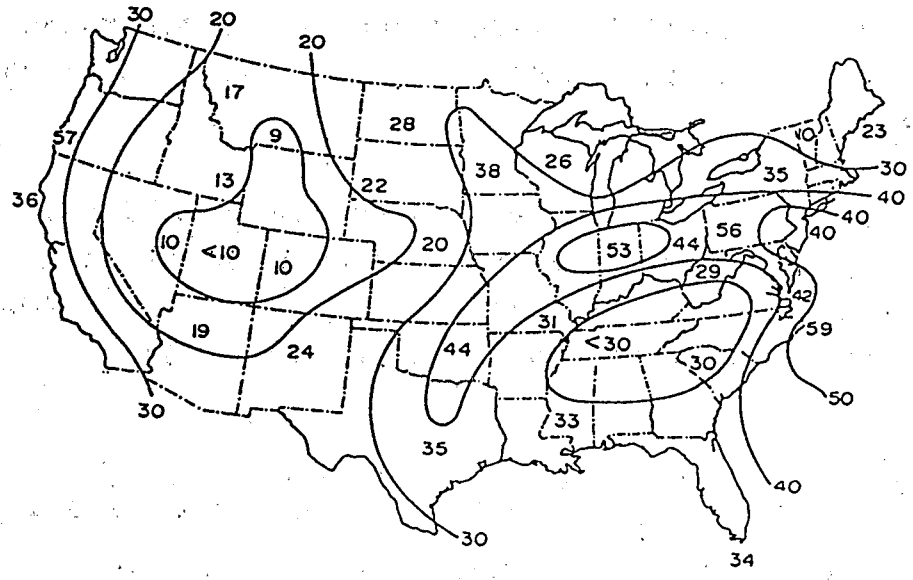
The mass loading approach assumes the loading of the air with particulates to be an index of resuspension and derives the airborne concentration of a specific radionuclide by a comparison with its concentration on the adjacent surface (11). Specifically,

$$\text{Air Concentration } (fCi/m^3) = \text{Soil Concentration } (uCi/m^2) \times \text{Mass Loading } (ug/m^3) \times \text{U.C.}$$

where U.C. is the units conversion factor based upon the depth of sampling and the soil density.

Airborne particulate mass loading is one of the criteria for clean air standards and measurements are widely available for urban and nonurban locations through the National Air Surveillance Network (NASN). The data recorded at nonurban stations are a better indicator of the levels of resuspended material than are urban measurements. In general, annual mean mass concentrations of airborne particulate material at the nonurban stations range from 5-50 micrograms per cubic meter (Figure 6-4); the mean arithmetic average for 1966 of all 30 nonurban NASN stations was 38 ug/m^3 (11). From Figure 6-4 an estimate can be made of the average mass loading for the general area in which Rocky Flats is located. It would appear that 15 ug/m is reasonably representative of this area on an annual basis.

Simple application of the mass loading approach without consideration of the activity distribution as a function of



ANNUAL MEAN MASS CONCENTRATIONS ($\mu g/m^3$) OF AIRBORNE PARTICLES FROM NON-URBAN STATIONS OF THE U.S. NATIONAL AIR SAMPLING NETWORK. 1964 - 1965

FIGURE 6-4

particle size is not appropriate, however, since that would imply a uniform distribution of activity with particle size as well as a uniform resuspension of all particle sizes. This has not been found to be the case at Rocky Flats (12) or at other plutonium contaminated sites (13).

In addition, an important consideration in assessing the potential exposure due to contaminated soil is the amount of activity associated with particles within the respirable size range. Johnson (14) has suggested that sampling of only those particles in a soil sample which are within the inhalable size range (generally < 10 μm) would give the best measure of risk to the public health around Rocky Flats. However, the weight fraction of particles in the less than 10 μm range is small in most soils, and sampling, separation, and analysis techniques are correspondingly more difficult and inaccurate. There is also considerable evidence that some of the larger particles really consist of aggregates and are relatively easily broken down into smaller ones, so that an instantaneous measurement of a single size range may not give a good picture of long-term trends. Also a substantial contribution to other possible pathways (e.g. ingestion) may be via larger particle sizes and measurement of the contribution of only the inhalable fraction would not provide all the information that is required.

6.2.5.1 ENRICHMENT FACTOR

The "Enrichment Factor" is intended to 1) give a mathematical view of the different fractions of the total radioactivity associated with particles of different size ranges, and 2) address the problem of the nonuniform resuspension of particle sizes.

The inhalable fraction of the soil is weighted by considering the relative distribution of activity and soil mass

as a function of particle size for representative samples of soil. To accomplish this, the sample of contaminated soil is segregated into "n" size increments and the activity and mass contained within each size increment is determined. The factor g_i is then defined as the ratio of the fraction of the total activity contained within an increment "i" to the fraction of the total mass contained within that increment. A value greater than 1 for g_i implies an enrichment of activity in relation to mass, while a value less than 1 indicates a dilution of the activity with respect to mass.

The nonuniform resuspension of particle sizes is also considered by measuring the mass loading as a function of particle size. The fraction of the airborne mass contained within each size increment "i" is then calculated and designated as f_i. The factors of f_i and g_i are then incorporated into the mass loading formulation for each size increment as follows:

$$\text{Air Conc}_i = \text{Air Mass Loading} \times f_i \times \text{Soil Conc} \times g_i$$

Summation over all the size increments results in the total air concentration:

$$\text{Air Conc} = \text{Air Mass Loading} \times \text{Soil Conc} \times \Sigma f_i g_i$$

The term $\Sigma f_i g_i$ weights the contribution of plutonium from each soil size fraction to the total resuspended material, thereby taking into account both the nonuniform resuspension of particles sizes as well as the nonhomogeneous distribution of activity with particle size.

Data on the distribution of plutonium with soil particle size has been obtained (12) for the vicinity around Rocky Flats (Table 6-5). The ratio, g_i has been calculated for each size increment and indicates an enrichment of activity to mass associated with soil particles within the respirable size range. To obtain f_i, the data obtained by Chepil (15) for fields

TABLE 6-5

EXPERIMENTAL DATA FOR WEIGHT AND ACTIVITY FRACTIONS
FOR SOILS IN THE ENVIRONS OF THE ROCKY FLATS PLANT
[Sampling and Analysis by US Environmental Protection Agency]

Sample	Size Increment (μm)	Wgt Fract	Act Fract	g_1	f_1	$\sum_i f_1 g_1$
RF 1A	2000-105	.62	.07	.12	-	
	105-10	.18	.40	2.21	.7	
	<10	.20	.53	2.65	.3	2.34
RF 1B	2000-105	.63	.39	.63	-	
	105-10	.17	.06	.34	.7	
	<10	.20	.55	2.74	.3	1.06
RF 1C	2000-105	.64	.43	.68	-	
	105-10	.16	.07	.46	.7	
	<10	.20	.49	2.47	.3	1.06
RF 2A	2000-105	.46	.13	.28	-	
	105-10	.34	.37	1.10	.7	
	<10	.20	.50	2.48	.3	1.51
					av.	1.49

undergoing wind erosion in Colorado and Kansas were used. The results of his findings have been conveniently plotted by Slinn (16) and reproduced as Figure 6-5. Comparison of Chepil's data with another study substantiates the applicability to the Rocky Flats situation. Chepil found 30% of the airborne mass to be below 10 μm versus a study by Willeke (17) in an area outside Denver where approximately 33% of the measured airborne mass was below 10 μm. Values for f_i used in this analysis are included in Table 6-5.

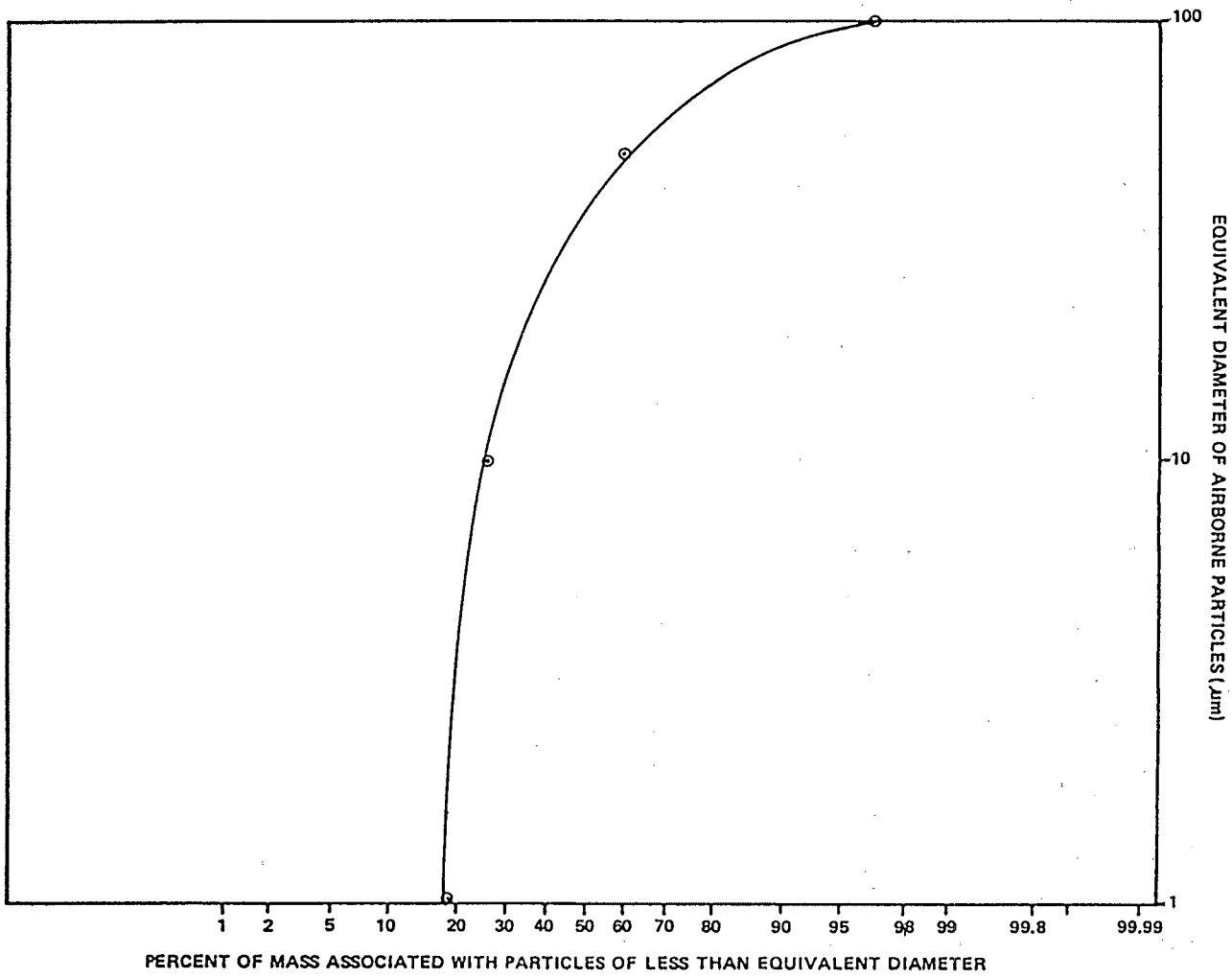
6.2.5.2 CORRECTION FOR AREA SIZE

Use of the mass loading approach implies that the air concentration is at equilibrium with the ground surface, i.e. , a steady state situation exists in which the amount of material coming up from the surface is balanced by the rate at which material is depositing back onto the surface. In the strictest sense this limit can only be achieved for source areas approaching infinite dimensions. For sources of finite dimensions, a correction must be applied for area size.

Although many techniques are presently under development to calculate the air concentration arising from an area source, no generally accepted method has yet been identified. Usually, these approaches make use of a standard diffusion equation, modified to handle area sources. One such equation is the Sutton-Chamberlain diffusion equation:

$$\frac{X}{Q_A} = \frac{1}{V_d} \left[\exp\left(-\frac{4\ V_d\ D_1^{n/2}}{\pi^{1/2}\ C_z\ n\ u}\right) - \exp\left(-\frac{4\ V_d\ D_2^{n/2}}{\pi^{1/2}\ C_z\ n\ u}\right)\right]$$

where X is the air concentration, Ci/m
Q is the amount of activity resuspended per unit area, per unit time, Ci/m^2 sec
V_d is the particle deposition velocity, m/sec
D_1 and D_2 are the distances from the receptor to the nearest and furthermost edges respectively of the source area
u is average wind speed, m/sec
C_z and n are Sutton parameters for meteorological conditions.



PARTICLE SIZE DISTRIBUTION OF RESUSPENDED SOIL

FIGURE 6-5

For source areas approaching infinite depth, $D_2 \rightarrow \infty$ and the above equation becomes

$$\frac{X}{Q_A} = \frac{1}{V_d}$$

Therefore, the correction term to be applied for areas of finite size is

$$1 - \exp\left(-\frac{4\ V_d\ D_2^{n/2}}{\pi^{1/2}\ C_z\ n\ u}\right)$$

The area under consideration in this analysis has been described earlier. It is bounded by Indiana Street and the 0.05 Ci/m^2 isopleth (Figure 6-3) with a width in the downwind direction of approximately 1 kilometer. This is the most highly contaminated off-site area and includes sites of projected residential development. The meteorology for the Rocky Flats area has been described (8) to have neutral stability at least 50% of the time with a mean wind speed of 4.2 m/sec in 1975. Healy (18) has suggested values for the parameters required for the situation of neutral stability: $C_z = 0.1$ and $n = 0.25$, while the ratio V_d/u, which depends upon the surface roughness, ranges between 0.003 and 0.008 for grassland. A value of 0.005 will be assumed. Therefore, the correction factor for the area under consideration is 0.66.

6.2.6 AVERAGE AIR CONCENTRATION DUE TO WIND RESUSPENSION

The average soil concentration for the area is not known, but it would be somewhere between 0.05 uCi/m^2 and the next higher isopleth of 0.5 uCi/m^2. For calculational purposes, 0.25 uCi/m^2 will be assumed or approximately 10 DPM/g (based upon 20% of the radioactivity within the first centimeter). By using the parameters developed in the previous sections for the Rocky Flats

area, one can estimate the average air concentration due to wind resuspension:

$$\text{Air Conc} = \text{Mass Loading} \times \text{Soil Conc} \times \text{Enrichment Factor} \times \text{Area Correction Factor}$$

$$\begin{aligned}\text{Air Concentration} &= 15\ \text{ug/m}^3 \times 10\ \text{DPM/g} \times 10^{-6}\ \text{g/ug} \\ &\quad \times \text{Ci}/2.22\text{x}10^{12}\ \text{DPM} \\ &= 0.066\ \text{fCi/m}^3\end{aligned}$$

This calculated value of 0.066 fCi/m agrees within a factor of 2 with the data obtained for the sampling stations along Indiana Street.

Inherent in the above calculation were some conservative assumptions. First of all, the wind was assumed to be blowing 100% of the time across the contaminated area in the direction of the receptor. In reality, the reported (8) wind rose for Rocky Flats indicates that the wind blows from the westerly direction only about 50% of the time; the remaining time it will be blowing from the direction of less contaminated land and, therefore, less radioactivity would be available for resuspension. Second, in deriving the area correction factor the effect of breathing height was ignored with the ground level concentration being calculated. This is a conservative assumption since the airborne concentration will decrease as a function of the height above the ground. Although such refinements may be incorporated in the calculation, the results represent a conservative approach to deriving the dose rates to potentially exposed persons.

6.2.7 RESUSPENSION OF SOIL BY MECHANICAL DISTURBANCES

The use of land contaminated with transuranium elements in the vicinity of Rocky Flats for agricultural or building purposes can result in localized resuspension and presents a potential inhalation hazard to individuals in the immediate vicinity of the

operation. In the vicinity of Rocky Flats, there is some farming of wheat and the raising of corn for livestock feed. Future development of the land for residential purposes is also being advocated. Although only a limited amount of experimental data are currently available to base an assessment of the inhalation hazard from such activities, some conclusions and recommendations can be made.

In assessing the agricultural situation, data obtained by Milham (19) have been utilized. In that study, a field contaminated with plutonium near the Savannah River Facility was subjected to various plowing and seeding activities associated with planting wheat. The increase in the airborne activity above that from normal wind resuspension was monitored at the location of the tractor operator and at the downwind edge of the field during the various activities. An average increase of a factor of 30 was observed in the level of resuspended plutonium at the location of the tractor operator and an increase of a factor of 5 at the edge of the field. Based upon these observations, the average air concentration for the year can be calculated for these two locations, assuming that the field is cultivated 30 days of the year for 8 hours per day. Again the area under consideration will be that area of highest off-site contamination described earlier with an average soil contamination level of 10 DPM/g. In the previous discussion of wind resuspension, this level of soil activity produced an air concentration of 0.066 fCi/m^3. From Milham's data, this activity level would increase to 2.0 fCi/m^3 at the location of the tractor operator and to 0.33 fCi/m^3 at the edge of the field during the agricultural operations. The annual average concentration at the tractor location is then:

$$2\ fCi/m^3 \times 8/24\ hr \times 30/360\ d + 0.33\ fCi/m^3 \times 330/360\ d + 0.066\ fCi/m^3 \times 16/24\ hr \times 30/360\ d = 0.07\ fCi/m^3$$

When these annual Pu-239 concentrations are compared to the value of 2.6 fCi/m^3 which was calculated by the PAID code to correspond with a dose rate of 1 mrad/year to the lung, one can conclude that agricultural operations in the area of Rocky Flats would produce activity levels well below levels of concern. In addition, after the first plowing cycle, the surface concentration should be diluted by mixing with soil from below the surface and subsequent plowings would produce air concentration lower than that of the first year.

One can also make projections for building activities based upon the agricultural situation examined above. There does not appear to be any reason why building activities, such as excavation and grading, should produce higher instantaneous air concentrations than those observed during agricultural plowing and, therefore, should not present a more restrictive situation.

6.2.8 RESUSPENSION OF DUST WITHIN THE HOME

The total amount of soil continuously in the home is not known but an assumption of 10 g/m^3 has been made (20). This amounts to about 3 lbs of soil in a modest 1500 square foot house. Because the floors are harder and smoother than outside surfaces, the resuspension from these surfaces will be higher. Resuspension factors of $10^{-6}/m$ have been used in the past to predict exposures in the work place and studies of PuO_2 deposited on indoor surfaces have been consistent with such a value (21).

The following exposure situation is postulated: the individual is exposed to contaminated dust in the home for 24 hrs/day, 7 days/week, for 70 years. The dust in the home has the same activity/gram as outside soil and has an areal distribution within the home of 10 g/m^2. The air concentration resulting from resuspended dust at 10 DPM/g would be:

$$10\ DPM/g \times Ci/2.22\times10^{12}\ DPM \times 10\ g/m^2 \times 10^{-6}/m = 0.045\ fCi/m^3$$

6.2.9 RESUSPENSION OF DUST FROM CONTAMINATED CLOTHING

Healy (18) has assumed that in a desert environment there will be 1 mg/cm (10 g/m^2) of dust on clothing. While it would certainly be less for nondesert environments, this value will also be assumed for Rocky Flats. Because of the proximity of the contamination to the nose and the mouth, a resuspension factor higher than the normal outdoor resuspension factor will be assumed. For this calculation, a value of $10^{-6}/m$ will be assumed to be sufficiently conservative. Therefore, the resultant air concentration is:

$$10\ g/m^2 \times 10\ DPM/g \times Ci/2.22\times10^{12}\ DPM \times 10^{-6}/m = 0.045\ fCi/m^3$$

6.3 INGESTION PATHWAY

Wastewater discharged from the Rocky Flats Plant as well as surface runoff from the Plant site is collected in a number of holding ponds where it is monitored for its radioactivity content before being discharged into either Walnut or Woman Creek. Walnut Creek empties into the Great Western Reservoir which provides part of the drinking water supply for the City of Broomfield, while Woman Creek eventually empties into Standley Lake which is a drinking water supply for the City of Westminster.

The Rocky Flats water monitoring program consists of 1) effluent monitoring of the water being discharged from the holding ponds into Walnut and Woman Creeks, 2) the monitoring of groundwater and 3) the monitoring of the regional water supplies. In monitoring public water supplies, samples are collected and analyzed from the drinking water reservoirs (Great Western and Standley Lake) as well as the finished water in several nearby communities. As with the air monitoring, the results of this sampling program are reported regularly to the responsible Federal, State, and local government agencies and published on a yearly basis. According to the 1975 published data (8)

the average concentrations of plutonium and americium in finished water for the region were $<0.027 \times 10^{-9}$ uCi/ml and $<0.032 \times 10^{-9}$ uCi/ml, respectively. The concentration levels of plutonium and americium in the drinking water of the various communities surrounding Rocky Flats are given in Table 6-6. Included in this table are results obtained by Poet and Martell (22) in 1970. Limited comparison of the two sets of data shows little change in the activity levels in the drinking water during this five year period.

6.3.1 BONE DOSE DUE TO INGESTION OF WATER

Assuming that the concentrations of Pu-239 and Am-241 in drinking water are those reported for the city of Broomfield (the highest concentrations reported for the more immediate surrounding communities) and that the consumption rate of water is 1.2 liters/day (ICRP Committee II) the annual water ingestion rates are:

<u>Pu-239, Annual Ingestion Rate</u>

0.04×10^{-9} uCi/ml x 1200 ml/day x 365 days/yr = 18 pCi/yr

<u>Am-241, Annual Ingestion Rate</u>

0.029×10^{-9} uCi/ml x 1200 ml/day x 365 days/yr = 13 pCi/yr

Conversion of the above ingestion rates into dose rates can be achieved through the use of Tables 6-7 and 6-8. Table 6-8 has been normalized to an ingestion rate of 1000 pCi/yr of various transuranium oxides and relates the years of ingestion to the resulting dose rate. Since plutonium and americium found in tap water would probably be in a chemical form other than the oxide, e.g. the hydroxide or some colloidal form, the solubility and, therefore, the transfer from the GI tract to the blood would be greater than for the oxide form. The factors for absorption from the gastro-intestinal tract as suggested in ICRP Publication 48, enhanced by an increased infant absorption factor of ten, have been used. Based upon these conversion factors, the bone

TABLE 6-6

PLUTONIUM AND AMERICIUM IN PUBLIC WATER SUPPLIES

Reservoirs	Number of Samples Taken	Plutonium Concentration ($x10^{-9}$) uCi/ml C minimum	C maximum	C average[b]
Great Western	36	<0.013	0.952	<0.099 ± 58%
Great Western[a]		.046	0.214	
Standley Lake	36	<0.013	0.142	<0.036 ± 23%
Finished Water				
Arvada	11	<0.005	0.019	<0.006 ± 50%
Boulder	12	<0.005	0.014	<0.007 ± 17%
Broomfield	39	<0.013	0.133	<0.041 ± 26%
Broomfield[a]			0.038	
Denver	11	<0.005	0.016	<0.008 ± 29%
Golden	11	<0.005	0.048	<0.009 ± 107%
Lafayette	12	<0.005	0.030	<0.007 ± 67%
Louisville	11	<0.005	0.012	<0.006 ± 21%
Thornton	12	<0.005	0.018	<0.009 ± 32%
Westminster	36	<0.013	0.210	<0.041 ± 31%
Average				<0.027 ± 49%

		Americium Concentration($x10^{-9}$) uCi/ml		
Great Western	38	<0.014	<0.090	<0.033 ± 20%
Standley Lake	37	<0.013	<0 090	<0.027 ± 19%
Finished Water				
Arvada	11	<0.001	0.239	<0.026 ± 180%
Boulder	11	<0.001	0.015	<0.006 ± 180%
Broomfield	37	<0.023	0.150	<0.029 ± 31%
Denver	11	<0.001	0.420	<0.043 ± 196%
Golden	11	<0.001	0.044	<0.009 ± 80%
Lafayette	12	<0.001	0.030	<0.007 ± 67%
Louisville	12	<0.001	0.400	<0.039 ± 185%
Thornton	12	<0.001	0.007	<0.005 ± 30%
Westminster	39	<0.013	0.079	<0.029 ± 18%
Average				<0.032 ± 25%

a Data of Poet and Martell (1970)
b Sample Average

TABLE 6-7

FACTORS FOR ABSORPTION FROM THE GASTRO-INTESTINAL TRACT FOR TRANSURANIUM ELEMENTS

Element/Chem Form		ICRP-30*	ICRP-48**
Pu-238	Oxide	10^{-5}	10^{-5}
	Nitrate	10^{-4}	10^{-4}
	Other	10^{-4}	10^{-3}
Pu-239	Oxide	10^{-5}	10^{-5}
	Nitrate	10^{-4}	10^{-4}
	Other	10^{-4}	10^{-3}
Am		5×10^{-4}	10^{-3}
Cm		5×10^{-4}	10^{-3}
Np		10^{-2}	10^{-3}

* ICRP-30 = occupational exposures

** ICRP-48 general population exposure (via food pathway)

for plutonium = 10^{-3}

for all other transuranium elements = 10^{-3}

children under one year = 10 x value for adults.

TABLE 6-8

ANNUAL DOSE RATE DUE TO CHRONIC INGESTION OF PLUTONIUM-239 OXIDE, AMERICIUM-241, PLUTONIUM-241, & CURIUM-244 (In Microrad/Year)

Annual Intake = 1000 pCi/Year

$f_1 = 10^{-3}$

Plutonium-239 Oxide

Duration of Ingestion (Years)	Bone: Red Marrow	Bone: Endosteal	Liver
1	7.6	1.1 E+2	24
5	36.5	5.0 E+2	116
10	71.2	9.8 E+2	220
15	102	1.4 E+3	320
20	136	1.9 E+3	410
30	204	2.8 E+3	560
40	254	3.5 E+3	690
50	314	4.3 E+3	810
70	407	5.6 E+3	980

Americium-241

Duration of Ingestion (Years)	Bone: Red Marrow	Bone: Endosteal	Liver
1	7.7	9.8 E+1	25
5	38	4.8 E+2	120
10	74	9.4 E+2	230
15	110	1.4 E+3	340
20	140	1.8 E+3	430
30	200	2.6 E+3	590
40	260	3.3 E+3	720
50	320	5.2 E+3	830
70	410	5.2 E+3	990

Plutonium-241/Americium-241

Duration of Ingestion (Years)	Bone: Red Marrow	Bone: Endosteal	Liver
1	0.006	0.08	0.02
5	0.14	1.8	0.45
10	0.51	6.5	1.6
15	1.0	13	3.1
20	1.7	22	4.9
30	3.2	41	8.7
40	4.9	62	12
50	6.5	82	16
70	9.4	119	21

Curium-244/Plutonium-240

Duration of Ingestion (Years)	Bone: Red Marrow	Bone: Endosteal	Liver
1	7.9	9.0 E+1	2.6 E+1
5	37	4.2 E+2	1.2 E+2
10	65	7.5 E+2	2.1 E+2
15	92	1.1 E+3	2.8 E+2
20	108	1.2 E+3	3.3 E+2
30	133	1.5 E+3	3.9 E+2
40	150	1.7 E+3	4.3 E+2
50	160	1.8 E+3	4.6 E+2
70	175	2.0 E+3	4.8 E+2

dose rate after 70 years of ingestion of drinking water would be 8.8×10^{-3} mrad/yr for Pu-239 and 6.2×10^{-3} mrad/yr from Am-241.

6.3.2 BONE DOSE DUE TO INGESTION OF FOODSTUFFS

At present limited agricultural production is carried out in the environs of Rocky Flats. Most of the food consumed locally is produced at considerable distances from the Rocky Flats Plant. Other than a few family garden plots, the only crops grown locally are wheat and alfalfa. A few cattle also are raised in the Plant vicinity. Since future residential development is projected for the Rocky Flats area, it would be reasonable to project a concurrent increase in family gardening. Therefore, an assessment has been carried out of the possible dose rates associated with the consumption of foodstuffs which might be produced locally. Because no food sampling data are presently available for the Rocky Flats area, estimates of the potential doses are based upon data developed in other areas contaminated with transuranium elements and from laboratory experiments of transuranium uptake by foodstuffs.

It is not expected that conditions at Rocky Flats would be such that they would invalidate the use of data developed in these other environments nor produce higher dose rate estimates. For purposes of this assessment, the ingestion rate of the transuranium elements by man is considered to be the product of the rates at which different contaminated materials are ingested and the concentration of the transuranium elements in each material.

To place these calculations into perspective, we have adopted the formulation of Martin and Bloom (23) which relates the ingestion rate H for a particular nuclide to the average

concentration of that nuclide in soil C_s through the following formulation:

$$H = C_s \times I_i \times D_i$$

where I_i is the ingestion rate of a particular item i and D_i is the discrimination ratio between that substance and soil.

This formulation makes for easy translation of environmental levels into dose rates and, thereby, direct comparison with appropriate guidance limits. The soil concentration used in this assessment is the same as that developed for the inhalation pathway calculations, i.e., 0.25 uCi/m^2 for Pu-239 and 0.045 uCi/m^2 for Am-241 (18% of Pu-239 levels at the time of maximum ingrowth). If as a result of plowing, this activity is evenly distributed throughout the top 20 cm, the average concentration, C_s in units of pCi/g would be:

$$0.25\ uCi/m^2 \times 10^6\ pCi/uCi \times cm^3/g \times 1/20\ cm \times m^2/10^4 cm^2$$
$$= 1.25\ pCi/g\ Pu\text{-}239$$
$$\text{and } 0.22\ pCi/g\ Am\text{-}241.$$

The materials considered to be produced on this land and consumed by individuals living in the area are: leafy vegetables, other food plants, cow milk, and beef. Also the casual and deliberate ingestion of contaminated soil will be considered.

Leafy Vegetables and Other Food Plants

Plants grown in soil containing the transuranium elements can become contaminated through uptake by the roots and systemic incorporation; in addition, the outer surfaces of the plant can have contaminated soil deposited upon them as a result of resuspension. Numerous studies have been conducted and several reviews (24, 25, 26) have been published covering the range of discrimination factors that have been observed in laboratory and field studies. Generally, the discrimination ratio for

incorporation of Pu-239 into the plant is between 10^{-4} and 10^{-6} on a fresh weight basis and 10^{-1} to 10^{-2} for deposition on the plant surface. In the case of americium-241, the internal incorporation may be as much as 50 times higher than plutonium due to its greater solubility. Generally, uptake factors for garden vegetables are at the upper end of the range, therefore, for calculational purposes a discrimination ratio of 10^{-4} will be assumed for internal deposition and 10^{-1} for external deposition when computing the intake of Pu-239, and a ratio of $5x10^{-3}$ for internal deposition and 10^{-1} for external deposition in the case of Am-241. Since the calculations are for food in a table-ready condition, decontamination of the food during processing must also be recognized. In doing so, the assumption of Bloom and Martin (23) will be employed; namely, 90% of the contamination is washed off leafy vegetables and 99% of the contamination is removed from other food plants during washing, peeling, etc. Likewise, the consumption rates of foodstuffs obtained by Martin and Bloom from the USDA have been utilized after conversion to a fresh weight basis (on the basis that vegetation is 70% water). Table 6-9 shows the resultant ingestion rates and discrimination ratios used in this assessment.

Equation 7 was used to convert the ingestion rates and discrimination factors of Table 6-9 into annual intakes of plutonium and americium. In carrying out the food pathway calculations, the assumption was made that 25% of the entire intake for an individual arises from foodstuffs produced locally on land contaminated with transuranium elements.

The resultant ingestion doses are given in Table 6-10. In converting the annual radionuclide intake to dose rates, Tables 6-7 and 6-8 were used with the following assumptions:

1. the duration of ingestion is 70 years,
2. externally deposited material is in the oxide form, with an absorption factor of 10^{-4},
3. material biologically incorporated in plants and

TABLE 6-9

FOOD INGESTION RATES AND RADIONUCLIDE DISCRIMINATION RATIOS

Substance	Ingestion Rate(g/day)	Discrimination Ratio	
Leafy Vegetables	270 [a]	Pu(ext)	10^{-1}x10%
		Pu(int)	10^{-4}
		Am(ext)	10^{-1}x10%
		Am(int)	$5x10^{-3}$
Other Vegetables	740	Pu(ext)	10^{-1}x1%
		Pu(int)	10^{-4}
		Am(ext)	10^{-1}x1%
		Am(int)	$5x10^{-3}$
Cow Milk	436 [b]	Pu	$3.17x10^{-8}$
		Am	$3.17x10^{-8}$
Beef Muscle	273	Pu	$3.29x10^{-5}$
		Am	$3.29x10^{-5}$
Beef Liver	13	Pu	$2.0x10^{-3}$
		Am	$2.0x10^{-3}$
Soil (casual)	0.01	Pu	1.0
		Am	1.0
Soil (deliberate)	20	Pu	1.0
		Am	1.0

a. assumes vegetation is 70% water

b. assumes retention and transport within cow is the same for Pu and Am

TABLE 6-10

ESTIMATED COMMITTED DOSES (70th Year) TO RED BONE MARROW OF CRITICAL GROUP NEAR THE ROCKY FLATS PLANT

Substance	Radionuclide	Ingestion Rates (pCi/yr)	70th Year Bone Dose Rate (mrad/yr)
Drinking Water	Pu	18	0.008
	Am	13	.006
Leafy Vegetables	Pu (ext.)	297	.014
	Pu (int.)	3	.071
	Am (ext.)	53	.026
	Am (int.)	27	.067
Other Vegetables	Pu (ext.)	82	.004
	Pu (int.)	9	.020
	Am (ext.)	15	.007
	Am (int.)	74	.018
Cow Milk	Pu	1.60×10^{-3}	$.40 \times 10^{-5}$
	Am	$.28 \times 10^{-3}$	$.67 \times 10^{-6}$
Beef Muscle	Pu	1.02	.0025
	Am	1.85×10^{-1}	.0003
Beef Liver	Pu	2.96	.0071
	Am	5.33×10^{-1}	.0013
Soil (casual)	Pu	18.0	.0009
	Am	3.2	.0016
(deliberate)	Pu	3.24×10^{4}	.14
	Am	5.84×10^{3}	.26

Total (without Pica) = 0.25 mrad/yr
(with Pica) = 0.65 mrad/yr

animals is assumed to have a greater fraction transferred from the G.I. tract to the blood. For plutonium, this results in an increase by a factor of 5 in the bone dose for both plutonium and americium.

Ingestion of Cow Milk

Martin and Bloom have developed a discrimination factor for dairy cows of 3.2×10^{-8} based upon assumptions of soil and vegetation consumption by cattle. Using this value and again assuming that 25% of the diet is locally produced, one can calculate the ingestion rates of Pu-239 and Am-241 as a result of milk consumption:

$$\begin{aligned} H\ (\text{Pu-239}) &= C_s \times I \times D \\ &= 1.25\ \text{pCi/g} \times 436\ \text{g/day} \times 365\ \text{days} \times 3.2 \times 10^{-8} \\ &= 1.6 \times 10^{-3}\ \text{pCi/yr} \end{aligned}$$

$$\begin{aligned} H\ (\text{Am-241}) &= 0.18\ H\ (\text{Pu-239}) \\ &= 0.28 \times 10^{-3}\ \text{pCi/yr} \end{aligned}$$

Since these transuranium elements would be biologically incorporated, an increased absorption by a factor of five has been assumed. The resultant bone doses attributable to the consumption of milk are shown in Table 6-9.

Ingestion of Beef

Martin and Bloom developed discrimination factors for beef muscle and beef liver and these have been utilized in the

following calculations of ingestion rates:

Beef Muscle

$$H\ (Pu\text{-}239) = C_s \times I \times D$$

$$= 1.25\ pCi/g \times 273\ g/day \times 0.25 \times 365\ d/yr \times 3.3\times10^{-5}$$

$$= 1.02\ pCi/yr$$

$$H\ (Am\text{-}241) = 0.18 \times H\ (Pu\text{-}239)$$

$$= 1.85\times10^{-1}\ pCi/yr$$

Beef Liver

$$H\ (Pu\text{-}239) = 1.25\ pCi/g \times 13\ g/day \times 0.25 \times 365\ d/yr \times 2\times10^{-3}$$

$$= 2.96\ pCi/yr$$

$$H\ (Am\text{-}241) = 5.33\times10^{-1}\ pCi/yr$$

Bone Dose due to Soil Ingestion

Casual Ingestion

Bloom and Martin (23) have assumed a casual ingestion rate for a desert environment to be approximately 3-4 g/year. Likewise, Rogers (20) has estimated the accidental ingestion rate of soil as a result of hand to mouth transfer to be 3-4 g/yr. Based upon these estimates, one can calculate the plutonium and americium ingestion and resulting dose rates. The ingestion period is assumed to be 70 years and the surface soil concentration of Pu-239 is assumed similar to that for unplowed,

undiluted soil in the vicinity of Indiana Street; i.e., 10 DPM/g (4.5 pCi/g). The americium concentration is assumed to be at its maximum contribution of 18% or 0.8 pCi/g. The resulting bone doses have been calculated assuming the transuranium elements are in the relatively insoluble oxide form with an absorption factor of 10^{-5}.

Deliberate Ingestion (Pica)

Healy (27) has addressed the problem of deliberate soil ingestion by children below the age of five. After reviewing the limited available data on the topic, he concluded that a deliberate soil ingestion rate of 20 g/day would be a reasonably severe case. Applying this estimate to the Rocky Flats situation would produce the following ingestion rates for deliberate soil ingestion:

$$H\ (\text{Pu-239}) = C_s \times I \times D$$
$$= 4.5\ \text{pCi/g} \times 20\ \text{g/day} \times 365\ \text{days/yr}$$
$$= 3.24\text{x}10^4\ \text{pCi/yr}$$

$$H\ (\text{Am-241}) = 5.84\text{x}10^3\ \text{pCi/yr}$$

Since this condition of excessive soil ingestion would occur over a relatively few years, the resultant dose rates are calculated assuming the period of ingestion to be 5 years. The results are included in Table 6-10.

REFERENCES

1. H. Volchok, M. Schonberg, and L. Toonkel, Pu-239 Concentration in Air Near Rocky Flats, Colorado, HASL-315, Health and Safety Laboratory, USEFDA (1977).

2. P. W. Krey and [. P. Hardy, Plutonium in Soil Around the Rocky Flats Plant, HASL-235, Health and Safety Laboratory, USERDA (1970).

3. Task Group on Lung Dynamics, Health Physics, 12, p173 (1966).

4. H. Volchok, R. Knuth, and N. Kleinman, "The Respirable Fraction of Plutonium at Rocky Flats," Health Physics, 23, p395 (1972).

5. G. A. Sehmel, Airborne ^{238}Pu and ^{239}Pu Associated with the Larger than Respirable Resuspended Particles at Rocky Flats During July 1973, BNWL- 2119, Battelle Pacific Northwest Laboratories (1976).

6. USEPA PAID Code to be published.

7. P. Krey et al., Plutonium and Americium Contamination in Rocky Flats Soil, 1973, HASL-304, Health and Safety Laboratory, USERDA (1976).

8. Environmental Monitoring at Major USERDA Contractor Sites for 1975, ERDA-76-104, Vol. 1, USERDA, Washington, D.C. (1976).

9. L. R. Anspaugh, L. H. Shinn, P. L. Phelps, and N. C. Kennedy, "Resuspension and Redistribution of Plutonium in Soils," Health Physics, 29, p571 (1975).

10. Proposed Guidance on Dose Limits for Persons Exposed to Transuranium Elements in the General Environment, USEPA, Washington, D.C. (September 1977).

11. L. R. Anspaugh, "The Use of NTS Data and Experience to Predict Air Concentrations of Plutonium Due to Resuspension on the Enewetak Atoll," The Dynamics of Plutonium in Desert Environment, NV0-14,, p299 (1974)

12. D. E. Bernhardt, "Resuspension of Plutonium; Particle Size Distribution in Soil," in Evaluation of Sampling and Collection Techniques for Environmental Plutonium, ORP/LV-76-5, LSEPA (1976).

13. T. Tamura, "Physical and Chemical Characteristics of Plutonium inExisting Contaminated Soils and Sediments," in Proceedings of the International Symposium on Transuranium Nuclides in the Environment (Nov. 1975), IAEA, Vienna.

14. C. J. Johnson, R. R. Tidball and R. C. Severson, "Plutonium Hazard in Respirable Dust on the Surface of Soil," Science, 193, p488 (1976).

15. W. S. Chepil, "Sedimentary Chacteristics of Dust Storms: III Composition of Suspended Dust," Am. J. Sci. , 225, p206 (1957)

16. W. G. Slinn, "Dry Deposition and Resuspension of Aerosol Particles-A New Look at Some Old Problems," in Atmospheric-Surface Exchange of Particulate and Gaseous Pollutants, CONF 740-921, ERDA, Washington, D.C. (1974).

17. K. Willeke, R. Whitby, W. Clark, and V. Mayle," Size Distribution of Denver Aerosols - A Comparison of Two Sites," Atm. Env., 8, p609 (1974).

18. J. W. Healy, A Proposed Interim Standard for Plutonium in Soil, LA 5483-MS, Los Alamos Scientific Laboratory (1974).

19. R. C. Milham, J. F. Schubert, J. R. Watts, A. L, Boni, and J. C. Corey, "Measured Plutonium Resuspension and Resulting Dose from Agricultural Operations on an Old Field at the Savannah River Plant in the Southeastern U.S.," in Proceedings of the International Symposium on Transuranium Nuclides in the Environment, (Nov. 1975), IAEA, Vienna.

20. D. R. Rogers, Mound Laboratory Environmental Plutonium Study 1974, MM2249, Mound Laboratory (1975).

21. J. S. Jones and S. F. Pond, "Some Experiments to Determine the Resuspension Factor of Plutonium from Various Surfaces," Surface Contamination, B. R. Fish (ed.) , Pergamon Press, New York, NY (1964), p83.

22. S. E. Poet and E. A. Martell, "Plutonium-239 and Americium-241 Contamination in the Denver Area, I I Health Physics, 23, p537 (1972)

23. W. E. Martin and S. G. Bloom, "Plutonium Transport and Dose Estimation Model," in Proceedings of the International Symposium on Transuranium Nuclides in the Environment, (Nov. 1975), IAEA, Vienna.

24. D. E. Bernhardt, and G. G. Eadie, Parameters for Estimating the Uptake of Transuranic Elements by Terrestrial Plants, ORP/LV-76- 2, USEPA (1976).

25. R. L. Thomas and J. W. Healy, An Appraisal of Available Information on Uptake by Plants of Transplutonium Elements and Neptunium, LA-6460-MS, Los Alamos Scientific Laboratory (1976).

26. R. A. Bulman, Concentration of Actinides in the Food Chain, NRPB-R44, Harwell (1976).

27. J. W. Healy, An Examination of the Pathways from Soil to Man for Plutonium, LA-6741-MS, Los Alamos Scientific Laboratory (1977).

7. PLANNING AND CONDUCT OF CLEANUP OF ENEWETAK ATOLL

(This Chapter was prepared, in part, by the staff of the Department of Energy and is included to provide a historical perspective on the implementation of a major remedial action)

Enewetak Atoll is located in the Marshall Islands and was part of the Pacific Proving Ground. Forty-three nuclear devices were detonated by the United States at this atoll from 1948 to 1958. The decision in 1972 to return the Enewetak people to their home atoll necessitated the removal of contaminated debris and soil from numerous islands. The experience of planning and conducting the Enewetak Cleanup Project, particularly that part related to removal and disposal of transuranium element contaminated soil, provides a valuable lesson in the practical aspects of developing and applying radiation protection criteria in a remote and complex environment.

Radiological cleanup and resettlement of Enewetak Atoll was a cooperative effort by the Department of Defense (DOD), the former Atomic Energy Commission (AEC) and current Department of Energy (DOE), and the Department of the Interior (DOI). These agencies had previously cooperated in cleanup of Bikini Atoll. Under a Memorandum of Understanding for Bikini Atoll, DOD performed the cleanup, AEC was responsible for radiological safety aspects of cleanup, and DOI performed agricultural rehabilitation and resettlement of people. Responsibilities of these agencies were essentially the same for Enewetak. The major difference between these two cleanup projects, a difference which greatly increased the difficulties in planning and conducting the Enewetak cleanup, was that at Enewetak there were significant island areas requiring cleanup of transuranium element contamination in soil. The cleanup of Enewetak Atoll represents the most recent experience in restoring a large area contaminated by transuranium elements.

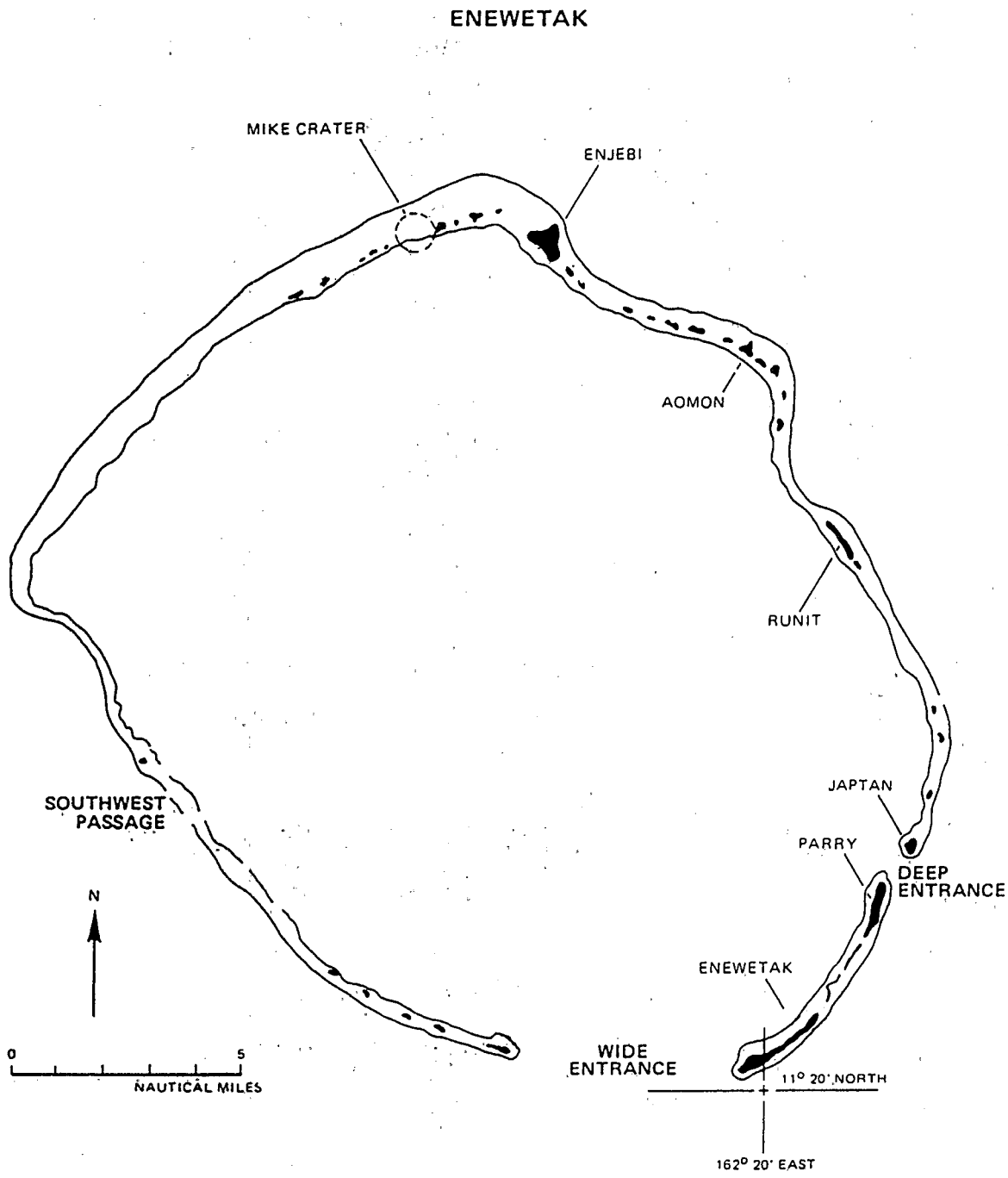
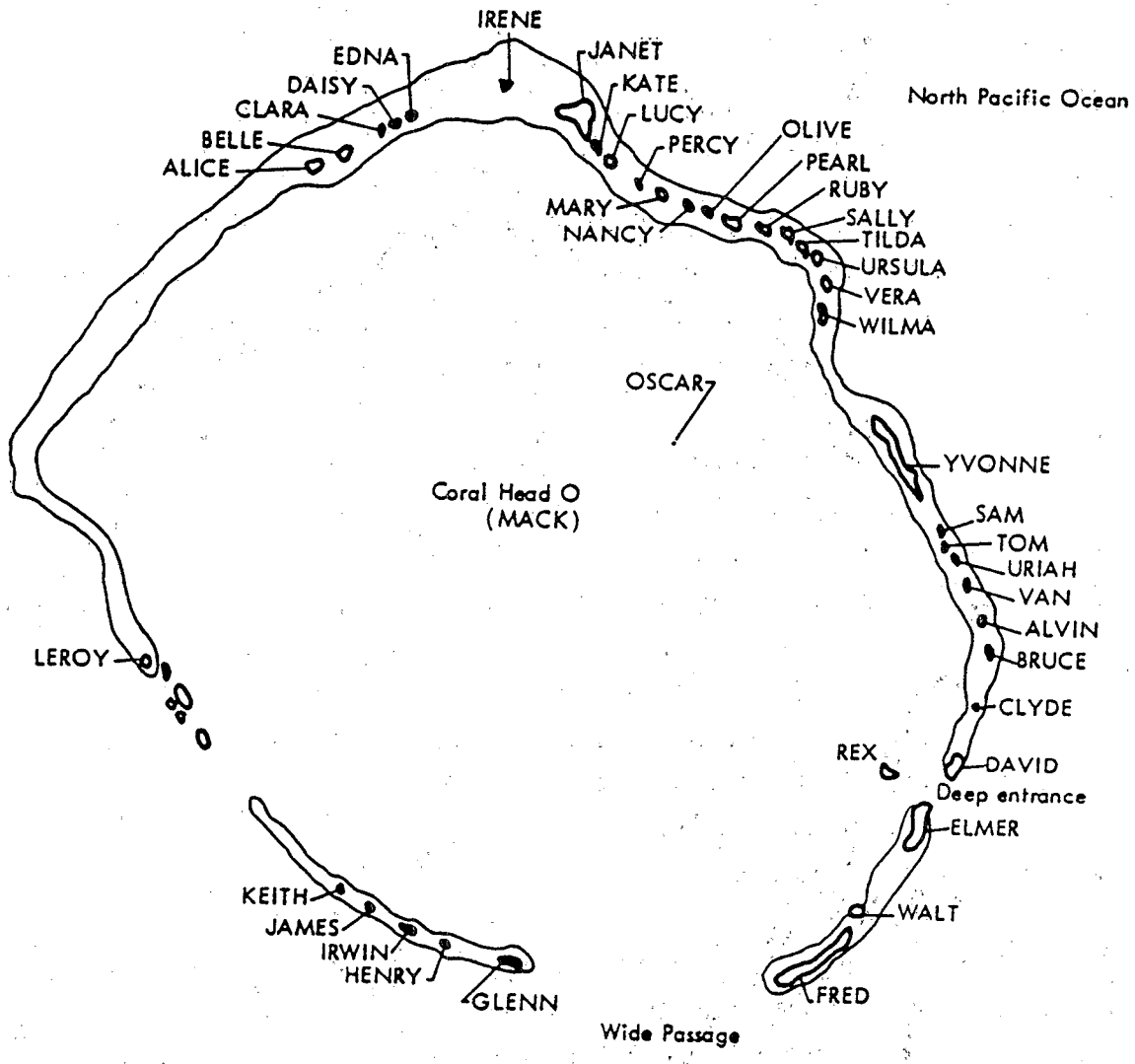

ENEWETAK
MIKE CRATER
ENJEBI
AOMON
RUNIT
JAPTAN
PARRY
DEEP ENTRANCE
SOUTHWEST PASSAGE
N
0
5
NAUTICAL MILES
ENEWETAK
WIDE ENTRANCE
11° 20' NORTH
162° 20' EAST

FIGURE 7-1



Map of Enewetak Atoll

(U.S. Name Designation)

FIGURE 7-2

A map of the Enewetak Atoll, with designation of the principal islands, is shown in Figures 7-1 and 7-2. Transuranium element contamination in soil and other environmental media on Enewetak prior to cleanup is summarized in Tables 7-1 and 7-2. A diagram showing the sequence of events related to the important decisions, judgments, advice, and agreements that were critical to Enewetak radiological cleanup is given in Figure 7-3. The diagram shows the major elements of the remedial action program from the decision in 1972 to return the islands in habitable condition to completion of field operations in 1980.

The AEC performed the necessary baseline radiological surveys in early 1973, and developed dose assessments for a series of assumed resettlement patterns. In July 1973, the AEC appointed a Task Group to prepare cleanup radiological criteria and recommendations. The approach adopted by the AEC Task Group, in development of radiological safety criteria for use in planning cleanup and rehabilitation, involved a conservative application of national and international radiation protection standards for individuals in the population expected to receive the highest radiation exposures.

For planning purposes, the Task Group recommended that the annual dose rate of individuals from exposure to fission products be limited to 50 percent of the then existing Federal Radiation Council standards for annual exposure of individuals, and 80 percent of the 30-year standard for a population. Of concern in the implementation of these criteria was the uncertainty inherent in predicting dose for returning inhabitants. The types and amounts of locally grown food that would be eaten, and the degree to which the inhabitants would comply with restrictions on land and food use, were among the factors contributing to this uncertainty.

TABLE 7-1

PLUTONIUM CONCENTRATIONS IN SOIL ON ENEWETAK ATOLL (PRIOR TO CLEANUP)

Island		Pu-239 in top 15 cm of soil Mean (pCi/g)[b]	Range (pCi/g)
Alice		12	4-68
Belle	dense[a]	26	7-130
	light[a]	11	6-26
Clara		22	4-88
Daisy	dense	41	22-98
	light	15	4-33
Edna		18	13-24
Irene		11	2-280
Janet		9	0.08-170
Kate	dense	17	9-50
	light	2	0.2-14
Lucy		8	2-22
Mary		8	2-5
Nancy		9	2-28
Percy		4	2-23
Olive	dense	8	2-30
	light	3	2-4
Pearl	hot spot	51	15-530
	remainder	11	1-100
Ruby		7	3-24
Sally		4	0.2-130
Tilda	dense	8	1-17
	light	3	1-34
Ursula		1	0.3-7
Vera		3	0.6-25
Wilma		1	0.1-5
Yvonne	southern	3.2	0.02-50
	northern beaches	3	0.3-18
David, Elmer, Fred		0.04	0.004-0.3
Leroy		0.6	0.02-2
All others		0.07	0.004-1.1

a. "dense" and "light" refer to vegetation cover

b. 1 pCi/g in the top 15 cm of soil is approximately equivalent to 0.23 $\mu Ci/m^2$ or 0.045 $\mu Ci/m^2$ if only the top 1 cm of soil is considered and 20% of the total activity is assumed to be in the top 1 cm of soil.

TABLE 7-2

PLUTONIUM AND AMERICIUM CONCENTRATIONS
IN VARIOUS ENVIRONMENTAL MEDIA ON ENEWETAK ATOLL
(PRIOR TO CLEANUP)

Media	Location	Radionuclide	Activity
Sediments	Lagoon	Pu-239	460 mCi/km^2
		Am-241	170 mCi/km^2
Surface Waters	Lagoon	Pu-239	9-40 fCi/ℓ
	Ocean (East)	Pu-239	0.3 fCi/ℓ
Coconuts	As Found	Pu-239	< 0.022 pCi/g[a]
Birds	As Found	Pu-239	
Muscle			0.001-0.1 pCi/g[a]
Liver			0.004-0.07 pCi/g[a]
Eggs			0.0005-0.02 pCi/g[a]
Coconut Crabs	As Found	Pu-239	0.001-0.01 pCi/g[a]

(a) dry weight

Table 7-4 shows the cleanup planning criteria recommended by the Task Group. It was recognized that the levels of fission products in soil (predominantly Cesium-137 and Strontium-90 with half-lives of about 30 years) on some of the northern islands at Enewetak Atoll could preclude their immediate use as village islands without removal of a significant portion of the soil of these islands. The levels of fission product contamination would be reduced through radiological decay by about 50 percent every 30 years. Removal of the top layer of soil, sufficient to make a significant reduction in fission product concentration, would remove much of the organic material and destroy the usefulness of such islands for agriculture. Temporary restrictions on land use were considered a preferred alternative to soil removal for such islands. The Task Group also considered the possibility of using health risk estimates in the development of cleanup criteria. The position taken on this approach is stated below:

> "The Task Group and its technical advisors have reviewed the available information from ICRP, UNSCEAR, and the National Academy of Sciences BEIR Committee that could be used to estimate the health risk that may be associated with long-term exposures at the level of the radiation dose and soil removal criteria being recommended. It is clear from this review that knowledge of the relationship between radiation dose and effects of that dose on man as characterized in dose-effect curves is incomplete even for external radiation exposures. For internal emitters and particularly for plutonium, the situation is even less satisfactory. Using a linear dose-effect curve, exposure at the level of the recommended criterion of 0.25 rem/y would give 2.2×10^2 cases (of cancer) per year. The Task Group views this as a pessimistic upper limit of risk. It could be inferred that there may be between zero and three cases of cancer in 100 years if the entire Enewetak population were continuously exposed to 0.25 rem/y over that time period. A lack of confidence in the statistics and risk

FIGURE 7-3

ENEWETAK ATOLL CLEANUP — SEQUENCE OF EVENTS

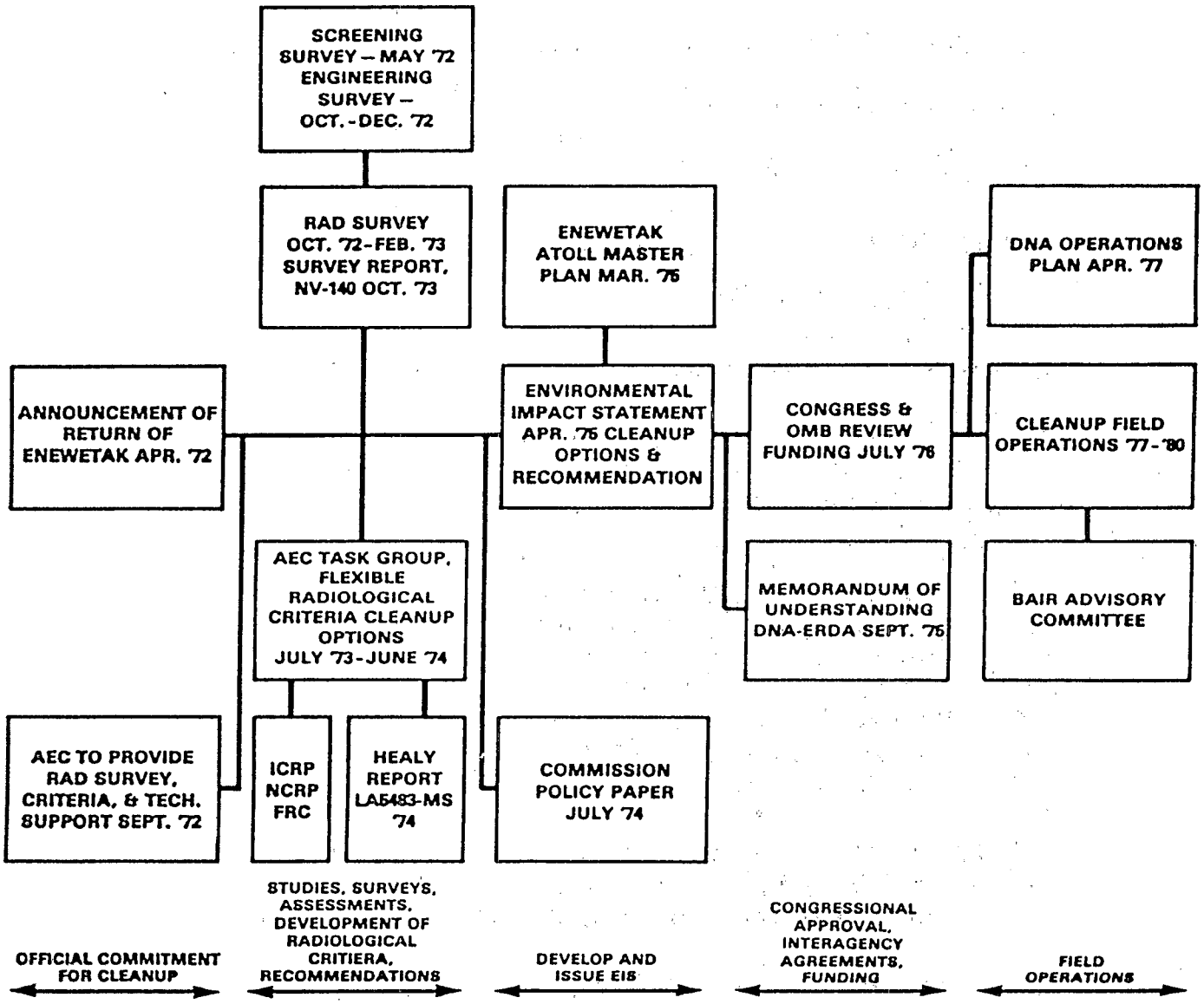


TABLE 7-3

TASK GROUP CONCLUSIONS

- Cleanup and Rehabilitation of Enewetak Atoll is Feasible
- Doses from Fission Products will Predominate
- The Degree of Cleanup of the Atoll Should be Dictated by the Requirement to Keep Exposure within Acceptable Standards
- National and International Standards Apply
- A Fraction of FRC's, RPG's for Individuals Should be Utilized to Evaluate Cleanup and Land Use Options Involving Fission Product Doses
- A Fraction of ICRP Standards for Lung for Individuals Should be Utilized to Develop Flexible Soil Cleanup Criteria Expressed as a Concentration of TRU Elements in Soil, i.e., pCi/gm*
- A Group of Experts Should Support Cleanup Operations with Advice on Application of Task Group Criteria to Specific Situations
- Land Use Restrictions, as Opposed to Soil Removal, are the Recommended Method for Controlling Exposure from Fission Products
- Removal and Disposal of Soil, or a Permanent Quarantive, are the Only Effective Measure Against Soil TRU Concentrations Exceeding Task Group Criteria

*The Task Group believed that site-specific criteria could be developed on a case-by-case basis using conservative assumptions and a safety factor, but that biological and environmental information is not adequate to establish general cleanup guidance.

TABLE 7-4

DEVELOPMENT OF CLEANUP CRITERIA

1974 TASK GROUP REPORT

DOSE BASED ON FEDERAL RADIATION COUNCIL LIMITS
— TO INDIVIDUALS, 50 PERCENT OF FRC ANNUAL RATE LIMIT
— TO POPULATION, 80 PERCENT OF FRC 30-YEAR GENETIC LIMIT

RESULTING GUIDANCE APPLICABLE TO PLUTONIUM CONCENTRATION IN SOIL:
— OVER 400 pCi/g, REMOVE SOIL
— UNDER 40 pCi/g, LEAVE IN PLACE
— BETWEEN 40 AND 400, CASE-BY-CASE DECISION

1977 SERIES OF FALL MEETINGS BETWEEN DOE AND DNA

— CRITERIA TO INCLUDE ALL TRANSURANICS, NOT JUST PLUTONIUM
— CLEANUP CRITERIA LINKED TO INTENDED ISLAND USE
— AGRICULTURAL ISLAND TO MEET CRITERIA OF 100 pCi/g
— CRITERIA INTENDED TO COMPLY WITH EPA PROPOSED GUIDELINES

1978 SERIES OF SPRING MEETINGS BETWEEN DOE AND DNA

PRELIMINARY DOSE ESTIMATES BY LLL INDICATED CLEANUP SHOULD BE ACCOMPLISHED TO THE FOLLOWING LEVELS TO MEET PROPOSED EPA CRITERIA:

— RESIDENCE ISLAND	10 pCi/g
— AGRICULTURAL ISLAND	20 pCi/g
— FOOD GATHERING ISLAND	40 pCi/g

1978 BAIR COMMITTEE RECOMMENDATIONS:

1st PRIORITY - CLEANUP TRANSURANICS ON RESIDENTIAL ISLANDS TO AVERAGE LESS THAN 40 pCi/g FOR EACH QUARTER-HECTARE AREA

2nd PRIORITY - CLEAN TRANSURANICS ON AGRICULTURAL ISLANDS TO AVERAGE LESS THAN 80 pCi/g FOR EACH HALF-HECTARE AREA

3rd PRIORITY - CLEAN TRANSURANICS ON FOOD GATHERING ISLANDS TO AVERAGE LESS THAN 160 pCi/g FOR EACH HALF-HECTARE AREA

estimate drawn therefrom has led the Task Group to have serious reservations about their validity. The Task Group holds the opinion that such estimates cannot be used in any definitive way to draw conclusions on whether current radiation standards are too high or too low or as a basis for decisionmaking relative to resettlement of Enewetak Atoll."

Soil contamination levels for the transuranium elements at Enewetak would not be reduced appreciably with time due to the long half life for Plutonium-239 (about 26,000 years). There appeared to be only two options for an island with unacceptably high soil concentrations of transuranium elements, namely, 1)*remove the contaminated soil or 2) place the island off limits. The Task Group treated transuranium element soil contamination as a separate problem.

Plutonium contamination in soil and the need for Federal standards for remedial actions were subject of considerable interest in the early 1970's. The Environmental Protection Agency was evaluating the need for standards or guides. There was Congressional interest, and the Enewetak people, through their legal counsel, were supporting "total" cleanup.

The Task Group favored use of conservative criteria for transuranium element contamination that could be related to a dose standard but expressed in terms of an environmental measurement that can be made in the field. The Task Group recommended a soil concentration below which cleanup was not required, a soil concentration above which cleanup was mandatory, and a range of soil concentrations between these two values where corrective actions should be determined on a case by case basis by a team of experts assembled for this purpose. The soil concentration value above which cleanup would be mandatory was taken from a LASL report which developed a relationship between soil concentration of a mixture of transuranium elements typical

of nuclear weapons and dose to lung through resuspension and inhalation. A soil concentration of 400 pCi/g (the level at which cleanup is mandatory) was estimated to be equivalent to the ICRP standard for lung dose for individuals, i.e., 1,500 mrem/y. The soil concentration value below which cleanup would not be required was arbitrarily set at one-tenth of 400 pCi/g, or 40 pCi/g.

The Task Group recommendations on soil concentrations were very general and did not specify details such as the degree of cleanup required for various land use options and the area over which soil radioactivity concentrations were to be averaged for each type of island. These issues were addressed later by the Bair Committee, a group of technical advisors to the cleanup operation, headed by Dr. William J. Bair, of the Pacific Northwest Laboratory, in the process of providing more detailed advice on cleanup in the range of soil concentrations between 40 and 400 pCi/g. Other issues, such as monitoring instruments and soil sampling-techniques, quality control, and statistical methods were also addressed later.

One of the key items in the task group's deliberation was the consideration of cleanup and rehabilitation options. The task group evaluated dose for a five by six matrix of cleanup levels and food production locations versus living patterns, and five options for cleanup of transuranium contaminated soil ranging from no cleanup to extensive soil removal. Six options for disposal of contaminated soil were also evaluated. The task group made recommendations on preferred options. The various options were presented in an Environmental Impact Statement developed by the Defense Nuclear Agency.

Preparation of an Environmental Impact Statement for Cleanup of Enewetak was an important part of planning this project, as were final agreements between agencies on responsibilities, funding, and staffing of the field organization that would

perform the cleanup. These agreements and final plans were documented and formally approved in a Memorandum of Understanding and in an Operation Plan. Since the cleanup criteria for soil and their implementation at Enewetak determined how much soil was to be removed for disposal, and to some extent the size of the task group and the time required, these criteria in large measure determined the cost of soil cleanup, a subject of considerable interest to those conducting and supporting cleanup. This relationship to cost generated a continuing requirement to explain and defend such criteria and to adapt them to unusual circumstances throughout the cleanup project.

Cleanup of contaminated soil was an iterative process. A typical sequence of events was as follows:

1. The history of use of the island plus information from recent radiological surveys, including information on any subsurface contamination, was reviewed.

2. Heavy vegetation was either removed or access lanes were cut.

3. A grid was established marked by wooden stakes bearing geographic coordinates of the locations. Maximum spacing of grid lines was 100 meters. In many places a closer spacing was used.

4. An in-situ survey of Am-241 in surface soil was performed using the grid points described previously. Measurements were reviewed by statisticians and recorded in a data base.

5. Soil samples were collected at locations devised by the statisticians. These samples were analyzed to determined the ratio of Pu-239 (and other transuranium elements) to Am-241. The analysis of this soil was performed in a

chemistry laboratory established for this purpose on Enewetak Island.

6. Using the in-situ data for Am-241, and the soil analysis data, the concentrations of transuranium elements in surface soil were determined. These concentrations, plotted on a map along with the cleanup criteria, were used to determined locations where soil removal was needed.

7. Bulldozers and front-end loaders were used to remove the contaminated soil. A 6-inch layer was usually removed. Some amount of crosscontamination of the new surface was unavoidable. The contaminated soil was hauled away for disposal on Runit Island.

8. After removal of soil, the area of cleanup was again monitored. If the new surface met the cleanup criteria, no further soil removal was needed. If the new surface was still above the criteria, more soil was removed. This process continued until the criteria were met. The deeper excavations were filled with clean soil.

9. The contaminated soil was pumped as a soil-cement slurry through a pipe to the bottom of a water filled bomb crater on Runit Island, displacing the water. The crater was filled with the soil-cement mixture plus other contaminated debris collected throughout the atoll. The soil-cement was mounded above the surface of the island and capped with 18 inches of concrete. When cleanup operations were completed, Runit Island was placed "Off Limits" and is to remain quarantined indefinitely.

Cleanup operations covered 81 acres on six island and 104,000 cubic yards of contaminated soil were removed. The total cost of the cleanup and rehabilitation effort was about $100

TABLE 7-5

RISK OF RADIATION-INDUCED CANCER DEATH AT ENEWETAK

NUMBER RESIDENTS, AVERAGE/YEAR, 30 YEARS	500
ADDITIONAL RADIATION-INDUCED CANCER DEATHS, 30 YEARS	0.026
ADDITIONAL CANCER DEATHS PER YEAR, PER 500 RESIDENTS	0.0009
RATE PER 1,000,000	1.7
APPROXIMATE RISK TO FUTURE RESIDENTS	1.7×10^{-6}

million and required an on-atoll task force of about 1,000 people for 3 years.

The task force was monitored continuously for radiological contamination. Personnel were exposed to radiation and to industrial hazards. Monitoring for intake of radioactivity was done by the collection and analysis of 24-hour urine samples. For more than 2,000 samples, only 6 had readings above the minimum detectable level. For external whole body radiation, where there were more than 12,000 individual records, only four exceeded 0.050 rem. The highest was 0.070 rem. There were 63 lost-time accidents and 4 work-related fatalities for a population of approximately 1,000 persons in the atoll at any one time over a period of 3 years.

The cleanup operation resulted in restoration of islands in the southern part of the atoll for full and unrestricted use, and in cleanup of transuranium contaminated soil on the northern islands. Soil concentrations of radionuclides were determined and projected doses to individuals were calculated. A range of living and dietary patterns were considered including the case of total dependence on the local food supply. Whole body doses for those resettled in the southern islands range from 4.5 to 8.6 mrem/y depending on the amount of imported food in the diet. A summary of projected radiation risks to the Enewetak population after cleanup is shown in Table 7-5. Predictions of whole body and bone marrow doses for Enjebi residents exceed the Task Group recommendations. Enjebi Island is not to be resettled until the fission products in the soil of that island have decayed to acceptable levels. Runit Island, where CACTUS crater contains the contaminated debris and soil from cleanup operations, is quarantined indefinitely.

*U.S.GOVERNMENT PRINTING OFFICE:1990-717-003:28019