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Radioactive Waste Management Complex Performance Assessment

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ABSTRACT

A radiological performance assessment of the Radioactive Waste Management Complex at the Idaho National Engineering Laboratory was conducted to demonstrate compliance with appropriate radiological criteria of the U.S. Department of Energy and the U.S. Environmental Protection Agency for protection of the general public. The calculations involved modeling the transport of radionuclides from buried waste, to surface soil and subsurface media, and eventually to members of the general public via air, ground water, and food chain pathways. Projections of doses were made for both offsite receptors and individuals intruding onto the site after closure. In addition, uncertainty analyses were performed.

Results of calculations made using nominal data indicate that the radiological doses will be below appropriate radiological criteria throughout operations and after closure of the facility.

Recommendations were made for future performance assessment calculations.

EXECUTIVE SUMMARY

This report provides documentation of the predicted environmental effects associated with the disposal of radioactive low-level waste (LLW) at the Idaho National Engineering Laboratory (INEL) Radioactive Waste Management Complex (RWMC). The predicted effects were compared with appropriate radiological criteria of the U.S. Department of Energy (DOE) and the U.S. Environmental Protection Agency (EPA) for protection of the general public.

The scope of the document covers both current and future operations of the RWMC. It addresses the impact of radionuclides in LLW, buried since 1964, on the general public. Occupational radiological doses and impacts of nonradioactive hazardous constituents are the subjects of other related assessments.

Three time periods of concern were addressed in this evaluation of the RWMC:

1. The operational period, 1964 through 2089, during which radioactive waste is actively disposed of at the facility.

2. The institutional period, 2089 through 2189, which follows site closure and during which periodic maintenance and monitoring activities are conducted. The facility is assumed to be stabilized but is still part of the INEL reservation and is fenced and patrolled.

3. The post-institutional period, 2189 through 11975, during which the facility is no longer maintained by the DOE and may be accessible to the public.

Two receptor types were assessed. The first is a member of the general public. During the operational and institutional period this individual was conservatively assumed to reside at or near the INEL Site boundary at the location of maximum concentration of airborne radionuclides in the transport medium of concern (i.e., air or ground water).

The second type of receptor evaluated is an intruder. This hypothetical receptor is assumed to inadvertently intrude on the RWMC during the post-institutional control period. Two general kinds of scenarios were evaluated. The first is an agriculture scenario in which the receptor obtains half of his produce from farming at the RWMC. This individual also drinks water from a well drilled at the edge of the waste. The second is an acute exposure scenario that includes a construction scenario and a well-drilling scenario. In the construction scenario, the receptor is an individual who is building a house at the RWMC and is exposed to contaminated soil while excavating the cellar. In the well-drilling scenario, the receptor is exposed to contaminated drill cuttings that are deposited in a mud pit.

Results of the monitoring, special studies, and modeling efforts to date indicate that the greatest potential for transport of radionuclides from the RWMC to offsite receptors (now and in the future) is via airborne transport of resuspended contaminated surface soil particles and ground water transport of radionuclides leached from buried waste. For this reason, the performance assessment only addresses these two transport pathways.

The exposure pathways evaluated include ingestion of food and water, inhalation of contaminated airborne particulates, and external exposure to radionuclides in air and soil. The agricultural products consumed by the general public are contaminated via food chain transport of radionuclides deposited from air onto soil or plant surfaces.

The performance assessment involved development of a near-field model and the use of environmental transport models to project the release and transport of radionuclides from buried waste to a receptor. The near-field model included waste inventory and radionuclide release and transport processes within the RWMC. The transport processes included infiltration, plant uptake, and burrowing by small mammals. The model was simulated by the DOSTOMAN code for periods up to 10,000 yr. The near-field model consisted of three sub-models. The old pit model simulates waste buried from 1964 through 1975 in shallow pits and trenches. The new pit model represents waste disposed since 1975 using current methods. The third sub-model represents soil vaults.

The waste inventory used in the near-field was derived from the Radioactive Waste Management Information System. The LLW buried since 1964 was used. Transuranic (TRU) waste and LLW intermixed with TRU waste that was buried before 1964 was not included. To simplify the assessment, the list of radionuclides was screened, using an index of potential risk, to a final list of 11 radionuclides that contribute more than 99% of the total risk from all the radionuclides. They are Co-60, Sr-90, Cs-137, Ra-226, Th-230, U-234, U-238, Pu-238, Pu-239, Pu-240, and Am-241.

Projections of radionuclide concentrations in surface soil and subsurface media, made by DOSTOMAN, were used as source terms for the environmental transport models.

It was assumed that the source of radionuclides for airborne transport to offsite receptors was contaminated surface soil at and around the RWMC and radon diffusing from buried waste. Projections of curie quantities in the surface soil compartment were used to calculate release rates by multiplying these quantities by a resuspension rate constant. Daughter radionuclides were included in the calculations; they were estimated using the RADDECAY code. The release rates (Ci/yr) of radionuclides were then input into the AIRDOS-EPA computer code to calculate dose to the offsite receptor.

The PATHRAE-EPA computer code was used to determine the impacts of subsurface migration of radionuclides. The RWMC was assumed to be an area source of uniform thickness. The waste was assumed to leach at a constant rate into the unsaturated zone. Radionuclides were assumed to migrate through the unsaturated zone, reach the aquifer, and be transported to a down-gradient receptor.

The ground water flow and transport codes FLASH and FLAME were also used to provide input to PATHRAE-EPA. PATHRAE-EPA contains a simple method for calculating the vertical ground water velocity. However, the geology of the INEL Site is so complex that it invalidates this method. Therefore, FLASH and FLAME were used to calculate the vertical ground water velocity, which was then used as input to PATHRAE-EPA.

The end points of the ground water flow and transport analysis were radionuclide concentrations in well water at hypothetical locations down-gradient of the RWMC.

In most cases, the doses calculated for this assessment are far less than the performance objectives. In one case, the dose received from drinking water obtained from a well at the RWMC perimeter is less than, but fairly close to, the objective. This dose was projected for 3.75 million yr and is due primarily to long-lived U-238. There is some question as to the validity of this calculation given the long time period involved and the unpredictable environmental conditions that may exist that far into the future.

The largest doses projected for airborne transport occur before closure and the addition of the final cover. Although the cover was allowed to erode, doses following institutional control because of long-lived radionuclides never exceed those projected for future operations.

Uncertainty analyses were performed focusing on waste release processes and ground water flow and transport parameters. Results for the near-field indicate that inventory is the most influential parameter for all radionuclides in terms of projected surface soil concentration. Release rate is the dominant contributor to overall uncertainty in terms of projected subsurface inventory available for ground water. The distribution coefficient, release rate, and ground water velocity have the greatest impact on doses because of ground water transport. The relative contribution of each varies with radionuclide.

Based on the results, recommendations were made for further performance assessment studies. The recommendations include

- Inclusion of nonradioactive components in the assessment
- A thorough investigation of past disposal practices to obtain better estimates of inventory before 1974
- Development of a mechanistic model of the waste release process to replace empirical data used
- Use of more detailed, site-specific vadose zone and ground water flow and transport models
- Consideration of more appropriate, state-of-the-art uncertainty analysis techniques.

CONTENTS

FIGURES

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TABLES

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ACRONYMS AND INITIALISMS

AEC	Atomic Energy Commission
AEC-ID	Atomic Energy Commission Idaho Operations Office
ANC	Aerojet Nuclear Company
ANL-E	Argonne National Laboratory-East
ANL-W	Argonne National Laboratory-West
CFA	Central Facilities Area
DOE	U.S. Department of Energy
EDE	effective dose equivalent
EH	Environmental Health
EPA	U.S. Environmental Protection Agency
FRP EA	Fuel Processing Restoration Environmental Assessment
ICRP	International Commission on Radiological Protection
ILTSF	Intermediate Level Transuranic Storage Facility
INC	Idaho Nuclear Corporation
INEL	Idaho National Engineering Laboratory
ISB	Intermountain Seismic Belt
LLW	low-level waste
NERP	National Environmental Research Park
NIMCO	National Industrial Maintenance Company
NOAA	National Oceanic and Atmospheric Administration
NRF	Naval Reactor Facility
NRTS	National Reactor Testing Station
PPCo	Phillips Petroleum Company
RESL	Radiological and Environmental Sciences Laboratory
RWMC	Radioactive Waste Management Complex
RWMIS	Radioactive Waste Management Information System
SDA	Subsurface Disposal Area
SSA	Special Study Area
SVR	soil vault row
SWEPP	Stored Waste Examination Pilot Plant
TRA	Test Reactor Area
TSA	Transuranic Storage Area

TRU transuranic
USGS United States Geologic Survey
WERF Waste Experimental Reduction Facility
WIPP Waste Isolation Pilot Plant
WVRF Waste Volume Reduction Facility

1. INTRODUCTION

1.1 Purpose and Scope

This report provides documentation of the predicted environmental effects associated with the disposal of radioactive low-level waste (LLW) at the Radioactive Waste Management Complex (RWMC) at the Idaho National Engineering Laboratory (INEL). The predicted effects will be used to demonstrate compliance with appropriate radiological criteria of the U.S. Department of Energy (DOE) and the U.S. Environmental Protection Agency (EPA) for protection of the general public and the environment.

A performance assessment is "a systematic analysis of the potential risks posed by waste management systems to the public and environment, and a comparison of those risks to established performance objectives" (DOE 1988a). In the context of this performance assessment, the waste management system consists of the LLW waste form at the RWMC, the RWMC disposal facility, and its environs. This performance assessment is a tool used to predict the potential environmental consequences of the LLW facility; its intent is to determine whether waste management activities will accomplish the goal of effectively containing LLW. This goal is considered met if compliance with performance objectives is demonstrated in the performance assessment.

The scope of the document covers both current and future operations of the RWMC. Related assessment activities (e.g., safety assessments, characterizations for siting or construction, engineering evaluations, and cost/design studies) are outside the scope of this document. Potential radiological doses to workers at the RWMC are not covered in this document. Although doses to workers are an important area of concern for facility operations, they are covered by regulations and guidance different than those covering performance assessments. Furthermore, compliance with occupational criteria is not necessarily demonstrated by the type of calculations associated with radiological performance assessments. Another area of concern that is excluded from the scope of this document is potential impacts of nonradiological hazardous constituents that may be in the waste. Occupational radiological doses and impacts of nonradioactive hazardous constituents are each the subject of other related assessments. Only buried LLW is considered in this document. Buried transuranic (TRU) waste, stored TRU waste, and buried commingled TRU and LLW is not included; neither is LLW that may be disposed as a result of programs/projects that are not currently at the INEL.

This performance assessment is a baseline assessment. It only addresses one closure design, the addition of soil to the cover. Other enhanced closure options, such as engineered barriers, will be the subject of future efforts.

The remainder of this introductory section provides background information relating to the RWMC and regulations, guidelines, and criteria (i.e., performance objectives) applicable to the radiological performance assessment of the RWMC.

1.2 General Description of the RWMC

The INEL is a DOE facility occupying approximately 2,300 km^2 in southeastern Idaho. Activities conducted at the INEL primarily involve nuclear research and development projects and experiments. The RWMC is one of several waste management facilities at the INEL; it is the only operating LLW disposal area at the INEL. There are several other waste treatment, certification, and storage facilities on the INEL Site.

The RWMC provides a shallow land burial site for solid LLW generated almost exclusively by INEL activities. It also serves as an interim storage location for TRU-contaminated radioactive waste. Most of the stored TRU waste is generated at other DOE sites.

The RWMC opened in 1952 near the southwestern corner of the INEL. The initial tract of land used as a burial ground for radioactive waste was

5.3 ha. This tract became the Subsurface Disposal Area (SDA) and was expanded in 1957 to 35.6 ha. In 1970, the 22.7-ha Transuranic Storage Area (TSA) was added to the RWMC. Over the years, service and operations buildings have been constructed. The SDA and TSA are surrounded by a security fence. A drainage system is incorporated at the RWMC to divert runoff away from the facility.

Most of the LLW arrives at the RWMC packed in containers, usually large wooden boxes sealed with plastic liners. Compactible waste is reduced in volume and repackaged at the Waste Experimental Reduction Facility (WERF) before burial. Waste is buried in large pits that are excavated to a nominal depth of 6 m. After the waste is impulsed, it is covered with several meters of earthen cover. Small quantities of LLW with higher radiation levels are placed in specially prepared soil vaults.

LLW generated at the INEL primarily consists of protective clothing, paper, rags, packing material, glassware, tubing, and other general-use items. Also include are contaminated equipment, such as gloveboxes and ventilation ducts, and process waste, such as filter cartridges and sludges. These materials are either surface contaminated with radioactive nuclides or are activated from nuclear reactions.

Most of the radioactivity in the LLW at the time of receipt stems from short-lived radionuclides. Most of this waste has low radiation levels, less than 500 mR/h at 0.9 m from the container surface.

As of 1988, the RWMC contained 130,000 m^3 of LLW. This includes approximately 50,000 m^3 of LLW that was buried commingled with TRU waste until 1970. This document does not address this commingled LLW.

Environmental surveillance programs are conducted both onsite and offsite to monitor for any inadvertent release of radioactivity from the RWMC and the INEL. These programs and data collected are described in Section 5.

1.3 Performance Objectives

Radiological performance objectives are radiological standards (i.e., limits) that must be met by DOE-LLW facilities; they are derived from DOE Orders and/or guidance and EPA regulations. Performance objectives derived from applicable regulations and guidelines are discussed in this section. These performance objectives are summarized in Table 1-1.

1.3.1 DOE Order 5820.2A

DOE Order 5820.2A, "Radioactive Waste Management," dated September 26, 1988, contains policies, guidelines, and minimum requirements by which the DOE manages its radioactive and mixed waste and contaminated facilities. Chapter III of this Order is applicable to the management of DOE LLW. The Order contains general policy statements regarding protection of the public health and safety and specific performance objectives for DOE LLW operations. This Order also requires a site-specific performance assessment to demonstrate compliance with the objectives. Requirements of the Order apply only to waste that was not disposed of before issuance of the Order. The specific performance objectives set forth in DOE Order 5820.2A state that DOE LLW that has not been disposed of before issuance of the Order shall be managed to accomplish the following:

- Protect public health and safety in accordance with standards specified in applicable Environmental Health Orders and other DOE Orders

- Ensure that external exposure to the waste and concentrations of radioactive material that may be released into surface water, ground water, soil, plants, and animals results in an effective dose equivalent (EDE) that does not exceed 25 mrem/yr to any member of the public. Releases to the atmosphere shall meet the requirements of 40 CFR 61. Reasonable effort should be made to maintain releases of radioactivity in effluents to the general environment as low as is reasonably achievable.

Table 1-1. Summary of regulations and radiological performance objective limits applicable to RWMC LLW performance assessment

Regulations	Exposure Group	Performance Objectives Limit (Annual)	Compliance Point	Compliance Period
DOE Orders				
5820.2A, Ch. III	Public	25 mrem EDE[a]	Point of restricted access (fence, guards, signs, etc.)	Indefinite future
	Intruder	100 mrem EDE (continuous exposure)	Source term	Indefinite future beginning at 100 yr or after the loss of institutional control
		500 mrem EDE (acute exposure)		
5480.xx	Public	100 mrem EDE (for all facilities on a site)	Point of restricted access	During operations
		25 mrem DE[b,c] (whole body)	Point of restricted access	Indefinite future
		75 mrem DE (critical organ)	Point of restricted access	Indefinite future
		4 mrem EDE (drinking water)	Closest public well	Indefinite future
EPA				
40 CFR 61 Subpart H	Public	25 mrem DE [air emissions (whole body)]	Point of maximum annual air concentration in an unrestricted area where the public resides or abides	Indefinite future
		75 mrem DE [air emissions (critical organ)]		
40 CFR 141	Public	4 mrem DE [water systems (whole body and organs)]	Any public water system	Indefinite future
40 CFR 193	Public	25 mrem EDE	Facility boundary Trench boundary	Operational, post-closure (10,000 yr)
		4 mrem EDE (water systems)	Facility boundary Trench boundary	Operational, post-closure (10,000 yr)

a. Effective dose equivalent (ICRP 1977; ICRP 1979, 1981, 1982).
b. Dose equivalent (ICRP 1960).
c. 25 mrem is considered the "action level" during the operational period.

- Ensure that the committed EDEs received by individuals who inadvertently may intrude into the facility after the loss of active institutional control (100 yr) will not exceed 100 mrem/yr for continuous exposure or 500 mrem for a single acute exposure

- Protect ground water resources consistent with Federal, State, and local requirements.

1.3.2 DOE Order 5480.xx

The DOE is responsible for the protection of members of the public from radiation exposures resulting from any DOE activity. This draft Order 5480.xx, "Radiation Protection of the Public and the Environment," was issued March 31, 1987, and contains the primary DOE standards for the protection of members of the public. When finalized, this draft Order will be issued and will replace DOE Order 5480.1A. This draft Order incorporates standards derived from the EPA in 40 CFR 61; 40 CFR 141; and in 40 CFR 191, "Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Wastes."

The Order requires that compliance with dose limits be demonstrated by a combination of measurements and calculations to evaluate potential doses. The performance objectives obtained from DOE Order 5480.xx are as follows:

- Routine DOE activities shall not cause any individual member of the public to receive, in a year, an EDE greater than 100 mrem. In addition, the exposure shall not cause a dose equivalent to any tissue greater than 5 rem in a year. These limits apply for all exposure modes.

- The airborne effluent pathway shall not result in any member of the public receiving, in a year, a dose equivalent greater than 25 mrem to the whole body and 75 mrem to the critical organ.

- An annual EDE of no more than 4 mrem shall be received by any person through ingestion of water from a drinking water supply operated by, or for DOE.

- Radioactive materials in liquid effluents released from DOE facilities shall not cause public or private drinking water systems downstream of the facility discharge to result in any member of the public receiving an annual dose equivalent exceeding 4 mrem to the whole body or to any organ.

1.3.3 40 CFR 61

Subpart H of the "National Emission Standards for Hazardous Air Pollutants (Clean Air Act)" contains EPA dose limits for members of the public resulting from airborne effluents from DOE facilities. This regulation requires the preparation and submittal of a request for construction or modification of any DOE facility demonstrating compliance with the regulation. The regulation requires that compliance with the stated dose limits be determined using the codes AIRDOS-EPA and RADRISK or other EPA-approved procedures. The following performance objective (which is also contained in DOE Orders) is contained in 40 CFR 61:

- The airborne effluent pathway shall not result in any member of the public receiving, in a year, a dose equivalent greater than 25 mrem to the whole body and 75 mrem to the critical organ.

1.3.4 40 CFR 141

The "National Interim Primary Drinking Water Regulations (Safe Drinking Water Act)" contains EPA regulations covering radioactivity from manmade radionuclides in community drinking water. This regulation contains radioactivity concentration limits for Ra-226/Ra-228, gross alpha activity, Sr-90, and tritium and a dose limit of 4 mrem/yr because of beta/gamma activity in drinking water.

1.3.5 40 CFR 193 (Proposed)

This proposed EPA regulation, "Environmental Standards for the Management, Storage, and Land Disposal of Low-Level Radioactive Waste and Naturally Occurring and Accelerator-Produced Waste," intends to set environmental radiation protection standards and/or guidelines for LLW to protect the public health and general environment. The regulation sets a proposed level of protection at 25 mrem/yr (effective whole body dose equivalent) to any member of the public in the general environment for the pre-disposal management and storage activities associated with LLW. The regulation also proposes a standard that requires that all LLW disposal be conducted in such a way that no individual receives a total dose from releases to the general environment in excess of 25 mrem/yr from all the LLW disposal in the United States. This would apply to total exposure from all pathways, including all uses of contaminated ground water and surface water and would apply for all time periods. This regulation also proposes a level of exposure of 4 mrem/yr to be below regulatory concern.

40 CFR 193 also contains requirements for protection of ground water. These requirements are different in philosophy than the pre- and post-disposal standards, which are designed to protect people. These requirements are specified for three classes of aquifers: for Class I aquifers, no further increase in the levels of radioactivity in the aquifer would be allowed; for Class II aquifers, two options are proposed, both of which essentially set a limit of 4 mrem/yr; for Class III aquifers, the limits set forth for pre- and post-disposal are invoked.

1.3.6 Summary of Performance Objectives

The specific, most restrictive performance objectives that the RWMC must meet can be summarized as follows:

- The annual EDE from all exposure pathways received by the maximum individual must not exceed 25 mrem from exposure to effluents from the RWMC.

- The whole body dose equivalent received by the maximum individual (i.e., the individual residing at the location of maximum airborne concentration) resulting from airborne effluents released from all INEL facilities cannot exceed 25 mrem/yr. Therefore, any projected dose resulting from the RWMC must be added to the airborne effluent doses for all other INEL facilities. The critical organ dose equivalents from all INEL facility operations must likewise be summed and must not exceed 75 mrem/yr.

- The committed EDE received by any individual who may inadvertently intrude into the facility after the loss of active institutional control (100 yr following the end of operations) shall not exceed 100 mrem/yr for continuous exposure or 500 mrem for a single acute exposure (from DOE Order 5820.2A).

- An annual EDE of no more than 4 mrem shall be received by any person through ingestion of water from a drinking water supply operated by or for DOE.

- Radioactive materials in liquid effluents released from the RWMC shall not cause public or private drinking water systems downstream of the facility discharge to result in any member of the public receiving an annual dose equivalent exceeding 4 mrem to the whole body or to any organ.

1.4 Other Dose Criteria

1.4.1 Time Periods of Concern

For the purpose of assessing the performance of the RWMC, three time periods of concern are evaluated: the operational period, the institutional control period, and the post-institutional control period. These periods are defined as follows:

- The operational period is assumed to continue until the year 2089, at which time the RWMC is assumed to be closed. The waste inventory accumulated during this time is assumed to be that already accumulated from 1964 through 1988 plus the amount projected to accumulate.

- The period of institutional control is assumed to last for 100 yr, 2089-2189, during which time maintenance and surveillance monitoring of the RWMC are assumed to continue. No additional waste is received during this time period.

- The post-institutional control period, beginning in the year 2189, is the period during which no maintenance nor surveillance monitoring occurs, and the area is available for unrestricted use by the public. The period has an indefinite ending point; analyses were made out to the point in time of maximum impact.

1.4.2 Receptors and Dose Locations

1.4.2.1 Maximum Individual. During the operational and institutional control periods, the maximally exposed individual is a hypothetical individual residing at or near the INEL Site boundary location of maximum exposure to radionuclides. During the post-institutional control period, the maximally exposed individual is a hypothetical individual who inadvertently intrudes onto the RWMC facility.

1.4.2.2 Populations. During the operational and institutional control periods, the population living within an 80-km radius of the RWMC is the population for which radiological doses are calculated. The potential population doses are not considered for the post-institutional control period.

1.4.2.3 Effective Dose Equivalent. In most cases in this analysis, radiation dose was expressed in terms of EDE or committed effective dose equivalent. The following paragraphs define EDE and committed effective dose equivalent.

EDE is a quantity defined by the

$\Sigma_T W_T H_T$

where

W_T = the weighting factor specified by the International Commission on Radiological Protection (ICRP) to represent the production of the stochastic risk resulting from irradiation of tissue T to the total risk when the whole body is irradiated uniformly

H_T = is the mean dose equivalent in tissue T.

H_T may be from external or internal sources.

Committed EDE is the time integral of the dose equivalent rate in a particular tissue following an intake of radioactive material into the body is defined as the committed dose equivalent. The committed effective dose equivalent is the sum of the committed dose equivalents to individual tissues resulting from an intake, each multiplied by the appropriate weighting factor W_T.

2. FACILITY DESCRIPTION

2.1 Site Description

This section describes the environment of the INEL, which includes the RWMC. The description includes the following topics: climate and meteorology, geology, hydrology, ecology, demography, land use, and archeology.

The INEL is located along the northwestern edge of the eastern Snake River Plain in southeastern Idaho (Figures 2-1 and 2-2). Lying at the foot of the Lost River, Lemhi, and Bitteroot Mountain ranges, the INEL comprises some contiguous 2305 km^2 of sagebrush-covered land.

During World War II, the U.S. Navy used about 700 km^2 of the Snake River Plain for a gunnery range. An area southwest of the naval area was once used by the U.S. Army Air Corps as an aerial gunnery range. The INEL includes all the former military area and a large adjacent area withdrawn from the public domain for use by the DOE. Most of the land withdrawn from public domain lies in Butte County, Idaho, although it extends into Bingham, Bonneville, Jefferson, and Clark Counties.

The INEL was established in 1949 as the National Reactor Testing Station (NRTS), a place where the Atomic Energy Commission (AEC) could build, test, and operate various types of nuclear reactors, support facilities, and equipment with maximum safety. As of October 1980, 52 reactors were built at the INEL; of which, 17 were operating or operable.

In 1952, the SDA of the RWMC was opened in the southwestern corner of the INEL. In 1957, the SDA was expanded to its present size of 35.6 ha. The RWMC was expanded in 1970 by the addition of the TSA, covering 22.7 ha. Several service and support buildings have been constructed over the years.

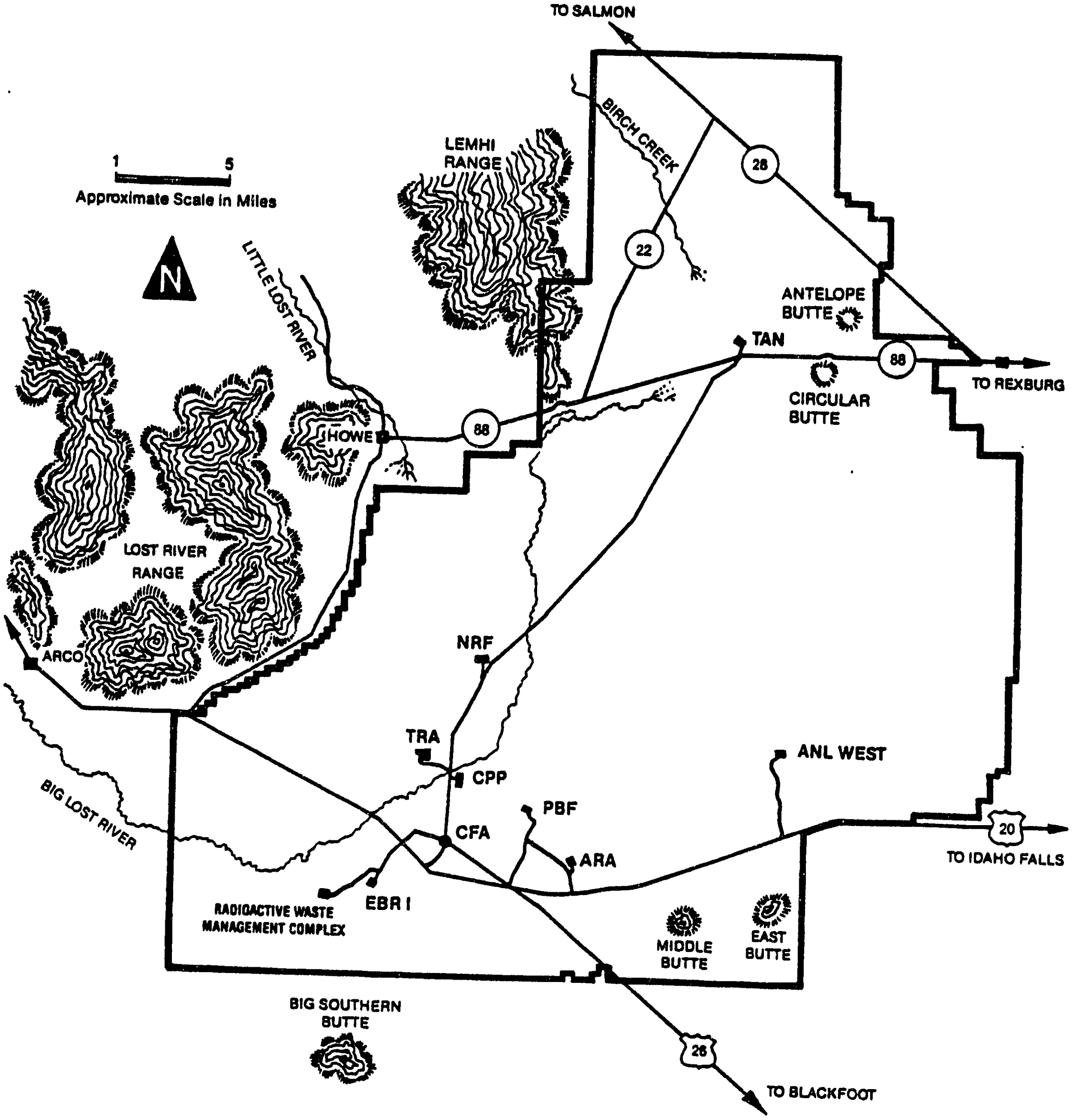

Figure 2-1. Location and principal features of the INEL.

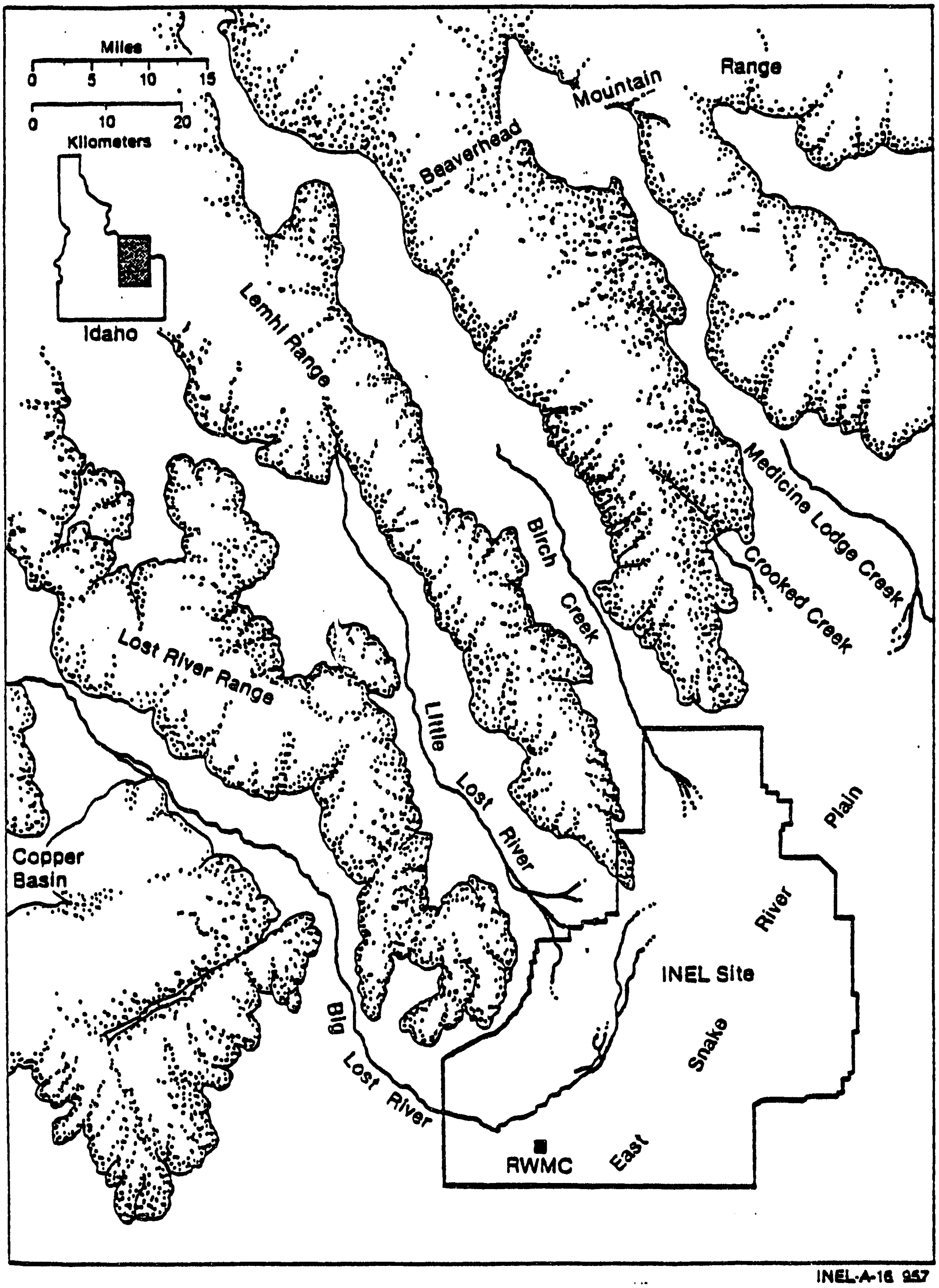

Figure 2-2. Location of the INEL in relation to nearby mountain ranges and the eastern Snake River Plain.

2.1.1 Climate and Meteorology[a]

The climate of the INEL is semiarid, with steppe characteristics. The topographic features that affect local weather patterns are the northeast-southwest orientation of the Plain and the mountain ranges to the north and west. Air masses entering the Snake River Plain must first cross mountain barriers, where much of the air moisture is precipitated. Thus, annual rainfall at the INEL is light.

Meteorological and climatological data summarized in this subsection are from a monitoring program conducted by the National Oceanic and Atmospheric Administration (NOAA). Temperature, wind, precipitation, evaporation, relative humidity, and severe weather conditions measured at locations near the RWMC are included.

2.1.1.1 Temperature. The extremes of temperatures at the INEL have varied from -42°C in January to 39°C in July. During winter, the average temperature varies from -16 to -3°C. During summer, the average temperature varies from 10 to 31°C.

Normal weather at the INEL includes adiabatic lapse conditions (the air temperature decreases with height above the ground surface) during daylight hours and inversion conditions (temperature increases with height) from about sunset until shortly after sunrise. Winds and clouds associated with stormy weather may prevent nighttime inversions. Daytime inversions may occur during winter and early spring if a snow cover is present. Annual averages show adiabatic lapse conditions 52% of the time and inversion conditions 48% of the time.

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a. This subsection is based on data collected by Yanskey et al. (1966) from 1954 to 1966. Most of the data reported in this section were gathered at the Central Facilities Area, approximately 8 km northeast of the RWMC.

2.1.1.2 Wind. The INEL is in a belt of prevailing westerly winds that are channeled by local terrain into a prevailing southwest-to-northeast direction. In summer a very sharp reversal in wind direction occurs daily; winds from the southwest predominate during daylight hours, and northeasterly winds persist at night. The reversals normally occur shortly after sunrise and sunset.

Wind roses (Figure 2-3) recorded at the Central Facilities Area (CFA) at the 6-m level indicate the percentage of time that the wind blows from a given direction and the associated wind speeds. Although the wind roses are similar for the four seasons, there is a fundamental difference between the forces controlling the winds in winter and those in the other three seasons. Winter winds are controlled almost exclusively by either large-scale weather systems or stagnation and show no significant diurnal characteristics. Winds in the other three seasons show diurnal characteristics in response to relatively strong local buoyancy forces resulting from the heating of the ground. Because of the absence of mountain-valley wind circulation in winter, there are frequent calms during periods of high atmospheric pressure.

The average hourly wind speed varies from 9 km/h in December to 14 km/h in April and May. The greatest hourly-average speed was 82 km/h from the west-southwest. On the average, two or three thunderstorm days per month occur during the months of June, July, and August. Strong wind gusts can occur in the immediate vicinity of thunderstorms. The highest instantaneous speed recorded 6-m aboveground at the CFA was 126 km/h, with the wind from the west-southwest. Calm conditions prevail 11% of the time.

Average airborne dust concentrations vary from 0.014 mg/m^3 in winter to 0.077 mg/m^3 in summer. Even with dust devils present, a concentration of only 0.15 mg/m^3 was recorded. Less than 1% of the airborne particles are larger than 10 μ in diameter. During the daytime, with strong winds present, dust concentration decreases sharply with altitudes up to 21 m.

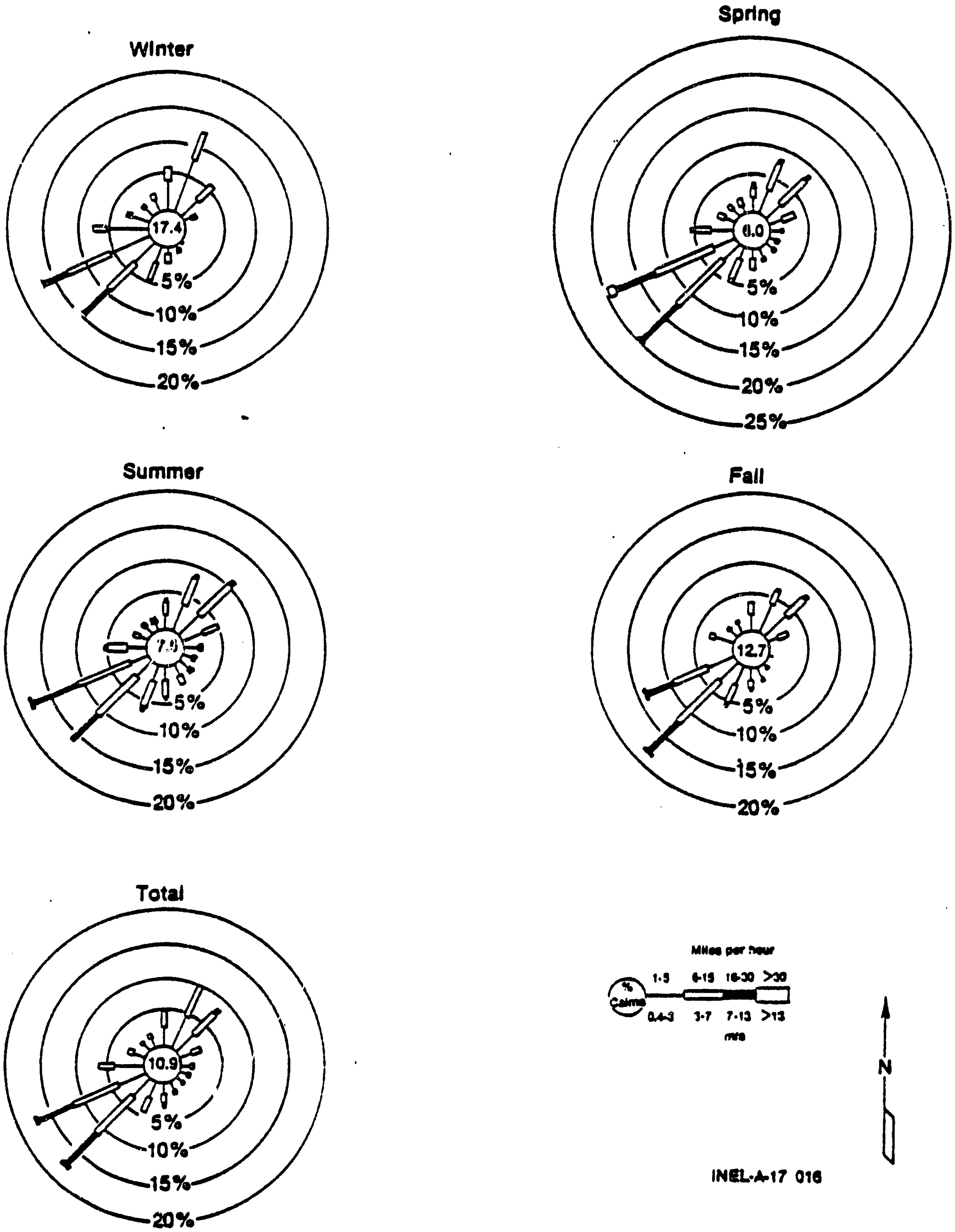

Figure 2-3. Wind rose for the INEL Central Facilities Area, 6.1-m level (January 1950-May 1962).

2.1.1.3 Precipitation. The average annual precipitation at the INEL is 22 cm. The maximum monthly precipitation occurs during May and June and the minimum during July. There have been 13 occasions from 1950 through 1982 when 2.5 cm of rain or more fell within a 24-h period at CFA. The greatest rainfall within a 24-h period was 4.4 cm, in June 1954. Only once did more than 1.3 cm of rain fall in 1 h; 3 cm of rain fell on June 10, 1969 (Yansky et al. 1966).

Snowfall ranges from 30 to 108 cm/yr, with an annual average of 72 cm. Although snow occurs mostly during November through April, it does occasionally fall during May, June, September, and October.

2.1.1.4 Evaporation. The potential annual evaporation from a saturated ground surface at the INEL is approximately 91 cm, with 80% of that occurring between May and October. During the warmest month (July), the daily rate is approximately 0.6 cm. From December through February, evaporation is small and may be insignificant. Actual evaporation rates are much lower than potential rates because the ground surface is rarely saturated. Evapotranspiration by the sparse native vegetation of the Snake River Plain is estimated to be 15 to 23 cm/yr. From late winter to spring, precipitation is most likely to infiltrate into the ground because of the low evapotranspiration rates (Mundorff et al. 1964).

2.1.1.5 Relative Humidity. The relative humidity at the INEL Site ranges from a monthly average minimum of 15% in August to a monthly average maximum of 89% in February and December. On a daily basis, humidity reaches a maximum just before sunrise, at the time of the lowest temperature, and a minimum late in the afternoon, near the time of the highest temperature.

2.1.1.6 Severe Weather Conditions. On the average, two or three thunderstorm days occur at the INEL during June, July, and August. The surface effects from thunderstorms over the Snake River Plain are usually much less severe than those east of the Rocky Mountains or even in the mountains surrounding the Plain. Although small hailstones frequently accompany the thunderstorms, damage from hail has not occurred at the INEL.

Since 1954, only three small tornadoes, which caused no damage, have been reported at the INEL. Only six funnel clouds (vortex clouds that do not reach the ground surface) were confirmed during the same period at the INEL.

2.1.2 Geology

2.1.2.1 Structure and Topography. The Snake River Plain stretches from the Oregon border in a curving arc across southern Idaho to Yellowstone National Park in northwestern Wyoming. The elevation is 762 m at the Oregon border and increases to over 1980 m at Henry's Lake near the Montana-Wyoming border.

The INEL Site is located on the northwestern portion of the eastern Snake River Plain, which is defined as that portion of the Plain that lies east of Twin Falls (Figure 2-4).

At the RWMC, the elevation is approximately 1500 m. Within the INEL Site, elevations generally range from 1450 to 1580 m. A broad topographic ridge extends along the northwest border of the INEL Site. This ridge effectively separates the drainage of the mountain ranges north and west of the INEL Site from the Snake River.

Mountain ranges bordering the Snake River Plain consist of Paleozoic and Mesozoic rocks folded, intruded, and uplifted along normal faults. These ranges terminate abruptly against both sides of the Snake River Plain. A general map of the geology of the eastern Snake River Plain is shown in Figure 2-5.

Figure 2-6 shows a typical geologic cross section through the RWMC. The subsurface geologic structure at the RWMC consists of successive lava flows with interbedded sediments. The wind- and water-deposited surface sediments range from 1- to 7.5-m deep, with an average depth of approximately 4.5 m. Two principal layers of sediment occur at approximately the 33- and 73-m levels, with an average thickness of about 4.2 m. Sediment layers

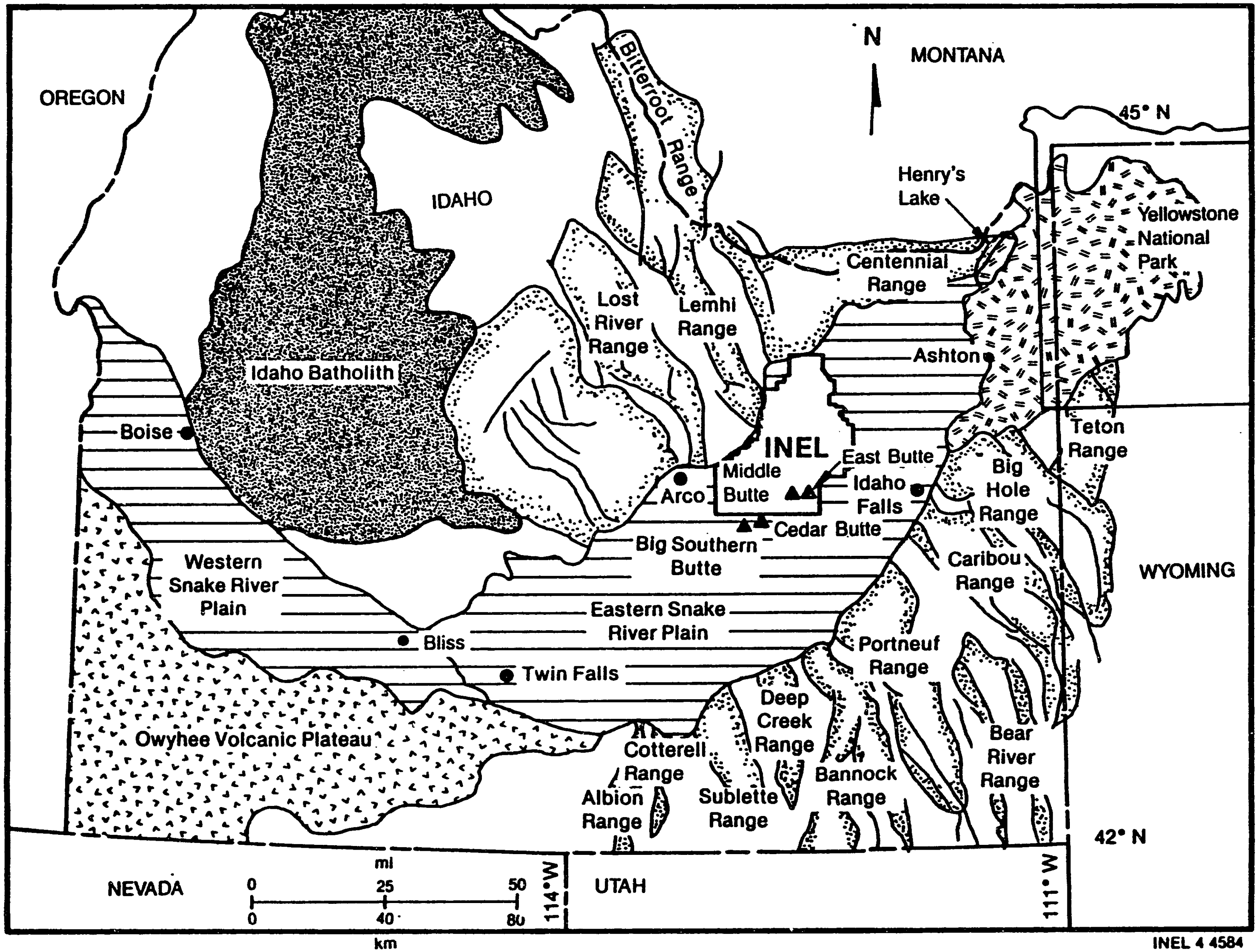

Figure 2-4. Generalized map of southern Idaho showing geographic and geologic features.

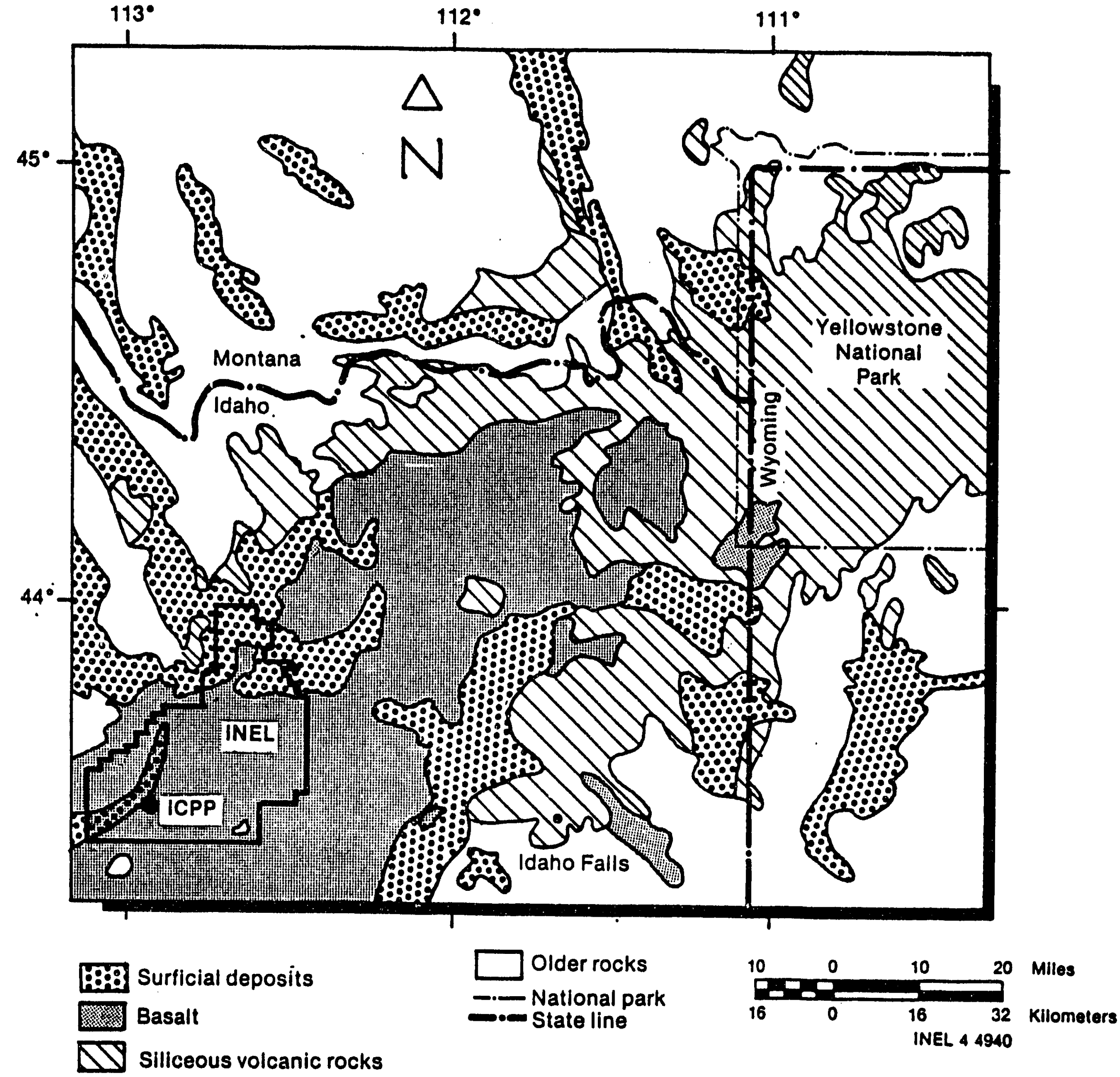

Figure 2-5. Generalized geologic map of the eastern Snake River Plain, Idaho, and vicinity.

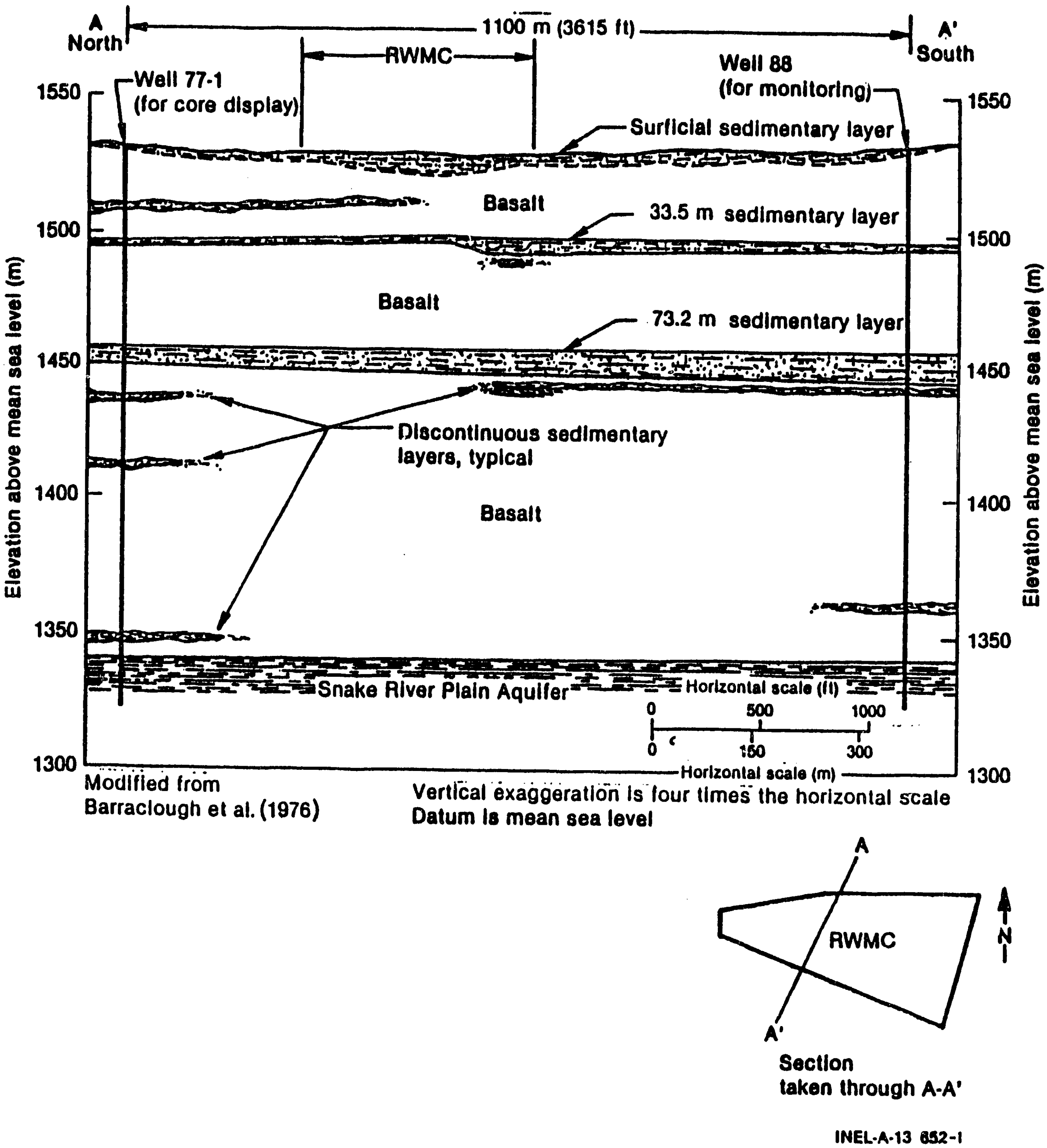

Figure 2-6. Geologic cross-section north to south through the RWMC.

occur at other depths, as shown in Figure 2-6, but are not continuous. The sediment layers are nearly identical in composition with the surface sediments.

The nature of the geologic layers varies with location at the RWMC. For example, the depth to sediment, the degree of fissuring of the basalt, and the thickness of the interbedded sediments all differ from one location to another. Thus, the properties that would affect the migration of waste constituents are difficult to project accurately.

2.1.2.2 Soils. The surface of the INEL Site includes various alluvial and sedimentary materials, sand dunes, and bare basalt. The surface soil varies in thickness and water-holding capacity. Figure 2-7 and Table 2-1 illustrate and list the soil types found at the INEL Site. Figure 2-7 also shows the irrigation limitations of the INEL Site surface because of soil depth and water-holding capacity. Further information on soils is available in McBride et al. (1978).

Barraclough et al. (1975) measured the cation-exchange capacities of 56 subsurface samples collected from wells drilled in and around the RWMC. An average cation-exchange capacity for RWMC soils is 15 milliquivalent of cesium per 100 g of sample. Cation-exchange capacity is the ability of sediments to exchange positively charged ions from solution and is generally dependent on the amount and the types of clay in the sediments. Radionuclides in the waste may be in the form of cations that could be sorbed, thereby retarding further migration. Soils with lower clay content do not bind radionuclides as effectively.

Studies of INEL Site surface sediments have indicated that significant sorption of plutonium and americium occurs, depending on the characteristics of the specific soils and actinide solutions (Glover et al. 1976). However, if the plutonium or americium is in a microcolloidal suspension (Adams and Fowler 1974), it may be much more mobile and less subject to sorption.

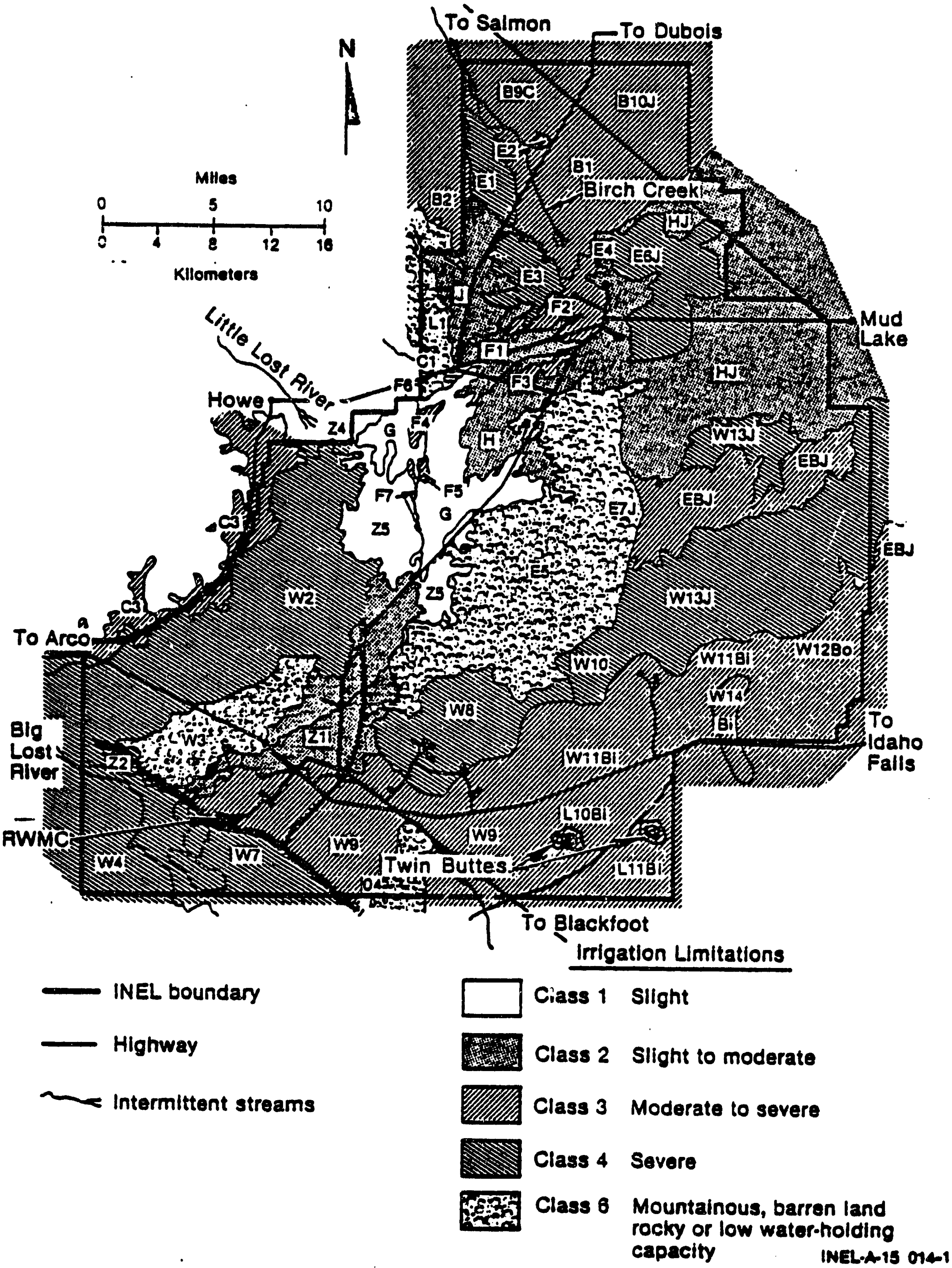

Figure 2-7. INEL soils map.

Table 2-1. Classification of soils at the INEL by mapping unit[a]

Mapping Unit	Description
B1, B2, B3, B4 B5, B6, B8, B9C, B10J, C1, C3	Thin loam over deep sands, gravels (surface glacial till underlying surface loam), and limestone alluvium.
E1, E2, E3, E4, E5, E6J, E7J, E8J	Sandy loams derived largely from windblown sands. Strongly calcareous, including cemented calcium carbonates. Overlies basalt rock. Stony to rocky north of the INEL.
F1	Playas in the sinks area. Strongly calcareous clay loam over low-permeability clay at approximately the root zone.
F2, F3, F4, F5, F6, F7	Similar to F1, with high sodium alkalinity.
G	Deep. well-drained, laminated clay loam. Moderately calcareous and slightly sodic. Lacustrine sediments in playa east and south of Howe.
H, HJ	Sandy loam surface, low-permeability clay at root zone. Sand dunes in places. (Includes remnants of prehistoric Lake Terreton near Mud Lake.)
J	Sandy loam on alluvial fans. Moderate water-holding capacity. Local rockiness and shallow depth.
L1, L10Bi, L11Bi	Mixed geologic materials from hills and mountains. Very shallow soils, very steep slopes, very rocky.
W2, W3, W4, W5 W7, W8, W9, W10, W11Bi, W12Bo, W13J, W14Bi	Thin loess-covered basalt plains. Small areas surrounded by bare basalt. Stony to rocky.
Z1, Z2, Z3	Stream bottoms of the Big Lost River at the INEL. Generally moderate depth of soil and moderate water-holding capacity.
Z4, Z5	Alluvial materials of the Little Lost River drainage.

a. See Figure 2-7 for mapping units.

2.1.2.3 Seismicity. The Intermountain Seismic Belt (ISB) is a zone of seismic activity extending from Arizona through eastern Idaho to western Montana (Figure 2-8). The belt is more than 1280 km-long and 99.2-km wide. Two zones are associated with the ISB. The first, the Idaho seismic zone, extends from the Yellowstone-Hebgen area westward into central Idaho. The second extends from southwestern Utah through southern Nevada where it joins the Nevada seismic zone.

Seismic and microseismic data collected by the United States Geological Survey (USGS) indicate regional earthquakes are centered in the ISB and not the eastern Snake River Plain. However, ground motion produced by earthquakes in the mountains can be transmitted onto the Plain. The INEL is classified as a Seismic Zone 2; however, the design levels for INEL facilities exceed those required for this classification.

The largest earthquake event in the vicinity of the INEL occurred in the Idaho seismic zone on October 28, 1983, and had a Richter scale magnitude of 7.3. The earthquake occurred because of slippage on a normal fault with relative movement down to the west. The epicenter for this event was located at the western flank of Borah Peak in the Lost River Range, approximately 40 mi north of Arco. The nearby communities of Mackay and Challis experienced substantial damage to older masonry construction. Although the shock was felt at the INEL Site, only minor nonnuclear building damage occurred in the form of hairline cracks and settlement. The RWMC experienced no structural failures or waste spills as a result of the earthquake. Waste storage facilities show no evidence of permanent movement or resulting damage. Data from this earthquake are currently being analyzed, and further studies are in progress.

Another large earthquake occurred on August 17, 1959, at Hebgen Lake, approximately 100 mi northeast of the INEL Site. This shock had a Richter scale magnitude of 7.1. It was felt at the INEL Site but caused no damage.

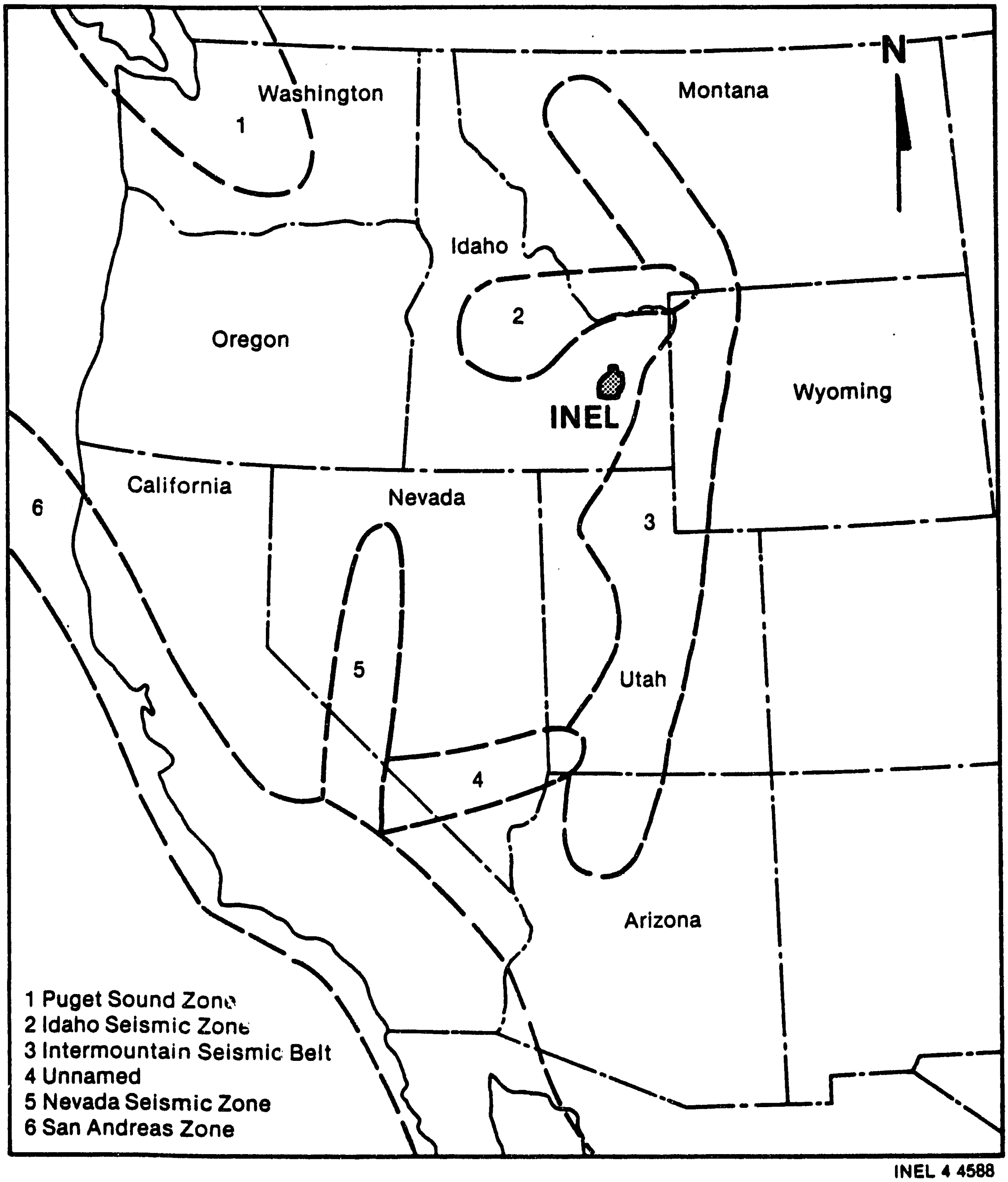

Figure 2-8. Index map of seismic zones.

The INEL has maintained a seismic network for monitoring earthquake activity on and about the eastern Snake River Plain since December 1971. The system initially consisted of a single seismograph and evolved to the present-day network of six stations. They are Cedar Butte (CIB), Big Grassy Butte (GBI), Howe Peak (HPI), Indian Meadow[a] (IMW), Juniper Gulch (JGI), and Taylor Mountain (TMI). Locations of these stations are shown in Figure 2-9. Also shown is the Special Study Area (SSA), which was chosen in 1981 for locating earthquake epicenters.

Earthquake data have been acquired by the INEL seismic network for about 11 yr. To date, activity has been detected in the adjacent mountains and in distant locations. Since January 1981, the HYPO-71 computer code has been used for final locations of earthquakes graphically located within the SSA. Figure 2-10 displays the location and size of 93 earthquakes that were analyzed by HYPO-71 from October 1973 through June 1982. The local magnitude range for the 93 earthquakes was 0.8 to 3.2 on the Richter scale. The seismicity for the SSA for this period is quite low. The eastern Snake River Plain is almost devoid of any earthquakes above the detection limits of the seismic network.

These data are in agreement with historical records of the eastern Snake River Plain and its margins. Data compiled from 1872 to 1977 show that, except for a few earthquakes at the northeastern end (Island Park area), the eastern Snake River Plain has been historically aseismic.

2.1.2.4 Volcanic Activity. Except for small areas along the mountain fronts and three buttes, the entire INEL Site is underlain by a succession of Pliocene, Pleistocene, and Oecent basalt flows. The basalt was formed chiefly from pahoehoe-type lavas. The flows have been extruded from rifts

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a. The Indian Meadow Station is operated by Ricks College at Rexburg, Idaho, and monitored by the INEL. The remaining stations are INEL-operated.

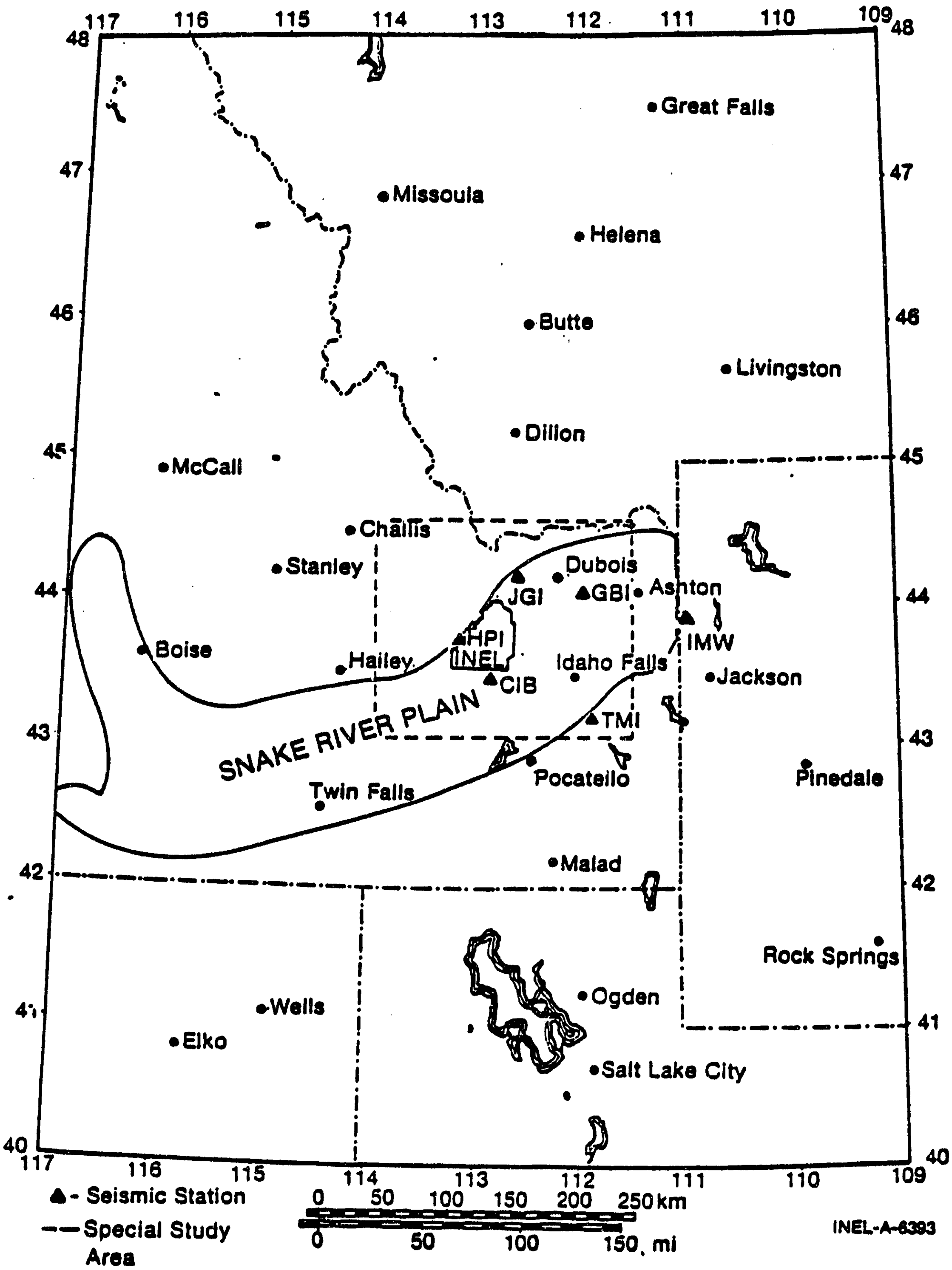

Figure 2-9. Regional map displaying INEL seismic station locations.

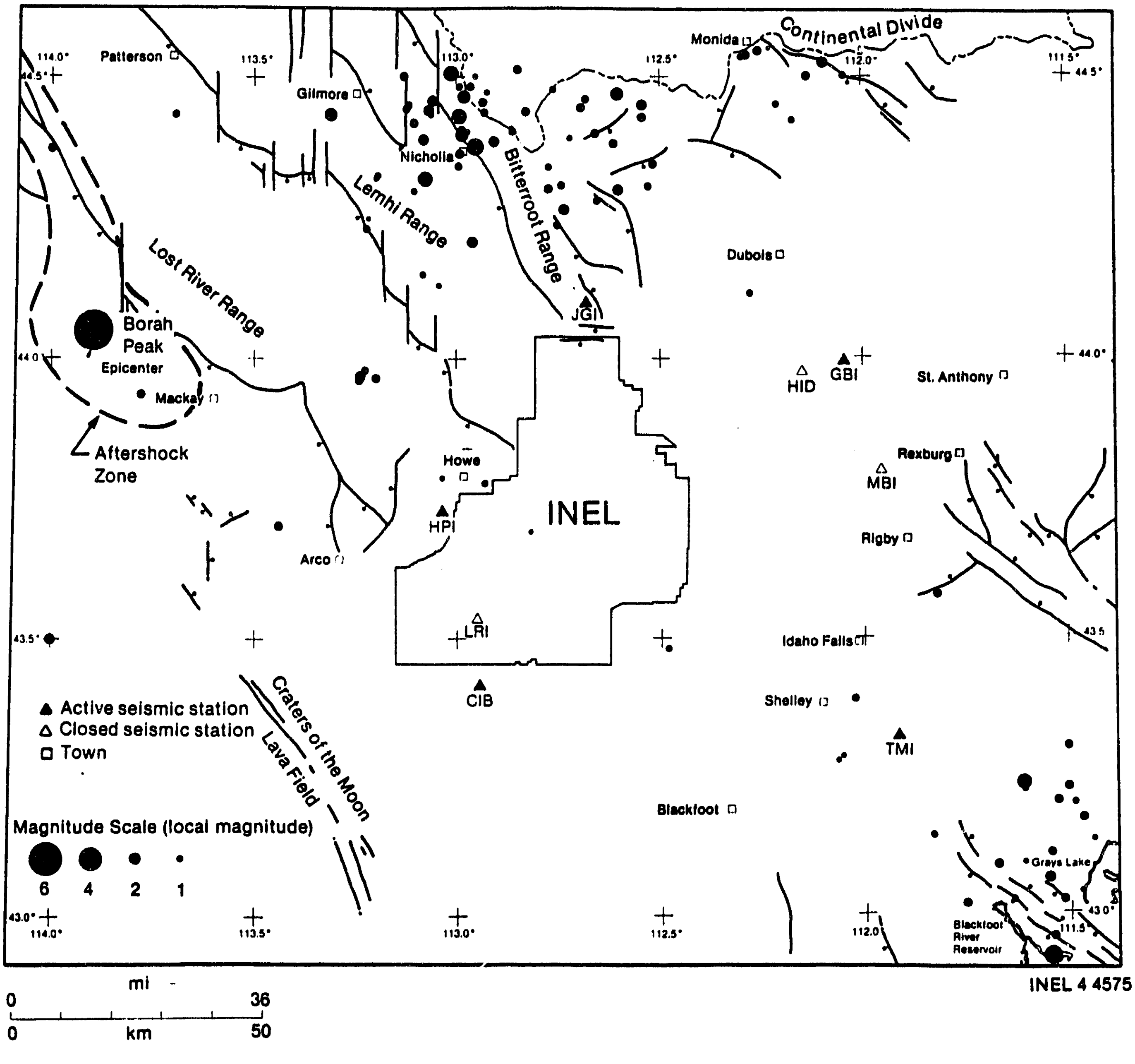

Figure 2-10. Location of earthquake epicenters in the Special Studies Area.

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and from volcanoes. The flows formed layers of hard rock from 3- to 30-m thick. The flows are fractured and fissured. Thus, physical characteristics, such as permeability and horizontal distribution of the flows, vary. Unconsolidated material, cinders, and rock fragments are interbedded with the basalt. The flows are nearly horizontal with no significant structural deformation.

Volcanic structures near and at the INEL Site are shown in Figure 2-11. The Arco Rift Zone is approximately 10-km wide and 48-km long and is the locus of volcanic structures. The youngest basalt flows in the Arco Rift Zone are approximately 10,500- to 12,000-yr old.

Volcanic and sedimentary rocks, perhaps ranging in age from Cambrian to Tertiary, are presumed to underlie basalt beneath the INEL Site. Rhyolitic volcanic rocks, ranging from approximately 4- to 10-million yr old, are exposed along the north and south margins of the eastern Snake River Plain.

A study of the Arco Rift Zone (Kuntz 1978) has led to the conclusion that the region has been active for the last 400,000 yr, that it has been the focus of much of the volcanic activity in the eastern Snake River Plain, and that it is likely to be the site of future volcanic activity. The study also suggests that the mean recurrence interval is 3000 yr for all types of volcanic activity in the Arco-Big Southern Butte area (see the area outlined in Figure 2-11).

Future volcanic occurrences are postulated to be of the same types that currently characterize the Plain. A small but significant number of eruptions have been of the hydromagmatic type. These were moderately violent eruptions that occurred when the molten lava encountered ground water at relatively shallow depths.

The RWMC lies at the edge of the Arco Rift Zone. The two most recent basalt flows at the RWMC are about 50,000- to 100,000-yr old and 60,000-yr old. The volcanic activities were episodic rather than periodic. The average frequency is two to five flows per 70,000 yr.

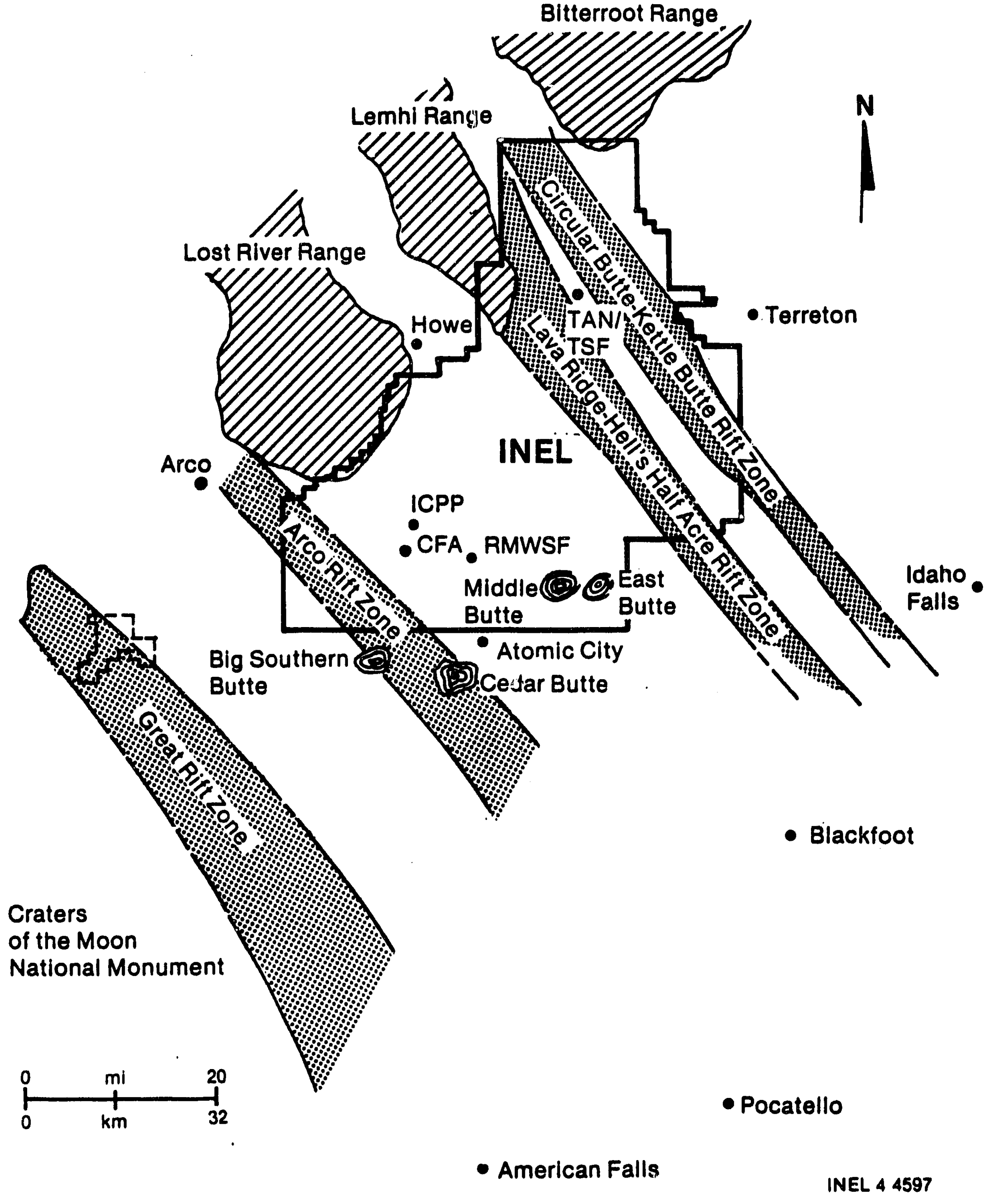

Figure 2-11. Volcanic structures near the INEL.

The most recent volcanic activity in the region occurred about 1500 to 2000 yr ago at the present site of the Craters of the Moon National Monument, approximately 40 km southwest of the RWMC. This area lies in the Great Rift Zone (Figure 2-11).

The estimated probability of a future volcanic eruption within the Arco-Big Southern Butte area with subsequent lava flow over the RWMC is 6 E-5 /yr. This probability corresponds to a recurrence frequency of about once in 20,000 yr in an area where flows could reach the RWMC (EG&G 1983).

2.1.3 Hydrology

2.1.3.1 The INEL. Surface water at the INEL Site comes from streams draining through intermountain valleys to the west and north, localized snowmelt, and rain. Streams entering the INEL Site include the Big Lost River, Little Lost River, and Birch Creek. Flows from the Little Lost River and Birch Creek are diverted for irrigation before reaching the INEL Site. Birch Creek is also diverted for electrical production. Thus, during dry years, water from those streams does not reach the INEL Site. These three drainages terminate in four playas in the north-central part of the INEL Site (Figure 2-12). The INEL Site is not crossed by any perennial streams. All surface outflows are a result of localized runoff.

Except for evaporation, all water from the Big Lost River in the Snake River Plain is recharged to the ground. Water infiltrates from the Big Lost River to the perched ground water beneath the river and into the Snake River Plain aquifer. This infiltration has been significant during wet years. There are zones of perched water, the exact extent and volume of which are not known, near large water sources within the INEL Site.

The Snake River Plain aquifer is a continuous body of ground water that underlies nearly all of the eastern Snake River Plain. Approximately 320-km long and 48- to 97-km wide, it comprises an area of about 25,000 km^2. The

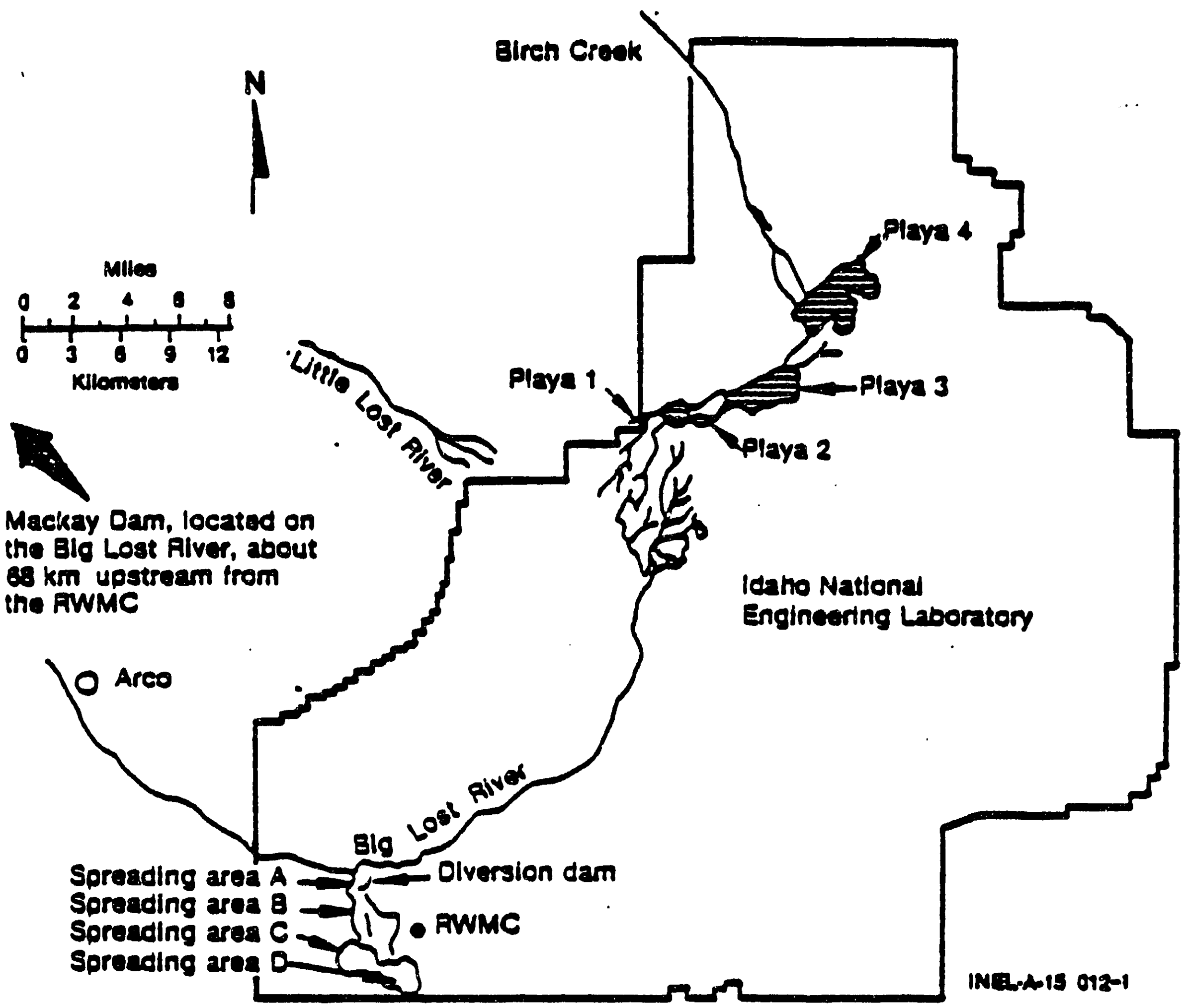

Figure 2-12. Surface water features at or near the INEL.

depth to the aquifer at the INEL Site varies from 61 m in the northern portion to 270 m in the southwest corner. Most of the permeable zones in the aquifer occur along the upper and lower edges of the basaltic flows.

The thickness of the aquifer is diffic lt to estimate. However, based on deep drilling activities at specific locations on the INEL Site in 1978 and 1979, the aquifer may range in thickness from 76 to 400 m.

Ground water in the aquifer flows generally southwest (Figure 2-13). Average and peak flow rates in the aquifer are difficult to assess. Tracer studies at the INEL Site indicate natural flow rates of 1.5 to 6.1 m/day, with an average near 3 m/day. However, these locally measured rates are not necessarily representative of flow rates throughout the aquifer (Robertson et al. 1974).

The aquifer may contain 2500 billion m^3 of water, of which 630 billion m^3 might be recoverable. It discharges about 8.0 billion m^3 annually through springs in the Hagerman area and in the region west of Pocatello. About 1.8 billion m^3 is withdrawn through irrigation well pumpage. The discharges from the springs significantly contribute to the flow of the Snake River downstream of Twin Falls, Idaho.

In addition to providing water for INEL Site operations, the aquifer supplies water for other industries. Water from springs in the Twin Falls-Hagerman area is used to raise fish commercially. The spring water flow of 47 m^3/s constitutes 76% of the water used for the commercial production of fish in Idaho. Most of these fish farms discharge water directly into the Snake River.

In the aquifer flow path, a stock-watering well is located 16 km from the RWMC and a domestic well at 29 km.

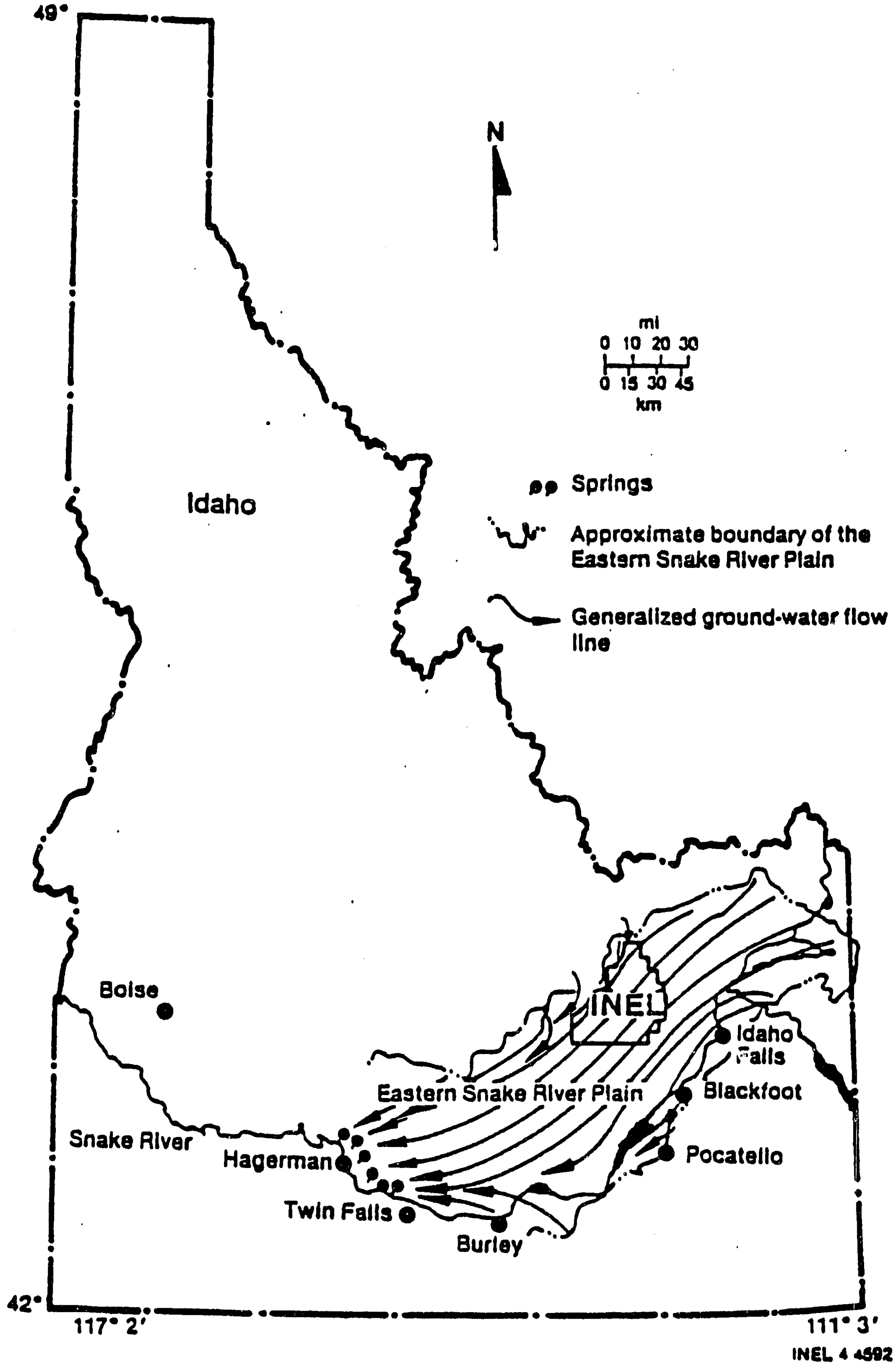

Figure 2-13. Location of generalized ground water flow lines hypothesized for the Snake River Plain aquifer.

2.1.3.2 The RWMC

2.1.3.2.1 Surface--The most important element of the surface water hydrology near the RWMC is the Big Lost River, which is 3 km northwest of the RWMC at its nearest point. A flood-control system was constructed on the Big Lost River in 1958. This system consists of earth-filled embankments that can divert part of the flow to four spreading areas near the southwestern corner of the INEL Site during periods of high runoff or flooding (Figures 2-13 and 2-14). During winter months, nearly all flow is diverted from the river channel to avoid accumulation of ice in the main channel downstream. The recharge of the aquifer from these spreading areas forms mounds in the ground water level and this, coupled with the upthrusted Big Southern Butte, can cause localized flow reversals in the aquifer. Flow reversals would influence the distribution of contaminants if any were introduced into the aquifer from the RWMC. Further details on the regime and hydraulics of the river near the RWMC are available (Lamke 1969).

Since the flood-control system was constructed, the largest runoff of the Big Lost River occurred in 1984. During this period, portions of the spreading areas were filled. If an exceptionally large runoff occurs, water would leave the spreading area over a weir and flow out of the INEL Site. This has not occurred since the system was built.

The effectiveness of the flood-control system has been evaluated by the USGS by means of mathematical models (Carrigan 1972). The results indicate that floods in the Big Lost River would overflow the embankments on the average of once every 55 yr. If the capacity of the diversion channels leading to the spreading area were doubled, the diversion embankments would be able to contain a flood with an expected average return period of 300 yr. In 1984, the flood-control system dikes were raised 6 ft. The diversion capacity is now 9300 ft^3/s. This represents about three times the flow that would overflow the embankments before the enlargement.

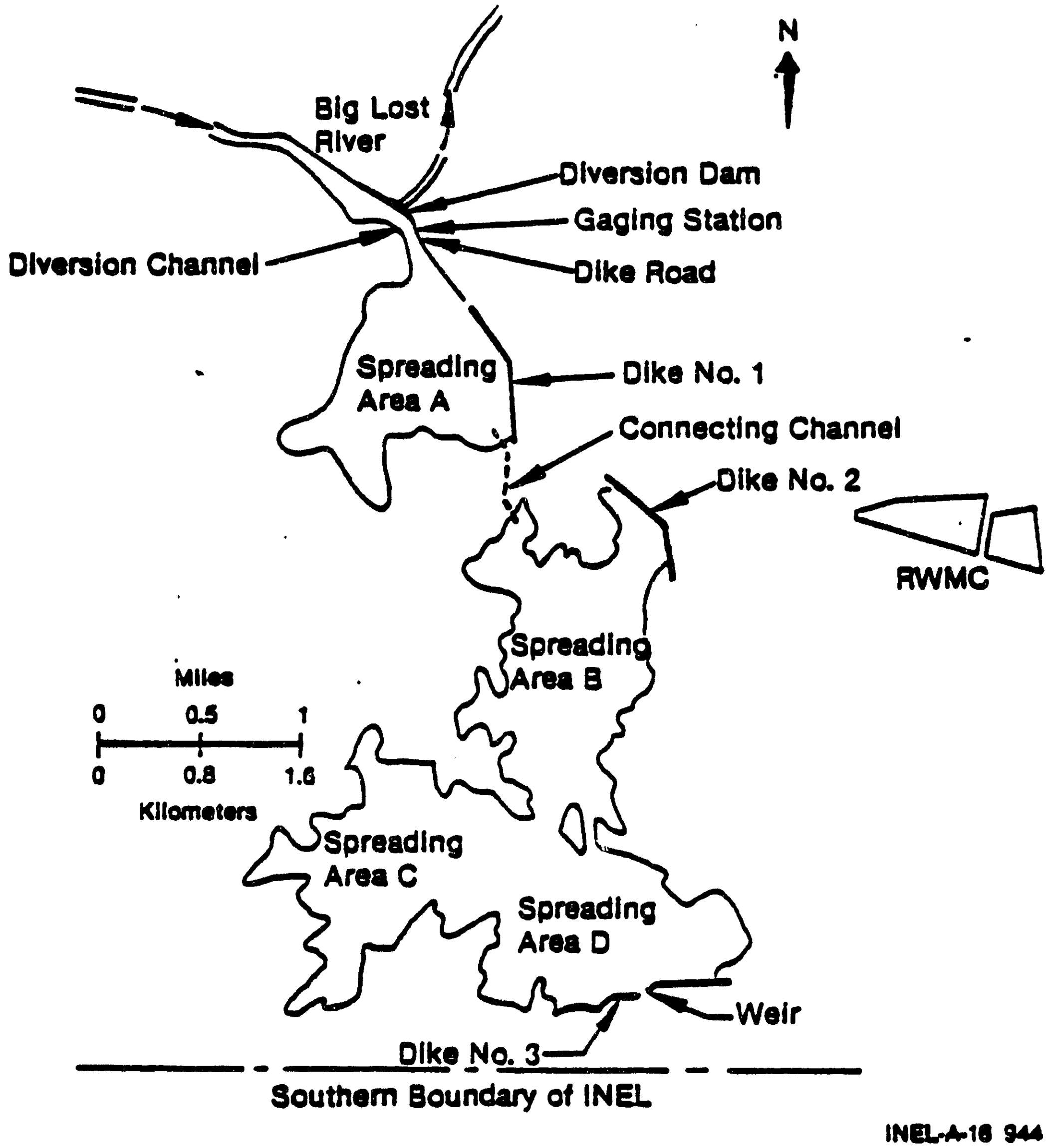

Figure 2-14. Map of the flood-control diversion system.

Surface water, in the form of snowmelt and runoff, is usually present at the RWMC for only a short period in the spring. However, in 1962 and again in 1969, unusually rapid snow melting and rain caused local flooding at the RWMC. The floodwater came in contact with buried TRU and other waste in partially filled pits and trenches. The diking system was then enlarged to protect the RWMC from runoff in the local drainage basin. The improved dikes and ditches were designed to withstand a major local flood even in the presence of deep snow drifts.

In 1971, the RWMC was graded to provide drainage channels for surface water. An outlet pipe with a flap valve was placed through the dike in the northeast corner of the RWMC to allow water to flow out and to prevent outside water from entering.

On February 12, 1982, a warm front characterized by strong winds and heavy rains moved into the RWMC area. Rapid thawing of snow over frozen ground resulted in localized snowmelt runoff. On February 17, a culvert became blocked with snow and ice in the southeast corner of the SDA. This blockage resulted in overtopping the peripheral dike. Water flowed into Pit 16, leaving 0.5 m of water in the north end of the pit and 1.2 m of water in the south end of the pit. Subsidence and cracking of the soil allowed water to seep into trenches 42 and 49.

Numerous flood-control measures were taken in the vicinity following the flooding in February 1982. The drainage channel inside and outside the SDA was widened. Culverts were installed in the road between the SDA and the dry lake bed south of the SDA, and the southeastern SDA culvert was removed. A second sump pump was moved from the SDA north fence (east of the Early Waste Retrieval site) and was installed in the SDA beside the sump pump near the east SDA fence (south of the access road). The second sump pump doubles the pumping capacity in the SDA. An additional emergency, forklift-portable sump pump was procured. Moisture-exclusion soil was placed and graded over disposed waste. In the spring of 1984 flood control Dike No. 1 was raised 1.8 m and Dike No. 2 was raised 2.4 m. Rock rip-rap was placed on both dikes.

2.1.3.2.1 Subsurface--The depth to the Snake River Plain aquifer at the RWMC is approximately 177 m. A geologic cross-section of the RWMC, indicating the depth to the aquifer and sedimentary layers, is shown in Figure 2-6.

At the RWMC, evidence of perched water has been found at depths from 9.1 to 70 m (Robertson et al. 1974, Humphrey and Tingey 1978, and Humphrey 1980).

2.1.4 Ecology

In 1975, the INEL Site was dedicated as one of five DOE National Environmental Research Parks (NERPs). It is an outdoor laboratory used to study ecological relationships and the effects of man's activities on natural systems. In addition, it provides a unique setting for scientific investigation because the public has been excluded from much of the area for the past 25 yr. Ecological data collected from the Idaho NERP provide a basis for analyzing environmental changes over time and assessing the effect of man's influence on the environment.

Research on the flora and the fauna of the INEL Site has largely been conducted by, or in conjunction with, the DOE's Radiological and Environmental Sciences Laboratory (RESL). The physical aspects of the INEL Site and its flora and fauna are typical of cold, high, sagebrush ecosystems found in many parts of the western United States.

2.1.4.1 Flora

The common and scientific names for the flora discussed here are presented in Table 2-2. For ease of reading, only the common names will be used in this discussion.

Extensive surveys of INEL vegetation were carried out in 1952, 1958, and 1967 using 150 permanent transects established and maintained for this purpose (Harniss and West 1973). Vegetation has also been described by McBride et al. (1978) and Jeppson and Holte (1978).

Table 2-2. Flora at the INEL Site[a]

Common Name	Latin Name
Cactus Family--Cactaceae	
Coryphantha	Coryphantha sp.
Prickly pear cactus	Opuntia polyacantha
Goosefoot Family--Chenopodiaceae	
Shadscale saltbush	Atriplex confertifolia
Nuttall saltbush	Atriplex nuttallii
Winterfat	Ceratoides lanata
Summer cypress	Kochia scoparia
Povertyweed	Monolepsis nuttalliana
Russian thistle	Salsola kali
Composite or Aster Family--Compositae	
Big sagebrush	Artemisia tridentata
Threetip sagebrush	Artemisia tripartita
Hoary false-yarrow	Chaenactis douglasii
Green rabbitbrush	Chrysothamnus viscidiflorus
Skeleton weed	Lygodesmia grandiflora
Common dandelion	Taraxacum officinale
Gray horsebrush	Tetradymia canescens
Goatsbeard or yellow salsify	Tragopogon dubius
Mustard Family--Cruciferae	
Flixweed tansy mustard	Descurainia sophia
Grass Family--Gramineae	
Crested wheatgrass	Agropyron cristatum
Bluebunch wheatgrass	Agropyron spicatum
Cheatgrass	Bromus tectorum
Giant wildrye	Elymus cinereus
Indian ricegrass	Oryzopsis hymenoides
Bottlebrush squirreltail	Sitanion hystrix
Rush Family--Juncaceae	
Baltic rush	Juncus balticus

Table 2-2. (continued)

Common Name	Latin Name
Pea Family--Leguminosae	
Painted milkvetch	Astragalus ceramicus Sheld. var. apus Barneby
Thistle milkvetch	Astragalus kentrophyta Gray var. kentrophyta
Woolly-pod milkvetch	Astragalus purshii Dougl. var. ophiogenes Barneby
Phlox Family--Polemoniaceae	
Large-flowered gymnosteris	Gymnosteris nudicaulis Greene
Longleaf phlox	Phlox longifolia
Buckwheat Family--Polygonaceae	
Buckwheat	Oxytheca dendroides[a], Nutt.
Willow Family--Salicaceae	
Willows	Salix sp.
Parsley Family--Umbelliferae	
Desert parsley	Lomatium sp.

a. This information is based on Hitchcock and Cronquist (1974).

The common vegetation type, found on approximately 80% of the INEL Site, is a mixture of big sagebrush, green rabbitbrush, and perennial forbs. Most of the trees on the INEL Site are scattered along the Big Lost River and in the Twin Buttes area. The INEL Site vegetation types are shown in Figure 2-15.

Vegetation in low-lying areas and along playa borders consists primarily of alkaline-tolerant species including shadscale saltbush, nuttal saltbush, and winterfat. Important associated grasses are bottlebrush squirreltail, giant wildrye, and Indian ricegrass.

Prickly-pear, painted milkvetch, and skeletonweed are common in sandy areas in the north. Willows, baltic rush, and povertyweed grow along the Big Lost River channel.

At the RWMC, most of the SDA has been seeded with crested wheatgrass. Russian thistle, summer cypress, and halogeton (invader species) grow over many recently disturbed sites that were not seeded with wheatgrass. Other plants observed within the SDA include threetip sage, tansy mustard, common dandelion, bushy birdsbeak, cheatgrass, rabbitbrush, desert parsley, longleaf phlox, gray horsebrush, hoary false yarrow, and goatsbeard.

Knowledge of the rooting depth of SDA vegetation is important in evaluating which plants should be used for reseeding and which should be monitored for radionuclide concentrations. One SDA study comparing radionuclide uptake by crested wheatgrass (rooting depth 75 cm) with that by Russian thistle (rooting depth 1 to 5 m) showed higher radionuclide concentrations in the deeper-rooted species (Arthur 1982). Examples of other deep-rooting species are rabbitbrush and sagebrush. General examples of shallow-rooting plant types are grasses and annual forbs.

A survey of rare plants on the INEL Site was initiated in 1981 (Cholewa and Henderson 1984). To date, the survey has identified the following: painted milkvetch and woolly-pod milkvetch (under Federal review for endangered or threatened status); coryphantha, large-flowered gymnosteris, and oxytheca (on the Idaho State Watch List); and thistle milkvetch, which

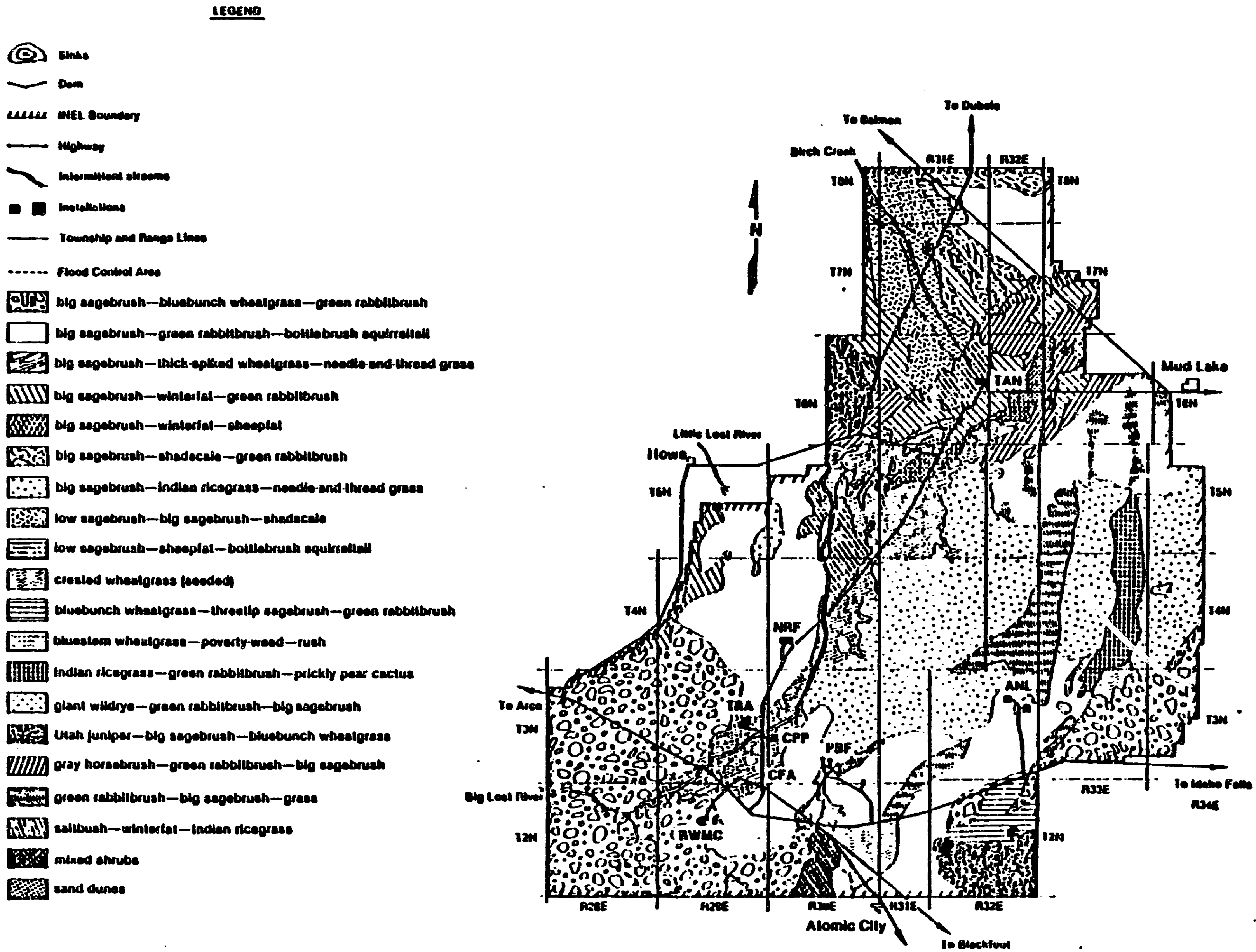

Figure 2-15. INEL vegetation map.

was previously unknown to occur in Idaho. The study is continuing, and actual and potential threats to the rare plant species on the INEL Site are being evaluated.

Total vegetative biomass in the SDA was estimated as 36,300 kg, of which crested wheatgrass and Russian thistle comprised 27,200 and 8,100 kg, respectively.

2.1.4.2 Fauna

The INEL Site supports a variety of wildlife including small mammals, birds, reptiles, and a few large mammals. The common and scientific names for the fauna discussed here are presented in Table 2-3. For ease of reading, only the common names will be used in this discussion.

The small mammals include chipmunks, ground squirrels, several species of mice, kangaroo rats, cottontail rabbits, and jackrabbits. Pronghorn inhabit the INEL Site during the entire year; however, many are migratory and summer to the north of the INEL Site. Pronghorn often bear young within the INEL Site, and Coyotes and bobcats live on the INEL Site.

Aquatic life on the INEL Site is limited and depends mainly upon the flow of the Big Lost River. During several months of the year, and even during some entire years, the river does not flow. However, during spring runoff and periods of high rainfall, the diversion system (southern boundary of the INEL Site) and the Big Lost River sinks (northern boundary of the INEL Site) support water flow during periods of water accumulation. This normally occurs less than 2 or 3 months in the spring; however, depending on annual conditions, water flow and accumulation may occur over much of the year.

Fish species observed in the Big Lost River on the INEL Site include rainbow trout, mountain whitefish, eastern brook trout, dolly varden char, Kokanee salmon, and the shorthead sculpin (Overton et al. 1976).

An investigation of amphibians and reptiles within the INEL was conducted from May through September 1975. The Great Basin spadefoot toad

Table 2-3. Fauna at the INEL Site

Common Name	Latin Name
Fish[a]	
Rainbow trout	Salmo gairdneri
Eastern brook trout	Salvelinus fontinalis
Dolly varden char	Salvelinus malma
Kokanee salmon	Oncorhynchus nerka
Mountain whitefish	Prosopium williamsoni
Shorthead sculpin	Cottus confusus
Reptiles and Amphibians[b]	
Leopard frog	Rana pipiens
Great Basin spadefoot toad	Spea intermontanus
Leopard lizard	Gambelia wislizenii
Sagebrush lizard	Sceloporus graciosus
Short-horned lizard	Phrynosoma douglassi
Western skink	Eumeces skiltonianus
Desert striped whipsnake	Masticophis taeniatus
Great Basin gopher snake	Pituophis melanoleucus
Terrestrial garter snake	Thamnophis elegans
Great Basin rattlesnake	Crotalus viridis
Mammals[c]	
Family--Canidae	
Coyote	Canis latrans
Family--Felidae	
Bobcat	Lynx rufus
Family--Antilocapridae'	
Pronghorn	Antilocapra americana
Family--Cervidae	
Mule deer	Odocoileus hemionus
Elk	Cervus canadensis
Birds[d]	
Family--Accipitridae	
Golden eagle	Aquila chrysaetos
Ferruginous hawk	Buteo regalis
Bald eagle	Haliaeetus leucocephalus

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Table 2-3. (continued)

Common Name	Latin Name
Family--Falconidae	
Merlin	Falco columbarius
Prairie falcon	Falco mexicanus
Peregrine falcon	Falco peregrinus
Family--Phasianidae	
Sage grouse	Centrocercus urophasianus
Family--Scolopacidae	
Long-billed curlew	Numenius americanus
Family--Strigidae	
Burrowing owl	Athene cunicularia
Family--Columbidae	
Mourning dove	Zenaida macroura
Family--Mimidae	
Sage thrasher	Oreoscoptes montanus
Family--Tyrannidae	
Say's phoebe	Sayornis saya
Family--Alaudidae	
Horned lark	Eremophila alpestris
Family--Emberizidae	
Western meadowlark	Sturnella neglecta
Sage sparrow	Amphispiza belli
Brewer's sparrow	Spizella breweri

a. Based on Simpson and Wallace 1978.
b. Based on Nussbaum et al. 1983.
c. Based on Jones et al. 1979.
d. Based on American Ornithologist's Union (1983).

was the only amphibian recorded; however, evidence indicates that the leopard frog may be an occasional resident (Sehman and Linder 1978). The sagebrush lizard and the short-horned lizard are common; the sagebrush lizard is the most abundant reptile. The western skink and the leopard lizard have also been observed. Four species of snakes, including the Great Basin rattlesnake and Great Basin gopher snake, were recorded. The western terrestrial garter snake and the desert striped whipsnake are present in lesser numbers and have more restricted distributions.

A total of 740 insect species have been recorded at the INEL Site; 227 of these species have not yet been identified beyond the family level. The majority of the abundant species belongs to the orders Hymenoptera and Diptera. About half of the abundant species are parasitic or predatory.

Birds are an integral component of the Great Basin ecosystem. Over 150 species of birds have been recorded on the INEL Site. Of these, about 60 species probably breed on the INEL Site. However, many of the bird species are relatively uncommon on the INEL, and only a few species are very abundant. The most common species on the INEL Site are the Brewer's Sparrow, sage thrasher, sage sparrow, horned lark, sage grouse, mourning dove, Say's phoebe, and western meadowlark (Arthur et al. 1984).

Species on the INEL Site that merit special consideration because of their sensitivity to disturbance or their threatened status include the ferruginous hawk, golden eagle, prairie falcon, merlin, long-billed curlew, and burrowing owl. The bald eagle and peregrine falcon are on the Federal Endangered Species List and occasionally visit the INEL Site.

Commonly occurring game animals are sage grouse, mourning dove, pronghorn, and mule deer. Limited data are available on the number of game animals seasonally inhabiting the INEL Site and on the harvest of these animals by hunters.

Radioecological research was initiated at the SDA in October 1977 to determine the role of ecological components in radionuclide uptake and transport throughout the RWMC area. This ongoing research is being directed by RESL.

Initial research efforts, directed toward determining the seasonal and relative abundance and distribution of wildlife at the RWMC, identified 34 species of vertebrates (Arthur and Markham 1978, Keller 1978, Groves 1978). The results of those studies indicated that cottontail rabbits, deer mice, montane voles, kangaroo rats, and pocket mice were the primary species inhabiting the SDA. Thus, subsequent ecological studies focused on those species.

Subsequent studies have evaluated small mammal species composition, diversity, local movements, and densities (Groves and Keller 1983); small mammal radiation doses (Arthur et al. 1986); the effects of chronic radiation exposure on small mammals inhabiting the SDA (Evenson 1981); radionuclide concentration in coyote feces (Arthur and Markham 1982); and radionuclide concentrations in vegetation (Arthur 1982).

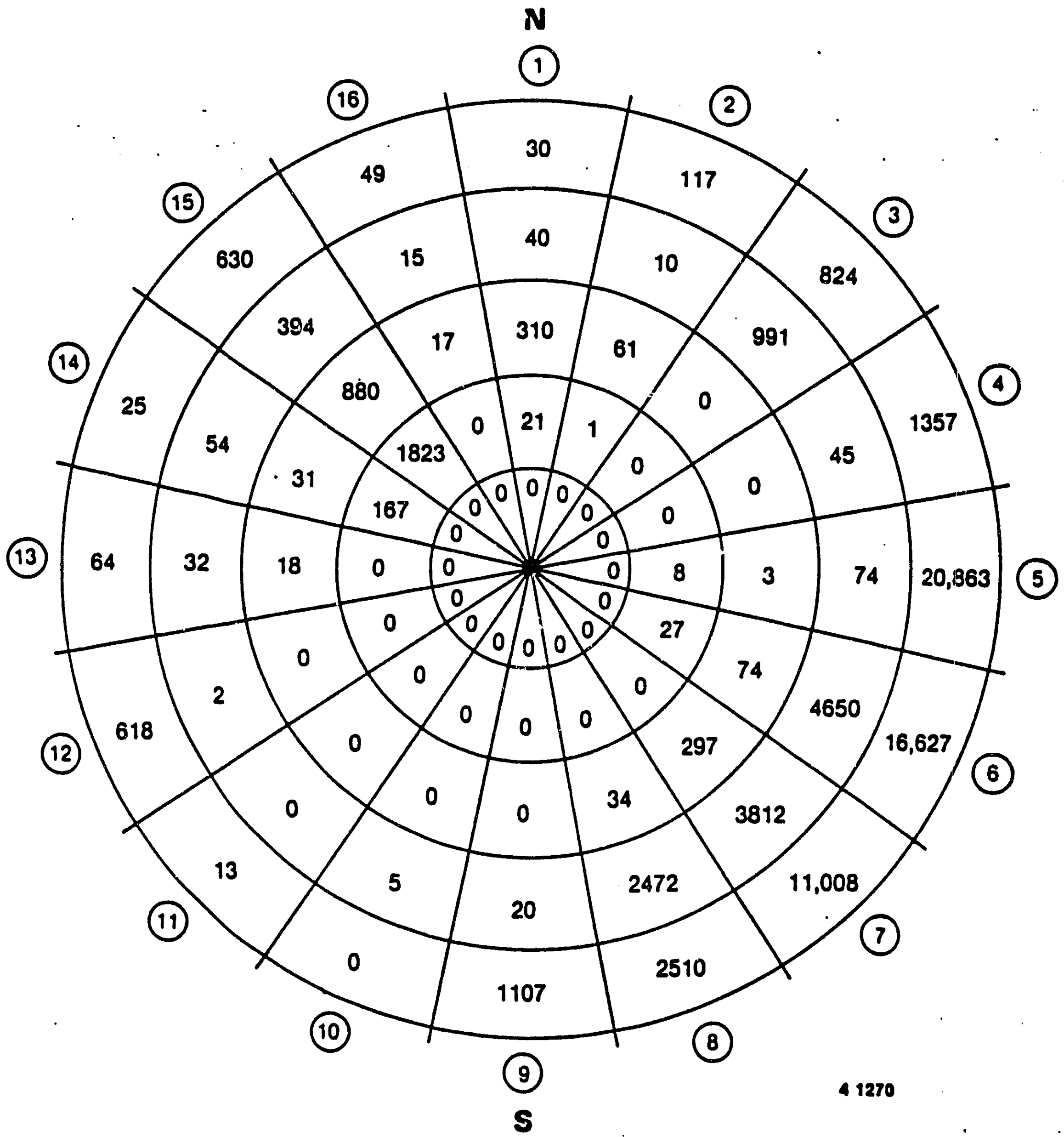
2.1.5 Demography

The distribution of population around the INEL Site is shown in Figure 2-16 by distance and direction from the RWMC. This figure shows the population distribution centered at the RWMC based on 1980 census data.

The nearest town is Atomic City, which is less than 1.5 km from the southern boundary and has about 35 residents. In 1980, the population residing within an 80-km radius was 72,226. The larger towns within 80 km are shown in Figure 2-17. The populations of those towns having more than 300 inhabitants are given in Table 2-4.

The growth characteristics of the cities and towns around the INEL Site are similar to those of the rest of the State. There is a distinct pattern of population increase in areas just outside cities, where more land is provided with each house than in towns. Idaho Falls, Blackfoot, and Pocatello are growing faster than the towns in the immediate vicinity of the INEL Site.

RWMC



Total Population: 72,226

Figure 2-16. Population distribution centered at the RWMC based on 1980 census data.

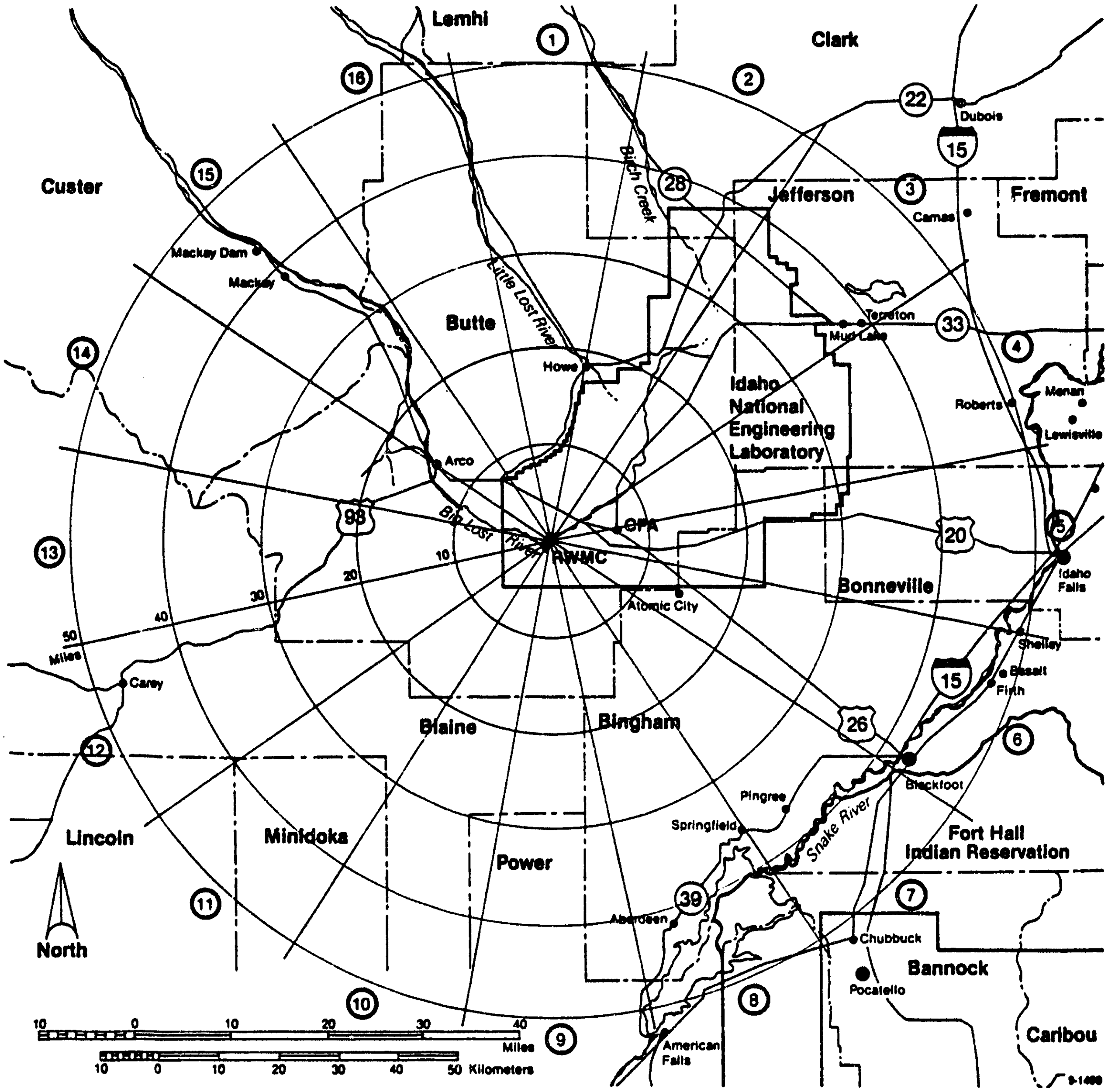


Figure 2-17. INEL vicinity map centered on the Central Facilities Area.

Table 2-4. City population within 80 km of the Central Facilities Area

City[b]	Population[a] 1970	1980
Aberdeen	1,542	1,528
American Falls[c]		3,626
Arco	1,244	1,241
Basalt	349	414
Blackfoot	8,716	10,065
Chubbuck	2,927	7,052
Firth	362	460
Idaho Falls[c]	35,776	39,739
Mackay	539	541
Roberts	393	466
Shelley	2,674	3,300

a. Source: 1970 U.S. Census and 1980 revised U.S. Census data (DOE 1987).
b. Cities with more than 300 inhabitants.
c. Portions of these communities are outside the 80-km radius.

There are no permanent residents at the INEL Site. The work force at the INEL Site varies depending on the levels of construction and research being performed at each of the facilities. Table 2-5 shows the INEL work force distribution for each INEL Site facility, based on 1989 employment data.

A survey taken in 1980 indicated that approximately 52% of the INEL employees lived in Idaho Falls. The remainder live in Ammon, Blackfoot, Pocatello, Shelley, Rigby, Rexburg, and other communities surrounding the INEL Site.

2.1.6 Land Use

The INEL Site has been committed for energy research and development and is designated a NERP. Approximately 95% of the land in the INEL Site has been withdrawn from the public domain. The remainder is owned and controlled by the DOE.

Existing facilities on the INEL Site lands are widely spaced for increased safety. They occupy a very small percentage of the available land.

Approximately 1335 km^2 of the INEL Site are open to controlled grazing by cattle or sheep (Figure 2-18). Those grazing areas are mutually agreed on by the DOE and the Department of the Interior, and grazing permits are administered through the Bureau of Land Management. Grazing is prohibited within 3 km of any nuclear facility, and no dairy cows are allowed. Because cattle occasionally wander to the edge of the RWMC, waste storage and disposal areas are fenced to exclude them.

Other uses of the land are limited because of the climate, lava flows, and general desert soil characteristics. The only lands suitable for farming are near the end of the Big and Little Lost Rivers, near the town of Howe, and at a distance 13 km southeast from Howe. Arable land (with

Table 2-5. INEL work force distribution as of June 1989

Facility	Total Employees[a,b]
Test Area North	727
Naval Reactor Facility	2734
Argonne National Laboratory-West	747
Waste Experimental Reduction Facility Special Power Excursion Reactor Test, and Power Burst Facility	129
Central Facilities Area	1129
Idaho Chemical Processing Plant	1564
Test Reactor Area	545
Radioactive Waste Management Complex	108
TOTAL	7683

a. Values are for employees working within INEL Site boundaries, Figure 2-1, including construction workers.
b. Does not take into account day shift versus night shift.

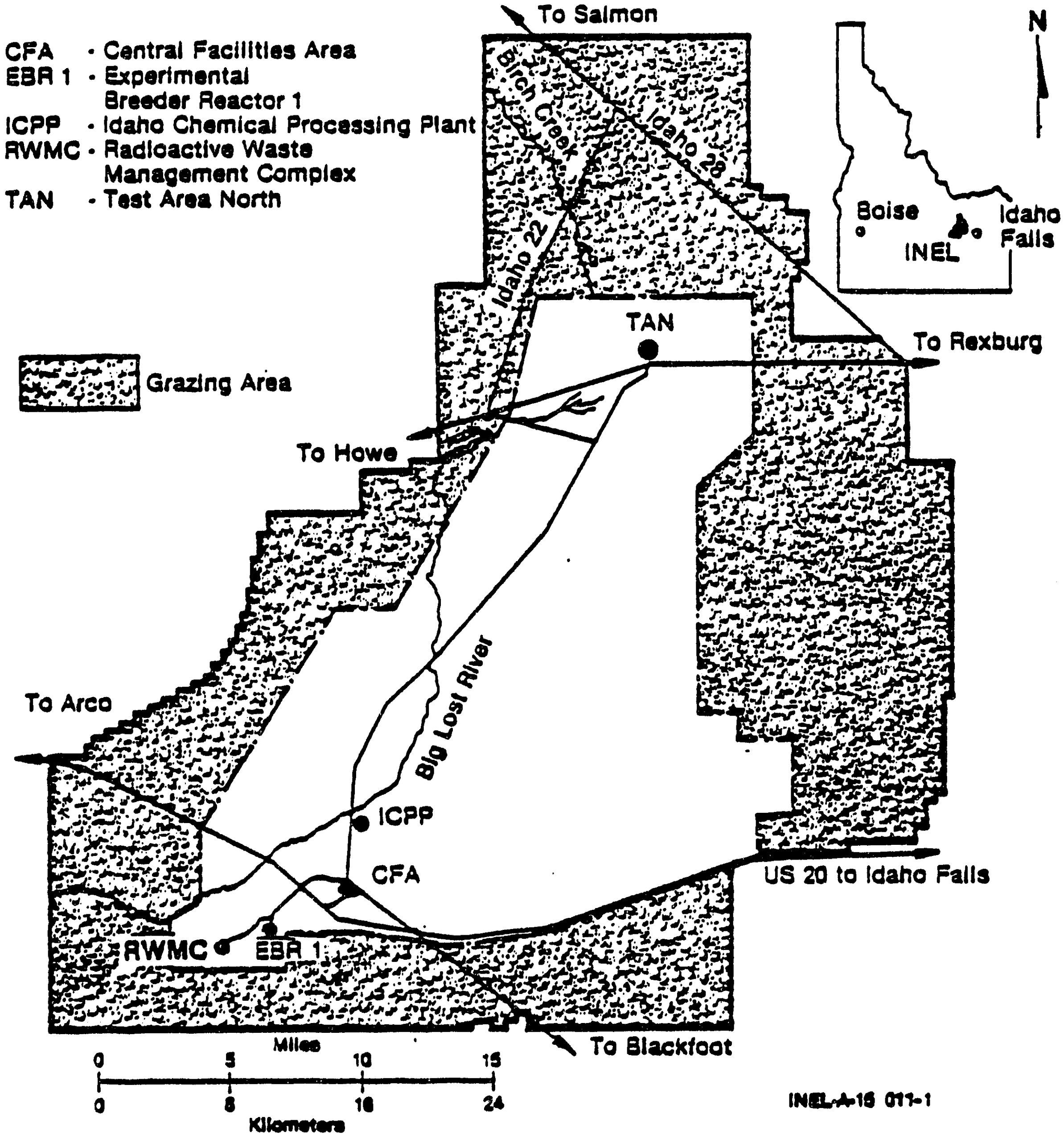


Figure 2-18. Grazing permit areas within the INEL.

moderate irrigation) is present on both sides of the Big Lost River and between Mud Lake and Howe.

The remainder of the INEL Site, approximately 65% of the surface area, has a low water-holding capacity, is rocky or covered with basalt, or is classified as having moderate-to-severe limitations for agricultural irrigation.

The Office of Budget and Policy Planning, State of Idaho, indicated that the State does not have plans or policies specifically related to land use either adjacent to, or within the boundaries of, the INEL Site. The East-Central Idaho Planning and Development Association is a regional economic planning agency serving a nine-county region, most of which encompasses the INEL Site. Like the State of Idaho, the Association does not have any policies or plans that involve lands or activities near the INEL Site . Butte County, which encompasses most of the INEL Site land, is sparsely populated. Because the county does not have a policy plan, comprehensive plan, or zoning ordinance, no plans or policies specifically related to land use are available.

Possible future uses of land at the RWMC are discussed in connection with radionuclide release scenarios in a later chapter.

2.1.7 Archaeology

Archaeological surveys of the INEL Site were performed during 1967 to 1969 and again from 1970 to 1972. These surveys have uncovered evidence that man has been in eastern Idaho for perhaps 10,000 to 12,000 yr.

Fossils of prehistoric mammals have been found in excavations at the INEL. It is postulated that the fossils are from camels and mastodons that inhabited the region during the latter part of the Pleistocene Epoch, about 35,000 yr ago. One fossil taken from carbonaceous strata below the surface is over 40,000-yr old. Areas of special archaeological interest have been identified outside the west and northwest boundaries of the RWMC.

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2.2 RWMC Description and Waste Characteristics

The RWMC includes the 35.6-ha SDA, the 22.7-ha TSA, and the Administrative Area. Within the SDA and TSA areas are smaller specialized disposal and storage areas. Solid waste is routed to the different areas depending on the waste's content. All LLW received at the RWMC is buried in the SDA. The layout of the RWMC areas and facilities is shown in Figure 2-19.

2.2.1 History of Waste Management at the RWMC

This section reviews past practices of waste management at the RWMC.

2.2.1.1 Original Burial Ground (1951-1957). In 1951, the AEC and the USGS selected a site for evaluation as a waste disposal area. An area of 40.5 ha near the southwestern corner of the INEL Site was chosen. After drilling 10 exploratory holes in the area and analyzing core samples, the USGS found acceptable geologic and hydrologic conditions. Some of these conditions were

- Several feet of clay sediment to slow water movement and to absorb nuclides
- Sufficient sediment in the vicinity for fill and cover
- An area not directly upstream from existing or potential reactor sites or other places where water production wells may be drilled

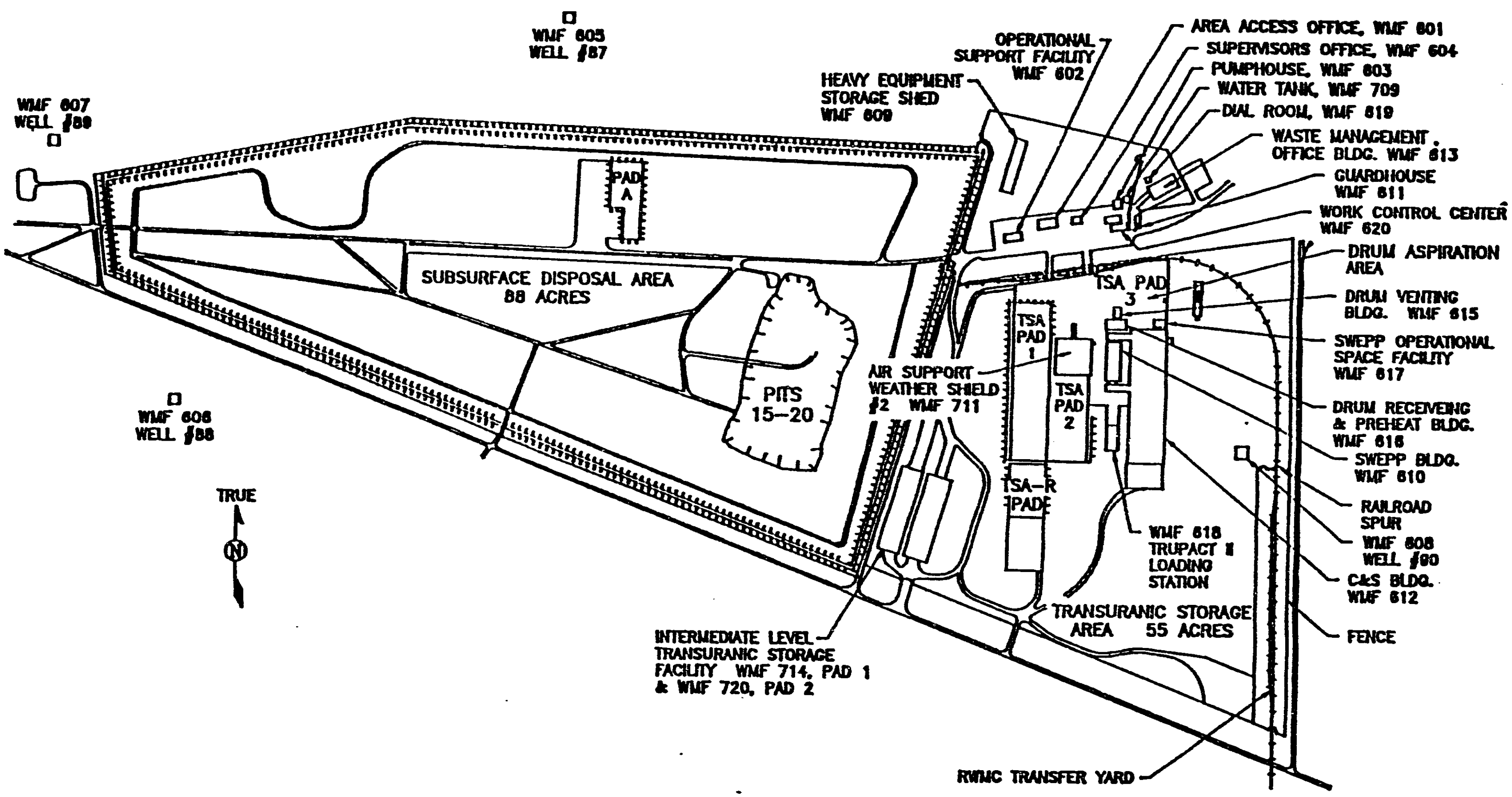

Figure 2-19. Layout of the RWMC areas and facilities.

- Good surface drainage leading away from existing or potential installations or water production sites.

In 1952, development of the SDA was started on a 5.3-ha tract of the 40.5-ha site. That same year the first shipments of radioactive waste from the INEL were received and buried in trenches at the SDA. This initial work was the beginning of the RWMC. The management of the RWMC was then the responsibility of the Site Survey Branch, Health and Safety Division, of the AEC-Idaho Operations Office (AEC-ID). The National Industrial Maintenance Company (NIMCO) conducted burial operations in 1952 and part of 1953. NIMCO was succeeded in 1953 by the Phillips Atomic Energy Company, a subsidiary of Phillips Petroleum Company (PPCo), which continued burial operations.

Generally, the waste received from 1952 through 1957 was buried in trenches. On July 8, 1952, the first trench was opened for the waste generated at the INEL Site . Between 1952 and 1957, Trenches 1 through 10 were excavated to basalt. Pits were also excavated starting in 1957 because of the large size of some containers and the amount of waste being received. The onsite low-level solid radioactive waste was placed in cardboard boxes and sealed with tape. The sealed boxes were placed in metal Dempster Dumpsters that were labeled and used only for radioactive waste. The dumpsters were transported to the SDA, and the waste was dumped into the pits or trenches. LLW was periodically covered with soil. Waste that could cause excessive personnel exposure was transported in special containers and transfer vehicles to reduce worker exposure. That waste was deposited into the trenches and was immediately covered with soil.

In 1953, the AEC decided that solid radioactive waste from the Rocky Flats Fabrication Facility near Golden, Colorado, would be sent to the RWMC. The first shipment of Rocky Flats waste was authorized in March of 1954. This shipment was a trial run to provide (a) handling and shipping experience and (b) cost information to compare with alternative disposal methods. The first drums containing TRU waste from Rocky Flats waste arrived on April 22, 1954. The trial run proved that such shipments could be handled satisfactorily, and the AEC authorized the shipment of Rocky Flats waste to the INEL. Between April 1954 and November 1957, the waste from Rocky Flats was interspersed with INEL waste in Trenches 1 through 10. In 1957, Rocky Flats waste destined for the pits was packed in steel 30- or 55-gal drums or, if bulky, in wooden crates. Waste arrived by railcar at the CFA and was then transferred to the SDA via truck. The drums were hand-stacked in the pit. The wooden crates were lifted from the trailer by crane and stacked around the edges of the pit. The waste in the pits was covered with soil periodically but on no set schedule.

2.2.1.2 Expanded SDA (1957-1970). The original 5.3-ha SDA was nearly filled by 1957. The SDA was then expanded to its present size, encompassing 35.6 ha of the original site evaluated by the USGS. The expansion was to the immediate east and south of the original area. The expansion also enclosed an acid pit that had been used for disposal of nonradioactive laboratory acids since January 1, 1954.

Trenches were used for the disposal of LLW and special waste. The Rocky Flats waste was placed in the pits because of the large volume being received and the low radiation level. Between May 1960 and August 1963, the RWMC served as an interim burial ground for waste generated by AEC licensees. Waste from a number of offsite generators was received. In October 1962, the responsibility for the RWMC was transferred from the Site Survey Branch, AEC-ID, to the PPCo, which had been acting as the AEC-ID agent in operating the RWMC. Beginning in November 1963, Rocky Flats waste was no longer stacked; it was dumped in pits to reduce labor costs and minimize personnel radiation exposures. Random dumping continued until 1969. In 1966, the Idaho Nuclear Corporation (INC) took over from PPCo. INC, a joint subsidiary of Aerojet-General Company and Allied Chemical Corporation, assumed responsibility for the RWMC.

Numerous changes in waste-handling practices took place from 1966 to 1970. The minimum required soil cover over buried waste was increased from 0.6 to 0.9 m. Minimum trench depth for future trenches was increased from 0.9 to 1.5 m. A heavy metal plate was dropped onto waste in trenches to compact the waste. Stacking of the waste containers within trenches and pits in the SDA was reinstated in 1969. In 1958, a flood control project was constructed on the Big Lost River adjacent to the RWMC to protect downstream INEL facilities and to protect the RWMC from flood waters. The project involved construction of a diversion dam and spreading areas for runoff water. The diversion system was later enlarged to protect the RWMC from runoff in the local drainage basin.

2.2.1.3 <u>SDA and TSA (1970-present)</u>. On March 20, 1970, the AEC issued Immediate Action Directive No. 0511-21, "Policy Statement Regarding Solid Waste Burial." That policy required segregation of all waste contaminated with TRU nuclides and storage of that waste to permit retrieval of contamination-free waste containers for 20 yr. In support of the directive, a decision was made to store and cover TRU waste aboveground on pads. The 22.7-ha TSA was established at the RWMC for storage; thus, the RWMC was expanded to its present size, 58.3-ha. In 1971, Aerojet Nuclear Company (ANC) replaced INC as the operations contractor for the RWMC. In 1976, EG&G Idaho, Inc., replaced ANC as the INEL prime contractor and assumed responsibility for operating the RWMC. A change in disposal methods for LLW occurred early in the 1970s with the beginning of waste volume reduction by compaction. Since then, radioactive waste has been separated into compactible and noncompactible waste. Early in the 1970s, the Naval Reactor Facility (NRF) began compacting waste, reducing the volume of compactible waste by approximately 10:1. In 1974, a hydraulic bale-type compactor (like the NRF compactor) was installed in the Waste Volume Reduction Facility (WVRF) at the RWMC to reduce the volume of INEL waste. The volume reduction varies because of the heterogeneous mixture of compactible waste. INEL-generated, compactible LLW was placed in polyethylene bags, deposited in dumpsters designated for this type of waste, and transported to the RWMC. At the WVRF, the waste was compacted into plastic-lined cardboard bales, which were steel-banded, wrapped in plastic, and placed in a disposal pit. This operation was transferred to WERF in 1986.

2.2.2 Description of the SDA

The SDA is a fenced, 35.6-ha area on the western part of the RWMC. Included in the SDA are pits, trenches, soil vault rows (SVRs), and Pad A, all of which have been used to dispose of LLW. Figure 2-20 illustrates the layout of the SDA. Support facilities are located east of the SDA. Table 2-6 lists the opening and closing dates of the trenches, pits, SVRs, and Pad A.

2.2.2.1 Pits. Pits are normally used for routine, solid, low-level beta-gamma contaminated waste with radiation levels below 500 mR/h at 0.9 m. Excavated in a previously surveyed area with scraper-carryall and bulldozers, pits average 5-m deep by 30.2-m wide and vary in length. As a means of making maximum use of the SDA, pits were excavated into the basalt and the exposed basalt was covered with 0.6 m of soil. After the waste was emplaced, the pits were backfilled with a least 0.9 m of soil. Current pits are excavated into rock to a depth of 9 m, then backfilled with 0.6 m of soil over rock.

In FY-1985, geotextile fabric was incorporated in the upper portion of the pit floor soil cover to add stability for the waste stack and for mobile equipment. After the flooding in 1982, the earth berm around Pit 17 was modified to eliminate the 0.3-m high vehicle access. The continuous berm is 0.6 to 1.5 m above grade. The earth berms serve as radiation shielding, firebreaks, and dikes. A crane pad was constructed for the bulk disposal area of the pit in FY-1985. Corners of the pits are located by concrete monuments. A brass plate on each monument includes the pit number, boundary directions, and the opening and closing dates.

2.2.2.2 Trenches. Trenches were dug along predetermined centerlines and were separated from adjacent centerlines by no more than 4.9 m. This allowed maximum use of available space without disturbing previously buried waste. The average width of the trenches was 3.1 m (those with collapsing walls were wider). Trench operation employed two metal trench liners that were leap-frogged down the trench as they were filled. The

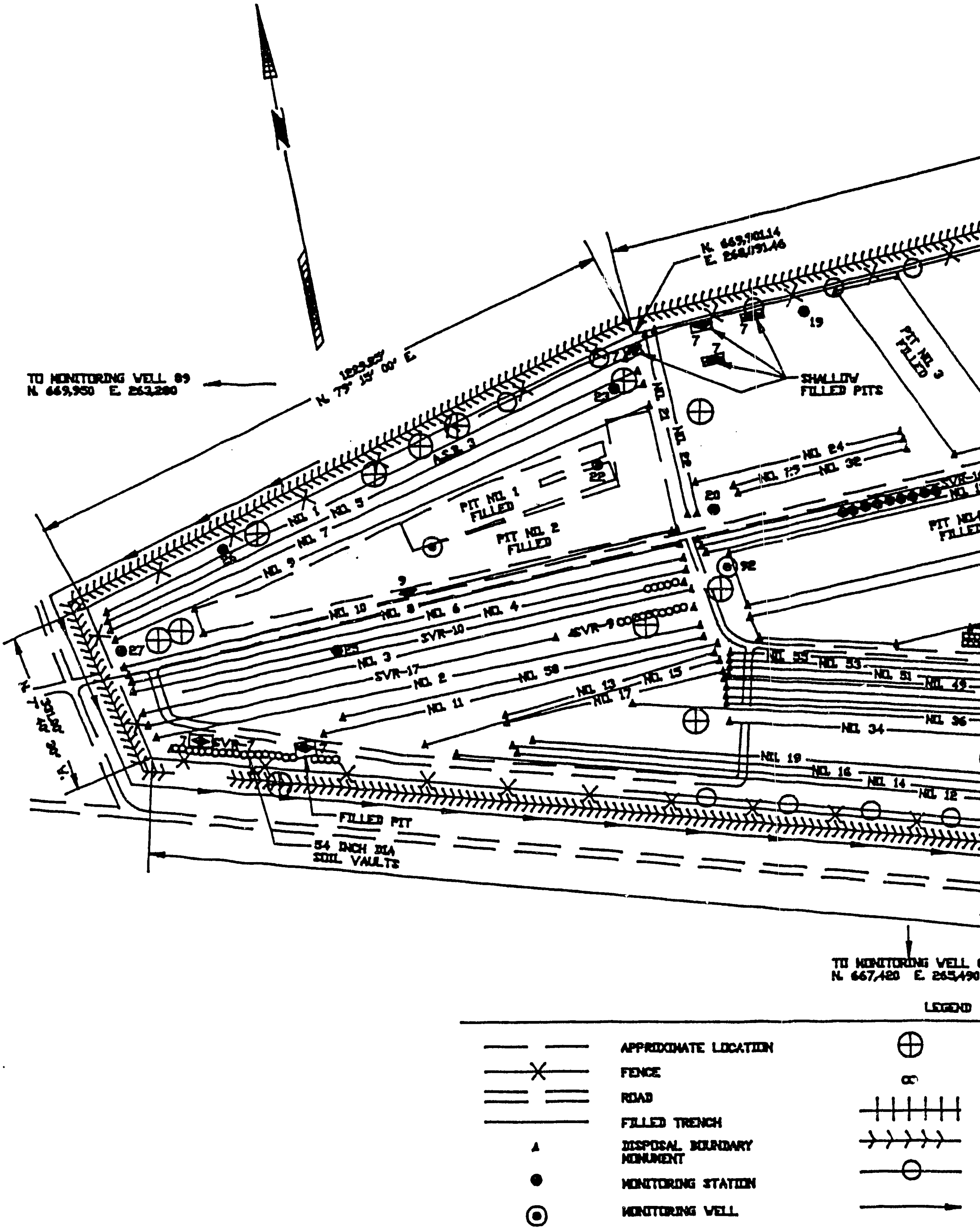

Figure 2-20. Layout o

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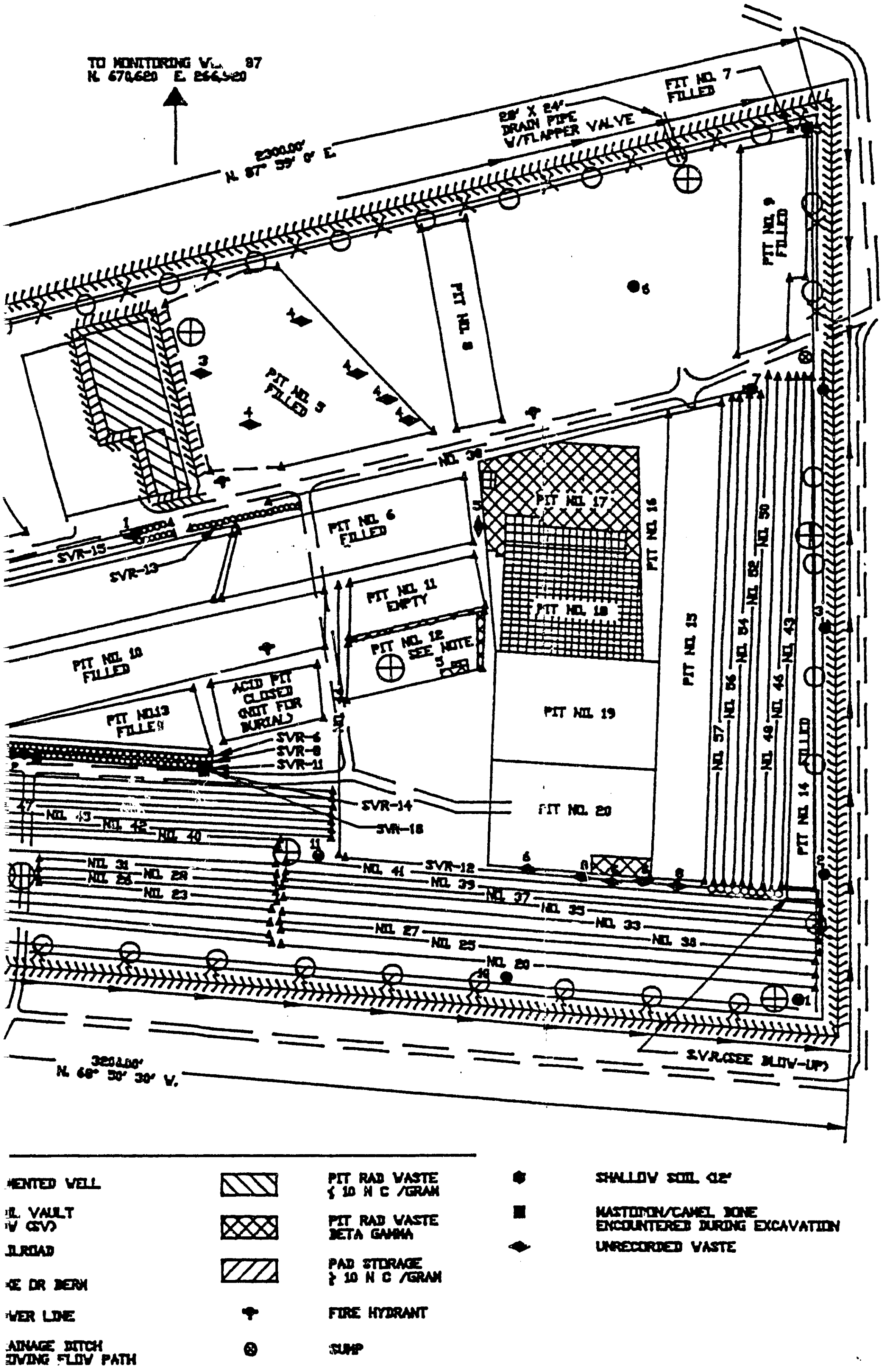

TO MONITORING W... 87
N. 670,620 E. 266,920
2300.00'
N. 87° 39' 0" E.
20" X 24" DRAIN PIPE W/FLAPPER VALVE
PIT NO. 7 FILLED
PIT NO. 9 FILLED
PIT NO. 8
PIT NO. 5 FILLED
PIT NO. 6 FILLED
PIT NO. 11 EMPTY
PIT NO. 12 SEE NOTE 5
PIT NO. 10 FILLED
ACID PIT CLOSED (NOT FOR BURIAL)
PIT NO. 13 FILLED
PIT NO. 17
PIT NO. 18
PIT NO. 19
PIT NO. 20
PIT NO. 16
PIT NO. 15
PIT NO. 14
SVR-15
SVR-13
SVR-6
SVR-8
SVR-11
SVR-14
SVR-18
SVR-12
NO. 30
NO. 43
NO. 42
NO. 40
NO. 31
NO. 26
NO. 28
NO. 23
NO. 41
NO. 39
NO. 37
NO. 35
NO. 33
NO. 38
NO. 27
NO. 25
NO. 20
NO. 50
NO. 52
NO. 54
NO. 56
NO. 57
NO. 48
NO. 46
NO. 44
S.V.R.(SEE BLOW-UP)
3201.00'
N. 68° 30' 30" W.
PIT RAD WASTE ≤ 10 N C /GRAM
PIT RAD WASTE BETA GAMMA
PAD STORAGE ≥ 10 N C /GRAM
FIRE HYDRANT
SUMP
SHALLOW SOIL <12"
MASTODON/CAMEL BONE ENCOUNTERED DURING EXCAVATION
UNRECORDED WASTE

the SDA.

Table 2-6. Opening and closing dates for waste locations in the SDA

Trench	Opened	Closed	Trench	Opened	Closed	Pit	Opened	Closed	Soil Vault Row	Opened	Closed	Pad	Opened	Closed
1	7- 8-52	10- 1-54	30	3- 2-63	9-12-63	1	11- 1-57	10- 1-59	1	3- 3-77	9- 7-77	A	9-26-72	11-17-78
2	10- 1-54	12-21-54	31	3-25-63	11-22-63	2	10- 1-59	7- 1-63	2	3-16-77	10-28-77			
3	12-22-54	4-22-55	32	4- 1-63	11-18-63	3	12-15-61	1- 3-63	3	3-14-77	10-27-77			
4	4-22-55	11-21-55	33	10-11-63	8-11-64	4	1- 3-63	9-26-67	4	3-17-77	11- 1-77			
5	11- 4-55	3-29-56	34	3-18-64	8-27-64	5	6-18-63	12-22-66	5	3-15-77	9- 2-77			
6	3-22-56	9- 4-56	35	8-38-64	1-19-65	6	5-18-67	10-22-68	6	3-25-78	2-27-81			
7	8-14-56	12-20-56	36	12- 1-64	7-24-65	7	9-19-66	10- 5-68	7	5- 8-78	1-23-79			
8	12-13-56	5- 7-57	37	12-24-64	7- 1-65	8	3- 6-67	11- -69	8	2-12-78	9- 8-81			
9	1- 7-57	9- 6-57	38	5-15-65	9-16-65	9	11- 8-67	6- 9-69	9	2- 6-79	7-15-81			
10	7-19-57	2- 7-58	39	7-20-65	11- 5-65	10	8- 7-68	7- 8-71	10	6- 9-81	11- 3-82			
11	2-11-58	7-25-58	40	10- 7-65	1-13-66	11	4-14-70	10-16-70	11	8- 7-81	12-12-84			
12	1- 3-58	1-16-59	41	1- 4-66	10- 4-66	12	7- 2-70	9-12-72	12	5- 5-82	7-27-83			
13	1- 9-58	4-24-59	42	5- 9-66	1-17-67	13	7-20-71	7-29-74	13	4- 4-83	12-21-84			
14	4-16-59	7-30-59	43	10-20-66	6- 1-67	14	7- 1-74	3-31-76	14	10-16-84				
15	7-31-59	10-16-59	44	1-13-67	3-24-67	15	6-25-75	7- 3-84	15	10-16-84				
16	10-17-59	4-12-60	45	2-28-67	9-27-67	16	5-22-78	10-25-84	16	10-16-84				
17	11- 1-59	7- 1-60	46	9-25-67	3-14-68	17	5- 5-84		17	4-24-87				
18	5-10-60	7-20-60	47	2-28-68	8- 5-68	18	9- 1-88		18	2-12-87				
19	7- 5-60	11-29-60	48	8- 8-68	5- 2-69	19	9- 1-88							
20	12- 1-60	6-30-61	49	11-18-68	6-30-69	20	3- 1-89							
21	12-13-60	1-10-61	50	7- 1-69	11- 1-69									
22	2 - 1-61	4-25-61	51	10-30-69	4- 8-70									
23	6-20-61	9-15-61	52	3- 4-70	7- 4-70									
24	10- 1-61	7-31-62	53	7- 1-70	10-12-70									
25	8- 1-61	7-27-62	54	9-23-70	5- 4-71									
26	4-13-62	8-17-62	55	4- 7-71	3-12-82									
27	8-20-62	1- 4-63	56	12-29-71	2- 1-73									
28	12-26-62	3-12-63	57	12-28-72	6-11-74									
29	11-19-62	3-20-63	58	2-20-74	8-17-81									

liners performed two functions: they prevented the trench from sloughing off, and they provided shielding. Trenches were used for all ranges of radioactive waste. Waste with high radiation levels was handled remotely using special shielded containers and boom cranes. As waste disposal became more rigorously controlled, the trenches were used more frequently for high radiation waste until they were replaced by the soil vault concept. When the trenches were full, they were covered with a minimum of 0.9 m of soil. Locations of all trenches and soil vaults are identified by concrete monuments. A brass plate on each monument was stamped with trench number and the opening and closing dates. All LLW packages exceeding 500 mR/h at 0.9 m were deposited in trenches or soil vaults. In July 1981, trench disposals were discontinued, and the unfilled trench area was redesignated for soil vault disposals.

2.2.2.3 Soil Vaults. Beginning in 1977, areas not suited for pits were set aside for drilling of soil vaults. This practice not only helped to conserve SDA space, but it also reduced personnel exposure to radiation. High-radiation (greater than 500 mR/h) beta-gamma waste is normally deposited in the soil vaults. Rows of these vaults are drilled along predetermined centerlines and each vault is separated from previously buried waste by approximately 0.6 m. Soil vault diameters vary from 0.4 to 2 m; minimum depth is 2 m. If the drilling exposes basalt, 0.6 m of soil is placed on the vault floor. Open soil vaults are surrounded by barriers denoting the hazard. Vault liners are used to prevent vault collapse. A shield cover is also placed over open vaults to provide protection from weather and to provide personnel shielding and protection.

2.2.2.4 Pad A. Pad A was constructed in September 1972 in the north central part of the SDA that was not suited for pits or trenches because of near-surface basalt outcroppings. Pad A was established to dispose of uranium waste and waste that was not TRU but did contain more than 0.1 nCi/g but less than 10 nCi/g of TRU alpha-emitting nuclides and had radiation levels less than 200 mR/h at the container surface. From 1972 through 1978, this waste was disposed on Pad A. Boxes were stacked around the periphery and drums were stacked horizontally in staggered layers.

Waste on the pads was covered with earth so that no more than one row of boxes or two rows of drums were exposed at anytime. Sufficient earth was placed around the pad to give at least a 0.9-m cover and a 3:1 maximum final slope. Since 1978, additional soil has been placed on top of the berm to correct for subsidence. The soil cover now ranges from 1- to 2-m deep. Pad A was closed in 1978.

2.2.2.5 Support Facilities. Operations within the SDA are supported by personnel and equipment housed in several structures and buildings located outside of the SDA.

- Building WMF-601 houses material storage areas and health physics offices.

- The Operational Support Facility (Building WMF-602) is used for technology development, thawing containers in cold weather, temporary storage, vehicle monitoring, equipment maintenance, and other similar activities.

- The water supply system located in Building WMF-603 provides domestic-and-fire-system water for the RWMC. A water supply is maintained in a 250,000-gal insulated storage tank adjacent to Building WMF-603.

- Building WMF-604 provides space for personnel change areas and the lunch room for RWMC/Stored Waste Examination Pilot Plant (SWEPP) personnel.

- Building WMF-609 provides a covered structure for storage and maintenance of heavy equipment used at the RWMC/SWEPP. To minimize cold weather startup problems, electric power is provided for vehicle head bolt heaters.

- Building WMF-611, a guardhouse on Adams Boulevard, the main access road to the RWMC/SWEPP, is staffed by uniformed security guards 24 h a day.

- Building WMF-613 provides a conference room and office space for personnel from RWMC/SWEPP Programs Management, Engineering, Technical Programs, and miscellaneous support.

- Building WMF-619 houses communications and alarms.

- The area manager and shift manager offices and other support offices are located in building WMF 620/621, which also houses an health physics office. All personnel are required to report to the shift manager's office for work authorization and radiological dosimetry before entering radiation areas and again for survey and work status report before leaving the RWMC/SWEPP.

2.2.3 Description of the Waste

The SDA contains LLW and TRU waste, including some that could pose nonradiological hazards. Early waste management practices allowed intermixing of LLW and TRU waste in pits and trenches. However, waste received since 1970 has generally been segregated depending on the waste type. Since 1970, TRU waste has been stored on pads in the TSA, and LLW has been buried in the SDA.

2.2.3.1 LLW. Disposal of contact-handled LLW recently has been averaging 3000 m^3 to 4000 m^3/yr. In addition, about 50 m^3/yr of remote-handled LLW has been received from waste generators; containers of this waste have been disposed at the RWMC in waste disposal pits or in soil vaults.

Beginning in 1977, soil vaults were used to dispose beta-gamma waste with high radiation levels (greater than 500 mR/h at 0.9 m); before then, trenches were used for waste with high radiation levels. The trenches were closed in 1981. Pits are used for routine, solid low-level beta-gamma contaminated waste with radiation levels below 500 mR/h at 0.9 m.

Waste disposed in the older trenches and the pits included plastics, paper, cloth, a variety of metals (stainless steel and aluminum), wood, contaminated soil, asphalt, gravel, concrete, glass, construction equipment and materials, filters, resins, rubber, biological waste, uranium fuel elements, reactor core components, and absorbed liquids. Soil vaults and the newer trenches contained waste from irradiated reactor and reactor core components, irradiated samples, and irradiated experimental fuel.

Until 1970, LLW and TRU waste packages were at times buried together at the RWMC. As of 1970, about 50,000 m^3 of waste classified as LLW (containing about 4.7 million Ci) had been buried commingled with about 62,000 m^3 of waste classified as TRU waste (containing about 250,000 Ci of TRUs). All of these waste packages were buried in an area of less than 20 ha within the SDA. From 1970 to the present, about 80,000 m^3 of additional waste classified as LLW (containing about 4.6 million Ci) has been placed in shallow land burial in the RWMC, occupying about 8 ha adjacent to the above-mentioned 20 ha. About 62,000 m^3 of additional waste classified as contact-handled TRU waste (containing about 470,000 Ci) has accumulated in retrievable storage at the TSA of the RWMC. Currently, this 62,000 m^3 of stored waste is undergoing re-examination in the SWEPP facility located at the TSA. Principal findings thus far have been

- Most (about 90%) of this stored waste in the TSA also contains EPA-hazardous constituents; therefore, it classifies as mixed waste.

- Many of these containers of waste have been found to contain TRU concentrations below 100 nCi/g; therefore, they do not fit the present definition for TRU waste. Projections indicate that when the re-examinations are completed, about 40% of the total number of containers of waste will have been found to contain TRU concentrations below 100 nCi/g.

Thus, it appears that about 27,000 m^3 of this stored waste could be reclassified to LLW or LLW-mixed waste (in most cases it could be classified as LLW-mixed waste).

2.2.3.2 TRU Waste. Receipt and shallow-land disposal of TRU waste began in 1954 and ended in 1970. About 62,000 m^3 of TRU waste was buried in pits and trenches at the RWMC SDA. In 1987, ongoing studies to address long-term management of buried TRU waste were accelerated in response to environmental monitoring that indicated migration of low concentrations of plutonium and organic chemicals from the buried waste. Remedial action requirements are currently being addressed to allow recommendation of an alternative for long-term management.

Since 1970, solid TRU waste received at the RWMC has been segregated from non-TRU solid waste and placed into interim retrievable storage at the RWMC TSA. Contact-handled wastes were either (a) stored on above-ground asphalt pads and protected by covering with plywood, plastic, and an earthen overburden or (b) placed on asphalt pads under an air supported weather shield. The majority of stored contact-handled-TRU waste was generated by the Rocky Flats Plant. Lesser amounts were generated by the Mound Laboratory, Argonne National Laboratory-East (ANL-E), Battelle Columbus Laboratory, Bettis Atomic Power Laboratory, and INEL onsite generators. Remote-handled-TRU wastes are stored in specially designed steel vaults at the Intermediate Level Transuranic Storage Facility (ILTSF) within the TSA. The primary generator of remote-handled-TRU waste in storage at the INEL Site is ANL-E and ANL-W; smaller amounts are generated by INEL onsite generators.

2.2.4 Present Waste Management Practices

The major burial areas presently open are Pits 17, 18, 19, and 20. Current practice expands the capacity of a pit by blasting and removing the basalt; then 0.6 m of dirt is placed over the basalt. After containers of waste are stacked in the pit, at least 2 m of dirt cover is placed over the containers.

As described below, LLW received at the RWMC is managed in one of several ways depending on the waste type, physical configuration, radioactivity, and container. The four categories of LLW are nonprocessible waste, compactible nonincinerable waste, incinerable waste, and metallic noncompactible waste.

2.2.4.1 Nonprocessible Waste (Direct Disposal). LLW that currently cannot be processed at the WERF because of radiation levels, size, or composition is directly disposed of at the RWMC SDA. This waste comes to the RWMC in wooden boxes, metal bins, 55-gal drums, etc. The current LLW acceptance criteria document prohibits disposal of free liquids, hazardous materials, and pyrophorics. It also requires physical and chemical waste characterization as well as encouraging void space minimization. Studies were conducted to determine the feasibility of using concrete or heavy-walled metal boxes for some wastes that have radiation levels greater than that allowed for contact handling (i.e., greater than 500 mR/h) to reduce the use of soil vaults, which are less space efficient and may interfere with SDA remedial actions. During CY-1988, 1268 m^3 (27% of the generated LLW) was shipped to the RWMC for direct disposal. Because this 27% of the generated waste received no volume reduction treatment while the rest did, it became 64% of the total LLW disposed of at the RWMC in 1988.

2.2.4.2 Compactible Nonincinerable Waste. LLW that cannot be incinerated but can be compacted generally contains halogens or sulfur and some rubber materials, with a radiation level less than 200 mR/h at the surface. In CY-1988, 859 m^3 of this waste was sent to WERF for compaction in a 200-ton compactor. The waste compacts into 1.2 x 1.2 x 1.8 m metal boxes and achieves a volume reduction ratio of about 5:1. The compacted waste is shipped to the RWMC for disposal.

2.2.4.3 Incinerables. Incinerable LLW material consists of rags, plastics, wood, and other combustible material with a radiation level currently limited to less than 20 mR/h at contact. Most incinerable waste is packaged in cardboard boxes at the generator, shipped to WERF in cargo containers, and burned in the WERF incinerator. In CY-1988, 1574 m^3 of this waste was sent to WERF. The incinerator achieves a volume reduction ratio of [illegible]0:1 to 300:1 depending on the type of material that is being incinerated. Test results have shown that the resulting ash is mixed waste because it contains leachable toxic metals (lead and cadmium). The incinerator ash is treated by solidification with cement in 71-gal drums to stabilize the chemically hazardous levels of lead and cadmium. The resultant product is dispassionate according to its EPA characteristics.

2.2.4.4 Metallic Noncompactible. Metallic noncompactible waste is defined as metal (aluminum, stainless and carbon steel, copper, and others with wall-thickness too great for compaction with the 200-ton compactor) having radiation levels less than 100 mR/h at contact and free of toxic and hazardous material. Metallic waste is shipped to WERF in bins. These bulk metal shipments are then size-reduced (providing a volume reduction of about 4:1), packaged, and shipped to the RWMC for disposal. In CY-1988, 913 m^3 of metallic waste was sent to WERF for sizing.

Sized metallic waste can be melted for a further volume reduction (of about 4:1) and for stabilization of the radionuclides it contains. However, the operational cost of melting is too high to justify the volume reduction benefit realized (at present); therefore, this option is reserved for uses such as melting of waste metal that has a classified shape for declassification.

2.2.5 Future Modifications to Waste Management Practices

Future LLW management practices should use improved treatment and disposal preferably with disposal at a new location.

Actions that can be taken include improving waste characterization, improving current LLW management practices, developing more widely applicable volume reduction and stabilization treatment methods, and defining the radiological performance of future LLW disposal. The following actions are planned:

- Modifying waste acceptance criteria to (a) require that significant (in risk to the general public) radionuclides be identified and quantified and that the waste's classification be determined according to an INEL LLW classification system; (b) require that each package of waste classifying higher than INEL LLW Class 1 be stabilized by accepted method; and (c) require waste generators to use waste separation and sorting methods to send the maximum practical proportion of their waste to WERF.

- Changes to the RWMC's operating procedures are being considered that would (a) require at least 2 m of radiologically uncontaminated cover over all LLW and at least 4.9-m cover for all INEL LLW Class 3; (b) permit disposal of INEL LLW Class 2 and Class 3 only if stabilized; and (c) prohibit disposal of INEL LLW greater-than-Class 3, or waste classifying as greater-than-Class C per 10 CFR 61, unless the disposal system(s) for such waste have been justified by a specific DOE-approved performance assessment.

- Planned upgrades to LLW management capabilities at WERF include (a) extending the new sizing building, (b) installing upgraded handling and waste sorting/separation capabilities and capabilities to add cement grout to treated LLW, (c) adding LLW storage space, and (d) modifying WERF waste acceptance criteria to allow acceptance of a wider range of materials and increased radiation/contamination levels.

- Radiological performance assessments will (a) define intruder-protection limits for all significant INEL radionuclides; (b) complete the ongoing radiological performance assessment of past and current waste disposal at the RWMC; and (c) make a projection of waste to be disposed at the INEL Site during the next 50 yr based on projected waste treatment, optimized waste form, and complete a radiological performance assessment of the optimized waste form.

- Design two upgraded LLW disposal installations (one for contact-handled LLW and the other for remote-handled LLW) to meet LLW storage as well as disposal requirements.

- Evaluate new facilities for the treatment of LLW and mixed LLW.

- Operations at WERF will emphasize accepting and treating as much LLW as practical. All INEL waste generators will emphasize sending the highest practical proportion of their waste to WERF, which will process all acceptable waste into wasteforms in waste packages suitable for disposal in upgraded new LLW disposal installations. Each generated package of waste that cannot be accepted at WERF will be evaluated by the waste generator and WERF personnel to determine what should be done to eliminate or reduce future such cases. All LLW that does not meet WERF waste acceptance criteria, but that meets RWMC waste acceptance criteria, will continue to go into disposal at the RWMC. All waste processed through WERF will continue to go into disposal in RWMC burial pits.

2.2.6 Determination of Waste Inventory

Inventories of past burials and predictions for the future are discussed in detail in this section. The information for the inventories generally comes from the available shipping records.

2.2.6.1 Data Base. For shipments made before 1971, the inventory information came from existing shipping invoices and other records. Some of these early documents did not contain complete information. The best information available regarding the types of waste shipped to the RWMC was used to develop assumptions for the volumes, radioactivity, and other information.

For shipments from 1971 to the present, the inventory data have been stored in the Radioactive Waste Management Information System (RWMIS). The RWMIS, a computerized data base, was started to record waste shipments to the RWMC as well as INEL airborne and liquid effluents. The available information for earlier waste shipments also has been compiled into the RWMIS. Data on shipments to the RWMC are furnished by the waste generator and include

- Type of waste
- Type of containers
- Date of shipment
- Waste generator location
- Waste description
- Gross volume and weight
- Gross radioactivity
- Nuclide identification including amount or percent of gross radioactivity.

The burial or storage location and date of disposal for each shipment are provided by RWMC operating personnel.

2.2.6.2 Waste Covered in This Document. This document addresses LLW buried since 1964. Waste buried before that time was generated primarily from Rocky Flats and is TRU waste intermixed with LLW. This TRU waste intermixed with LLW will either be retrieved or treated in place and is subject to other environmental compliance assessments.

A very small amount of TRU waste is included in this document. This TRU waste originated on the INEL Site or at offsite locations other than Rocky Flats. No Rocky Flats TRU waste is considered in this document.

The majority of radionuclides considered in this document are beta-gamma emitters.

Table 2-7 lists waste locations and categories covered by this document. The information in Table 2-7 is based on yearly waste receipt records and on records for opening and closing of waste locations.

2.2.6.2.1 Waste Volumes--For the waste covered in this document (see Table 2-7), the volume is about 105,489 m^3 through 1988. The breakdown by year is shown in Table 2-8.

2.2.6.2.2 Waste Containers. The following types of containers have been used to contain waste emplaced in the SDA: cardboard boxes, fiber barrels, metal barrels, wooden and metal boxes, bales of compacted waste, ingots, M-III steel bins, inserts, and other containers. The number of each type of container of LLW is listed in Table 2-9. From 1964 through 1988, the total number of waste containers buried in the SDA for the waste covered by this document was 140,969.

2.2.7 Waste Radioactivity Inventory

Knowledge of the inventory of radionuclides in the disposed waste is essential to the performance assessment. The amounts of radionuclides disposed have been entered into the RWMIS data base and were used to estimate the radionuclide inventories for this assessment. The radionuclide disposal history and projections of future disposal of radionuclides are presented in this section.

Table 2-7. Waste evaluated in this document

Location	Waste Evaluated[a]
Trenches 19, 20, 26, 27	ONS-TRU
Trench 33	LLW received after 1963
Trenches 34-58	All LLW. Also, ONS-TRU in Trenches 39, 45, 47, 48, 51, 52, 55
Pit 2	OFS-TRU
Pit 4	LLW received after 1963 and the OFS-TRU
Pit 5	LLW received after 1963
Pits 6-10	LLW
Pits 13-20	LLW
Soil vault rows	LLW

a. ONS-TRU is TRU waste generated at the INEL; OFS-TRU is TRU waste generated at non-INEL facilities. OFS-TRU does not include waste from Rocky Flats.

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Table 2-8. Volumes of waste covered in this document

Year	Volume (m)
1964	3,132
1965	4,077
1966	4,634
1967	3,820
1968	3,947
1969	4,743
1970	4,032
1971	4,026
1972	3,548
1973	3,879
1974	3,693
1975	5,692
1976	6,212
1977	6,591
1978	5,932
1979	5,348
1980	5,074
1981	3,067
1982	3,185
1983	5,474
1984	3,906
1985	3,140
1986	3,394
1987	2,963
1988	1,980
TOTAL	105,489[a]

a. The volumes of ONS-TRU and OFS-TRU listed in Table 2-8 are included in this volume. They are so small as to be a completely negligible fraction of the total volume.

Table 2-9. Types and quantities of waste containers covered in this document (1964-1988)

Container Type	Number of Containers
Bales	5,299
Bins	1,643
Cardboard boxes	77,190
Fiber barrels	191
Ingots	45
Inserts	1,748
Metal barrels	28,663
Metal boxes	23
Other[a]	10,361
Steel boxes	96
Wooden boxes	15,710
TOTAL	140,969

a. "Other" includes container types not listed and waste that is not in a container (i.e., trucks and large tanks).

Table 2-10. Estimate of radioactivity disposed by year and radionuclides before 1971 (in curies)

Nuclide	1960	1962	1964	1965	1966	1967	1968	1969	1970
H 3	0.	0.	3.240E-02[b]	1.519E-01	1.902E-01	1.851E-01	5.953E-02	2.072E-01	1.069E-01
BE 10	0.	0.	6.066E-01	2.843E+00	3.561E+00	3.466E+00	1.114E+00	3.878E+00	2.001E+00
C 14	0.	0.	1.218E-08	5.711E-08	7.152E-08	6.962E-08	2.239E-08	7.790E-08	4.019E-08
NA 22	0.	0.	4.126E-02	1.934E-01	2.422E-01	2.357E-01	7.579E-02	2.638E-01	1.361E-01
NA 24	0.	0.	1.211E+00	5.675E+00	7.107E+00	6.919E+00	2.224E+00	7.741E+00	3.993E+00
CL 36	0.	0.	1.685E-09	7.900E-09	9.894E-09	9.630E-09	3.096E-09	1.078E-08	5.559E-09
SC 46	0.	0.	3.628E+00	1.701E+01	2.130E+01	2.073E+01	6.666E+00	2.320E+01	1.197E+01
CR 51	0.	0.	7.480E+04	3.506E+05	4.391E+05	4.274E+05	1.374E+05	4.782E+05	2.467E+05
MN 54	0.	0.	1.322E+04	6.195E+04	7.758E+04	7.552E+04	2.429E+04	8.450E+04	4.359E+04
MN 56	0.	0.	2.468E+01	1.157E+02	1.449E+02	1.410E+02	4.533E+01	1.578E+02	8.139E+01
FE 59	0.	0.	8.898E+03	4.171E+04	5.223E+04	5.084E+04	1.635E+04	5.689E+04	2.935E+04
CO 58	0.	0.	1.717E+04	8.047E+04	1.008E+05	9.809E+04	3.154E+04	1.098E+05	5.662E+04
CO 60	0.	0.	2.113E+04	9.902E+04	1.240E+05	1.207E+05	3.881E+04	1.351E+05	6.968E+04
NI 59	0.	0.	2.543E+02	1.192E+03	1.493E+03	1.453E+03	4.672E+02	1.626E+03	8.389E+02
ZN 65	0.	0.	1.559E+01	7.306E+01	9.150E+01	8.906E+01	2.863E+01	9.966E+01	5.141E+01
RB 86	0.	0.	3.288E+00	1.541E+01	1.930E+01	1.878E+01	6.039E+00	2.102E+01	1.084E+01
SR 89	0.	0.	8.694E-02	4.075E-01	5.104E-01	4.968E-01	1.597E-01	5.559E-01	2.868E-01
SR 90	0.	0.	2.981E+02	1.397E+03	1.750E+03	1.703E+03	5.477E+02	1.906E+03	9.833E+02
ZR 95	0.	0.	7.380E+03	3.459E+04	4.332E+04	4.217E+04	1.356E+04	4.719E+04	2.434E+04
NB 95	0.	0.	2.166E+01	1.015E+02	1.272E+02	1.238E+02	3.979E+01	1.385E+02	7.144E+01
TC 99	0.	0.	2.091E-08	9.803E-08	1.228E-07	1.195E-07	3.842E-08	1.337E-07	6.898E-08
RU103	0.	0.	4.177E+02	1.958E+03	2.452E+03	2.387E+03	7.673E+02	2.671E+03	1.378E+03
RU106	0.	0.	1.004E+02	4.704E+02	5.891E+02	5.734E+02	1.844E+02	6.416E+02	3.310E+02
AG110M	0.	0.	1.224E-01	5.738E-01	7.186E-01	6.995E-01	2.249E-01	7.827E-01	4.038E-01
CD109	0.	0.	5.154E-08	2.416E-07	3.026E-07	2.945E-07	9.468E-08	3.295E-07	1.700E-07
SB125	0.	0.	4.044E+01	1.896E+02	2.374E+02	2.311E+02	7.429E+01	2.585E+02	1.334E+02
I131	0.	0.	4.600E-01	2.156E+00	2.700E+00	2.628E+00	8.450E-01	2.941E+00	1.517E+00
CS134	0.	0.	3.318E+01	1.555E+02	1.948E+02	1.896E+02	6.096E+01	2.122E+02	1.095E+02
CS137	0.	0.	8.004E+02	3.752E+03	4.699E+03	4.573E+03	1.470E+03	5.117E+03	2.640E+03
BA133	0.	0.	1.896E-08	8.887E-08	1.113E-07	1.083E-07	3.483E-08	1.212E-07	6.254E-08
BA140	0.	0.	2.987E+00	1.400E+01	1.753E+01	1.706E+01	5.496E+00	1.909E+01	7.850E+00
LA140	0.	0.	3.430E+00	1.608E+01	2.014E+01	1.960E+01	6.302E+00	2.193E+01	1.131E+01
CE141	0.	0.	1.223E+03	5.735E+03	7.182E+03	6.990E+03	2.247E+03	7.822E+03	4.035E+03
CE144	0.	0.	4.667E+02	2.188E+03	2.740E+03	2.667E+03	9.574E+02	2.984E+03	1.539E+03
PM147	0.	0.	3.233E-02	1.515E-01	1.898E-01	1.847E-01	5.939E-02	2.067E-01	1.066E-01
SM153	0.	0.	1.442E-01	6.761E-01	8.467E-01	8.242E-01	2.650E-01	9.222E-01	4.758E-01

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Table 2-10. (continued)

Nuclide	1960	1962	1964	1965	1966	1967	1968	1969	1970
EU152	0.	0.	1.730E+01	8.109E+01	1.015E+02	9.884E+01	3.179E+01	1.106E+02	5.706E+01
EU154	0.	0.	1.604E+01	7.516E+01	9.413E+01	9.162E+01	2.946E+01	1.025E+02	5.289E+01
EU155	0.	0.	6.803E+00	3.189E+01	3.993E+01	3.887E+01	1.250E+01	4.349E+01	2.244E+01
HF181	0.	0.	6.399E-02	2.999E-01	3.756E-01	3.656E-01	1.175E-01	4.091E-01	2.110E-01
TA182	0.	0.	1.729E-01	8.105E-01	1.015E+00	9.880E-01	3.177E-01	1.106E+00	5.703E-01
W187	0.	0.	2.249E-01	1.054E+00	1.320E+00	1.285E+00	4.132E-01	1.438E+00	7.418E-01
BI210	0.	0.	0.	0.	0.	0.	0.	0.	0.
PO210	0.	0.	0.	0.	0.	0.	0.	0.	0.
RA226	0.	0.	3.570E-02	1.673E-01	2.096E-01	2.040E-01	6.559E-02	2.283E-01	1.178E-01
TH230	0.	0.	4.941E-03	2.316E-02	2.901E-02	2.823E-02	9.077E-03	3.159E-02	1.630E-02
TH232	0.	0.	1.459E-04	6.837E-04	8.563E-04	8.335E-04	2.680E-04	9.326E-04	4.811E-04
U232	0.	0.	0.	0.	0.	0.	0.	0.	0.
U233	0.	0.	0.	0.	0.	0.	0.	0.	6.015E-01
U234	0.	0.	3.993E-02	1.872E-01	2.344E-01	2.282E-01	7.335E-02	2.553E-01	1.317E-01
U235	0.	0.	2.128E-03	9.974E-03	1.249E-02	1.216E-02	3.909E-03	1.361E-02	7.018E-03
U236	0.	0.	1.009E-03	4.728E-03	5.921E-03	5.764E-03	1.853E-03	6.449E-03	3.327E-03
U238	0.	0.	5.439E-02	2.549E-01	3.193E-01	3.107E-01	9.991E-02	3.477E-01	1.794E-01
NP237	0.	0.	0.	0.	0.	0.	0.	0.	0.
PU238	0.	0.	2.234E-01	1.047E+00	1.311E+00	1.276E+00	4.104E-01	1.428E+00	7.368E-01
PU239	3.171E-01	1.531E+00	9.977E-02	9.694E-01	2.383E+00	1.322E+00	3.996E+01	6.379E-01	9.727E-01
PU240	0.	0.	2.814E-03	1.319E-02	1.652E-02	1.608E-02	5.170E-03	1.799E-02	9.292E-03
PU241	0.	0.	4.151E-01	1.945E+00	2.437E+00	2.372E+00	7.625E-01	2.654E+00	1.369E+00
PU242	0.	0.	2.455E-05	1.151E-04	1.441E-04	1.403E-04	4.510E-05	1.570E-04	8.098E-05
AM241	0.	0.	1.022E-04	4.789E-04	5.997E-04	5.838E-04	1.877E-04	6.532E-04	3.370E-04
TOTAL	3.171E-01	1.531E+00	1.463E+05	6.860E+05	8.591E+05	8.362E+05	2.699E+05	9.356E+05	4.827E+05

a. Units are curies (Ci). Inventories include those disposed on Pad A.

b. Numbers are written in scientific notation: 3.240E-02 = 3.240×10^{-2} = 0.0324. Waste inventories are not actually known to the accuracy listed.

Table 2-11. Radioactivity disposed by year and radionuclides (1971-1980) (in curies)

NUCLIDE	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
AC-227										
AG-108M										
AG-110	2.338E-02									
AG-110M						2.180E-01	5.960E-02	2.583E+00		
AM-241		1.000E-05			1.850E-07		3.240E-07		3.700E-04	
AM-243										
BA-133						4.000E-07	3.400E-08			
BA-137M										
BA-140	2.022E+00	8.629E+00			1.430E+00	4.368E+01			3.279E+00	9.334E+00
BE-10	4.290E+00		1.000E+01							
BE-7										
BI-210						3.930E-08				
BK-249										
C-14						2.870E-07				
CA-45										
CD-104										
CD-109							1.180E-06			
CE-141	2.944E+01	2.789E+04	2.954E+00	1.717E+00	1.895E+00	2.889E+01	1.316E+01	2.331E+01	1.359E+00	2.055E+01
CE-144	5.465E+01	1.083E+01	4.130E+02	8.047E+02	9.517E+02	3.981E+02	2.270E+03	1.609E+03	2.553E+02	2.030E+03
CF-249										
CF-250										
CF-252										
CL-36						3.970E-08				
CM-243										
CM-244										
CO-56										
CO-57							1.110E-06			
CO-58	8.477E+00	6.108E+00	3.900E+03	2.079E+00	3.154E-01	3.080E+01	6.250E+02	7.797E+02	1.196E+00	3.591E+00
CO-60	4.610E+04	1.445E+04	2.313E+05	7.754E+03	7.303E+03	6.596E+04	9.808E+04	8.268E+03	1.078E+03	2.636E+02
CR-51	2.359E+05	5.163E+03	8.003E+04	8.170E+01	2.233E+02	1.512E+05	5.023E+05	1.425E+02	7.285E+02	7.842E+02
CS-134	2.119E+00	3.288E+00	5.243E+01	6.636E+01	4.619E+01	5.711E+00	1.706E+01	1.055E+02	1.971E+01	3.435E+02
CS-136										1.584E-01
CS-137	4.675E+02	3.004E+02	1.024E+03	2.185E+03	8.563E+02	6.855E+02	9.457E+02	2.628E+03	8.179E+02	9.690E+03
EU-152					1.060E+00	4.380E-01	1.712E+02	1.150E+02	5.350E+00	1.024E+02
EU-154				4.199E+01	3.521E+01	5.005E-01	8.403E+01	9.817E+01	4.901E+00	1.023E+02
EU-155				2.422E+01	2.154E+01	9.000E-02	2.001E+01	3.732E+01	2.778E+00	4.981E+01
FE-55					3.600E+02	2.576E+04	5.059E+04	9.578E+03	1.218E+03	
FE-5°	3.221E+04	1.849E+04	6.723E+02	1.469E+03	2.136E+02	1.879E+04	6.198E+04	1.178E+01	1.391E+01	1.859E+01
H-3	5.000E-01		2.300E-01						1.200E-02	
HF-181	2.805E-01			7.000E-02	4.882E-02	7.310E-02	5.960E-02	1.032E+00		1.292E-02
HG-203										
I-125										
I-131	1.569E+00				8.167E-03	8.800E-01	5.500E+00	1.297E+00	1.170E+00	1.072E-01
I-132	1.638E-01								8.280E-03	
I-133	4.830E-01								2.898E-02	
I-135	3.510E-02									
IR-192	2.800E-04									
K-40										

Table 2-11. (continued)

NUCLIDE	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
KR-85										1.500E-01
LA-140	3.533E-01	3.775E-01			2.053E+00	5.892E+01			4.722E+00	1.213E+01
MN-53										
MN-54	1.241E+00	4.370E+00	2.081E+04	7.201E+01	3.669E+02	2.973E+01	6.005E+02	6.923E+02	2.653E+00	3.059E+00
MN-56	1.485E+00	2.600E+01			5.538E+02					
NA-22							1.160E-06		8.718E-01	1.000E-01
NA-24	3.537E+00					2.499E+01				
NA-25	1.270E-01									
NB-94										
NB-95	3.724E+00			3.196E-01	3.096E-01	2.671E+00	5.502E+01	8.873E+01	2.508E+01	4.785E+01
NI-59	5.000E+02	1.299E+03	9.931E+02	3.200E+03						
NI-63						1.472E+03	2.891E+03	5.473E+02	6.961E+01	
NP-237			6.345E-07			4.200E-06				
NP-239										
P-32										
PA-231										
PB-210										
PB-212										
PM-147			7.400E-01							
PO-210	1.100E-01	3.020E-01	4.368E-01	1.604E-02	1.791E-03	5.327E-03				
PU-236										
PU-238						6.200E-04	2.285E-01	3.022E-02	4.190E-02	7.670E-01
PU-239	1.842E-01	1.604E-03	1.600E-01	3.416E-04	8.903E-02	3.052E-03	1.508E-01	3.797E-02	3.886E-02	3.208E-01
PU-240	9.000E-04		9.560E-06		1.054E-05	1.700E-05	9.132E-03	4.299E-03	1.257E-03	8.922E-03
PU-241	1.000E-04		6.720E-04						8.166E-02	1.421E+00
PU-242			3.900E-09						4.607E-06	8.432E-05
RA-225										
RA-226	5.576E+00	1.250E+00	2.299E-01	1.000E+00	3.382E-08	2.021E-01			1.293E-01	
RA-228										
RB-86		4.210E+00	4.160E+00	6.322E+01	5.851E+00					
RN-222										
RU-103	2.570E-02	9.558E+03	1.076E+00	9.644E-02	2.033E+00	8.026E-02	2.980E-02			1.258E-01
RU-106	8.307E+00	1.093E+01	1.989E+02	3.379E+02	2.614E+02	1.358E+02	1.530E+02	1.647E+02	7.006E+01	8.470E+01
S-35										
SB-124										
SB-125	1.931E+01	1.915E+00	8.932E+01	1.074E+02	7.997E+01	1.405E+04	2.753E+04	5.269E+03	6.904E+02	1.850E+01
SC-46	4.948E+00	3.121E+00								
SE-75					4.556E-03					
SM-151										
SM-153						3.302E+00				
SN-119						3.680E+03	7.226E+03	1.368E+03	1.740E+02	
SR-89						1.008E-01		1.890E+00		
SR-90	1.678E+01	2.103E+01	1.872E+02	1.579E+03	1.764E+03	2.814E+02	2.536E+02	6.885E+02	1.430E+02	8.985E+02
TA-182						7.310E-02				
TC-99						3.961E-07	3.200E-09		7.940E-08	
TE-129										
TE-132	7.840E-01									
TH-228										
TH-229										

Table 2-11. (continued)

NUCLIDE	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
TH-230					5.405E-09				1.789E-02	
TH-232	2.180E-04	1.090E-07	5.450E-05	1.916E-05	1.091E-02	9.810E-08	3.646E-04	1.304E-04	5.166E-04	1.155E-05
TH-234										
U-232					8.360E+00					
U-233		6.000E-06		1.040E-08		9.527E-03				
U-234	3.710E-04		1.857E-05		1.760E-04	6.178E-04	2.782E-02	7.673E-03	2.780E-02	1.168E-01
U-235	1.018E-01	7.406E-02	3.199E-03	1.360E-03	4.582E-03	5.526E-03	4.247E-03	7.841E-04	2.908E-03	4.780E-03
U-236	1.584E-06		2.751E-06		2.280E-06	3.170E-05	2.049E-04	1.268E-04	3.089E-04	3.345E-03
U-238	7.734E+00	5.603E+00	4.277E-02	2.063E-03	5.034E-03	1.497E-01	3.568E-02	1.530E-02	1.867E-01	1.011E-02
V-48										
W-187	5.298E+00									
Y-91M										
ZN-65	4.272E+00			3.605E+02	4.000E-01	1.701E+00	5.960E-02	7.828E-03	1.310E-01	1.052E-01
ZR-95	3.554E+04	1.374E+05	1.383E+02	1.535E+02	1.166E+02	7.453E+03	1.452E+04	2.815E+03	3.677E+02	3.368E+01

Table 2-12. Radioactivity disposed by year and radionuclides (1981-1988) (in curies)

NUCLIDE	1981	1982	1983	1984	1985	1986	1987	1988
		0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00		
AC-227						1.593E-02	1.460E-01	
AG-108M							1.000E-03	
AG-110		1.250E-02				1.314E-06	5.104E-02	2.370E-02
AG-110M				3.000E-02		1.259E-06	1.913E+00	
AM-241		1.329E-02	1.620E-02	6.045E-06	1.091E-01	6.075E-02	1.269E-01	3.501E-03
AM-243				9.250E-07	1.297E-03	2.242E-04	1.850E-05	2.040E-04
BA-133	1.070E-03				1.000E-06			
BA-137M			1.686E-01					
BA-140	2.282E+00	3.256E+00	3.501E+00	1.084E+00	1.078E+00			
BE-10								
BE-7		3.511E-01	3.320E-05			6.584E-04		
BI-210								
BK-249					1.700E-02	2.366E-08		
C-14		1.607E-03	9.000E-06	2.434E-04	5.000E-07	1.085E-03	7.623E-03	1.211E-02
CA-45								1.015E-03
CD-104		1.500E-07						
CD-109		1.747E-04	1.370E-03	1.120E-03		5.862E-04	5.483E-04	1.700E-05
CE-141	1.167E+00	1.140E+00	9.256E-01	1.038E+00	3.800E-01		2.400E-02	
CE-144	8.122E+01	4.273E+01	5.272E+01	5.883E+01	2.002E+01	4.639E+01	4.082E+01	3.672E+01
CF-249					2.055E-04	4.091E-06	8.180E-10	
CF-250						1.080E-04		
CF-252			2.140E-03	9.945E-11	4.296E-04	2.505E-05		
CL-36								
CM-243						5.000E-07		
CM-244		1.000E-06			9.991E-08			
CO-56						7.822E-06		
CO-57	4.570E-01	4.314E+00	1.002E-04			2.750E-05	3.605E-05	
CO-58	5.088E+00	8.524E-02	2.865E-01	1.794E+00	2.175E-01	1.284E+01	2.569E+01	8.340E-01
CO-60	5.629E+01	1.286E+02	1.709E+03	7.886E+03	9.646E+01	1.875E+02	1.361E+02	6.017E+01
CR-51	7.753E+02	7.979E+02	6.644E+02	7.328E+02	2.019E+03	1.028E+03	2.619E+02	1.346E+02
CS-134	6.201E+00	4.994E-01	6.728E-01	4.142E-01	5.130E+01	1.506E-02	7.075E-01	3.100E-03
CS-136								
CS-137	1.890E+02	2.212E+02	1.328E+02	2.870E+02	5.571E+02	1.353E+02	4.754E+02	1.159E+02
EU-152	2.500E-03	1.668E-03	1.000E-03	1.000E-05	1.175E-03	1.000E-01	6.486E+00	1.000E-05
EU-154	6.573E-01	4.500E-04	1.960E-03		2.570E-01	1.200E-05	4.578E+00	
EU-155	2.746E-01	9.703E-04	9.800E-05				9.684E-01	
FE-55			6.100E+01	3.830E+03				1.700E-01
FE-5°	4.343E+01	8.567E+01	6.079E+01	5.618E+01	2.536E+01	8.767E+00	7.511E+00	3.595E+00
H-3	1.100E+00	2.063E-01	3.317E+03	2.236E+00	2.097E+01	1.100E+02	8.252E+02	4.713E+01
HF-181	1.820E-01				2.832E-01		2.741E+00	7.570E-02
HG-203						1.000E-06		
I-125	2.000E-02	9.300E-03					1.155E-03	
I-131								
I-132								
I-133								
I-135								
IR-192								
K-40					1.000E-06	2.132E-05		

Table 2-12. (continued)

NUCLIDE	1981	1982	1983	1984	1985	1986	1987	1988
KR-85								
LA-140	2.513E+00	4.410E+00	1.978E+00	1.186E+00	8.460E-02			
MN-53		1.000E-03						
MN-54	2.125E+01	9.210E+01	5.170E-01	6.328E+01	3.795E+00	1.221E+01	9.680E+00	3.190E-01
MN-56								
NA-22	2.180E-04	7.018E-03	2.500E-02	2.001E-02	5.000E-05	3.339E-04	3.814E-05	
NA-24						2.200E+00		
NA-25								
NB-94			2.000E+00					
NB-95	1.082E+01	7.322E+00	8.777E+00	9.286E+00	3.541E+00	5.825E+00	4.188E+00	5.479E+00
NI-59			4.000E+00					
NI-63		2.500E-04	6.730E+02	1.141E+04			2.002E-03	5.400E-02
NP-237	4.371E-03	7.355E-05	8.178E-04	1.346E-05	5.133E-04	7.578E-04	3.751E-04	4.900E-05
NP-239					1.000E-06			
P-32				1.000E-03	7.500E-03	5.000E-05		
PA-231				4.720E-03				
PB-210		9.100E-06		2.000E-05		1.000E-06	1.000E-05	
PB-212		2.000E-05			4.000E-03	3.000E-06		
PM-147			2.097E-01	6.000E-03				
PO-210		1.262E-03						
PU-236					1.012E-07	1.141E-06	1.961E-06	
PU-238		3.267E-05	1.960E-02	1.740E-02	1.796E-05	1.358E-05	3.913E-04	2.114E-04
PU-239	1.686E-02	5.146E-02	9.800E-02	5.635E-02	6.910E-02	6.834E-02	2.821E-02	1.760E-02
PU-240	9.746E-03	1.837E-02	2.021E-01	2.043E-02	5.730E-03	9.725E-04	4.859E-03	1.567E-03
PU-241			5.880E-03			1.550E-04	6.581E-02	2.127E-02
PU-242		9.498E-06		9.922E-07	2.104E-04	5.953E-05	2.588E-05	4.087E-05
RA-225			2.000E-06			1.500E-06		
RA-226	1.001E-03	4.785E-03		1.426E-04	7.718E-02	1.023E+00	6.998E-03	1.005E-01
RA-228				1.000E-03		2.000E-06	1.000E-07	
RB-86						3.000E-05		
RN-222				1.000E-06	1.000E-03			
RU-103	2.360E-01					4.395E-02		
RU-106	3.649E+01	1.598E+01	2.604E+01	2.753E+01	9.851E+00	1.841E+01	1.348E+01	1.765E+01
S-35		2.050E-02				1.202E-04	1.000E-05	
SB-124						3.848E-06		
SB-125	1.611E+01	7.030E+00	1.173E+01	1.211E+01	4.274E+00	8.102E+00	8.256E+00	7.764E+00
SC-46						8.030E-06		
SE-75								
SM-151			1.960E-03					
SM-153								
SN-119								
SR-89						2.680E+01		
SR-90	3.300E+01	1.621E+01	2.620E+01	2.753E+01	9.713E+00	3.054E+01	1.600E+01	1.780E+01
TA-182					5.000E-04	1.268E-01		
TC-99	3.230E-08	2.000E-06				3.970E-05	1.110E-05	1.000E-06
TE-129						1.634E-02		
TE-132								
TH-228					1.003E-03	1.473E-02	8.230E+00	1.000E-05
TH-229						2.129E-06		

Table 2-12. (continued)

NUCLIDE	1981	1982	1983	1984	1985	1986	1987	1988
TH-230						2.003E-05	8.788E-06	
TH-232	1.090E-15	2.107E-04	3.088E-05	3.581E-03	2.708E-03	2.048E-04	2.916E-03	1.824E-04
TH-234				1.308E-07		2.000E-06		
U-232						2.090E-04	2.090E-04	2.218E+00
U-233	3.788E-05	2.983E-06	4.735E-09	1.360E-05	1.820E-03	4.025E-04	7.415E-04	
U-234	9.601E-06			1.302E-02		2.931E-05	3.405E-04	3.630E-04
U-235	2.457E-04	1.365E-02	3.241E-03	9.837E-03	8.518E-04	5.973E-03	1.367E-02	1.767E-02
U-236	4.800E-08			2.009E-04	4.167E-16			
U-238	4.312E-02	1.828E+00	6.943E-02	2.065E-01	2.000E-01	2.756E-02	7.470E-02	3.519E-01
V-48				2.501E-02				
W-187								
Y-91M						6.582E-01		
ZN-65	1.343E+00	6.118E-02	3.576E-01	4.760E-01	3.264E-01	3.156E-05	1.948E+01	2.493E-01
ZR-95	1.118E+01	7.410E+00	9.040E+00	9.661E+00	3.283E+00	3.304E+01	4.779E+00	5.472E+00

2.2.7.3 Estimates of Radionuclides Disposed in Soil Vaults. Radionuclides have been disposed in soil vault rows (described in Section 2.2.1.3) since 1977. This disposal technique has been used for wastes with high external exposure rates. The radionuclides disposed in soil vaults were treated separately from those disposed in pits. The annual quantities of radionuclides disposed in solid vaults are listed in Table 2-13 for the period 1977-1988.

2.2.7.4 Estimates of Future Radionuclide Disposal Rates. Two methods were used to estimate future disposal rates of radionuclides at the RWMC. The first was to survey the organizations shipping wastes to the RWMC to obtain their projections of future disposal rates. The second method was to use the recent historical data as the basis for estimates of future disposal rates.

Table 2-14 compares the results of the two methods of estimating future disposal rates for pits at the RWMC. The shippers' estimates for pits and soil vaults are shown together with the 10- and 12-yr average disposal rates, respectively. In both cases, the recent disposal experience suggests that the amounts of radionuclides disposed in future years will generally be larger than the shippers' projections. For some radionuclides, including those believed to be the most important to the performance assessment, the differences between the projections and historical values is quite large. Because use of the projections would appear to substantially underestimate the future inventories, historical average disposal rates were used to estimate future disposal rates.

2.3 Waste Treatment, Certification, and Disposal

2.3.1 Waste Treatment

Currently, there are no waste treatment facilities/processes in operation at the RWMC. Waste treatment is performed at WERF before shipment to the RWMC.

Table 2-13. Radionuclides disposed in soil vaults (1971-1988) (in curies)

NUCLIDE	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
CD-109										
CE-144							1.000E+00	7.938E+02	5.840E+02	5.109E+02
CO-58							1.055E+05	9.217E+04	1.312E+05	7.033E+04
CO-60							1.585E+03	9.436E+04	3.274E+04	1.576E+04
CR-51							1.237E+04	7.536E+05	1.160E+04	7.592E+03
CS-134								8.521E+01	1.249E+01	
CS-137							3.000E+00	6.841E+02	4.529E+02	3.596E+02
EU-152										
FE-55								2.682E+03	3.698E+04	1.372E+04
FE-59							1.223E+03	9.319E+04	1.148E+03	8.310E+02
GD-153										
IR-192										
MN-54							7.331E+04	7.625E+04	9.022E+04	4.892E+04
NB-95								1.176E+02	8.695E+01	8.184E+01
NI-63								1.533E+02	2.113E+03	7.843E+02
PU-239							1.491E-04	2.604E-03	2.559E-04	1.480E-03
PU-240							2.152E-05	6.232E-04	5.433E-06	6.007E-06
RU-106								3.567E+02	2.637E+02	2.614E+02
SB-124										
SB-125								1.623E+03	2.020E+04	7.567E+03
SC-46								7.740E+01		
SN-119								3.832E+02	5.283E+03	1.961E+03
SR-90							1.000E+00	4.422E+02	2.934E+02	2.547E+02
TA-182								4.000E+00		
TH-228										
U-235							7.728E-05	5.331E-04	6.420E-06	1.200E-05
U-238							4.612E-06	4.466E-04	2.331E-05	1.100E-06
ZR-95								8.841E+02	1.065E+04	4.003E+03
	==========	==========	==========	==========	==========	==========	==========	==========	==========	==========
	3.509E+05	2.147E+05	3.399E+05	1.832E+04	1.318E+04	2.901E+05	9.643E+05	1.153E+06	3.495E+05	1.875E+05

Table 2-13. (continued)

NUCLIDE	1981	1982	1983	1984	1985	1986	1987	1988	TOTAL
CD-109	4.000E-08								4.000E-08
CE-144	1.119E+03	5.694E+01	5.154E+02	4.087E+02	6.149E+01	1.390E+02	9.100E+00	6.000E+00	4.205E+03
CO-58	7.076E+04	1.533E+05	2.508E+04	6.508E+04	6.076E+04	2.404E+04	9.791E+04	7.580E+04	9.719E+05
CO-60	9.404E+03	1.699E+05	1.733E+04	1.269E+05	6.900E+04	2.537E+04	4.950E+04	1.638E+04	6.281E+05
CR-51	2.981E+03	7.007E+03	7.990E+02	1.942E+03	2.574E+03	6.591E+02	4.007E+03	2.244E+03	8.074E+05
CS-134	8.534E+02	5.875E+01	1.121E+02	9.957E+01	3.359E+01	3.305E+01	1.362E+01	1.200E+00	1.303E+03
CS-137	3.832E+03	4.947E+04	2.472E+02	2.269E+02	1.210E+02	1.162E+02	2.737E+03	2.400E+00	5.825E+04
EU-152							3.900E+00		3.900E+00
FE-55	3.081E+03	1.446E+03	6.235E+03	5.472E+04	2.268E+04	5.747E+03	4.743E+03	1.077E+03	1.531E+05
FE-59	8.571E+02	3.179E+04	1.494E+02	3.610E+02	4.664E+02	1.233E+02	6.200E+02	3.380E+02	1.311E+05
GD-153							1.300E+00		1.300E+00
IR-192							6.500E-01		6.500E-01
MN-54	4.387E+04	1.026E+05	1.703E+04	4.402E+04	4.315E+04	1.845E+04	7.115E+04	4.974E+04	6.787E+05
NB-95	8.686E+02	5.028E+01	9.622E+00	2.310E+00	1.157E+01				1.229E+03
NI-63	9.435E+03	4.427E+03	1.909E+04	1.676E+05	6.945E+04	1.760E+04	1.453E+04	3.297E+03	3.085E+05
PU-239	2.431E-03	2.559E-03	1.003E-02	5.768E-03	3.283E-03	1.428E-02	2.736E-04	3.787E-04	4.350E-02
PU-240	1.535E-04	5.231E-05	2.625E-03	1.043E-04	9.589E-04	2.265E-04	5.866E-06	4.947E-06	4.788E-03
RU-106	2.904E+02								1.172E+03
SB-124							1.800E-01		1.800E-01
SB-125	1.234E+02								2.951E+04
SC-46									7.740E+01
SN-119									7.627E+03
SR-90	2.716E+02	8.400E+00	2.034E+02	1.594E+02	1.840E+01	[illegible].440E+01	2.400E+00	2.400E+00	1.712E+03
TA-182		4.000E+00		5.700E+01	2.080E+02	9.784E+02	2.680E+02	3.383E+02	1.858E+03
TH-228	9.999E-09								9.999E-09
U-235	1.662E-04	1.273E-05	5.153E-04	3.894E-04	1.010E-04	[illegible].135E-04	5.560E-05	5.334E-07	1.983E-03
U-238	6.276E-05	5.410E-05	4.224E-04	8.739E-06	1.212E-03	[illegible].019E-03	1.155E-01	5.259E-03	1.240E-01
ZR-95	4.883E+02	2.581E+01	4.940E+00	6.050E+00	2.826E+01	2.452E+01	1.400E+01		1.613E+04
	==========	==========	==========	==========	==========	==========	==========	==========	==========
	1.495E+05	5.216E+05	9.361E+04	4.859E+05	2.714E+05	9.501E+04	2.475E+05	1.497E+05	5.895E+06

Table 2-14. Comparison of shipper projections and average disposal rates

Estimates for Pits			Estimates for Vaults		
Nuclide	Shipper Projected Disposal Rate (Ci/y)	10-yr Average Disposal Rate (Ci/y)	Nuclide	Shipper Projected Disposal Rate (Ci/y)	12-yr Average Disposal Rate (Ci/y)
H-3	2.1E-01	4.3E+02			
C-14		2.3E-03	Sc-46		6.5E+00
Cr-51	1.2E+02	7.9E+02	Cr-51	5.5E+03	6.7E+04
Mn-54	2.7E+02	2.1E+01	Mn-54	1.0E+05	5.7E+04
Co-58	5.2E-02	5.2E+00	Fe-55	1.7E+03	1.3E+04
Co-60	2.4E+00	1.2E+03	Fe-59	7.4E+02	1.1E+04
Ni-59		4.0E-01	Co-58	1.7E+05	8.1E+04
Ni-63		0.0E+00	Co-60	2.3E+04	5.2E+04
Sr-90	1.3E+01	1.2E+02	Ni-59		
Zr-95	4.2E+00	4.9E+01	Ni-63	5.2E+03	2.6E+04
Tc-99		5.4E-06	Sr-90	7.7E+00	1.4E+02
Ru-106	1.3E+01	3.2E+01	Zr-95		1.3E+03
Sb-125	6.0E+00	7.8E+01	Nb-95		1.0E+02
Cs-134	3.4E-03	4.2E+01	Ru-106		9.8E+01
Cs-137	1.3E+01	1.3E+03	Cs-134	3.9E+00	1.1E+02
Ce-144	2.9E+01	2.7E+02	Cs-137	7.7E+00	4.9E+03
Eu-152		1.1E+01	Ce-144	1.9E+01	3.5E+02
Eu-154		1.1E+01	Eu-152		3.3E-01
Eu-155		5.4E+00	Ta-182	2.0E+01	1.5E+02
Hf-181	3.1E-02	3.3E-01	U-235	1.7E-06	1.7E-04
Ra-226		1.3E-01	U-238	1.7E-02	1.0E-02
Th-230		1.8E-03	Pu-239	1.2E-03	3.6E-03
U-234		1.6E-02	Pu-240	1.5E-05	4.0E-04
U-235	1.3E-02	7.3E-03			
U-238	2.7E-03	3.0E-01			
Np-237		7.0E-04			
Pu-238		8.5E-02			
Pu-239	1.1E-03	7.7E-02			
Pu-240	9.8E-05	2.7E-02			
Pu-241		1.6E-01			
Pu-242		4.4E-05			
Am-241	7.7E-09	3.3E-02			

2.3.2 Waste Certification

Generators of LLW must be approved to ship LLW to the RWMC for disposal in the SDA. In order to maintain this approval, the waste generator must comply with the INEL LLW acceptance criteria. Future updates to this acceptance criteria will require waste generators to have an approved Waste Certification Program on file with RWMC/SWEPP Programs. At least annually, the Waste Certification Program of each waste generator will be given a competency review by RWMC/SWEPP Programs.

The Waste Certification Program Plan shall invoke the waste acceptance criteria requirements for the waste generator. It also will identify the LLW management responsibilities for each organization associated with the LLW management process and will list the generating organization's procedures required to manage LLW in a competent manner.

2.3.3 Waste Disposal

The RWMC is operated for disposal of LLW and interim storage of TRU waste. Receipt and shallow-land disposal of TRU waste began in 1954 and ended in 1970. Remedial actions are currently being addressed to allow recommendation of an alternative for long-term management of this buried TRU waste. Since 1970, solid TRU waste received at the RWMC has been segregated from non-TRU solid waste and placed into interim retrievable storage at the RWMC. This waste is planned to be shipped to the Waste Isolation Pilot Plant (WIPP).

LLW disposal at the RWMC has been underway since 1952. Until 1983, solid LLW management consisted of shallow land burial of waste in trenches, pits, and soil vaults. Since 1983, WERF operations have reduced the LLW disposal volume and have converted the waste to a reduced form through a combination of incineration, compaction, and metal sizing operations.

Soil vaults and pits are excavated to provide sufficient space for the anticipated waste volume and to minimize the infiltration of water. Before excavation of a row of soil vaults or a pit, probe holes are drilled to determine the usable soil depth. A minimum of 0.6 m of soil covering is left above the basalt, or placed over rock, when rock removal operations are required to attain the necessary depth for proper disposal operations. This soil cover ensures a smooth surface without rock projections for placement of the waste containers; it also provides for filtration, absorption, and ion exchange that inhibits migration of the radionuclides that escape from the waste containers.

At the SDA, pits are used to dispose of routine waste (solid, low-level, beta-gamma contaminated waste with radiation levels normally below 500 mR/h at 0.9 m). Soil vaults and the bulk disposal pit are used to routinely dispose of waste packages whose unshielded contents exceed 500 mR/h at 0.9 m and/or the waste contained in odd size or bulk containers such as tanks, metal gates, reactor vessels, etc.

A few nonstandard, nonroutine waste packages are accepted on a case-by-case basis and must have approval before shipment. Records are kept of all disposed waste. These records show the distance (in feet) and direction of the waste from a presurveyed reference point.

Most of the noncompactible waste received for disposal in the SDA is contained in 1.2 x 1.2 x 2.4 m, 1.2 x 1.2 x 1.2 m, and 0.6 x 1.2 x 2.4 m fire-retardant, painted wooden boxes. These boxes are stacked in pits in a close-packaged array to conserve space. Large bulky items such as support stands and tanks are placed in the bulk pit located in an area separate from the box stack.

Waste packages are covered with soil to minimize their exposure to the weather, to provide fire protection, and to reduce radiation levels to less than 1 mR/h at 0.9 m (at least 0.9 m of soil is used). The contoured soil cover is crowned and compacted to allow efficient natural drainage.

A LLW classification system is being developed for the INEL using INEL Site characteristics to derive the limits. The classification system will provide protection for future inadvertent intruders onto the INEL LLW disposal site by providing criteria for identifying and classifying waste radionuclide concentrations having differing potentials for exposure to future inadvertent intruders. The limits will be equivalent or more restrictive than the limits in 10 CFR 61. Requirements for disposal will be specified for each class of waste defined in the waste classification system.

3. ANALYSIS OF PERFORMANCE

3.1 Nuclide Inventory for Performance Assessment

The tabulations of radionuclide disposal shown in Tables 2-10 through 2-13 show that many different nuclides have been disposed in portions of the RWMC. To simplify the performance assessment, it was necessary to focus the analysis on the most important of the disposed radionuclides. It was also important to project the future disposal rates for the most important radionuclides, so the effects of continued operation of the RWMC can be included in the assessment. Calculations of relative hazard of the disposed radionuclides are described in Section 3.1.1. Projections of future disposal rates for these nuclides, by container type, are discussed in Section 3.1.2. Radionuclide concentrations in wastes disposed in soil vaults are described in Section 3.1.3.

3.1.1 Measures of Relative Hazard

Comparisons of the total activities (measured in Ci) of the disposed radionuclides does not provide a good measure of the relative hazards of the nuclides. Some of the nuclides have short half-lives and will not persist in the disposal area; others are very long-lived and will be present for many years. The radiations emitted by the various nuclides differ widely, and there are differences in radionuclide metabolism that make some nuclides more hazardous to man than others.

To provide a better measure of the potential hazards of the disposed radioactivity, an index of potential risk, defined below, was developed that reflects both the half-life of the radionuclide and its inherent toxicity.

For a particular time (t), the risk index of radionuclide (i) is defined here to be the ratio of the total inventory of that radionuclide at the time [$Q_i(t)$, Ci] to the annual limit on intake for the radionuclide (ALI_i, Ci). Because both $Q_i(t)$ and ALI_i have the same units, the risk index (RI_i) is dimensionless.

$$RI_i = Q_i(t)/ALI_i$$

The annual limit on intake has been computed for both ingestion and inhalation of radionuclides by the ICRP. For either intake mode, the ALIs reflect the differences in radionuclide metabolism and radiation emissions that affect human radiation exposure from the nuclide. An intake of 1 ALI would result in a 50-yr committed dose equivalent equal to the dose equivalent limit for an occupationally exposed person. The bases for the calculations of ALIs and the ICRP estimates for a large list of nuclides are presented in a series of reports (ICRP 1977, ICRP 1979, 1981, 1982).

Calculations of risk indices for the radionuclides in pits at the RWMC were performed for the years 1988, 2088, 2188, and 2588. The inventories of radionuclides during those years reflect the continued disposal of radionuclides at the projected rates (10 yr average disposal rate in Table 2-14) for 100 yr as well as the decay of disposed radionuclides during the periods of interest. Tables 3-1 and 3-2 contain the fractions of the total potential ingestion and inhalation risk, respectively, contributed by specific radionuclides in the waste. The 11 most important radionuclides, from Tables 3-1 and 3-2, contribute slightly more than 99% of the total risk (based on the risk index) from all radionuclides at each of the times considered.

The tables show that relatively short-lived fission and activation products are important contributors to the total risk at early times, while the long-lived nuclides dominate the risk at times greater than about 200 yr from now. The results of these calculations provide the proper focus for the assessment without ignoring any important fraction of the total risk at the times of interest.

Table 3-1. Fractions of ingestion risk contributed by the most important radionuclides

Nuclide	Fraction of Total Risk at Specified Time 1988	2088	2188	2588
Co-60	4.54E-01	5.29E-02	--	--
Sr-90	2.56E-01	2.30E-01	9.03E-02	--
Cs-137	2.09E-01	5.51E-01	2.42E-01	--
Ra-226	--	1.39E-02	5.82E-02	7.87E-02
U-234	--	--	--	2.15E-03
U-238	--	4.04E-03	1.76E-02	2.83E-02
Pu-238	5.74E-03	1.23E-02	2.42E-02	--
Pu-239	6.60E-02	1.20E-01	5.21E-01	8.28E-01
Pu-240	--	6.48E-03	2.80E-02	4.31E-02
Am-241	--	--	1.30E-02	1.10E-02
Total	9.91E-01	9.91E-01	9.94E-01	9.91E-01

Table 3-2. Fractions of inhalation risk contributed by the most important radionuclides

Nuclide	Fraction of Total Risk at Specified Time 1988	2088	2188	2588
Co-60	2.30E-01	1.89E-02	--	--
Sr-90	1.86E-01	1.17E-01	1.33E-02	--
Cs-137	1.01E-02	1.88E-02	--	--
Th-230	--	3.64E-03	4.57E-03	5.04E-03
U-234	--	6.28E-03	7.90E-03	8.73E-03
U-238	1.75E-02	5.16E-02	6.49E-02	7.18E-02
Pu-238	6.24E-02	9.42E-02	5.38E-02	2.53E-03
Pu-239	4.78E-01	6.12E-01	7.67E-01	8.40E-01
Pu-240	3.56E-03	3.31E-02	4.12E-02	4.38E-02
Am-241	3.20E-03	3.57E-02	3.83E-02	2.23E-02
Total	9.91E-01	9.91E-01	9.91E-01	9.94E-01

3.1.2 Projections of Radionuclide Disposal by Container Type

Records of the numbers of containers of various types that have been used for waste disposal in the pits at the RWMC have been maintained in the RWMIS. Review of the historical data reveals that although many different types of containers have been used, the types that account for most of the volume of disposed waste are cardboard boxes, metal containers, and wooden boxes. These three types of containers were employed in modeling the movement of disposed radionuclides in pits.

For the set of 11 radionuclides found to contribute more than 99% of the potential risk (Tables 3-1 and 3-2), disposal rates for "old pits" and "new pits" were estimated for each container type. Assigning the disposed activities of the most important radionuclides to three container types is an approximation that is believed to be reasonable for the performance assessment. For the years between 1964 and 1988, the actual distribution of container types is known, and the fractional waste volume associated with wooden and cardboard boxes and with metal containers can be estimated. For future years, the disposal rates by container type have been projected. This procedure assumes that future container usage for pit disposal will reflect that of the recent past. See Appendix A, Section A.2, for more information.

In the case of Ra-226, it was known that the radionuclide sources containing that nuclide were most frequently disposed in "2-R" pipe containers; therefore, all of the Ra-226 disposal was assumed to be in metal containers. No other preferential associations of radionuclides and container types are known to have occurred. However, if the other 10 radionuclides were preferentially disposed in one type of container, some bias in the assessment could occur. The potential magnitude of possible bias will be estimated by the uncertainty analysis (see Section 4.2).

3.1.3 Concentrations of Long-Lived Radionuclides Disposed in Soil Vaults

To assess the potential exposure to radionuclides disposed in soil vaults, the radionuclide concentrations in the waste that could be encountered while drilling through it were needed. Because the 100-yr institutional control period allows for nearly complete decay of the short-lived activation products (i.e., <30 yr), only concentrations of longer-lived radionuclides were evaluated. The four most important long-lived radionuclides in wastes disposed in soil vaults were Sr-90, Cs-137, Pu-239, and Pu-240.

Concentrations (measured in Ci/m^3) of these nuclides in the waste at the time of disposal were computed using data from the RWMIS. A very wide range of concentrations was found for all of the nuclides. Mean values were 44, 340, 0.0014, and 0.00018 Ci/m^3 for Sr-90, Cs-137, Pu-239, and Pu-240, respectively. The highest concentrations for these four radionuclides were 1.1 E+4, 1.2 E+3, 5.2 E-2, and 1.8 E-2, respectively. As would be expected, the median concentrations were much lower than the mean values. The median concentrations were 18, 8.5, 1.8 E-5 and 5.3 E-7, respectively, for Sr-90, Cs-137, Pu-239, and Pu-240. The geometric standard deviations for the distributions of nuclide concentrations were generally very large, 14, 4, 19, and 24, respectively, for the four radionuclides.

The statistics for Sr-90 differ from those for Cs-137. This difference is probably an artifact of reporting of the waste concentrations. When radionuclide concentrations are small, it is less likely that an analysis for Sr-90 will be performed and more probable that no value will be reported on the waste manifest. This would reduce the range of reported concentrations and the geometric standard deviation calculated for Sr-90.

Details of the methodology used to determine radionuclide input rates into the near-field model can found in Appendix A.

3.2 Pathways and Scenarios

3.2.1 Time Periods of Concern

Three time periods of concern were addressed in this evaluation of the RWMC:

1. The operational period, 1964-2089, during which radioactive waste is actively disposed at the facility.

2. The institutional period, 2089-2189, which follows site closure and during which periodic maintenance and monitoring activities are conducted. The facility is assumed to be stabilized but is still part of the INEL reservation and is fenced and patrolled.

3. The post-institutional period, 2189-11975, during which the facility is no longer maintained by DOE and may be accessible to public.

3.2.2 Receptors and Scenarios

Two receptor types were assessed. The first is a member of the general public. For the airborne transport pathway, this individual was conservatively assumed to reside at or near the INEL Site boundary at the location of maximum concentration of airborne radionuclides in the transport medium of concern (i.e., air). For the ground water transport pathway, the receptor was assumed to reside at the INEL Site perimeter during operational and institutional periods. During the post-institutional period, the receptor was assumed to reside at the RWMC perimeter. The dose to the hypothetical maximum individual was assessed for each of the three time periods of concern discussed previously.

The second type of receptor evaluated is an intruder. This hypothetical receptor is assumed to inadvertently intrude on the RWMC during the post-institutional control period. Two general kinds of scenarios were evaluated. The first is an agriculture scenario in which the receptor obtains half of his produce from farming at the RWMC. This individual also drinks water from a well drilled at the edge of the waste. The second is an acute exposure scenario that includes a construction scenario and a well-drilling scenario. In the construction scenario, the receptor is an individual who is building a house at the RWMC and is exposed to contaminated soil while excavating the cellar. In the well-drilling scenario, the receptor is exposed to contaminated drill cuttings that are deposited in a mud pit.

3.2.3 Radionuclide Transport Pathways

Environmental surveillance of the RWMC has been conducted since 1960. The current RWMC environmental surveillance program consists of several routine monitoring activities designed to monitor contaminant transport from the RWMC facility (EG&G 1989a). Special studies are also conducted to identify contaminants in the environment. For example, the Site Characterization Program (EG&G 1989b) is currently being conducted to determine the extent of contaminant migration in subsurface media below the RWMC. The RESL also conducts radioecological studies at and around the RWMC (DOE 1985). Many of the RESL studies have focused on radionuclide transport via biota.

Results of the monitoring and special studies to date indicate that the greatest potential for transport of radionuclides from the RWMC to offsite receptors (now and in the future) is via airborne transport of resuspended contaminated surface soil particles and ground water transport of radionuclides leached from buried waste. For this reason, the performance assessment only addresses these two transport pathways.

The exposure pathways evaluated include ingestion of food and water, inhalation of contaminated airborne particulates, and external exposure to radionuclides in air and soil. The agricultural products consumed by the general public are contaminated via food chain transport of radionuclides deposited from air onto soil or plant surfaces.

3.3 Assumptions and Methods

The following is an overview of the assumptions and methods used to evaluate the performance of the RWMC. A detailed description of methods can be found in Appendix A.

3.3.1 Near-Field Model

The near-field model describes the release of radionuclides from the buried waste and subsequent transport within the RWMC to surface soil and subsurface media. Projections of radionuclide concentrations in surface and subsurface media were used as source terms for the environmental transport models. Figure 3-1 illustrates the relationship between the near-field and other categories of models used in the performance assessment.

Because current operations involve the excavation of deeper pits and the emplacement of a thicker soil cover, two distinct near-field models were developed for the pits and trenches. One addresses the waste emplaced from 1964 through 1975 in shallow pits and trenches. The second depicts the burial of waste in deep pits (i.e., pits deeper than 5 m) from 1975 on. The former model is termed the old pits model. The latter model is called the new pits model. Soil vaults were addressed separately from the pits and trenches.

Near-field models do not include the TRU waste and LLW intermixed with TRU waste buried from 1954 through 1970 (i.e., the waste evaluated in DOE 1982). It was assumed this waste will either be retrieved or treated in situ. This waste is the subject of environmental evaluations being performed by the EG&G Idaho Buried Waste Program. For similar reasons, the near-field evaluation also excludes retrievable TRU waste stored at Pad A and at the TSA.

Finally, the near-field models do not include the nonradioactive hazardous components of the waste buried at the RWMC in the inventory. This has been and continues to be the subject of other evaluations (e.g., Walton et al. 1989).

DRAFT

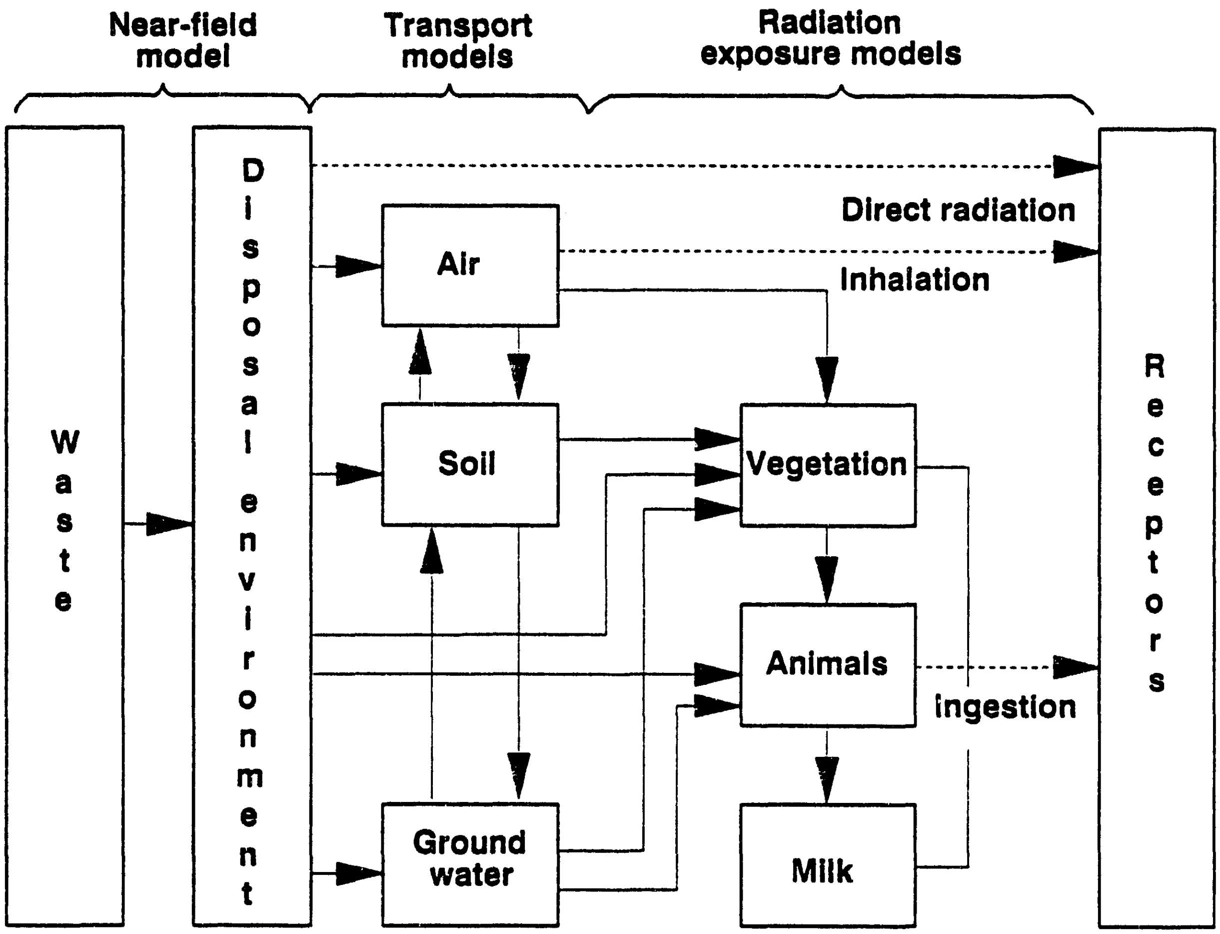


Figure 3-1. Performance assessment model components.

3.3.1.1 Old pits

The near-field model for old pits addresses LLW buried from 1964 through 1975. It was assumed that the waste was disposed in a square-shaped area approximately equivalent to the combined areas of each pit and trench.

The waste was assumed to disposed by emplacing waste to an average depth of 3.66 m and placing an initial soil cover of 0.91 m over the waste (EG&G 1984). A later minimum soil cover of 0.75 m was added in 1985. It was assumed that a final total cover of approximately 5 m would exist at closure in 2089. Enhanced closure designs (e.g., biobarriers, denser covers, grouting, etc.) were not modeled.

After the institutional control period, the cover was allowed to erode to an extent such that the final surface elevation would be even with the surrounding ambient topography. Because the Snake River Plain is a depositional area (i.e., wind deposits material from eroding mountains surrounding the plain) it was assumed that the soil would not erode below the current ambient surface elevation. It was estimated that erosion from wind and surface water runoff would result in a final cover of 2.4 m approximately 4980 yr after closure (i.e., the year 7069).

The conceptual model for the old pits is shown in Figures 3-2 through 3-4. The model is shown in three figures because of its complexity. Each figure corresponds to a different time period and associated cover depth. Note that there is no separate figure for the time period between 2089 and 7069, when cover depth is greater than 2.4 m. During this time period the cover is sufficient to preclude animal or plant intrusion into the buried waste. It was assumed that until the cover eroded to a depth at which biotic intrusion could occur (in the year 7069) that contamination of the surface soil would be insignificant. Thus, during this time period the model shown in Figure 3-4 was applied; however, the biotic transport processes were suppressed.

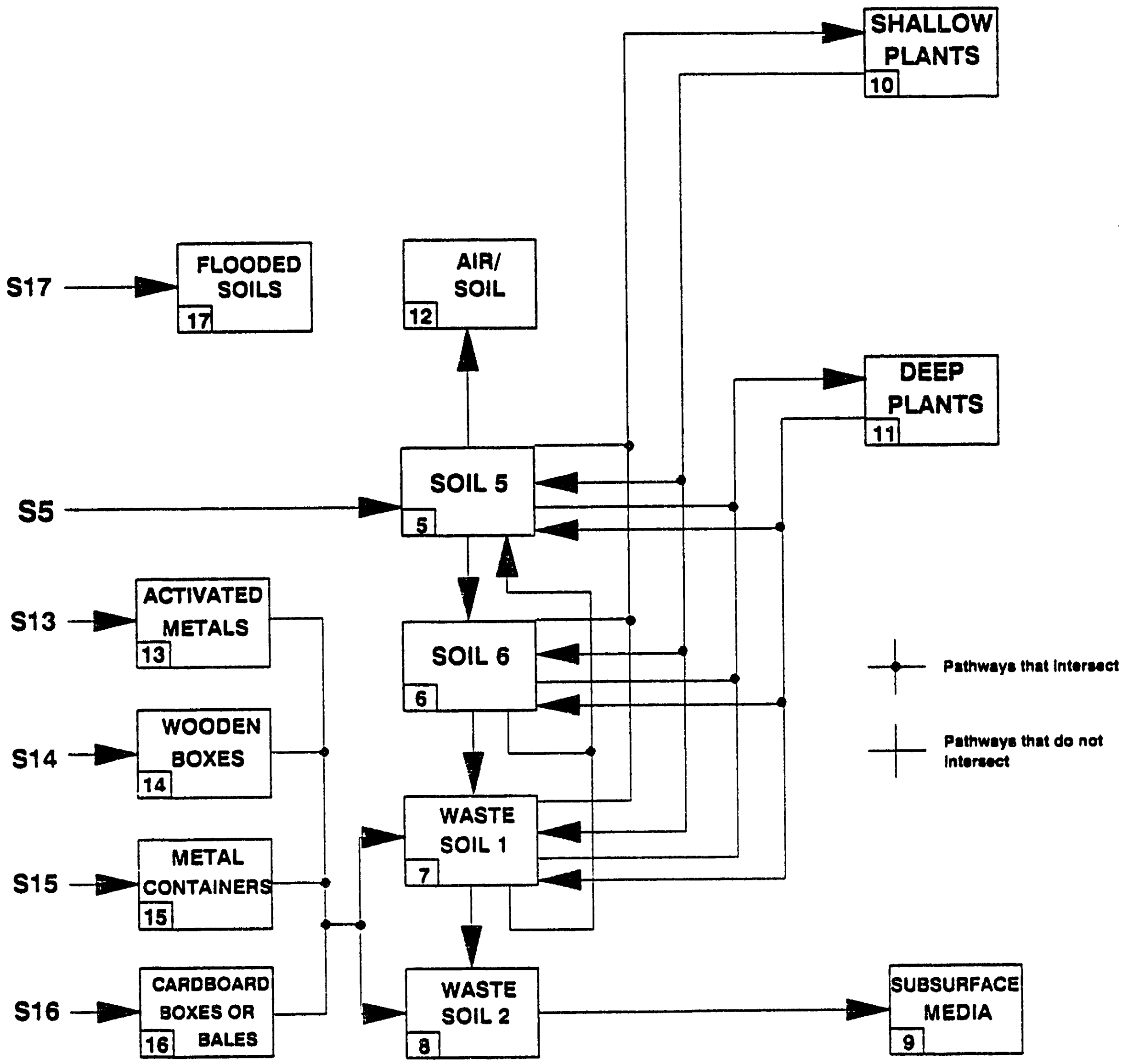


Figure 3-2. Conceptual model of the transport of radionuclides in the near-field of the old pit disposal area from 1964 through 1984.

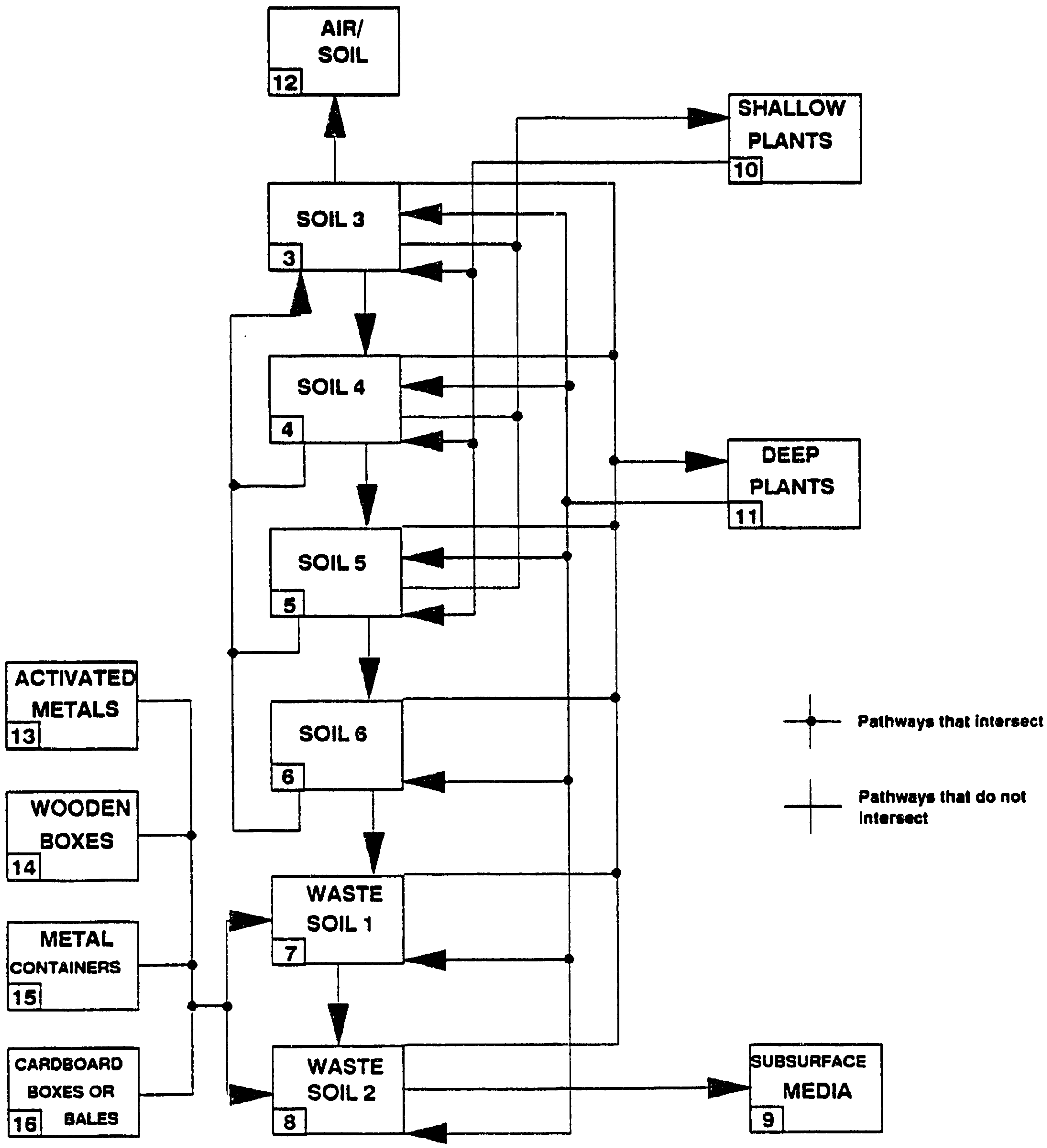


Figure 3-3. Conceptual model of the transport of radionuclides in the near-field of the old pit disposal area from 1985 through 2089.

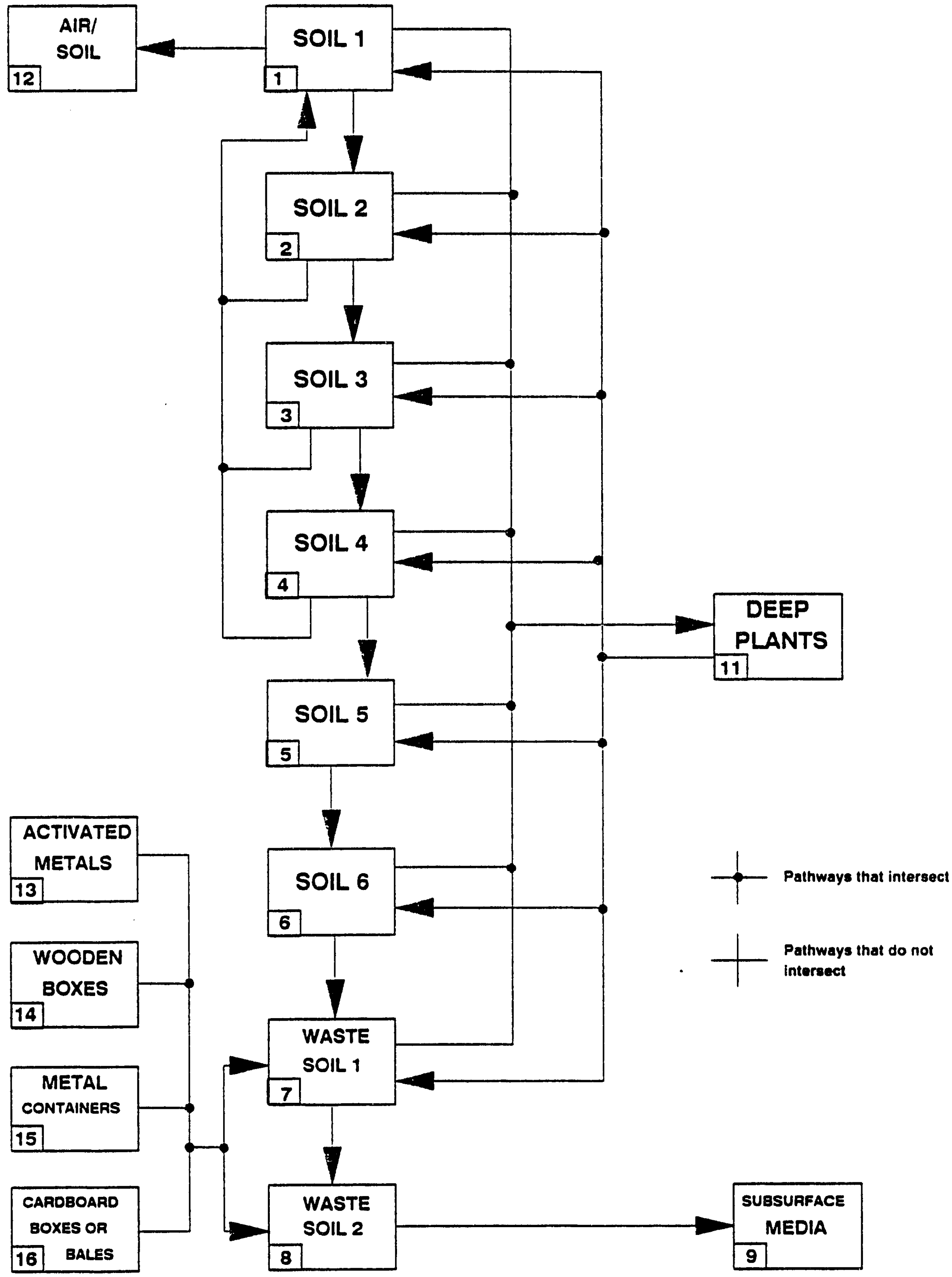


Figure 3-4. Conceptual model of the transport of radionuclides in the near-field of the old pit disposal area from 7069 through 12089.

Each box represents the quantity of radionuclides in an environmental medium or compartment. Compartment names and descriptions are presented in Table 3-3. Arrows between the boxes indicate the transfer of radionuclides. The movement of radionuclides between boxes is controlled by rate constants, which specify the fraction of radionuclides entering or leaving a compartment during a specified period of time. Such factors as plant biomass, concentration ratios, animal densities, soil density, and radionuclide distribution constants are used in the estimation of rate constants. The transport processes are listed in Table 3-4. Sources of radionuclides into the buried waste compartments are provided as input and are also described in Table 3-4. Note that soil compartment descriptions may change with time (e.g., surface soil is covered and becomes an upper soil layer). Similarly, certain transport processes may only apply to certain time periods. These changes are implemented in the code through the use of time switches.

The conceptual model was simulated on a computer using the DOSTOMAN code, which is described in Appendix B.

3.3.1.2 New Pits. The near field model for new pits addresses LLW buried from 1975 through 2089. It was assumed that the waste was disposed in a rectangular-shaped area equivalent to the combined areas of Pits 15 through 20.

The waste was assumed to be disposed by the current practice of blasting into the basalt and emplacing waste to a depth of 5.3 m, with an initial cover of 2 m and a final total cover of 5 m of soil at closure (2089). Enhanced closure designs (e.g., biobarriers, denser covers, grouting, etc.) were not modeled.

After the institutional control period, the cover was allowed to erode to an extent described in Section 3.3.1.1. Therefore, a final cover of 2.4 m approximately 4980 yr after closure (i.e., the year 7069) was assumed.

Table 3-3. Definition of compartments in the old pit near-field model

Compartment Number	Compartment Name	Compartment Description
1	Surface soil	Top 40 cm of cover soil (2089-11964)
2	Upper soil	40 cm of cover soil (2089-11964)
3	Surface soil	Top 40 cm of cover soil (1985-2089)
	Upper soil	40 cm of cover soil (2089-11964)
4	Upper soil	40 cm of cover soil (1985-11964)
5	Surface soil	Top 40 cm of cover soil (1964-1984)
	Upper soil	40 cm of cover soil (1985-11964)
6	Upper soil	40 cm of cover soil (1964-2089)
7	Waste soil	183 cm of waste soil
8	Waste soil	183 cm of waste soil
9	Subsurface media	Vadose zone and aquifer beneath disposed waste
10	Shallow rooted plants	Crested Wheatgrass
11	Deep-rooted plants	Russian Thistle (1964-2089) Sagebrush (2089-11964)
12	Air/soil	Air and offsite soil
13	Activated metals	Activated metal waste
14	Wooden boxes	LLW disposed in wooden boxes
15	Metal containers	LLW disposed in drums

Table 3-3. (continued)

Compartment Number	Compartment Name	Compartment Description
16	Cardboard boxes or bales	LLW disposed in cardboard boxes or bales
17	Flooded soils	Soils outside the RWMC contaminated during spring snowmelt in 1962 and 1969.

Table 3-4. Transport processes and source terms represented in the old pits near-field model

Compartment Number From	To	Transport Process
1	12	Resuspension of soil
3,5	12	Erosion of soil
1,2,3,4 5,6,7,	11	Uptake of nuclides by deep-rooted plants
3,2,5,6,7	10	Uptake of nuclides by shallow-rooted plants
11	1,2,3, 4,5,6, 7	Death and decay of deep-rooted plants in soil
10	1,2,3, 4,5,6, 7	Death and decay of shallow-rooted plants in soil
2,3,4	1	Movement of soil to surface by burrowing mammals
3,4,5,6	3	Movement of soil to surface by burrowing mammals
6,7	5	Movement of soil to surface by burrowing mammals
1	2	Radionuclide transport via infiltration
2	3	Radionuclide transport via infiltration
3	4	Radionuclide transport via infiltration
4	5	Radionuclide transport via infiltration
5	6	Radionuclide transport via infiltration
6	7	Radionuclide transport via infiltration
7	8	Radionuclide transport via infiltration
8	9	Radionuclide transport via infiltration
13	7,8	Release of activation products from metal to burial soil
14	7,8	Release of radionuclides from wooden boxes to burial soil
15	7,8	Release of radionuclides from metal containers to burial soil
16	7,8	Release of radionuclides from cardboard boxes and bales to burial soil

Table 3-4. (continued)

Compartment Number		Source Terms
From	To	
S5	5	Radionuclides deposited on RWMC surface during flooding of 1962 and 1969.
S13	13	Radionuclide inventory disposed as activated metals
S14	14	Radionuclide inventory disposed in wooden boxes
S15	15	Radionuclide inventory disposed in metal containers
S16	16	Radionuclide inventory disposed in cardboard boxes or bales
S17	17	Radionuclides deposited outside the RWMC during flooding of 1962 and 1969

The conceptual model for the new pits is shown in Figure 3-5. As in the old pits model, the biotic transport processes were suppressed during the time period between 2089 and 7069, when plant roots resume penetration of buried waste. This and other time dependent processes are controlled by time switches.

Compartment names and descriptions are presented in Table 3-5. The transport processes and source terms are listed in Table 3-6.

The conceptual model was simulated on a computer using the DOSTOMAN code, which is described in Appendix B.

3.3.1.3 Soil Vaults. The inventory in the soil vaults consists of primarily of relatively short-lived, high-energy, gamma-emitting radionuclides. It was concluded that the limiting exposure scenario for the soil vaults would probably be the acute exposure intruder scenario in which a well driller is exposed to contaminated well cuttings. For this reason, the near-field model consists of the average inventory in a vault of average dimensions (diameter of 2.0 m and a depth of 3.6 m). It was assumed that the waste is covered with .91 m of soil and has a final total cover of 5 m.

3.3.2 Airborne Transport

It was assumed that the source of radionuclides for airborne transport to offsite receptors is contaminated surface soil at and around the RWMC. Projections of curie quantities in the surface soil compartment were used to calculate release rates by multiplying these quantities by a resuspension rate constant (3.44 E-3 yr^{-1}). Daughter radionuclides were included in the calculations. These were estimated using the RADDECAY code. Details of these calculations may be found in Appendix A.

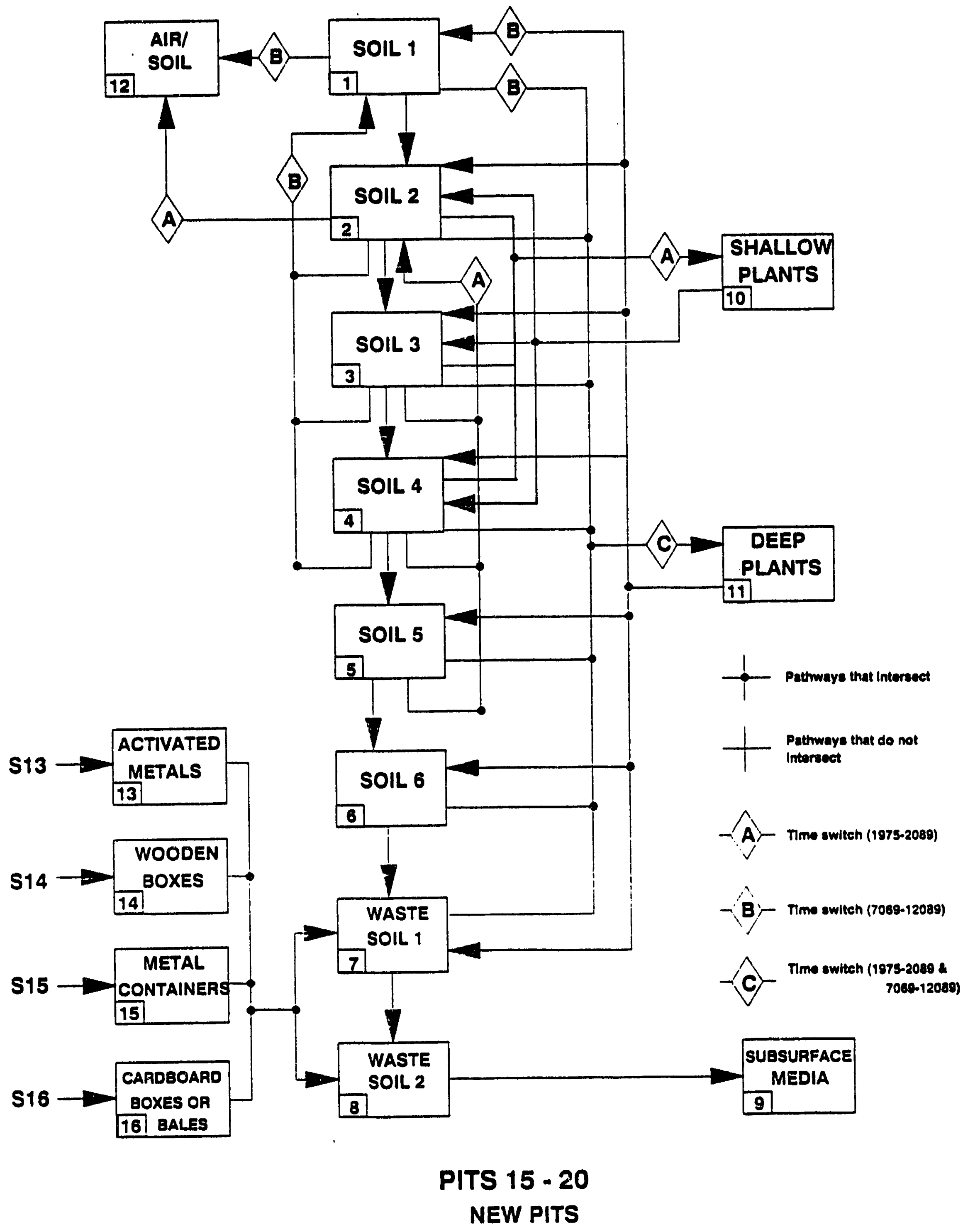


Figure 3-5. Conceptual model of the transport of radionuclides in the near-field of the new pit disposal area.

Table 3-5. Definition of compartments in the new pit near-field model

Compartment Number	Compartment Name	Compartment Description
1	Surface soil	Top 40 cm of cover soil (2089-11975)
2	Surface soil	Top 40 cm of cover soil (1975-2089)
	Upper soil	40 cm of cover soil (2089-11975)
3	Upper soil	40 cm of cover soil (1985-11975)
4	Upper soil	40 cm of cover soil (1985-11975)
5	Surface soil	40 cm of cover soil (1985-11975)
6	Upper soil	40 cm of cover soil (1985-11975)
7	Waste soil	183 cm of waste soil
8	Waste soil	183 cm of waste soil
9	Subsurface media	Vadose zone and aquifer beneath disposed waste
10	Shallow rooted plants	Crested Wheatgrass (1975-2089)
11	Deep-rooted plants	Russian Thistle (1975-2089) Sagebrush (2089-11975)
12	Air/soil	Air and offsite soil
13	Activated metals	Activated metal waste
14	Wooden boxes	LLW disposed in wooden boxes
15	Metal containers	LLW disposed in drums
16	Cardboard boxes or bales	LLW disposed in cardboard boxes or bales

Table 3-6. Transport processes and source terms represented in the new pits near-field model

Compartment Number From	To	Transport Process
1	12	Resuspension of soil
2	12	Erosion of soil
1,2,3,4 5,6,7	11	Uptake of nuclides by deep-rooted plants
2,3,4	10	Uptake of nuclides by shallow-rooted plants
11	1,2,3, 4,5,6, 7	Death and decay of deep-rooted plants in soil
10	2,3, 4	Death and decay of shallow-rooted plants in soil
2,3,4	1	Movement of soil to surface by burrowing mammals
3,4,5,6	2	Movement of soil to surface by burrowing mammals
1	2	Radionuclide transport via infiltration
2	3	Radionuclide transport via infiltration
3	4	Radionuclide transport via infiltration
4	5	Radionuclide transport via infiltration
5	6	Radionuclide transport via infiltration
6	7	Radionuclide transport via infiltration
7	8	Radionuclide transport via infiltration
8	9	Radionuclide transport via infiltration
13	7,8	Release of activation products from metal to burial soil
14	7,8	Release of radionuclides from wooden boxes to burial soil
15	7,8	Release of radionuclides from metal containers to burial soil
16	7,8	Release of radionuclides from cardboard boxes and bales to burial soil

Table 3-6. (continued)

Compartment Number From	To	Source Terms
S13	13	Radionuclide inventory disposed as activated metals
S14	14	Radionuclide inventory disposed in wooden boxes
S15	15	Radionuclide inventory disposed in metal containers
S16	16	Radionuclide inventory disposed in cardboard boxes or bales

The release rates (Ci/yr) of radionuclides were then input into the AIRDOS-EPA computer code to calculate dose to the offsite receptor. This code is described in Appendix B.

3.3.3 Ground Water Transport

The computer code PATHRAE-EPA was used to determine the impacts of subsurface migration of radionuclides. The RWMC was assumed to be an area source of uniform thickness. The waste was assumed to leach at a constant rate into the unsaturated zone. Radionuclides were assumed to migrate through the unsaturated zone, reach the aquifer, and be transported to a down gradient receptor. It was assumed that longitudinal dispersion occurs, but transverse dispersion was neglected. Retardation is incorporated into both the unsaturated zone and the aquifer through the use of distribution coefficients. More detail on the ground water flow and transport portion of PATHRAE-EPA can be found in Appendix A.

The near-field model (see Section 3.3.1) was used to provide input for PATHRAE-EPA in the areas of waste inventory and release rate. Output from the near-field model consisted of inventory as a function of time in compartments from which ground water transport could occur. This inventory was used as input to PATHRAE-EPA. The inventory available for transport is not equivalent to the inventory contained in drums and other containers. The former inventory accounts for container failure, biointrusion, and transport through the trench. The latter inventory only accounts for radioactive decay and ingrowth of radionuclides in the container.

The ground water flow and transport codes FLASH and FLAME were also used to provide input to PATHRAE-EPA. PATHRAE-EPA contains a simple method for calculating the vertical ground water velocity. However, the geology of the INEL Site is sufficiently complex as to invalidate this method. Therefore, FLASH and FLAME (see Appendix B) were used to calculate the vertical ground water velocity, which was then used as input to PATHRAE-EPA.

The end point of the ground water flow and transport analysis were radionuclide concentrations in well water at hypothetical locations down gradient of the RWMC.

3.3.4 Intruder Scenarios

Three general classes of intruder scenarios were assessed: intruder-agriculture, intruder-construction, and intruder-drilling The intruder-agriculture scenario was used to assess compliance with the chronic performance objectives of DOE Order 5820.2A. The scenario incorporated inhalation of contaminated soil, ingestion of contaminated food products, and external exposure to gamma-emitting radionuclides. The intruder pathway arises when the intruder excavates a cellar into the waste and spreads the resulting contamination around the area. The ingestion pathway results from growing food crops in contaminated soil. Ingestion of contaminated well water is also included in this scenario. External exposures result from exposure to contaminated soil that has been excavated from the cellar. PATHRAE-EPA was used to model the inhalation and ingestion pathways and MICROSHIELD was used to model the external exposure pathway.

The intruder-construction scenario was similar to the intruder-agriculture scenario but was an acute exposure scenario. The intruder was assumed to excavate a basement to a home into the waste. This results in an inhalation exposure and an external exposure. Both the inhalation exposure and internal exposure are of short duration, assumed to be 500 h. PATHRAE-EPA was used to model the inhalation exposure, and MICROSHIELD was used to model the external exposure.

The intruder-drilling scenario was assumed to apply only to soil vaults. Because of the increased cover over the waste, excavation of the waste material was not assumed to occur. However, intrusion into the waste via well drilling was assumed to take place. The intruder is assumed to be exposed to contaminated drill cuttings that are deposited in a mud pit. This exposure was assumed to be of short duration (6 h). The intruder was then assumed to occupy the site for 494 h, for a total exposure time of 500 h.

In each of these exposure scenarios, ingrowth of radioactive progeny is accounted for by explicitly determining the quantity of material present and calculating the resulting doses. The intruder-agriculture and intruder-construction scenarios were assumed to take place 3000 yr after site closure. This time corresponds to the maximum penetration of the waste by the intruder and yields the maximum intruder dose. The intruder-drilling scenario was assumed to take place 100 yr after site closure, which also yields the maximum intruder dose.

3.3.5 Dosimetry

Dose conversion factors were generally derived from DOE/EH-0070 (DOE 1988b) and DOE/EH-0071 (DOE 1988c), with one exception. The EPA RADRISK dose conversion factors were used in the AIRDOS-EPA simulations in order to compare the results with EPA dose standards in 40 CFR 61. Both sets of dose conversion factors are derived using ICRP 26 (ICRP 1977) and ICRP 30 (ICRP 1979, 1981, 1982) methodology.

4. RESULTS OF ANALYSIS

4.1 Projected Doses

4.1.1 Doses to the General Public

4.1.1.1 Airborne transport. As stated in Section 3.3.2, the radionuclide inventories in surface soil, as projected using the near-field model and the DOSTOMAN code, were used to calculate release rates for input into the AIRDOS-EPA code. The AIRDOS-EPA code was then used to calculate doses to the maximum individual during the operational and institutional periods. After closure and loss of institutional control (i.e., in 2189), the maximum individual is the intruder (see Section 4.1.2).

Figures 4-1 through 4-11 show the radionuclide inventories in the surface soil of the old pits area. The dramatic dips in inventory reflect the emplacement of cover soil over the pits and trenches 20 and 120 yr after initiation of burial activities. Later increases in the inventories of long-lived nuclides (i.e., U-234, U-238, Th-230, Ra-226, Pu-239, Pu-240, and Am-241), after 5000 yr, corresponds to the time when the cover has eroded to a depth at which plant roots can penetrate buried waste. Note that although the surface soil inventories are plotted for 10,000 yr, only the years before 2189 were used in AIRDOS-EPA calculations.

Results of the AIRDOS-EPA calculations for the old pits are contained in Table 4-1. The highest doses are projected to occur 20 yr after disposal began (i.e., 1984). This was the year before the addition of new cover soil at the RWMC. The waste was buried at a depth that could be easily penetrated by vegetation, as evidenced by the Environmental Surveillance Program (EG&G 1984). The major contributors to the projected doses are Sr-90 and Cs-137, which are readily assimilated by plants. The highest projected doses during future operations occur in 2024. Strontium-90 and Cs-137 are again the major dose contributors.

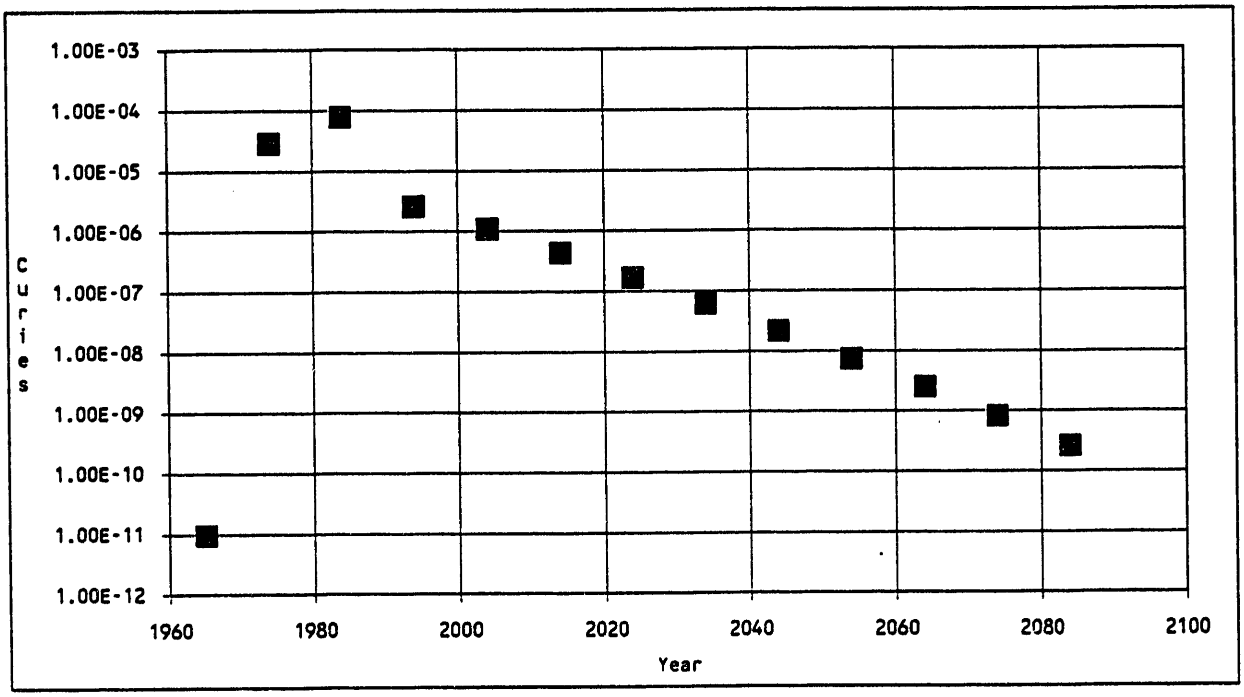


Figure 4-1. Cobalt-60 concentration in surface soil at old pit area.

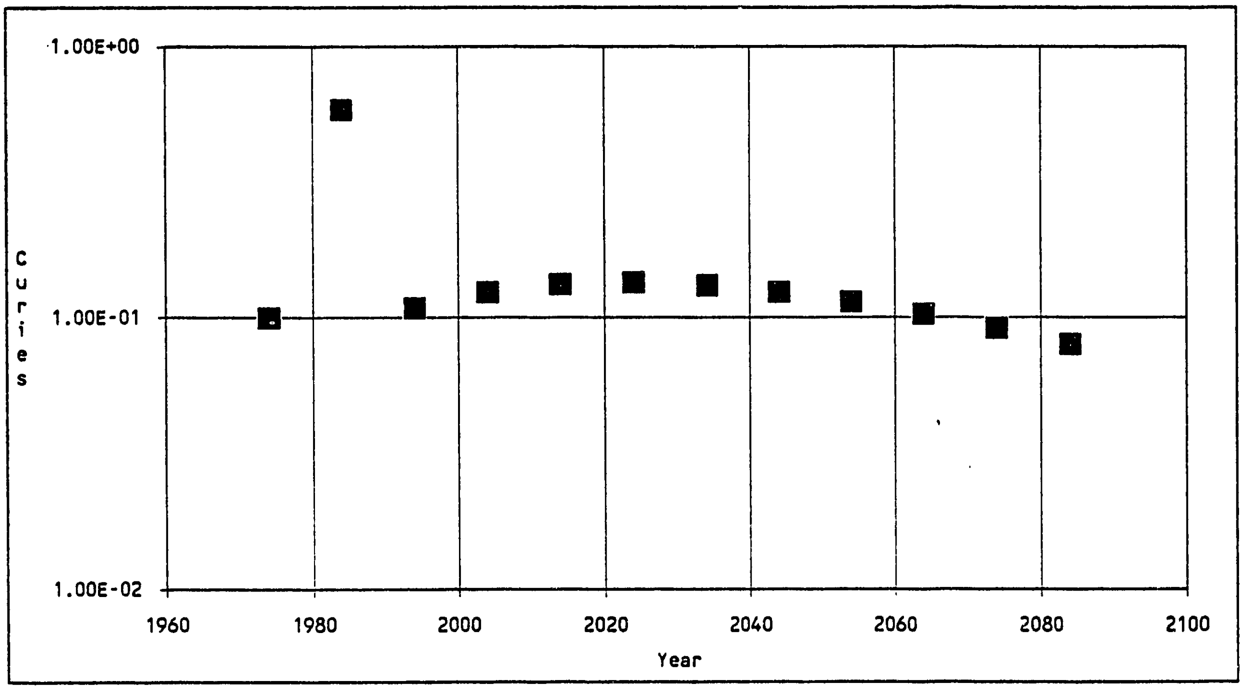


Figure 4-2. Strontium-90 concentration in surface soil at old pit area.

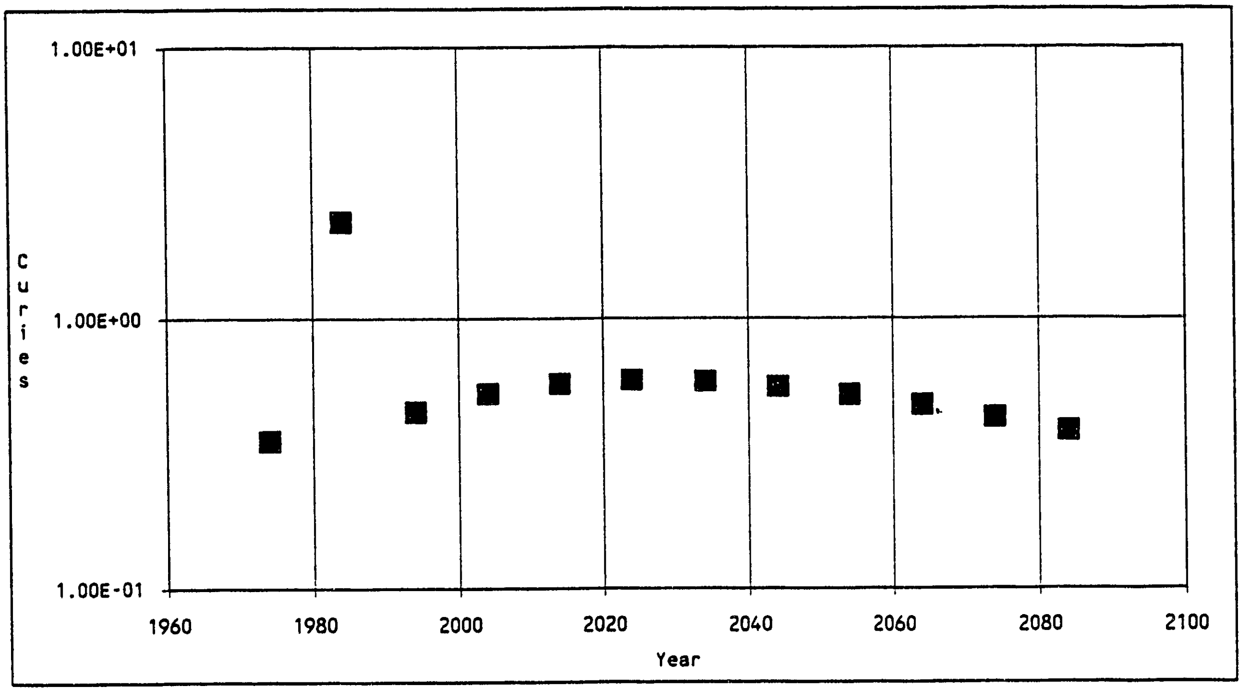
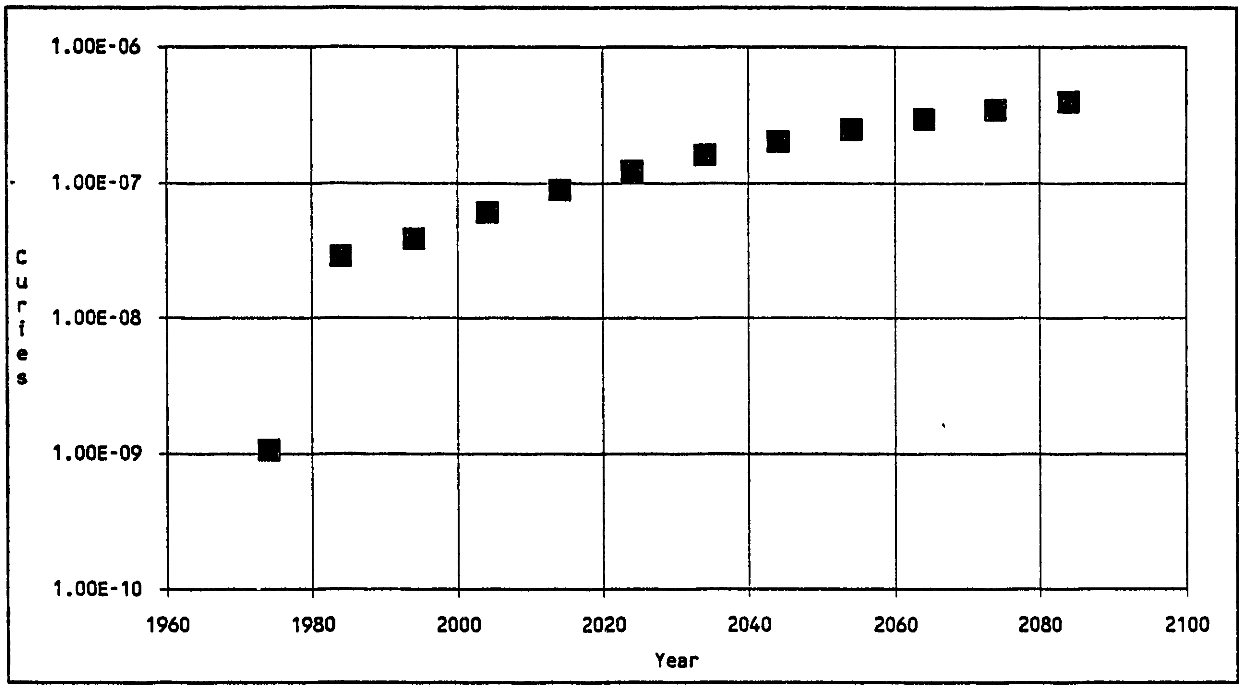


Figure 4-3. Cesium-137 concentration in surface soil at old pit area.



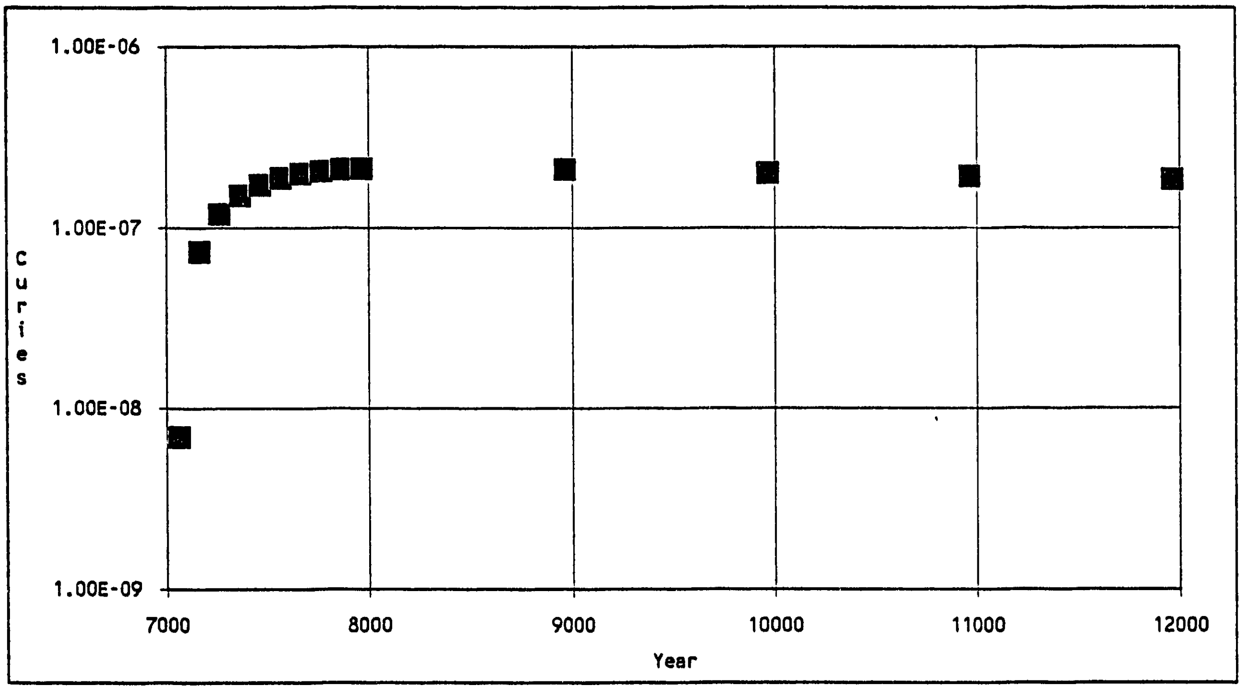


Figure 4-4. Radium-226 concentration in surface soil at old pit area.

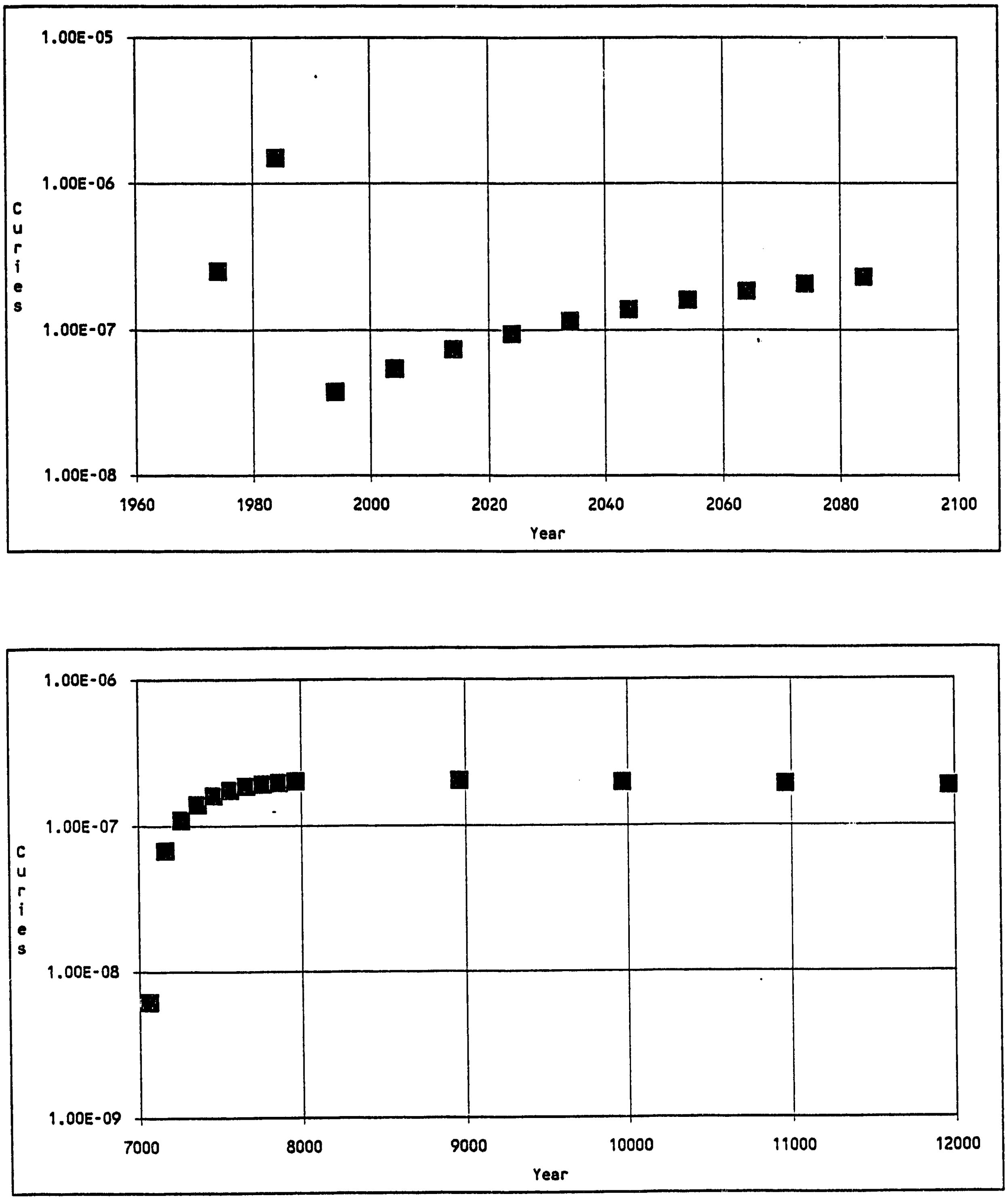


Figure 4-5. Thorium-230 concentration in surface soil at old pit area.

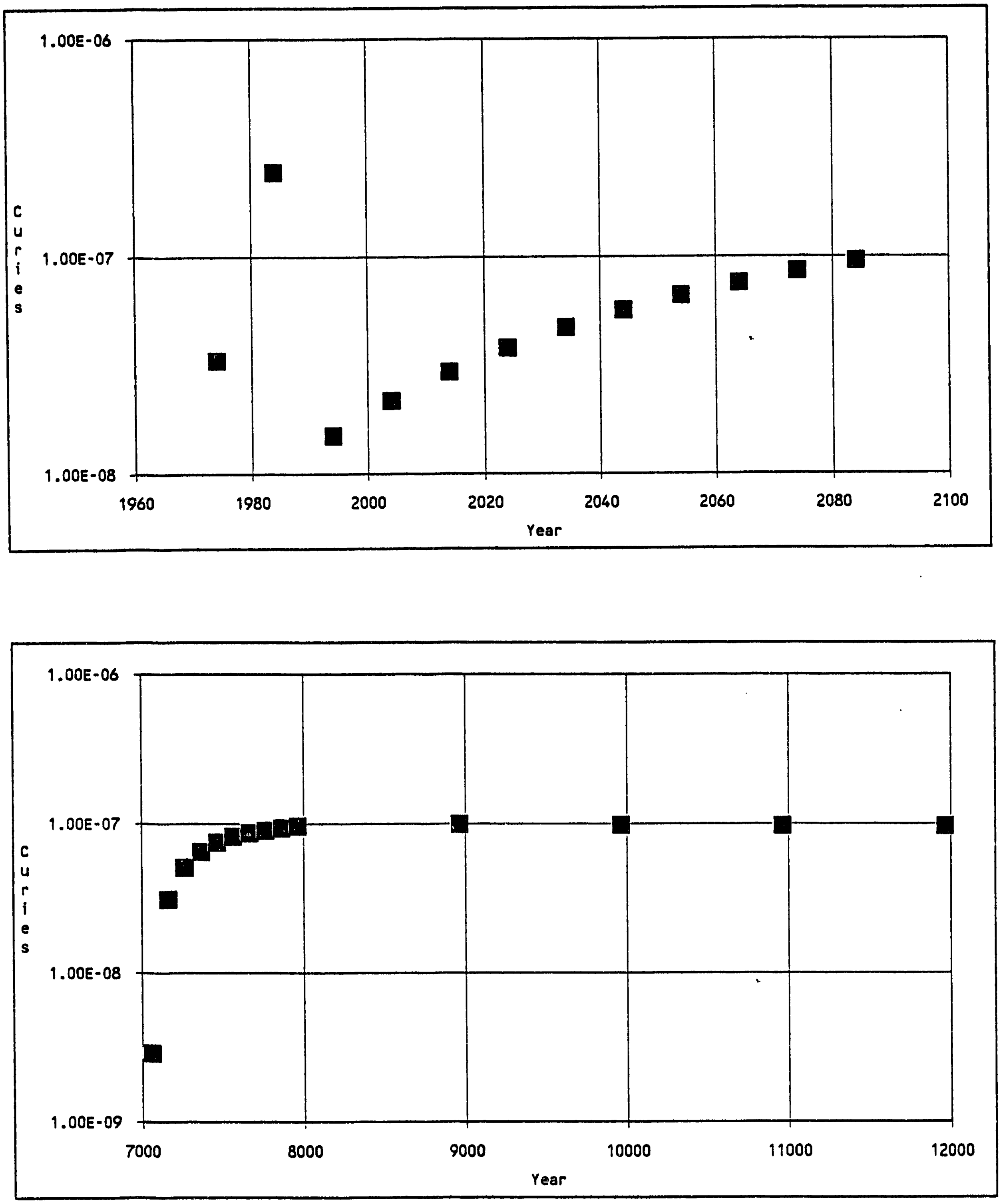


Figure 4-6. Uranium-234 concentration in surface soil at old pit area.

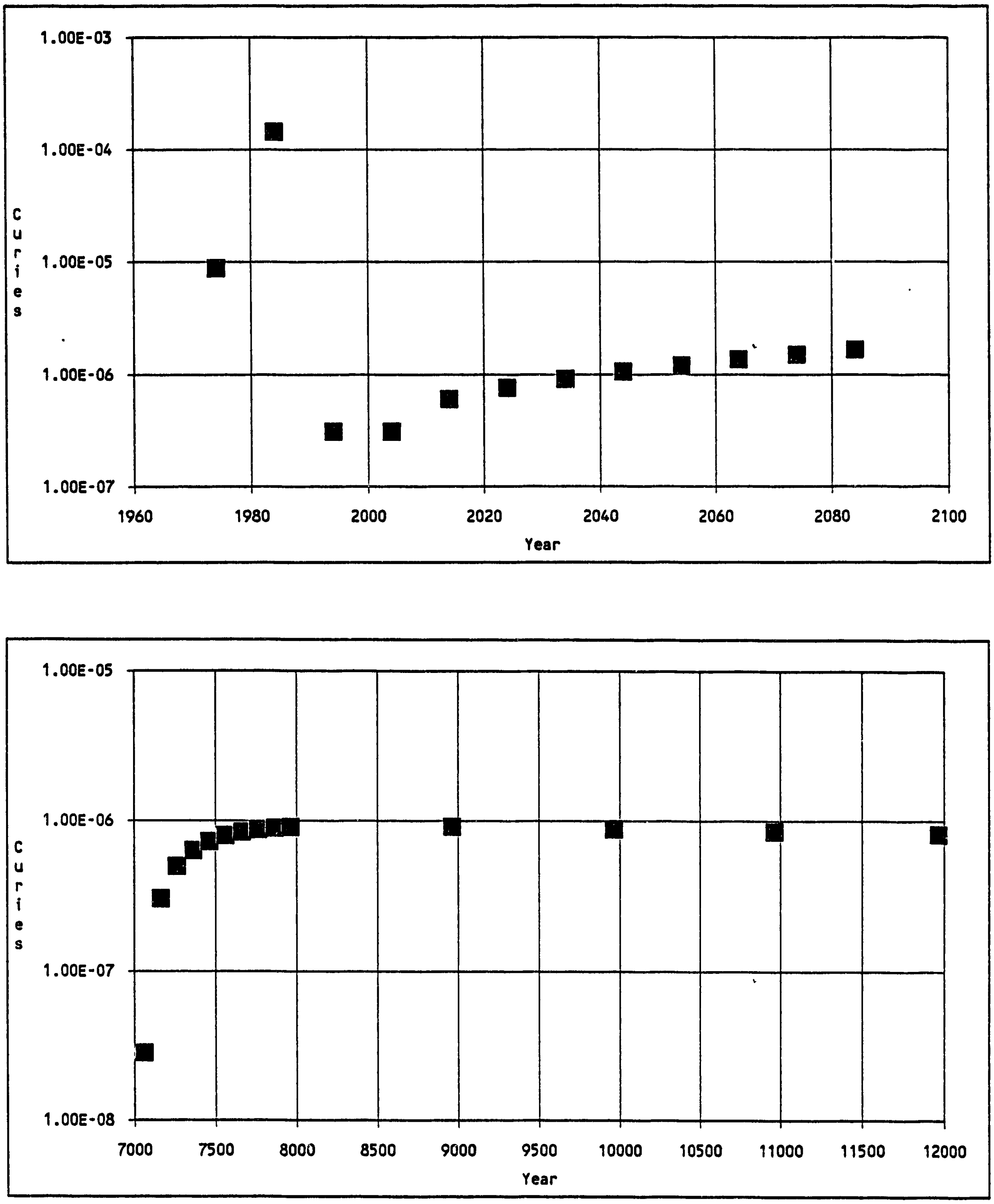


Figure 4-7. Uranium-238 concentration in surface soil at old pit area.

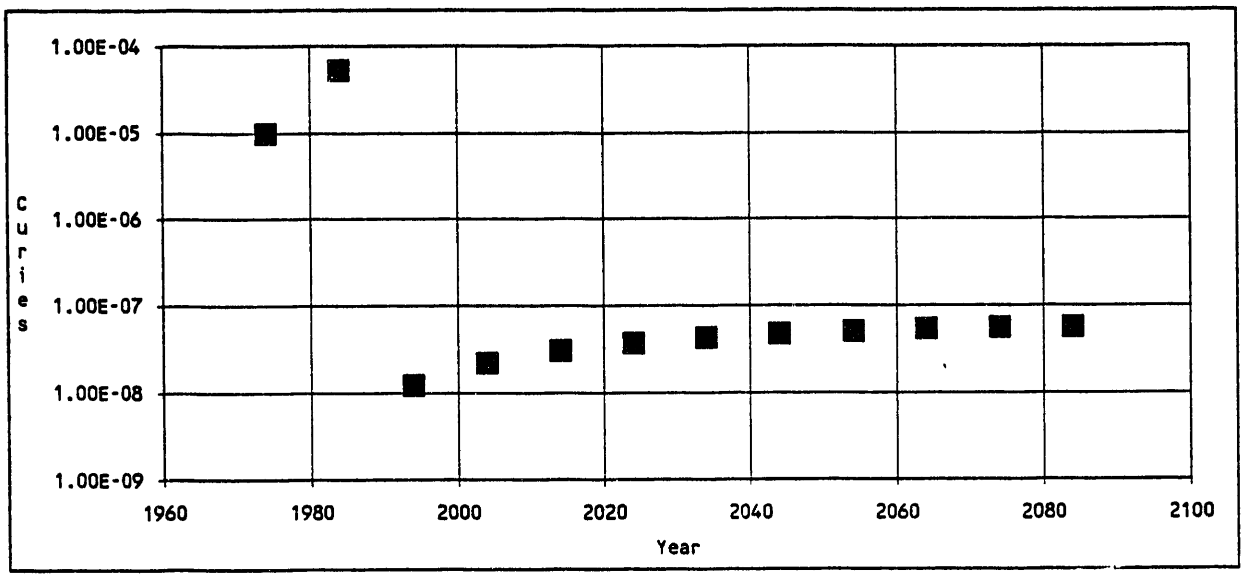


Figure 4-8. Plutonium-238 concentration in surface soil at old pit area.

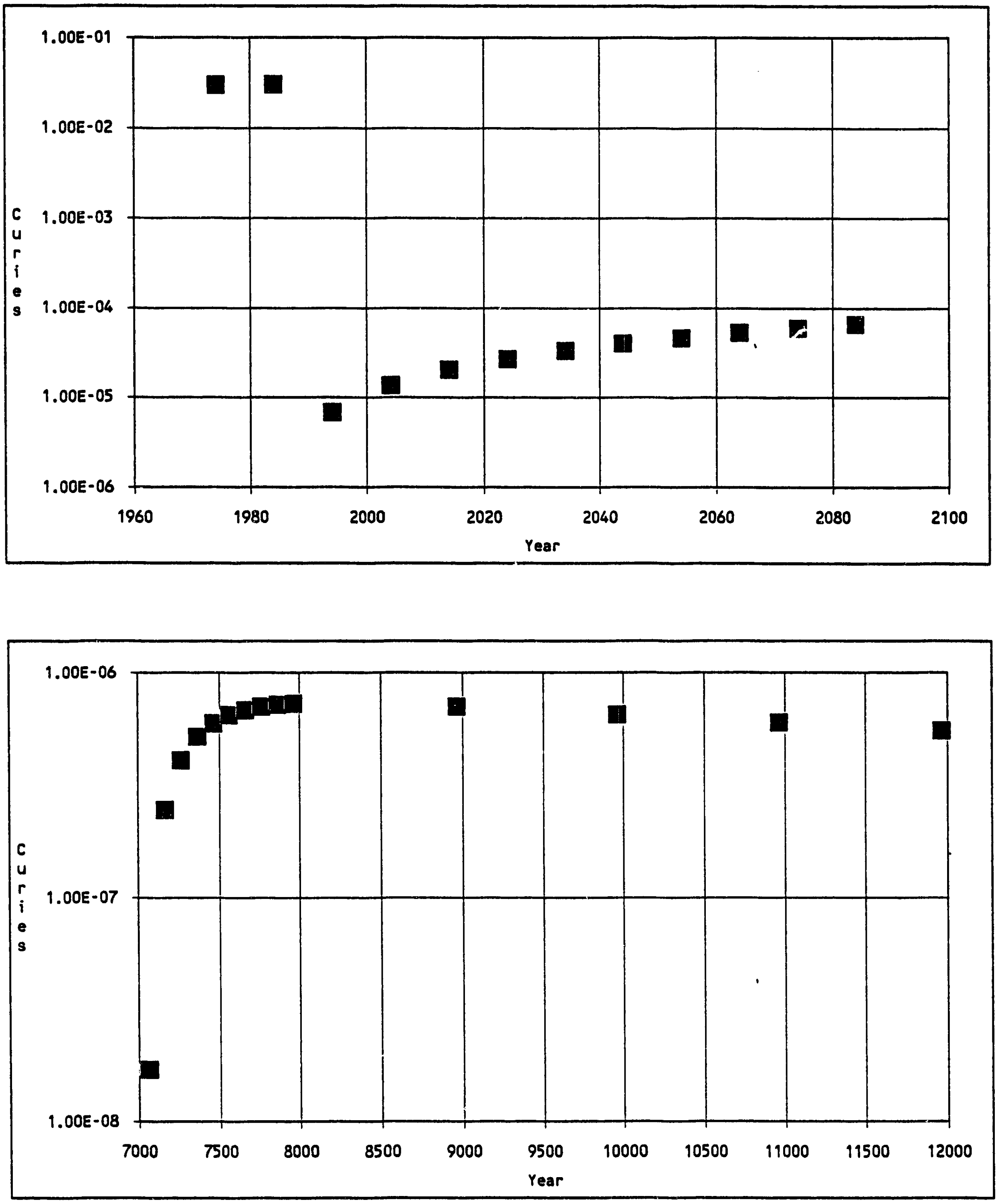


Figure 4-9. Plutonium-239 concentration in surface soil at old pit area.

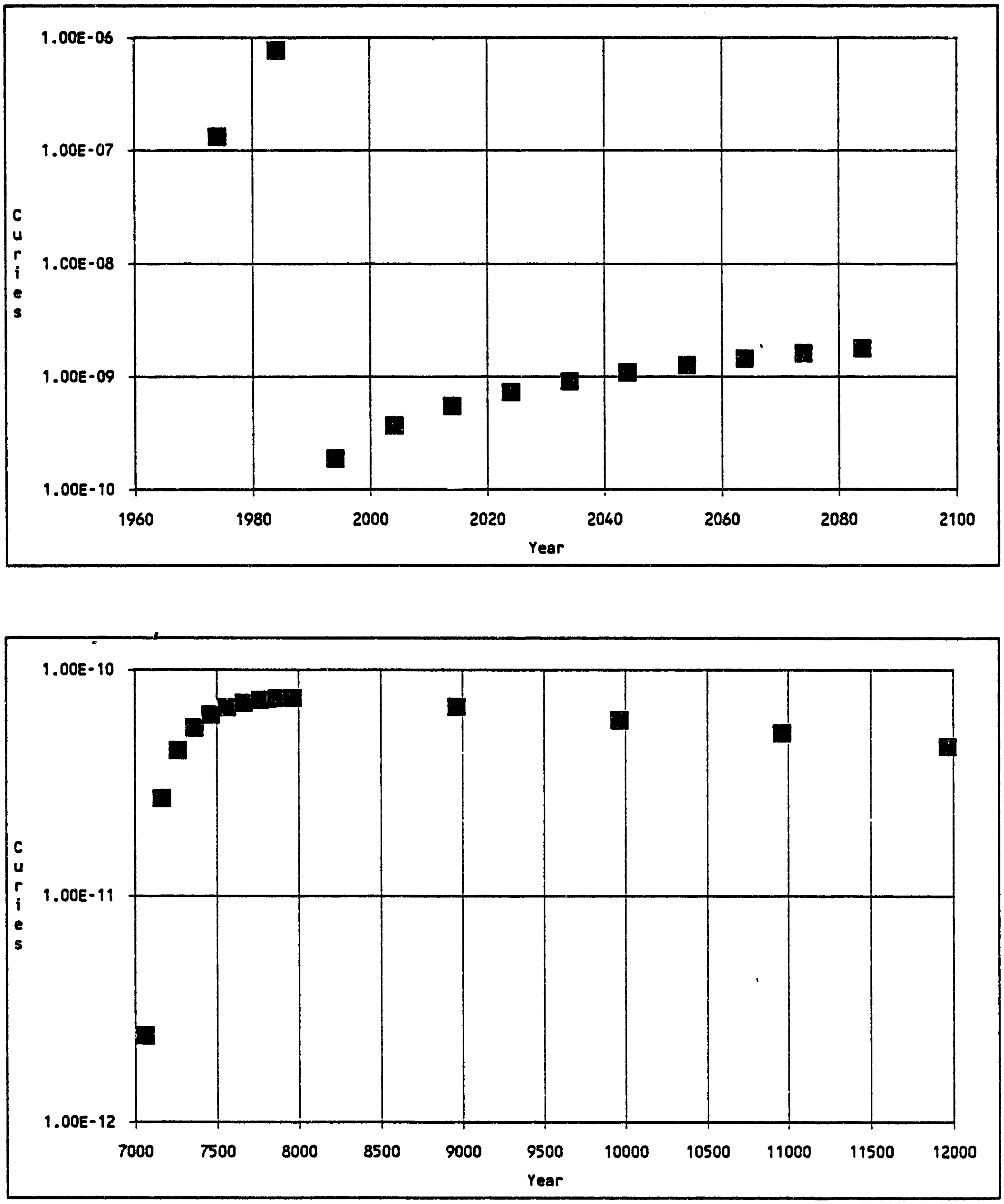


Figure 4-10. Plutonium-240 concentration in surface soil at old pit area.

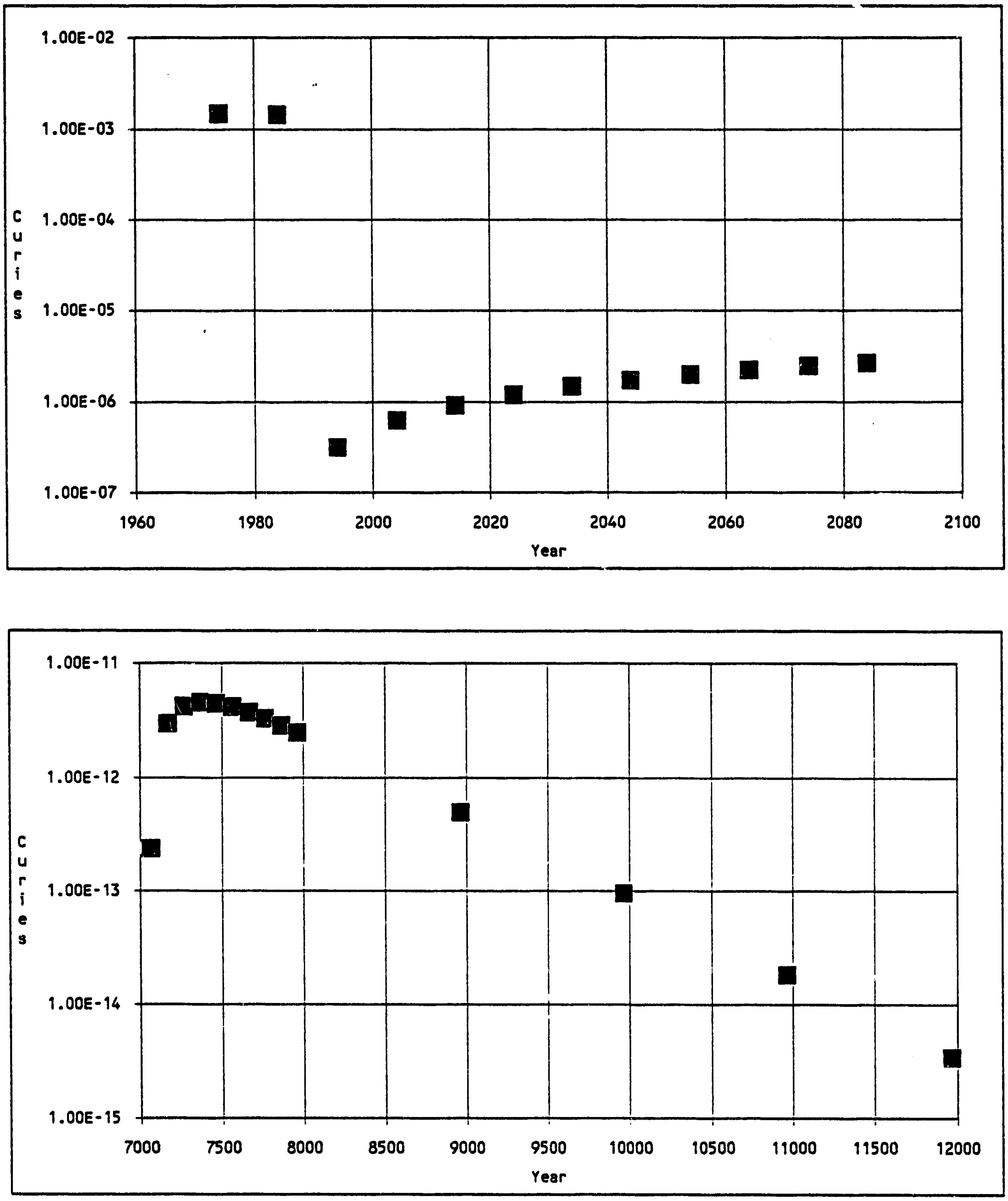


Figure 4-11. Americium-241 concentration in surface soil at old pit area.

TABLE 4-1. FIFTY-YEAR DOSE COMMITMENTS (MREM) TO THE MAXIMUM INDIVIDUAL FROM AIRBORNE TRANSPORT OF RADIONUCLIDES RESUSPENDED FROM SURFACE SOIL AND FROM RADON AT OLD PITS DURING OPERATIONAL AND INSTITUTIONAL PERIODS.

	ORGAN										
YEAR	Whole Body	Gonads	Breast	Red Marrow	Lungs	Thyroid	Bone Surface	Liver	Stomach Wall	Kidneys	Effective Dose Equivalent
1964	2.35E-14	2.88E-14	2.60E-14	2.23E-14	2.49E-14	2.74E-14	2.35E-14	2.12E-14	2.06E-14	2.21E-14	2.51E-14
1974	1.55E-03	1.57E-03	6.96E-04	6.42E-03	1.33E-03	7.17E-04	7.24E-02	1.59E-02	5.52E-04	6.02E-04	5.28E-03
1984	4.64E-03	5.11E-03	4.01E-03	9.70E-03	5.27E-03	4.15E-03	7.66E-02	1.87E-02	3.09E-03	3.41E-03	8.65E-03
1994	1.09E-03	1.22E-03	1.16E-03	8.96E-04	1.58E-03	1.19E-03	1.70E-03	7.66E-04	1.04E-03	8.26E-04	1.16E-03
2004	1.68E-03	1.85E-03	1.79E-03	1.20E-03	2.60E-03	1.81E-03	2.86E-03	1.05E-03	1.71E-03	1.15E-03	1.77E-03
2014	2.18E-03	2.38E-03	2.31E-03	1.43E-03	3.47E-03	2.34E-03	3.86E-03	1.28E-03	2.28E-03	1.42E-03	2.29E-03
2024	2.59E-03	2.80E-03	2.74E-03	1.60E-03	4.20E-03	2.76E-03	4.70E-03	1.44E-03	2.76E-03	1.62E-03	2.71E-03
2034	2.92E-03	3.15E-03	3.08E-03	1.72E-03	4.80E-03	3.10E-03	5.42E-03	1.56E-03	3.16E-03	1.76E-03	3.04E-03
2044	3.18E-03	3.42E-03	3.35E-03	1.79E-03	5.31E-03	3.37E-03	6.02E-03	1.64E-03	3.49E-03	1.86E-03	3.31E-03
2054	3.39E-03	3.63E-03	3.57E-03	1.83E-03	5.73E-03	3.59E-03	6.53E-03	1.70E-03	3.77E-03	1.93E-03	3.52E-03
2064	3.57E-03	3.80E-03	3.75E-03	1.84E-03	6.09E-03	3.76E-03	6.96E-03	1.73E-03	4.00E-03	1.98E-03	3.69E-03
2074	3.69E-03	3.93E-03	3.88E-03	1.84E-03	6.37E-03	3.89E-03	7.31E-03	1.74E-03	4.19E-03	2.00E-03	3.82E-03
2084	1.30E-03	1.42E-03	1.37E-03	8.99E-04	2.00E-03	1.39E-03	2.34E-03	8.18E-04	1.33E-03	8.71E-04	1.37E-03
2094	7.22E-04	7.53E-04	7.53E-04	2.68E-04	1.33E-03	7.49E-04	1.52E-03	2.67E-04	8.69E-04	3.31E-04	7.38E-04
2104	7.54E-04	7.86E-04	7.87E-04	2.80E-04	1.39E-03	7.82E-04	1.59E-03	2.79E-04	9.08E-04	3.46E-04	7.71E-04
2114	7.83E-04	8.16E-04	8.17E-04	2.91E-04	1.44E-03	8.12E-04	1.65E-03	2.90E-04	9.42E-04	3.59E-04	8.00E-04
2124	8.08E-04	8.43E-04	8.44E-04	3.00E-04	1.49E-03	8.38E-04	1.70E-03	2.99E-04	9.73E-04	3.70E-04	8.26E-04
2134	8.31E-04	8.66E-04	8.67E-04	3.09E-04	1.53E-03	8.62E-04	1.75E-03	3.07E-04	1.00E-03	3.81E-04	8.49E-04
2144	8.51E-04	8.87E-04	8.88E-04	3.16E-04	1.57E-03	8.82E-04	1.79E-03	3.15E-04	1.02E-03	3.90E-04	8.69E-04
2154	8.68E-04	9.05E-04	9.06E-04	3.22E-04	1.60E-03	9.00E-04	1.83E-03	3.21E-04	1.04E-03	3.98E-04	8.87E-04
2164	8.83E-04	9.21E-04	9.22E-04	3.28E-04	1.63E-03	9.16E-04	1.86E-03	3.27E-04	1.06E-03	4.05E-04	9.02E-04
2264	9.53E-04	9.94E-04	9.95E-04	3.54E-04	1.75E-03	9.88E-04	2.01E-03	3.52E-04	1.15E-03	4.37E-04	9.74E-04

During the institutional period (2089-2189), no radionuclides are expected to reach the surface soil via biotic intrusion, which is suppressed because of cover depth. As a result, the dose during this period is due entirely to radon, which is produced by Ra-226 and emanates through the soil cover.

Figures 4-12 and 4-13 show Pu-239 and Am-241 concentrations in surface soil surrounding the RWMC. These radionuclides were the major constituents of contamination resulting from flooding events in 1962 and 1969. The doses resulting from these nuclides are shown in Table 4-2.

Figures 4-14 through 4-24 illustrate the radionuclide inventories in the surface soil of Pits 15 through 20. As in previous results, early decreases in inventory reflect the emplacement of cover soil over the pits (in 2089). Although only the inventories prior to 2089 were used for AIRDOS-EPA calculations, the inventories after 5000 years, when the cover has eroded to the point where plant roots can penetrate buried waste, are also plotted.

Results of the AIRDOS-EPA calculations for the new pits during the operational and institutional periods are contained in Table 4-3. The highest doses are projected to occur during the late operational period, just before closure and the addition of final cover. The major contributors to the projected doses are Sr-90 and Cs-137. During the institutional period, no radionuclides are expected to be transported to the surface via biotic intrusion because of the addition of a thick soil cover. Consequently, the dose in this time period is due to radon, which diffuses from the waste through the soil cover.

The AIRDOSE-EPA code was also used to calculate the collective dose (man-mrems) to the population living within 80 km of the RWMC. The maximum population doses from the three areas modeled, projected to occur in 2074, are presented in Table 4-4. There is no performance objective to compare the results with. However, other studies have compared such data with cancer risk estimates based on human exposure studies. For example,

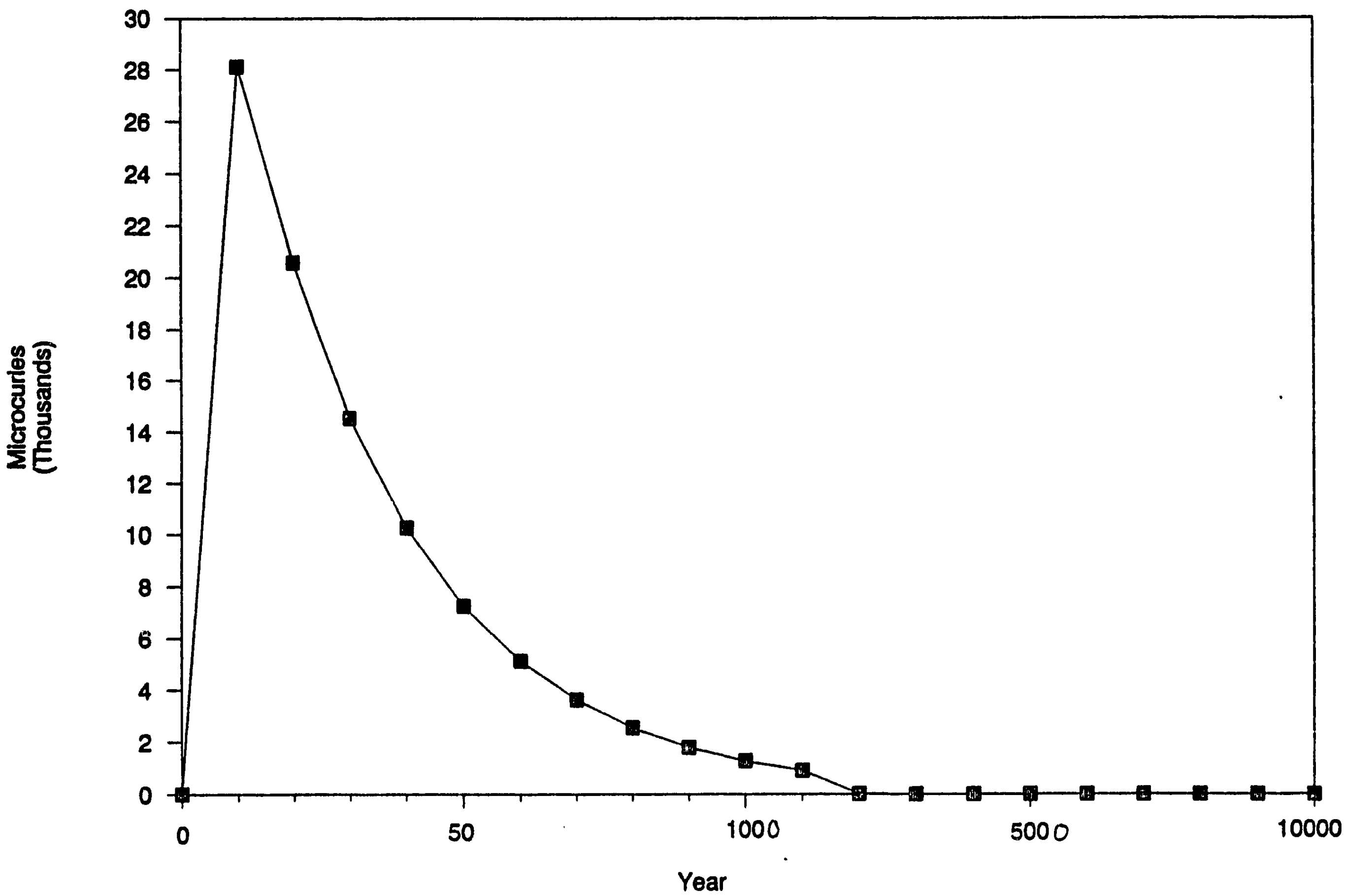


Figure 4-12. Plutonium-239 concentration in surface soil outside the RWMC.

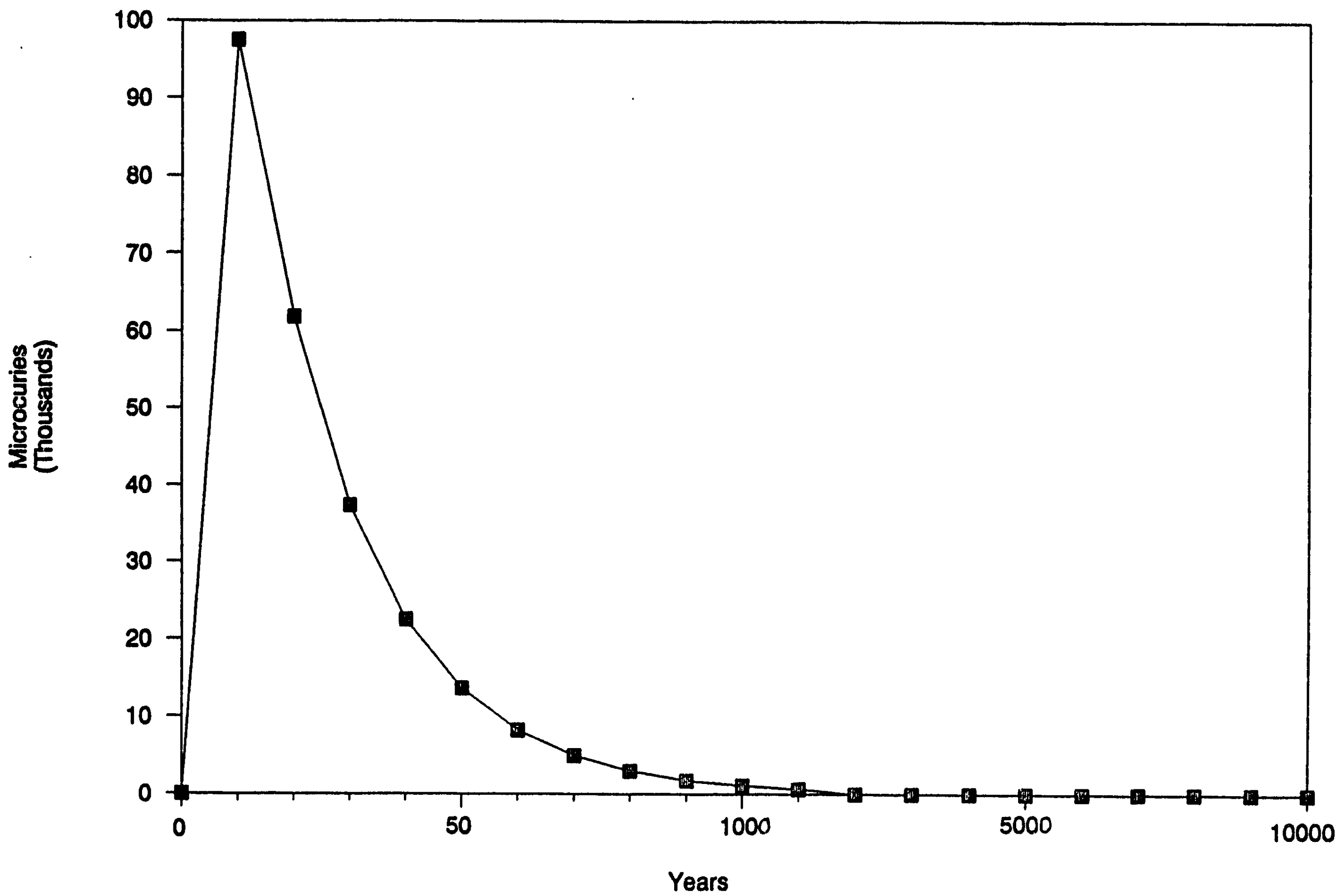


Figure 4-13. Americium-241 concentration in surface soil outside the RWMC.

TABLE 4-2. FIFTY-YEAR DOSE COMMITMENTS (MREM) TO THE MAXIMUM INDIVIDUAL FROM AIRBORNE TRANSPORT OF RADIONUCLIDES RESUSPENDED FROM CONTAMINATED SURFACE SOIL OUTSIDE THE RWMC.

	ORGAN										
YEAR	Whole Body	Gonads	Breast	Red Marrow	Lungs	Thyroid	Bone Surface	Liver	Stomach Wall	Kidneys	Effective Dose Equivalent
1964	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1974	4.06E-03	3.79E-03	3.93E-04	2.39E-02	2.48E-03	3.86E-04	2.94E-01	6.35E-02	3.75E-04	3.79E-04	1.91E-02
1984	3.87E-03	3.61E-03	3.75E-04	2.28E-02	2.37E-03	3.68E-04	2.80E-01	6.06E-02	3.58E-04	3.61E-04	1.83E-02
1994	3.69E-03	3.45E-03	3.57E-04	2.17E-02	2.26E-03	3.51E-04	2.68E-01	5.78E-02	3.41E-04	3.45E-04	1.74E-02
2004	3.52E-03	3.29E-03	3.41E-04	2.07E-02	2.16E-03	3.35E-04	2.55E-01	5.51E-02	3.26E-04	3.29E-04	1.66E-02
2014	3.36E-03	3.14E-03	3.25E-04	1.98E-02	2.06E-03	3.20E-04	2.44E-01	5.26E-02	3.11E-04	3.14E-04	1.59E-02
2024	3.21E-03	2.99E-03	3.10E-04	1.89E-02	1.96E-03	3.05E-04	2.32E-01	5.02E-02	2.96E-04	2.99E-04	1.51E-02
2034	3.07E-03	2.87E-03	2.97E-04	1.81E-02	1.88E-03	2.92E-04	2.23E-01	4.81E-02	2.84E-04	2.87E-04	1.45E-02
2044	2.92E-03	2.73E-03	2.82E-04	1.72E-02	1.79E-03	2.78E-04	2.12E-01	4.57E-02	2.70E-04	2.73E-04	1.38E-02
2054	2.79E-03	2.60E-03	2.69E-04	1.64E-02	1.71E-03	2.65E-04	2.02E-01	4.36E-02	2.57E-04	2.60E-04	1.32E-02
2064	2.66E-03	2.48E-03	2.57E-04	1.56E-02	1.63E-03	2.53E-04	1.93E-01	4.16E-02	2.46E-04	2.48E-04	1.26E-02
2074	2.44E-03	2.28E-03	2.36E-04	1.44E-02	1.50E-03	2.32E-04	1.77E-01	3.83E-02	2.26E-04	2.28E-04	1.15E-02
2084	2.33E-03	2.18E-03	2.25E-04	1.37E-02	1.43E-03	2.21E-04	1.69E-01	3.65E-02	2.15E-04	2.18E-04	1.10E-02
2094	2.31E-03	2.16E-03	2.23E-04	1.36E-02	1.42E-03	2.20E-04	1.68E-01	3.62E-02	2.14E-04	2.16E-04	1.09E-02
2104	2.21E-03	2.06E-03	2.13E-04	1.30E-02	1.35E-03	2.10E-04	1.60E-01	3.46E-02	2.04E-04	2.06E-04	1.04E-02
2114	2.11E-03	1.97E-03	2.04E-04	1.24E-02	1.29E-03	2.00E-04	1.53E-01	3.30E-02	1.95E-04	1.97E-04	9.95E-03
2124	2.01E-03	1.88E-03	1.94E-04	1.18E-02	1.23E-03	1.91E-04	1.46E-01	3.15E-02	1.86E-04	1.88E-04	9.50E-03
2134	1.92E-03	1.79E-03	1.85E-04	1.13E-02	1.18E-03	1.82E-04	1.39E-01	3.01E-02	1.77E-04	1.79E-04	9.07E-03
2144	1.83E-03	1.71E-03	1.77E-04	1.08E-02	1.12E-03	1.74E-04	1.33E-01	2.87E-02	1.69E-04	1.71E-04	8.66E-03
2154	1.75E-03	1.64E-03	1.69E-04	1.03E-02	1.07E-03	1.66E-04	1.27E-01	2.74E-02	1.62E-04	1.63E-04	8.27E-03
2164	1.67E-03	1.56E-03	1.61E-04	9.84E-03	1.02E-03	1.59E-04	1.21E-01	2.62E-02	1.54E-04	1.56E-04	7.90E-03
2264	1.06E-03	9.87E-04	1.02E-04	6.22E-03	6.46E-04	1.00E-04	7.66E-02	1.65E-02	9.75E-05	9.84E-05	4.99E-03

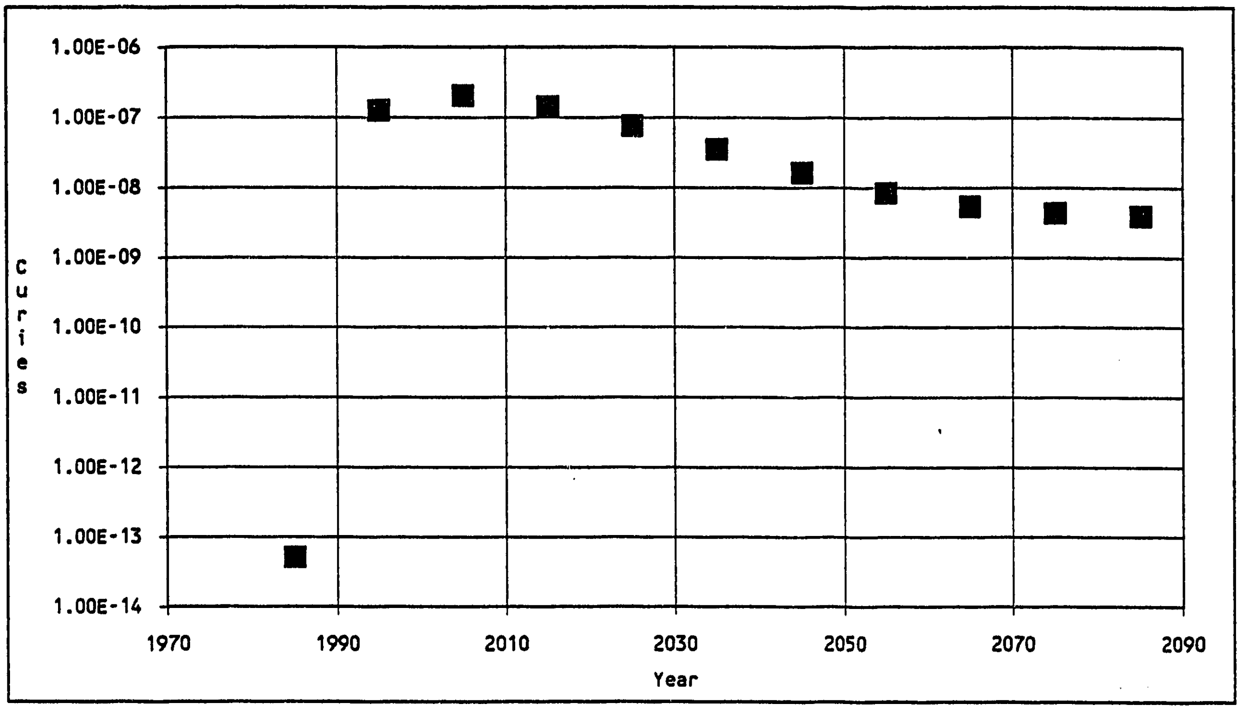


Figure 4-14. Cobalt-60 concentration in surface soil at new pit area.

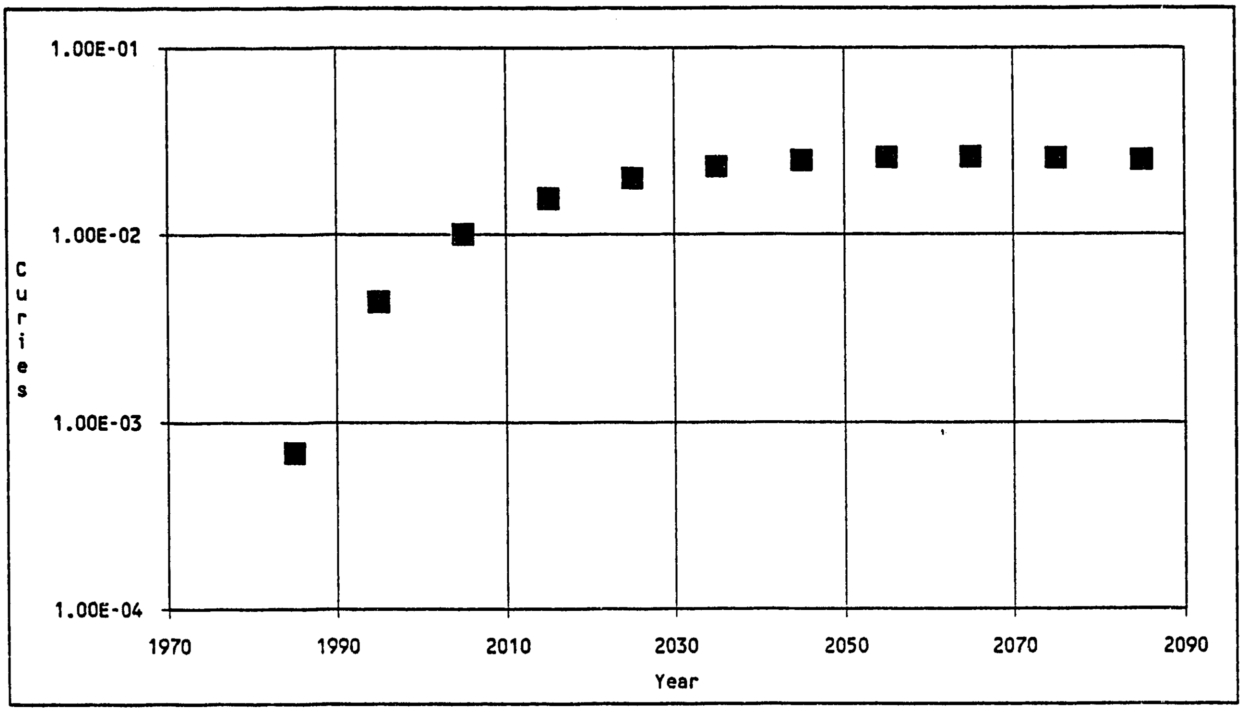


Figure 4-15. Strontium-90 concentration in surface soil at new pit area.

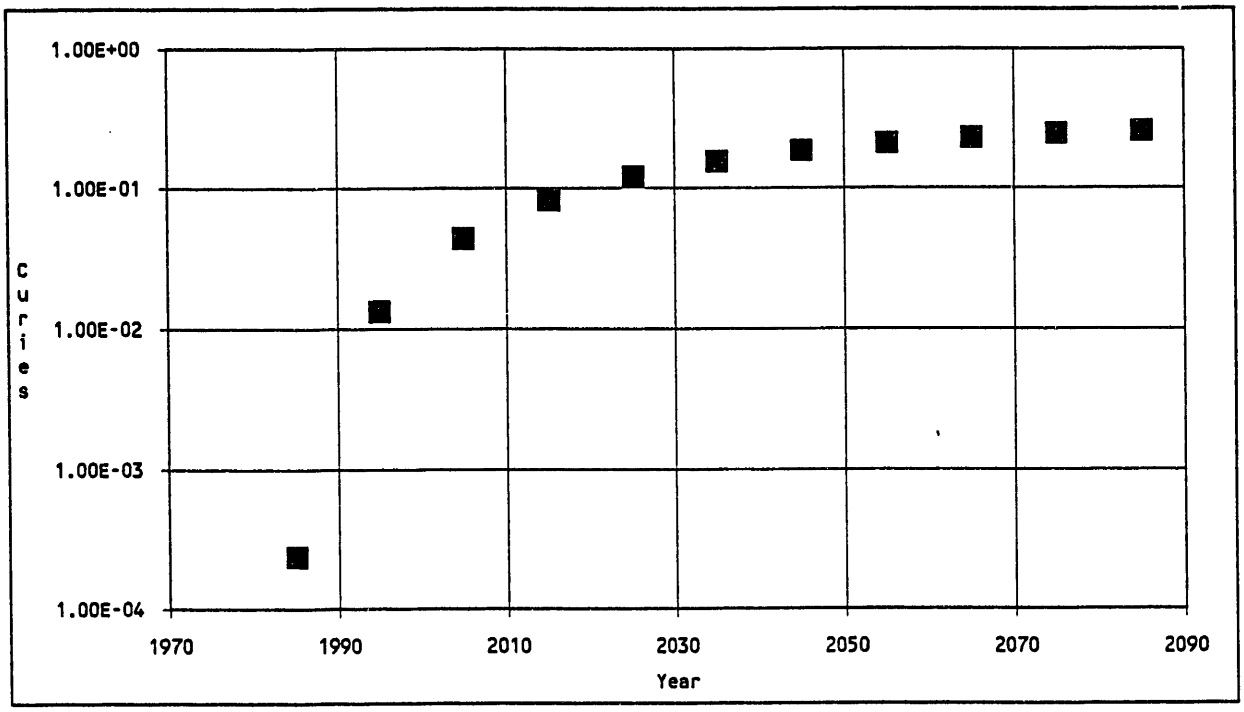
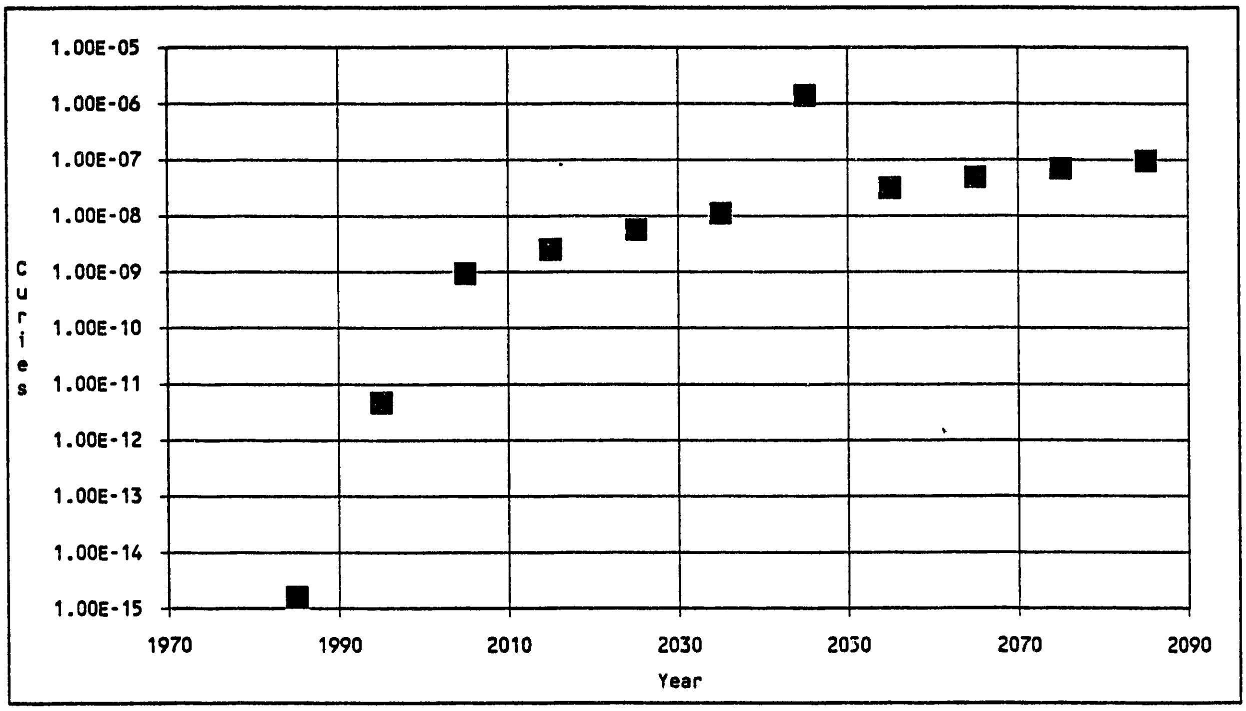


Figure 4-16. Cesium-137 concentration in surface soil at new pit area.



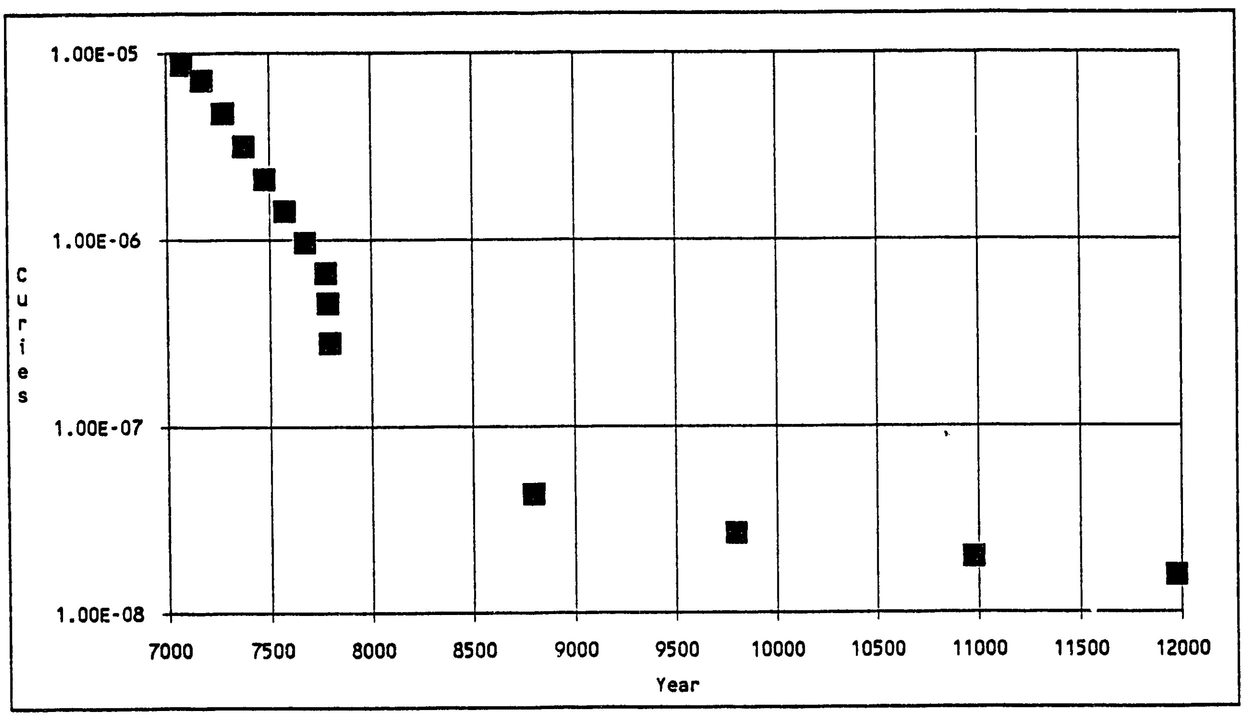


Figure 4-17. Radium-226 concentration in surface soil at new pit area.

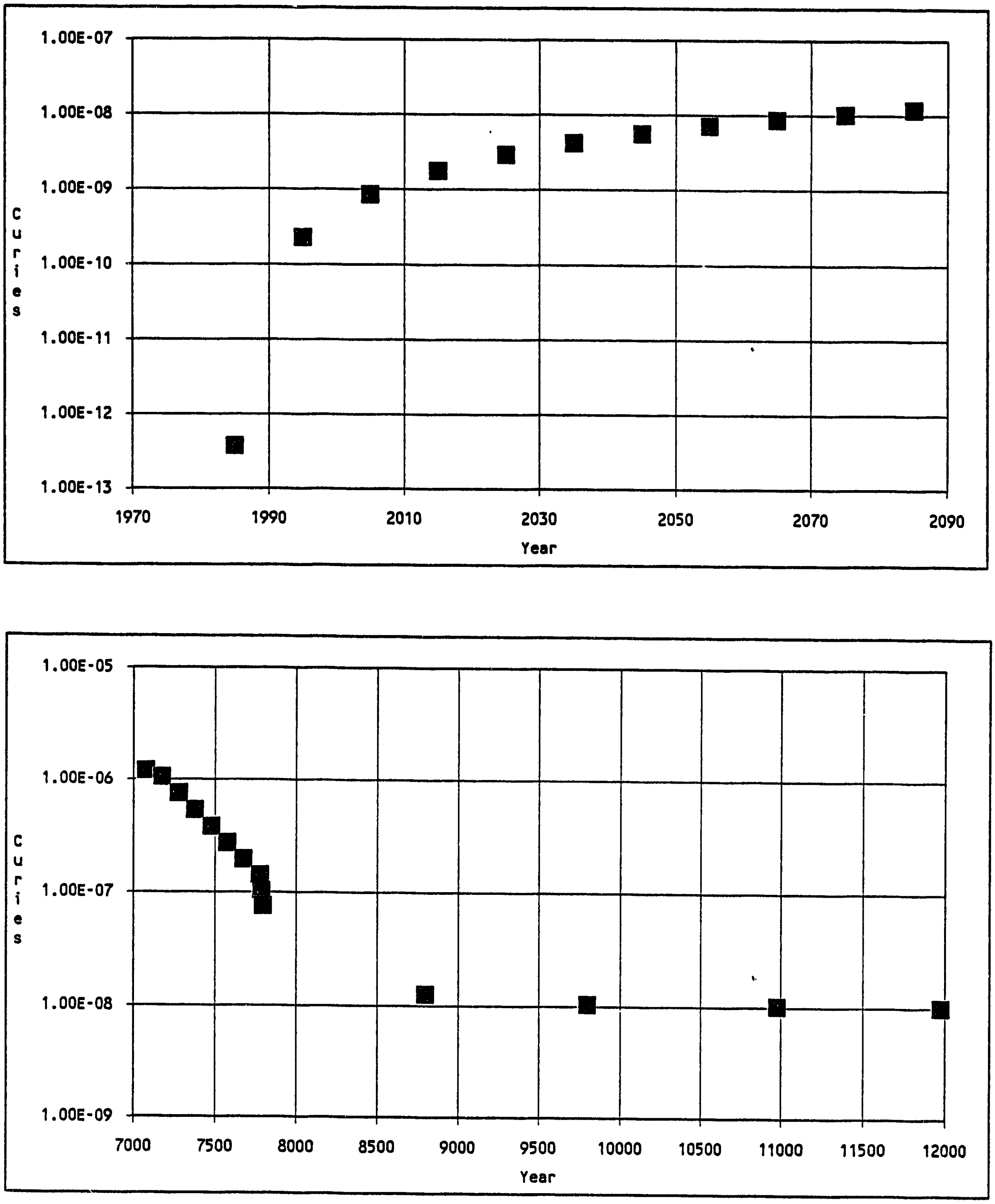


Figure 4-18. Thorium-230 concentration in surface soil at new pit area.

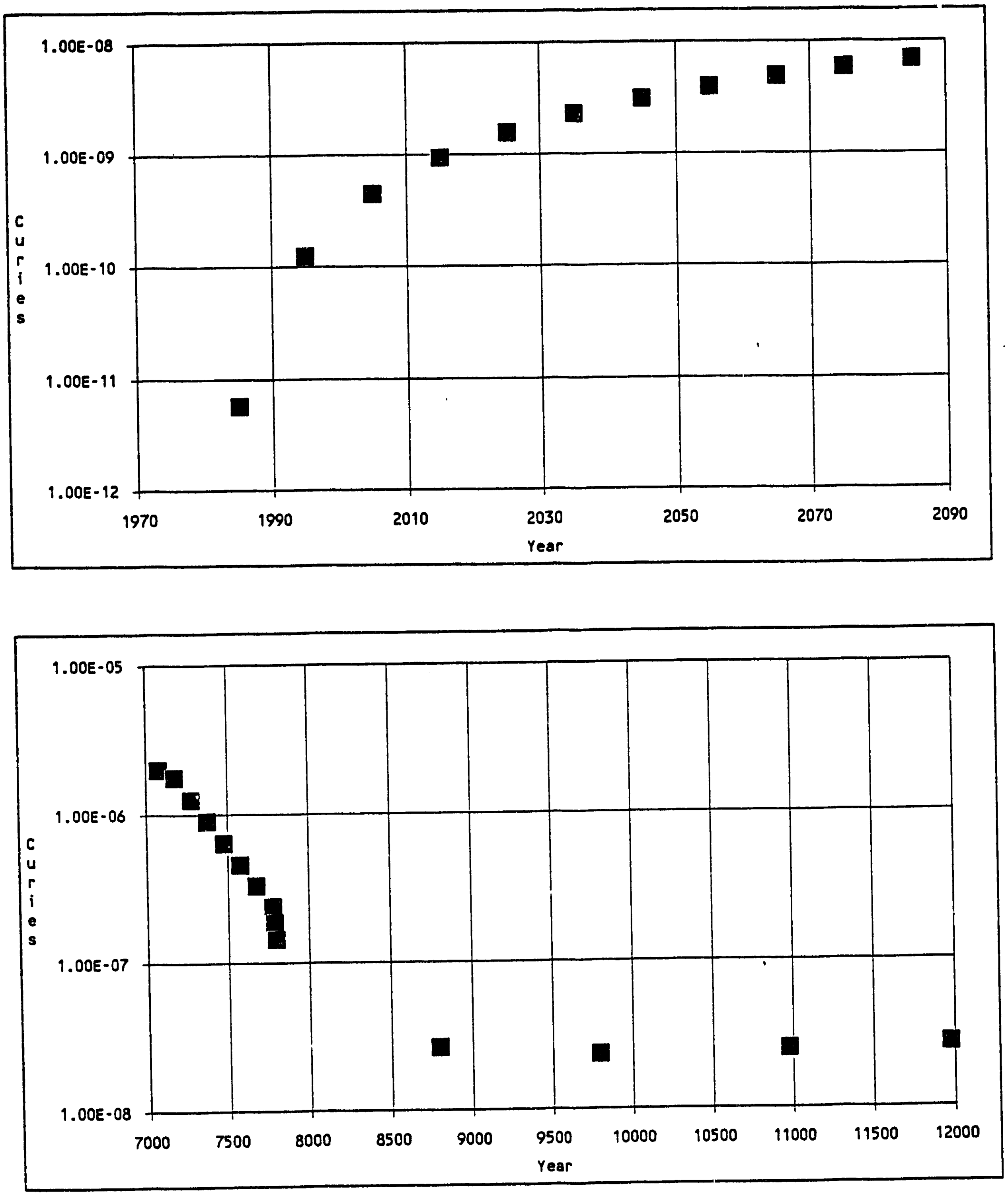


Figure 4-19. Uranium-234 concentration in surface soil at new pit area.

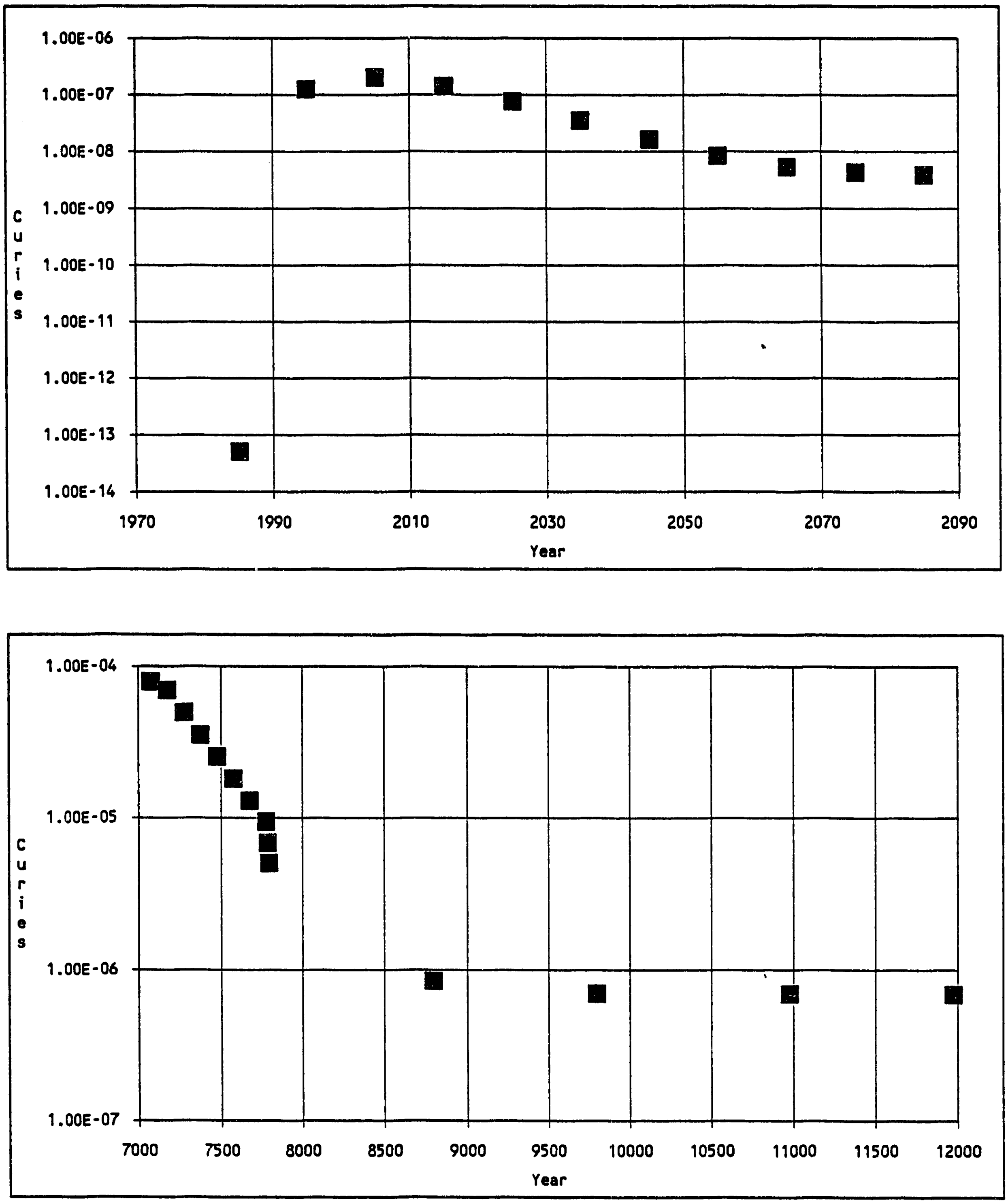


Figure 4-20. Uranium-238 concentration in surface soil at new pit area.

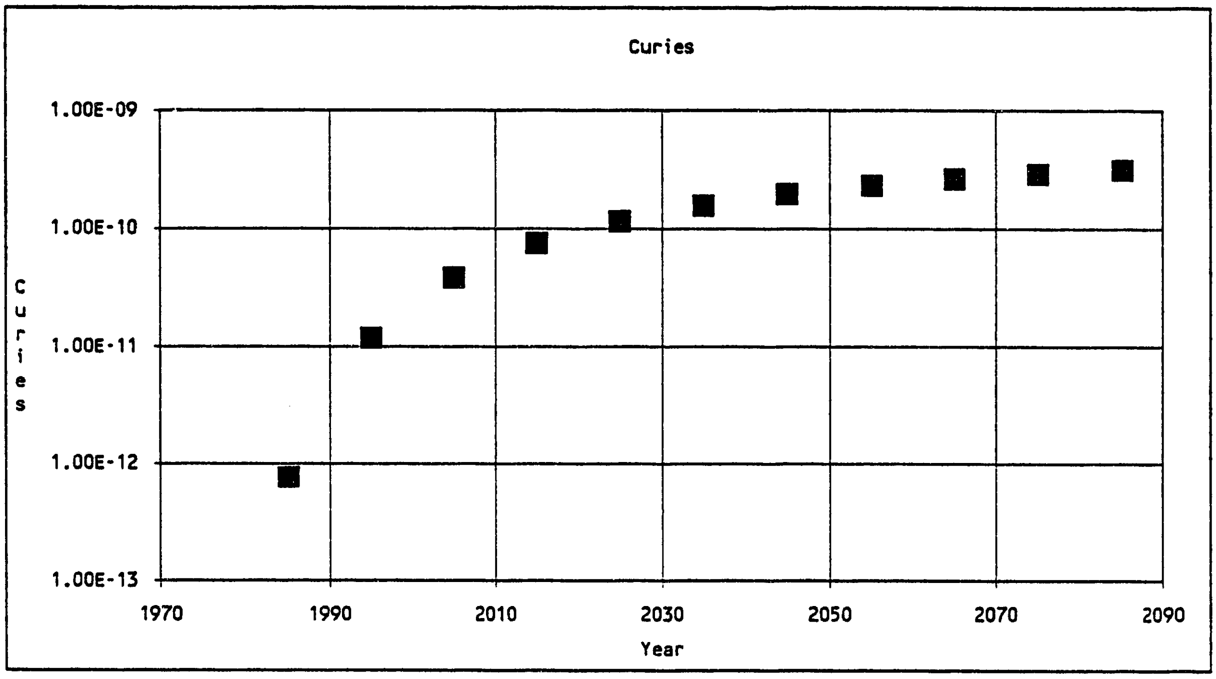


Figure 4-21. Plutonium-238 concentration in surface soil at new pit area.

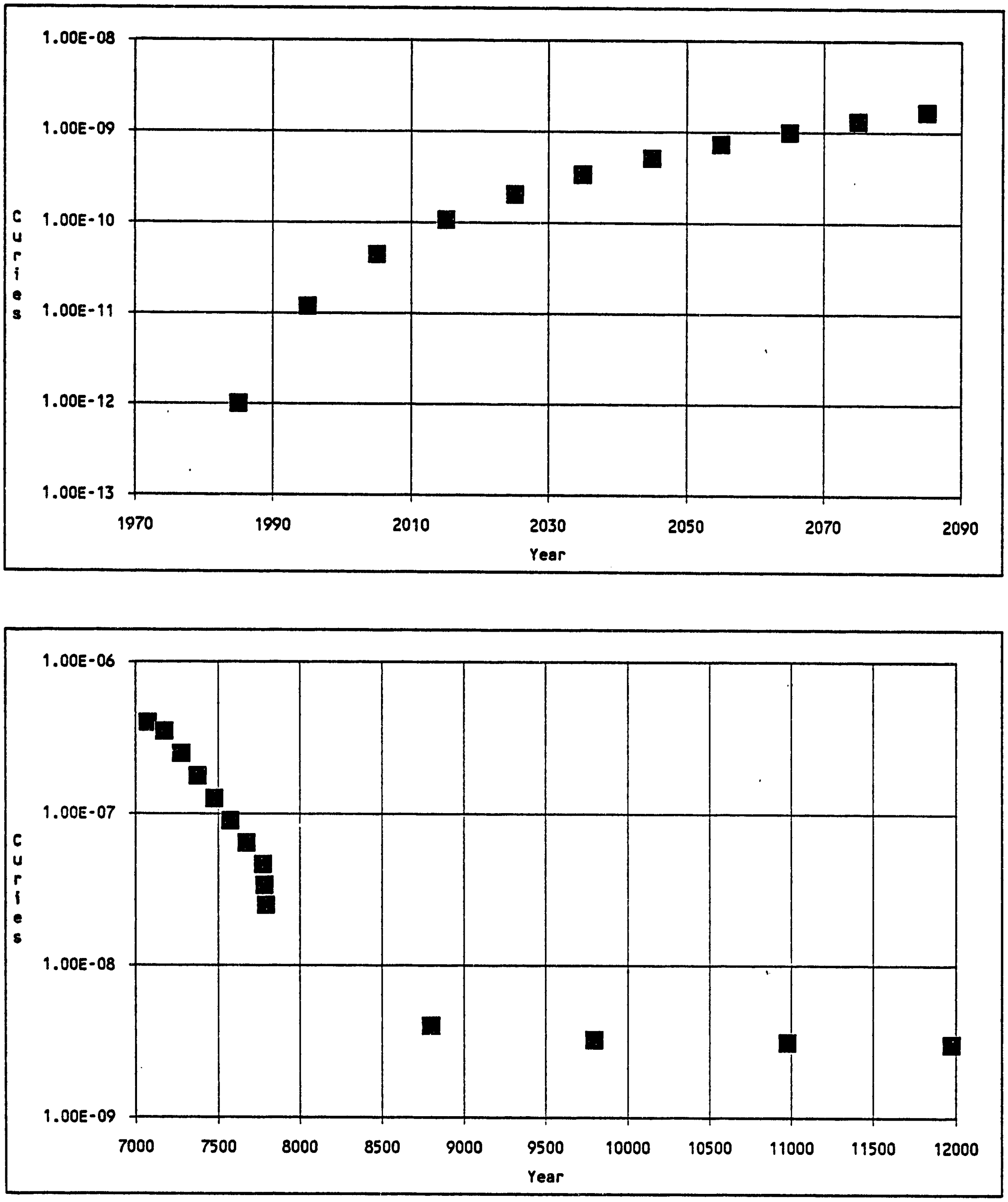
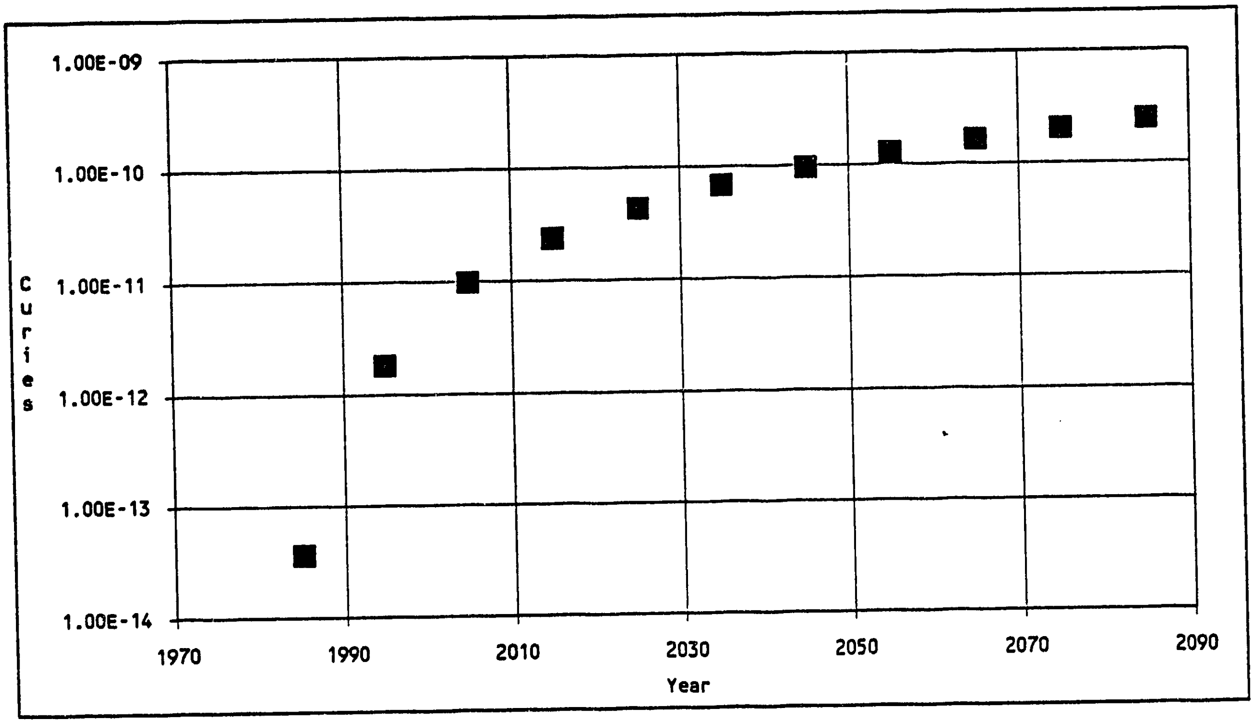


Figure 4-22. Plutonium-239 concentration in surface soil at new pit area.



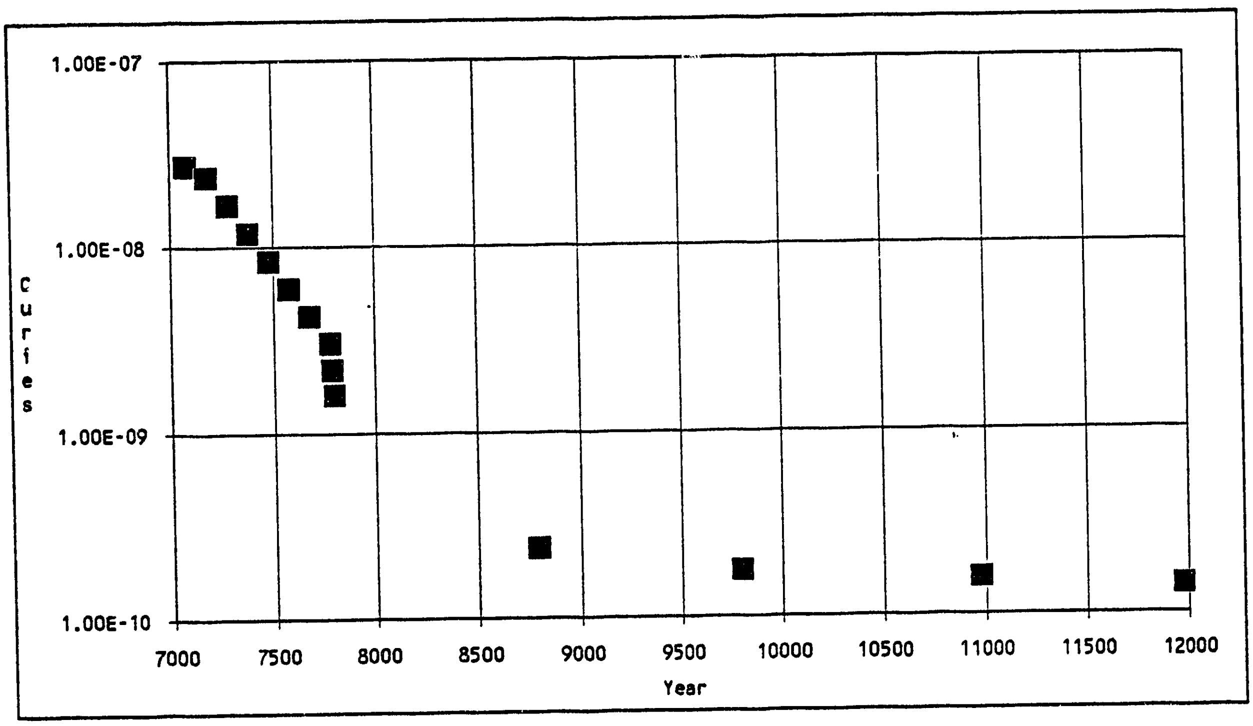


Figure 4-23. Plutonium-240 concentration in surface soil at new pit area.

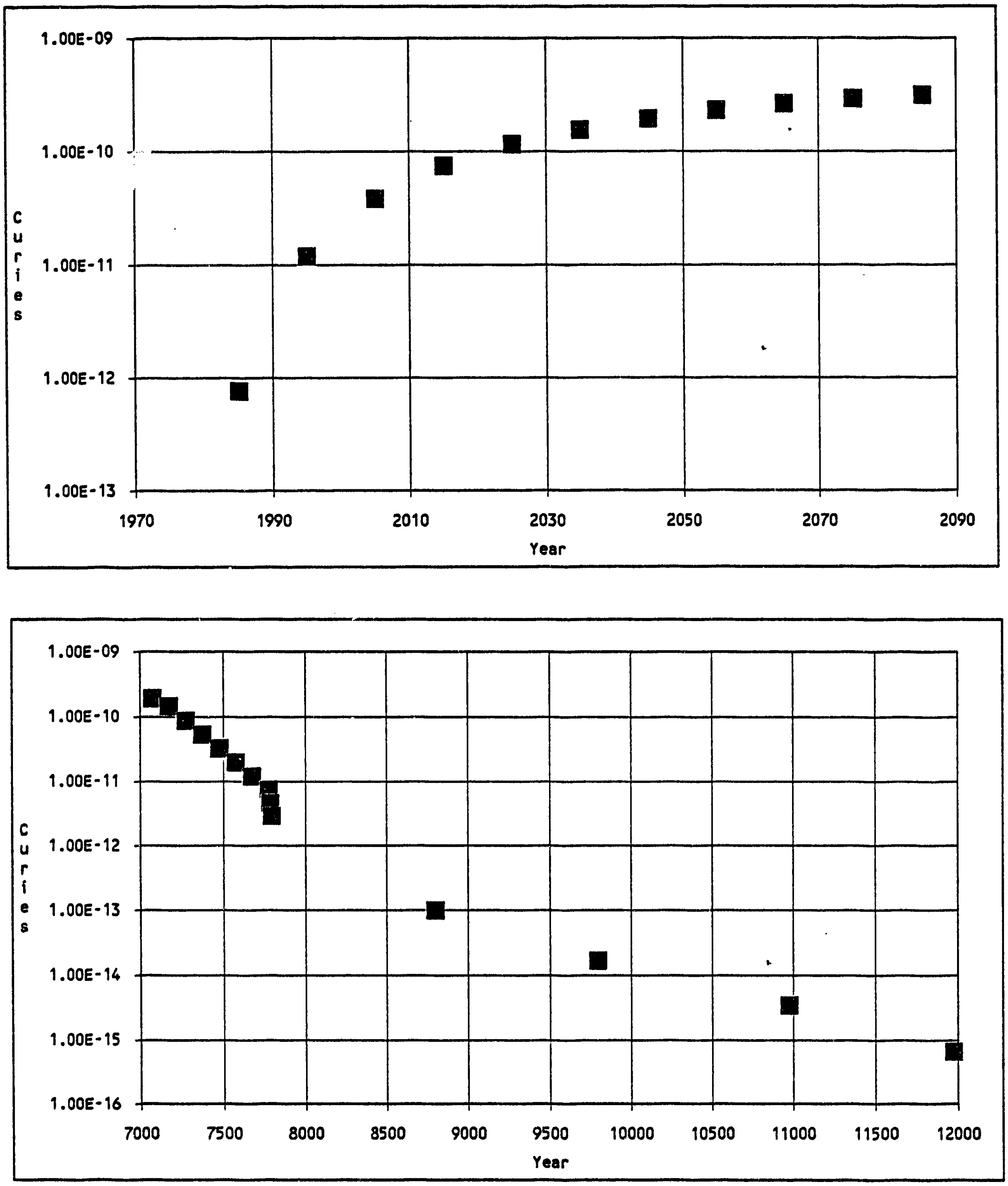


Figure 4-24. Americium-241 concentration in surface soil at new pit area.

TABLE 4-3. FIFTY-YEAR DOSE COMMITMENTS (MREM) TO THE MAXIMUM INDIVIDUAL FROM AIRBORNE TRANSPORT OF RADIONUCLIDES RESUSPENDED FROM SURFACE SOIL AND FROM RADON AT PITS 15 THROUGH 20 DURING OPERATIONAL AND INSTITUTIONAL PERIODS.

	ORGAN										
YEAR	Whole Body	Gonads	Breast	Red Marrow	Lungs	Thyroid	Bone Surface	Liver	Stomach Wall	Kidneys	Effective Dose Equivalent
1975	1.16E-16	1.41E-16	1.28E-16	1.10E-16	1.22E-16	1.35E-16	1.16E-16	1.04E-16	1.01E-16	1.08E-16	1.24E-16
1985	4.87E-07	4.03E-07	3.77E-07	8.84E-07	1.74E-06	3.91E-07	1.58E-06	3.06E-07	3.12E-07	3.20E-07	6.68E-07
1995	2.19E-05	2.47E-05	2.32E-05	2.22E-05	3.08E-05	2.40E-05	3.11E-05	1.77E-05	1.87E-05	1.87E-05	2.38E-05
2005	8.59E-05	9.67E-05	9.20E-05	7.51E-05	1.19E-04	9.43E-05	1.25E-04	6.39E-05	7.90E-05	6.86E-05	9.16E-05
2015	2.30E-04	2.54E-04	2.45E-04	1.64E-04	3.45E-04	2.49E-04	3.76E-04	1.45E-04	2.32E-04	1.60E-04	2.42E-04
2025	4.46E-04	4.86E-04	4.74E-04	2.79E-04	7.02E-04	4.79E-04	7.77E-04	2.54E-04	4.72E-04	2.85E-04	4.65E-04
2035	7.22E-04	7.80E-04	7.64E-04	4.11E-04	1.17E-03	7.70E-04	1.31E-03	3.81E-04	7.85E-04	4.35E-04	7.48E-04
2045	1.05E-03	1.13E-03	1.11E-03	5.58E-04	1.74E-03	1.11E-03	1.95E-03	5.24E-04	1.16E-03	6.05E-04	1.08E-03
2055	1.42E-03	1.52E-03	1.50E-03	7.16E-04	2.39E-03	1.50E-03	2.69E-03	6.79E-04	1.60E-03	7.91E-04	1.46E-03
2065	1.83E-03	1.95E-03	1.93E-03	8.85E-04	3.12E-03	1.93E-03	3.52E-03	8.46E-04	2.08E-03	9.93E-04	1.88E-03
2075	2.27E-03	2.42E-03	2.39E-03	1.06E-03	3.91E-03	2.39E-03	4.44E-03	1.02E-03	2.61E-03	1.21E-03	2.34E-03
2085	2.75E-03	2.91E-03	2.89E-03	1.25E-03	4.77E-03	2.89E-03	5.42E-03	1.21E-03	3.17E-03	1.43E-03	2.82E-03
2095	7.45E-04	7.76E-04	7.77E-04	2.76E-04	1.37E-03	7.72E-04	1.57E-03	2.75E-04	8.96E-04	3.41E-04	7.61E-04
2105	8.79E-04	9.16E-04	9.17E-04	3.26E-04	1.62E-03	9.11E-04	1.85E-03	3.25E-04	1.06E-03	4.03E-04	8.98E-04
2115	1.01E-03	1.05E-03	1.05E-03	3.74E-04	1.85E-03	1.04E-03	2.12E-03	3.73E-04	1.21E-03	4.62E-04	1.03E-03
2125	1.12E-03	1.17E-03	1.17E-03	4.17E-04	2.07E-03	1.16E-03	2.37E-03	4.15E-04	1.35E-03	5.15E-04	1.15E-03
2135	1.23E-03	1.28E-03	1.28E-03	4.55E-04	2.25E-03	1.27E-03	2.58E-03	4.53E-04	1.47E-03	5.62E-04	1.25E-03
2145	1.32E-03	1.37E-03	1.37E-03	4.89E-04	2.42E-03	1.37E-03	2.77E-03	4.87E-04	1.59E-03	6.04E-04	1.35E-03
2155	1.40E-03	1.46E-03	1.46E-03	5.19E-04	2.57E-03	1.45E-03	2.94E-03	5.17E-04	1.68E-03	6.41E-04	1.43E-03
2165	1.47E-03	1.53E-03	1.54E-03	5.46E-04	2.71E-03	1.53E-03	3.10E-03	5.44E-04	1.77E-03	6.74E-04	1.50E-03
2175	1.54E-03	1.60E-03	1.60E-03	5.70E-04	2.82E-03	1.59E-03	3.23E-03	5.68E-04	1.85E-03	7.04E-04	1.57E-03
2275	1.87E-03	1.95E-03	1.96E-03	6.96E-04	3.45E-03	1.94E-03	3.95E-03	6.93E-04	2.26E-03	8.59E-04	1.91E-03

TABLE 4-4. FIFTY-YEAR DOSE COMMITMENTS (MAN-MREM) TO THE 80-KM POPULATION FROM AIRBORNE TRANSPORT OF RADIONUCLIDES RESUSPENDED FROM CONTAMINATED SURFACE SOIL FROM RADON FROM AND AROUND THE RWMC BEFORE CLOSURE

		ORGAN										
AREA	YEAR	Whole Body	Gonads	Breast	Red Marrow	Lungs	Thyroid	Bone Surface	Liver	Stomach Wall	Kidneys	Effective Dose Equivalent
Old pits	2074	1.30E+01	1.38E+01	1.36E+01	6.01E+00	2.29E+01	1.36E+01	2.62E+01	5.75E+00	1.50E+01	6.75E+00	1.34E+01
New pits	2075	9.94E+00	1.05E+01	1.04E+01	4.26E+00	1.76E+01	1.04E+01	2.00E+01	4.15E+00	1.16E+01	4.99E+00	1.02E+01
Outside	2074	6.14E+00	5.73E+00	5.93E-01	3.61E+01	3.76E+00	5.83E-01	4.45E+02	9.61E+01	5.67E-01	5.73E-01	2.90E+01

the Final Environmental Impact Statement for the Special Isotope Separation Project (DOE 1988d) used the review published by the Committee on Biological Effects of Ionizing Radiation of the National Academy of Sciences (BIER, 1980) to assess the health risks associated with radiation-induced cancer. The Special Isotope Separation Project Environmental Impact Statement used the health effects estimators of 33 and 72 cancer fatalities per million person-rem for gamma and beta emitters and for TRUs, respectively, for comparison with the EDE. Because the great majority of the projected doses were due to low LET radiation, the health effects estimator of 33 cancer fatalities per million person-rem is more appropriate for this study. Using this estimator, the projected health effects (in the form of cancer fatalities) because of airborne radionuclides released from all three areas is 1.76 E-6.

4.1.1.2 Ground Water Transport. During the operational and institutional control periods, radionuclides were not projected to reach the receptor, who was assumed to be located at the edge of the INEL Site, 4800 m from the RWMC. The travel time of the ground water to the edge of the INEL Site was determined to be approximately 1000 yr. The travel time in the unsaturated zone accounts for most of this time; the travel time in the aquifer was approximately 8 yr. The retardation by the geologic media increases the radionuclide travel time by factors of 20-4000, depending on the radionuclide. Appendix A.4 contains a detailed explanation of the ground water transport methodology.

During the post-institutional control period, the hypothetical receptor was moved from the edge of the INEL Site to the edge of the RWMC. The ground water travel time to this receptor was also determined to be approximately 1000 yr, with flow in the unsaturated zone accounting for most of this time. Because of the long ground water travel times and retardation by geologic media, many radionuclides in the RWMC inventory do not reach the receptor. Long-lived radionuclides do reach the receptor, but the presence of long-lived radionuclides is augmented by the presence of radioactive progeny. In some cases, relatively short-lived radionuclides decay to long-lived progeny, which then are transported to the receptor. In other cases, the progeny are more hazardous than the parents. Therefore, the ingrowth of radioactive progeny from both short- and long-lived radionuclides was explicitly accounted for in the calculation of radionuclide doses.

Table 4-5 illustrates the radionuclide doses from old pits, new pits, and soil vaults. The total dose was 2.2 mrem/yr in the year of peak dose. U-238 and its decay products were the dominate contributors to the peak dose, which occurred 3.7 million yr after site closure. The new pits were responsible for the vast majority of the dose, 1.7 mrem/yr. The bulk of the dose associated with U-238 came from Ra-226, Pb-210, and Po-210, which are relatively short-lived radioactive progeny of U-238.

4.1.2 Doses to Intruders

The inadvertent intruder-agriculture scenario resulted in a peak dose of 1.7 mrem/yr from intrusion into the old pits (see Table 4-6). This was approximately 2% of the regulatory requirement of 100 mrem/yr. The dominant contributor to this dose was external exposure from uranium and plutonium decay products. The dominant radionuclide for inhalation exposures was Pu-239 and its decay products; the dominant radionuclide for ingestion exposures was Ra-226 and its decay products.

The inadvertent intruder-construction scenario resulted in a peak dose of 7.0 mrem from intrusion into the old pits (see Table 4-6). This was approximately 1.4% of the regulatory requirement of 500 mrem. The dominate radionuclides were uranium and plutonium decay products, via the external exposure pathway.

The inadvertent intruder-drilling scenario resulted in a peak dose of 12 mrem from intrusion into the soil vaults (see Table 4-6). This was approximately 2.4% of the regulatory requirement of 500 mrem. The dominant radionuclide was Cs-137. The scenario was assumed to take place at year 100, while the intruder-construction and intruder-agriculture scenarios were assumed to take place at year 3000.

Table 4-5. Ground water transport to well at edge of Site

Area	Effective Dose Equivalent (mrem/yr)
New pits	1.7
Old pits	0.54
Soil vaults	1.2 E-4
Total	2.2

Table 4-6. Dose to inadvertent intruders

Area	Scenario	Effective Dose Equivalent (mrem/yr)
New Pits	I-A[a]	0.45
	I-C[b]	1.4
	I-D[c]	--
Old Pits	I-A	1.7
	I-C	7.0
	I-D	--
Soil Vaults	I-A	3.0 E-03
	I-C	--
	I-D	12

a. Intruder-agriculture scenario
b. Intruder-construction scenario
c. Intruder-drilling scenario

4.1.3 Comparison with Performance Objectives

Table 4-7 summarizes the maximum doses projected with the performance objectives. In most cases, the calculated doses are far less than the objectives. In one case, the dose received from drinking water obtained from a well at the RWMC perimeter, is less than but fairly close to the objective. This dose was projected for 3.75 million yr and is due primarily to long-lived U-238. There is some question as to the validity of this calculation given the long time period involved and the unpredictable environmental conditions that may exist that far in the future.

Uncertainties associated with the calculations are discussed in Section 4.2. A discussion of further studies recommended help clarify and reduce these uncertainties in presented in Section 6.

4.2 Sensitivity and Uncertainty Analysis

4.2.1 Introduction

Computer codes have been used in many areas of radiological and performance assessments to model many complex systems and processes. In this analysis, AIRDOS-EPA (Moore et al. 1979) was used to estimate the dose to man from atmospheric releases of radionuclides, DOSTOMAN (King et al. 1985, Root 1981) was used to estimate release from the near-field at the RWMC, and PATHRAE-EPA (Rogers and Hung 1987) was used to estimate the dose to man from ground water contamination and inadvertent intrusion. These codes are deterministic. A set of parameters is used as input, and output values are estimated. In reality, input parameters are not single values but exhibit a range of values. There is uncertainty in the input values; therefore, there is uncertainty in the output values. The objective of a parameter uncertainty analysis is to quantify this uncertainty by propagating input uncertainty through the model.

Table 4-7. Comparison of results with performance objectives

Receptor	Media	Performance Objective	Maximum doses doses projected for future periods[a]				
			Old pits	New pits	Outside soils	Soil vaults	Total
General public	Air	25 mrem/yr (whole body)	3.7 E-03 mrem/yr	2.8 E-03 mrem/yr	3.7 E-03 mrem/yr	N/A	1.0 E-02 mrem/yr
		75 mrem/yr (organ)	7.3 E-03 mrem/yr (bone surface)	5.4 E-03 mrem/yr (bone surface)	2.68 E-01 mrem/yr (bone surface)	N/A	2.8 E-01
		N/A	1.34 E+01 man-mrems/yr[b]	1.02 E+01 man-mrems/yr	2.90 E+01 man-mrems/yr	N/A	5.26 E+01 man-mrems/yr
	Well	4 mrem/yr (EDE)	5.4 E-01 mrem/yr	1.7 mrem/yr	N/A	1.2 E-04 mrem/yr	2.2 mrem/yr
Intruders:							
-Chronic	All	100 mrem/yr (EDE)	1.7 mrem/yr	0.45 mrem/yr	N/A	1.2 E-04 mrem/yr	N/A
-Acute	All	500 mrem (EDE)	7.0 mrem	1.4 mrem	N/A	12 mrem	

a. Doses projected before 1989 were not included.
b. Represents the 50-mile population dose. There is no performance objective for this category.

There is also uncertainty in the formulation of the model itself; this is known as structural uncertainty (Rish 1982). Structural uncertainty results from an incomplete understanding of the system or process, while parameter uncertainty results from the stochastic nature of the parameters and an incomplete understanding of the parameters.

Implicit in the development of these computer models is an attempt to include all variables that could be important to the system. As a result, models tend to have many input parameters whose influence on model output is unknown. For example, a model may have hundreds of input parameters, but relatively few may contribute to the majority of output uncertainty. Sensitivity analysis is used to determine the relative influence of input parameters on overall parameter uncertainty. Therefore, sensitivity can be defined as the change in the model output relative to the change in model input. By identifying the major contributors to output uncertainty, areas of concern and important input variables can be identified.

The objective of a parameter uncertainty analysis is to determine the uncertainty in an output parameter, based on the uncertainty in the input parameters and a model of the system. There are four basic techniques that have been commonly used to assess uncertainty (Cox and Baybutt 1981):

1. Analytical methods
2. Monte Carlo methods
3. Differential methods
4. Response surface methods.

Each method uses different assumptions about model parameters, complexity, and correlations. Therefore, a technique that works well with one particular model or set of models will not necessarily be applicable to another model.

Analytical methods are most often applicable when the model to be evaluated has a simple structure, and the data have known and well behaved distributional characteristics. This method does not work well when the models are complex; hence, it was not used in this analysis.

Monte Carlo methods entail sampling values from each input parameter probability distribution and propagating these values through the model to yield a probability distribution for the output parameter of interest. This method is the most useful when statistical data are available to estimate input parameter probability distributions. A Monte Carlo analysis also requires substantial computer resources as well as modifications of the computer code. For these reasons, a Monte Carlo analysis was not performed.

Differential methods require that partial derivatives for each output parameter with respect to each input parameter of interest be estimated. In many cases, the partial derivatives are too complex to be evaluated analytically. Adjoint analysis (Worley 1987) may be used to estimate the partial derivatives. This type of analysis is typically the method of choice for large computer codes with hundreds of parameters and a system of equations (Harper 1983); therefore, it was not chosen for use in this analysis.

A response surface analysis is based on using an experimental design to select values and pairings of input parameters that are then used to make runs of the computer code (Iman and Helton 1985). Most often, factorial and fractional factorial experimental designs are chosen. In some instances, a complex computer model may be replaced by a simpler response surface. In other cases, multiple systematically selected runs are used to establish the overall range or uncertainty in the results. In addition, data from previously performed sensitivity analysis can be incorporated readily into the experimental design matrix. The multiple systematically selected runs derivative of response surface methods was selected for use in this analysis.

4.2.2 Analysis Strategy

The first step in any analysis is to clearly formulate the questions that the analysis should answer. At any given waste disposal site, there are literally an infinite number of questions that may be asked. Therefore, the RWMC was divided into areas, and questions were formulated for each area. The following areas were defined: near-field, ground water flow and transport, and surface soil.

For the near-field area, the key question was the uncertainty in the amount of radioactive material available for transport out of the facility and to postulated receptors. In this context, transport was limited to transport in ground water. An experimental design was formulated to assess the range of possible releases as well as to identify possible interactions between key output parameters.

In the area of ground water flow and transport, the key question was the uncertainty in the radionuclide concentration in a postulated well near the RWMC. Because radionuclide concentration is directly proportional to dose, uncertainty in concentration can be used to estimate uncertainty in dose. An experimental design was developed to estimate the range of radionuclide concentration.

For surface soil, the key question was the uncertainty in the amount of radioactive material available for atmospheric transport to postulated receptors. This quantity is also directly proportional to dose, so the uncertainty in the quantity of radioactive material available for transport can be used to estimate uncertainty in dose. An experimental design was formulated to assess the range of possible quantities.

A previous sensitivity study was performed on an earlier version of the near-field model used in this analysis (Shuman et al. 1985). The major differences between the current near-field model and the earlier version is that it included additional biotic pathway (e.g., small mammals consuming vegetation) and Rocky Flats waste (primarily TRU waste). The rate constant calculations are basically the same; although, in some cases parameters were updated to reflect current literature values. It was assumed that the models are similar enough to apply the sensitivity results to this study. A discussion of this study follows.

The sensitivity study addressed 5 radionuclides (Co-60, Sr-90, Cs-137, Pu-239, and Am-241) and the following 10 transport processes: (1) waste release, (2) hydrologic transport in the unsaturated zone, (3) surface runoff, (4) resuspension, (5) plant uptake, (6) plant death, (7) surface litter decay, (8) small mammal ingestion, (9) small mammal death and elimination, and (10) small mammal burrowing. The controlling rate constant for each of these processes was perturbed by 1%. The change in model response because of this perturbation was compared mathematically with the nominal model response. The transport processes were then ranked according to relative sensitivity. This was done for several time periods. Interactions between transport processes were also quantified.

In designing the uncertainty analysis, the following conclusions from the sensitivity study were considered.

- The most sensitive transport process for all nuclides during early operations (20 yr after initial burial) was waste release.

- The most sensitive transport process for most radionuclides, in particular the longer-lived nuclides, during late operations (100 yr after initial burial) was waste release.

- Plant uptake and small mammal burrowing were usually ranked within the top three in terms of relative sensitivity.

In light of the above observations, it was decided to focus the uncertainty analysis on parameters that affect waste release. This decision was also tempered by the facts that (a) less data were available on waste release at the RWMC than on biotic processes, and (b) there may be considerable uncertainty associated with waste related data (i.e., inventory, container lifetimes, and release rates).

4.2.3 Near-Field

The end point of the near-field uncertainty analysis was the amount of radioactive material available for transport out of the facility. Three parameters were varied: the inventory, container lifetime, and release rate from the facility. Each parameter was examined at two levels: a nominal value and an adjusted value. For the old pits, inventory was increased by 300%, container lifetime was assumed to be 0, and the release rate was doubled. For the new pits, inventory was increased by 30%, container lifetime was assumed to be 0, and the release rate was doubled. A two-level full-factoral design was used to evaluate the impacts of the changes in the input parameter values.

Two radionuclides were examined in detail: U-238 and Pu-239. These two radionuclides are representative of less mobile and slightly mobile radionuclides. Separate runs were made for the old pits and the new pits.

4.2.3.1 Results. For each of the radionuclides, a two-level factorial design was used to establish the range over which the quantity of radioactive material available for transport could vary. The amount available for transport was defined as the peak inventory contained in the compartment.

- U-238. The inventory available for transport exhibited a range of 9.5 to 12 Ci for the new pits and 6.0 to 22 Ci for the old pits (see Table 4-8). For the new pits, no substantial interactions between pairs of parameters were observed, although

Table 4-8. Experimental Results for U-238

New Pits

Experiment	Inventory	Container Lifetime	Release Rate Constant	Inventory Available for Release
1	-1	-1	-1	9.46
2	1	-1	-1	11.9
3	-1	1	-1	9.46
4	1	1	-1	12.3
5	-1	-1	1	9.46
6	1	-1	1	11.9
7	-1	1	1	9.46
8	1	1	1	12.3

Old Pits

Experiment	Inventory	Container Lifetime	Release Rate Constant	Inventory Available for Release
1	-1	-1	-1	5.97
2	1	-1	-1	22.3
3	-1	1	-1	7.46
4	1	1	-1	22.3
5	-1	-1	1	7.46
6	1	-1	1	22.3
7	-1	1	1	7.46
8	1	1	1	22.3

release rate had a smaller effect than inventory or container lifetime.

- For the old pits, inventory was the prime contributor to the overall uncertainty. In addition, no substantial interactions between parameters were observed.

- Pu-239. The inventory available for transport exhibited a range of 2.5 to 3.3 Ci for the new pits and 20 to 61 Ci for the old pits (see Table 4-9). For both the new and old pits, inventory was the overwhelming contributor to overall uncertainty. No substantial interactions were observed between parameters.

4.2.4 Ground Water Flow and Transport

The end point in the uncertainty analysis of ground water flow and transport was defined to be the radionuclide concentration in well water at a postulated location near the RWMC. The computer code PATHRAE-EPA (Rogers and Hung 1987) was used for this portion of the analysis.

The actual transport of material from radioactive waste to a human receptor entails substantial interaction between near-field, ground water flow and transport, and food chain transport phenomena. For the purposes of this analysis, flow and transport has been decoupled from the near-field and food chain processes in order to clearly focus the analysis. The near-field was assessed separately, and food chain processes have been assessed in many other studies (Maheras 1988, Otis 1983, Hoffman et al. 1982, Schwarz and Hoffman 1980).

Preliminary sensitivity analyses of the PRESTO-EPA-CPG computer code have already been performed (Shuman and Rogers 1987, EPA 1988). This code is similar in structure to PATHRAE-EPA; therefore, the results of these analyses were used as a basis for constructing an experimental design applicable to the RWMC. Because of the structure of the RWMC and the 1

Table 4-9. Experimental Results for Pu-239

New Pits

Experiment	Inventory	Container Lifetime	Release Rate Constant	Inventory Available for Release
1	-1	-1	-1	2.51
2	1	-1	-1	3.27
3	-1	1	-1	2.52
4	1	1	-1	3.27
5	-1	-1	1	2.52
6	1	-1	1	3.27
7	-1	1	1	2.45
8	1	1	1	3.27

Old Pits

Experiment	Inventory	Container Lifetime	Release Rate Constant	Inventory Available for Release
1	-1	-1	-1	20.5
2	1	-1	-1	61.6
3	-1	1	-1	20.5
4	1	1	-1	61.6
5	-1	-1	1	20.5
6	1	-1	1	61.6
7	-1	1	1	20.5
8	1	1	1	61.6

relative flow rates of the unsaturated zone and the Snake River Plain aquifer, emphasis was placed on those parameters that affect transport in the unsaturated zone.

Analysis of PRESTO-EPA-CPG identified the following ground water flow and transport parameters as exhibiting medium to high sensitivity:

- Waste release fraction
- Distribution coefficients
- Trench and sub-trench porosity and residual saturation
- Distance from trench to well and trench to aquifer
- Aquifer porosity and thickness
- Ground water velocity.

The porosity and residual saturation parameters are used to calculate the vertical ground water velocity. Therefore, the uncertainty in these parameters was lumped into the uncertainty of the vertical ground water velocity. The distances from trench to well and from trench to aquifer are fixed because of the site-specific nature of the analysis and were not evaluated. Aquifer porosity and thickness were not evaluated because of the emphasis of the analysis on the unsaturated zone. Three parameters were evaluated: waste release function, distribution coefficients, and vertical ground water velocity.

A full factorial experimental design was used to evaluate the uncertainty in radionuclide concentration because of the uncertainty in these three input parameters. This design has a number of advantages over other designs. For example, if interactions between parameters occur, then this design will be able to assess them. In addition, the entire parameter space is sampled in a minimum number of computer runs.

Each parameter was examined at two levels: a nominal value and an adjusted value. The nominal values represent reasonably conservative estimates of parameter values used in this analysis. The adjusted values represent values that lead to increased radionuclide concentration in well water. For the purposes of this analysis, radionuclide distribution coefficients were decreased by a factor of 10, waste release fractions were increased by a factor of 100, and the vertical ground water velocity was increased by a factor of 10.

The following radionuclides were examined in detail: Ra-226, U-238, and Pu-239. In general, these radionuclides are representative of mobile, less mobile, and slightly mobile radionuclides. A unit concentration (1 Ci/m^3) of each radionuclide was assumed to be present in the waste inventory. Separate computer runs were made for the old and new pits, but the data were analyzed together. Tables 4-10, 4-11, and 4-12 contain the factorial design matrices for Ra-226, U-238, and Pu-239, respectively.

4.2.4.1 Results. For each of the radionuclides, a two-level factorial design was used to establish the range over which the radionuclide concentration in well water could reasonable vary. A unit concentration (1 Ci/m^3) of each radionuclide was assumed to be present in the waste and the results from both old and new pits were aggregated. The following examples were analyzed: Ra-226, U-238, and Pu-239 (see Tables 4-13 through 4-15).

- Ra-226. Ra-226 exhibited a range of concentration in well water water of 8.6 E-41 to 7.7 E-4 Ci/m^3 (see Table 4-14). This translates to a range in dose of 3.1 E-35 to 1.7 E+3 mrem. The upper range only occurs when the adjusted values of all parameters are used. If only the distribution coefficient and ground water velocity are changed, the upper range becomes 17 mrem. It can also be seen that there is substantial interaction between the distribution coefficient, release rate, and ground water velocity. In addition, each of the parameters contributed approximately the same amount to the overall uncertainty in concentration and dose.

Table 4-10. Factorial design matrix for Ra-226

Experiment	Distribution Coefficient (cm^3/g)	Distribution Coefficient (coded)	Release Fraction (1/yr)	Release Fraction (coded)	Vertical Ground Water Velocity (m/yr)	Vertical Ground Water Velocity (coded)
1	5	-1	5.02 E-05	-1	0.18	-1
2	0.5	1	5.02 E-05	-1	0.18	-1
3	0.5	1	5.02 E-03	1	0.18	-1
4	0.5	1	5.02 E-03	1	1.8	1
5	5	-1	5.02 E-03	1	0.18	-1
6	5	-1	5.02 E-03	1	1.8	1
7	5	-1	5.02 E-05	-1	1.8	1
8	0.5	1	5.02 E-05	-1	1.8	1

Table 4-11. Factorial design matrix for U-238

Experiment	Distribution Coefficient (cm^3/g)	Distribution Coefficient (coded)	Release Fraction (1/yr)	Release Fraction (coded)	Vertical Ground Water Velocity (m/yr)	Vertical Ground Water Velocity (coded)
1	100	-1	2.51 E-06	-1	0.18	-1
2	10	1	2.51 E-06	-1	0.18	-1
3	10	1	2.51 E-04	1	0.18	-1
4	10	1	2.51 E-04	1	1.8	1
5	100	-1	2.51 E-04	1	0.18	-1
6	100	-1	2.51 E-04	1	1.8	1
7	100	-1	2.51 E-06	-1	1.8	1
8	10	1	2.51 E-06	-1	1.8	1

Table 4-12. Factorial design matrix for Pu-239

Experiment	Distribution Coefficient (cm^3/g)	Distribution Coefficient (coded)	Release Fraction (1/yr)	Release Fraction (coded)	Vertical Ground Water Velocity (m/yr)	Vertical Ground Water Velocity (coded)
1	200	-1	1.26 E-06	-1	0.18	-1
2	20	1	1.26 E-06	-1	0.18	-1
3	20	1	1.26 E-04	1	0.18	-1
4	20	1	1.26 E-04	1	1.8	1
5	200	-1	1.26 E-04	1	0.18	-1
6	200	-1	1.26 E-04	1	1.8	1
7	200	-1	1.26 E-06	-1	1.8	1
8	20	1	1.26 E-06	-1	1.8	1

Table 4-13. Experimental results for Ra-226

New Pits

Run	Distribution Coefficient	Release Rate Constant	Vertical Ground Water Velocity	Concentration (Ci/m^3)
1	-1	-1	-1	1.24 E-40
2	1	-1	-1	3.75 E-09
3	1	1	-1	3.75 E-07
4	1	1	1	3.62 E-04
5	-1	1	-1	1.24 E-38
6	-1	1	1	5.20 E-07
7	-1	-1	1	5.20 E-09
8	1	-1	1	7.67 E-06

Old Pits

Run	Distribution Coefficient	Release Rate Constant	Vertical Ground Water Velocity	Concentration (Ci/m^3)
1	-1	-1	-1	8.75 E-41
2	1	-1	-1	2.61 E-09
3	1	1	-1	2.60 E-07
4	1	1	1	5.33 E-04
5	-1	1	-1	8.57 E-39
6	-1	1	1	3.60 E-07
7	-1	-1	1	3.60 E-09
8	1	-1	1	5.33 E-06

Table 4-14. Experimental results for U-238

New Pits

Run	Distribution Coefficient	Release Rate Constant	Vertical Ground Water Velocity	Concentration (Ci/m^3)
1	-1	-1	-1	9.07 E-07
2	1	-1	-1	9.07 E-07
3	1	1	-1	9.07 E-05
4	1	1	1	9.07 E-05
5	-1	1	-1	9.07 E-05
6	-1	1	1	9.07 E-05
7	-1	-1	1	9.07 E-07
8	1	-1	1	9.07 E-07

Old Pits

Run	Distribution Coefficient	Release Rate Constant	Vertical Ground Water Velocity	Concentration (Ci/m^3)
1	-1	-1	-1	6.30 E-07
2	1	-1	-1	6.31 E-07
3	1	1	-1	6.31 E-05
4	1	1	1	6.31 E-05
5	-1	1	-1	6.28 E-05
6	-1	1	1	6.29 E-05
7	-1	-1	1	6.31 E-07
8	1	-1	1	6.31 E-07

Table 4-15. Experimental results for Pu-239

New Pits

Run	Distribution Coefficient	Release Rate Constant	Vertical Ground Water Velocity	Concentration (Ci/m^3)
1	-1	-1	-1	0
2	1	-1	-1	2.26 E-16
3	1	1	-1	2.26 E-14
4	1	1	1	5.23 E-06
5	-1	1	-1	0
6	-1	1	1	2.07 E-14
7	-1	-1	1	2.07 E-16
8	1	-1	1	5.23 E-08

Old Pits

Run	Distribution Coefficient	Release Rate Constant	Vertical Ground Water Velocity	Concentration (Ci/m^3)
1	-1	-1	-1	0
2	1	-1	-1	1.57 E-16
3	1	1	-1	1.57 E-14
4	1	1	1	3.63 E-06
5	-1	1	-1	0
6	-1	1	1	1.42 E-14
7	-1	-1	1	1.42 E-16
8	1	-1	1	3.63 E-08

- U-238. U-238 exhibited a range of concentration in well water of 6.3 E-7 to 9.1 E-5 Ci/m^3 (see Table 4-14). This yields a range in dose of 0.54 to 170 mrem. Unlike Ra-226, the upper ranges occur when the release rate is high; the values of the other parameters have no effect. No interactions between pairs of parameters were observed. Release rate is also the dominant contributor to the overall uncertainty in concentration and dose.

- Pu-239. The dose from Pu-239 ranges from 1.2 E-4 to 0.97 mrem. Because of the long travel times in the unsaturated zone, Pu-239 does not reach the well in some cases (see Table 4-15). The highest concentrations occur when the distribution coefficient and ground water velocity are adjusted. There is also a slight interaction between the distribution coefficient and ground water velocity.

4.2.5 Surface Soil

The end point of the uncertainty analysis of surface soil was the quantity of radioactive material available for transport from surface soil through the atmospheric pathway. Three parameters were varied: the inventory, container lifetime, and release rate (through the ground water pathway). Each parameter was examined at two levels: a nominal value and an adjusted value. As with the near-field analysis, the old pit inventory was increased by 300%, container lifetime was assumed to be 0, and the release rate was doubled. For the new pits, inventory was increased by 30%, container lifetime was assumed to be 0, and the release rate was doubled. A full factorial experimental design was needed to evaluate the uncertainty in inventory available for release. This design enables the main effects of parameters and any interactions between parameters to be assessed. Three radionuclides were chosen for evaluation: Cs-137, U-238, and Pu-239. These radionuclides are representative of mobile, less mobile, and slightly mobile radionuclides. Separate runs were made for the old and new pits.

4.2.5.1 Results

Cs-137

The inventory available for transport exhibited a range of 0.26 to 0.86 Ci for the new pits and 0.59 to 2.5 Ci for the old pits (see Table 4-16). The resulting doses ranged from 4.2 E-4 to 1.4 E-3 mrem for the new pits and 9.5 E-4 to 4.0 E-3 mrem for the old pits. For the new pits, inventory was the most sensitive parameter, followed by container lifetime and release rate. There was also interaction exhibited between inventory and container lifetime.

For the old pits, inventory was also the most sensitive parameter, followed by release rate and container lifetime. In this case, interactions between inventory and release and inventory and container lifetime were exhibited. No interactions were exhibited between container lifetime and release rate.

U-238

The inventory available for transport exhibited a range of 1.0 E-3 Ci (3.3 E-5 mrem) to 1.3 E-3 Ci (4.3 E-5 mrem) for the new pits and 5.5 E-6 Ci (1.8 E-7 mrem) to 2.1 E-5 Ci (6.9 E-7 mrem) for the old pits (see Table 4-17). For the new pits, inventory was the most sensitive parameter. The quantity available for transport was relatively insensitive to container lifetime and release rate.

For the new pits, inventory was also the most sensitive parameter. Little sensitivity was shown to container lifetime and release rate.

Pu-239

The inventory available for transport exhibited a range of 4.1 E-7 to 6.3 E-7 Ci for the new pits and 3.8 E-7 to 4.5 E-7 Ci for the old pits (see Table 4-18). The resulting doses ranged from 6.1 E-8 to 9.3 E-8 mrem

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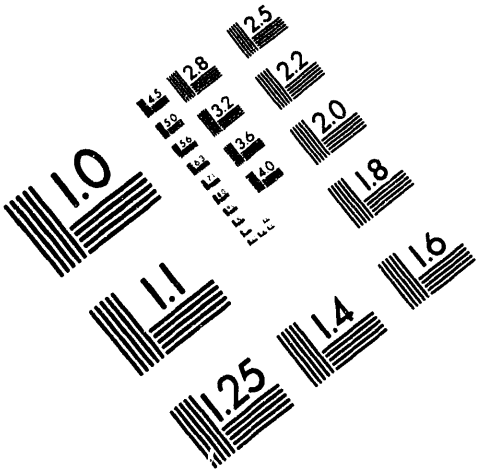

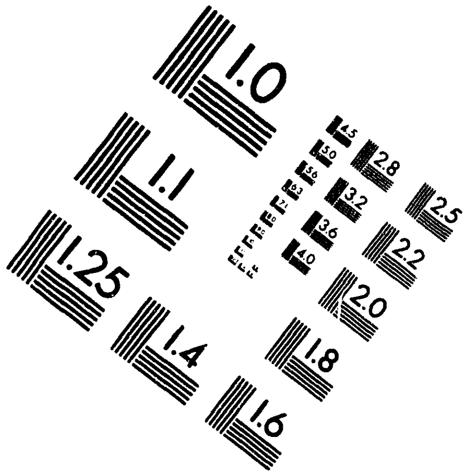

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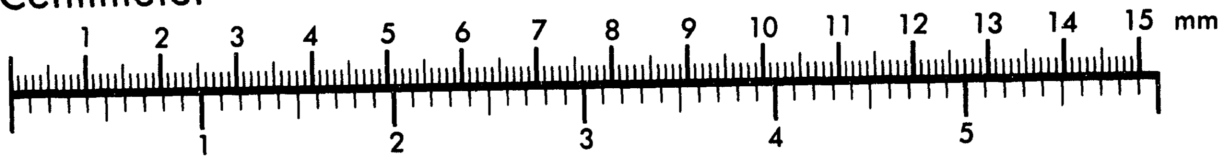

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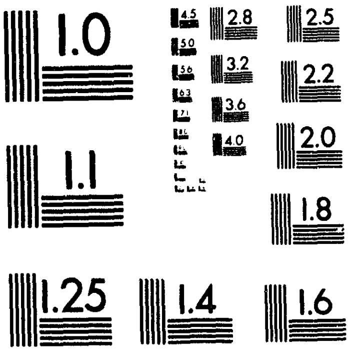

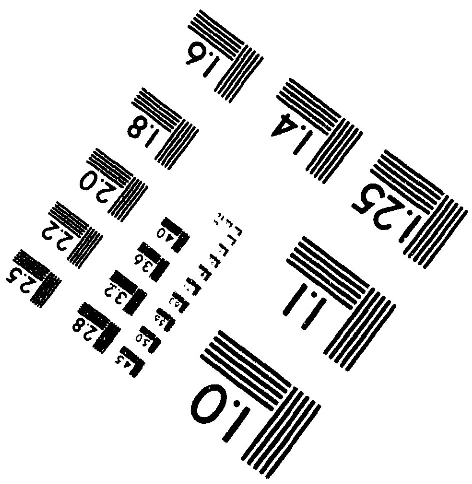

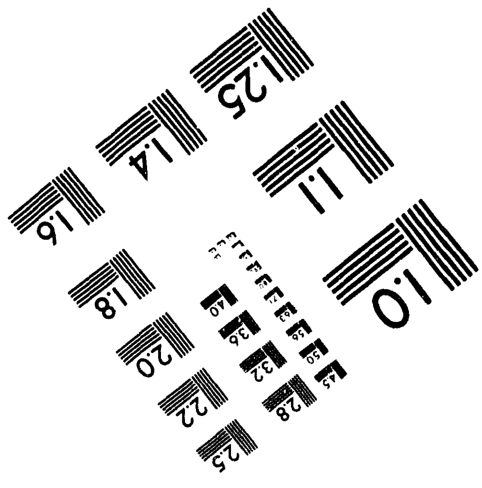

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Table 4-16. Experimental Results for Cs-137

New Pits

Experiment	Inventory	Container Lifetime	Release Rate Constant	Inventory Available for Transport
1	-1	-1	-1	0.258
2	1	-1	-1	0.360
3	-1	1	-1	0.264
4	1	1	-1	0.601
5	-1	-1	1	0.352
6	1	-1	1	0.488
7	-1	1	1	0.359
8	1	1	1	0.860

Old Pits

Experiment	Inventory	Container Lifetime	Release Rate Constant	Inventory Available for Transport
1	-1	-1	-1	0.588
2	1	-1	-1	1.76
3	-1	1	-1	0.612
4	1	1	-1	1.83
5	-1	-1	1	0.794
6	1	-1	1	2.38
7	-1	1	1	0.826
8	1	1	1	2.48

Table 4-17. Experimental Results for U-238

New Pits

Experiment	Inventory	Container Lifetime	Release Rate Constant	Inventory Available for Transport
1	-1	-1	-1	1.00 E-3
2	1	-1	-1	1.27 E-3
3	-1	1	-1	1.00 E-3
4	1	1	-1	1.30 E-3
5	-1	-1	1	1.01 E-3
6	1	-1	1	1.27 E-3
7	-1	1	1	1.01 E-3
8	1	1	1	1.30 E-3

Old Pits

Experiment	Inventory	Container Lifetime	Release Rate Constant	Inventory Available for Transport
1	-1	-1	-1	5.54 E-6
2	1	-1	-1	2.11 E-5
3	-1	1	-1	7.07 E-6
4	1	1	-1	2.11 E-5
5	-1	-1	1	7.09 E-6
6	1	-1	1	2.12 E-5
7	-1	1	1	7.10 E-6
8	1	1	1	2.12 E-5

Table 4-18. Experimental Results for Pu-239

New Pits

Experiment	Inventory	Container Lifetime	Release Rate Constant	Inventory Available for Transport
1	-1	-1	-1	4.14 E-7
2	1	-1	-1	6.30 E-7
3	-1	1	-1	4.87 E-7
4	1	1	-1	6.31 E-7
5	-1	-1	1	4.88 E-7
6	1	-1	1	6.32 E-7
7	-1	1	1	4.88 E-7
8	1	1	1	6.32 E-7

Old Pits

Experiment	Inventory	Container Lifetime	Release Rate Constant	Inventory Available for Transport
1	-1	-1	-1	3.77 E-7
2	1	-1	-1	4.51 E-7
3	-1	1	-1	3.77 E-7
4	1	1	-1	4.51 E-7
5	-1	-1	1	3.77 E-7
6	1	-1	1	4.52 E-7
7	-1	1	1	3.78 E-7
8	1	1	1	4.53 E-7

for the old pits. For both the old and the new pits, inventory was the most sensitive parameter. Little sensitivity was shown to waste container lifetime or release rate.

5. PERFORMANCE EVALUATION

A radiological performance assessment is used to project whether or not a facility will meet performance objectives. However, the monitoring program and related environmental programs are the primary mechanisms by which RWMC compliance with applicable performance objectives will be determined. Aspects of the monitoring program are summarized in the following text and in Table 5-1. Details may be found in the annual reports for the Environmental Monitoring Program (e.g., Tkachyk et al. 1989).

Airborne transport is the most likely mechanism by which radionuclides could be transported from the RWMC facility. Consequently, extensive air monitoring is conducted on and around the RWMC to detect the presence of radionuclides. Air samples are collected on a routine basis and analyzed for gross levels of radioactivity as well as for specific radionuclides.

The USGS monitors ground water in the Snake River Plain aquifer downstream of the RWMC. Samples of ground water are analyzed for radionuclides and hazardous materials from waste at the RWMC. Samples from four monitoring wells around the RWMC are collected and analyzed quarterly.

Although no surface water flows from the RWMC, except during or after heavy rainfalls, surface water samples are collected quarterly (as rainfall permits) and analyzed for radionuclide concentrations. These samples are important in determining whether radionuclide transport from the RWMC via surface water is possible.

Soil monitoring and plant and animal sampling are conducted at regular intervals at and around the RWMC. Surface soils at the RWMC are slightly contaminated with radionuclides from past flooding events, from transportation and handling of LLW, and from physical and biological transport processes.

Table 5-1. Aspects of the monitoring program

Sample	Description	Frequency of Analysis	Type of Analysis
Air	8 low-volume air samplers operated at 0.14 m^3/min (includes 1 control and 1 replicate)	Biweekly Biweekly Monthly Quarterly	Gross alpha Gross beta Gamma spectrometry Radiochemistry[a]
Water surface	4-L samples from SDA and control location	Quarterly, but depends on precipitation	Gross alpha Gross beta Gamma spectrometry Radiochemistry[a,b,c]
Subsurface (sampled by the USGS)	2-L samples from each of 6 wells	65-m well annually 183-m wells quarterly Production well quarterly (see Table 13 for additional drinking water samples taken at WMF-603).	Gamma spectrometry H-3, Sr-90, Pu-238 Pu-239, -240, Am-241 Specific conductance Chloride, sodium, nitrate
Direct radiation surface gamma	Truck-mounted VRM-1 detector system	Semiannually	External radiation levels
Ionizing (conducted by RESL and EG&G Idaho)	25 TLD packets (RESL), 2 TLD packets (EG&G Idaho) and 7 background communities (RESL)	Semiannually	External radiation levels
Small mammal	3 composites in each of 5 major areas (plus 1 control area)[c]	Annually, but species sampled varies each year	Gamma spectrometry Radiochemistry[a]
Soil	5 locations in each of 5 major areas (plus 1 control area)	Biennially	Gamma spectrometry Radiochemistry[a]
Vegetation	3 composites in each of 5 major areas (plus 1 control area)[c]	Annually, but species sampled varies each year	Gamma spectrometry Radiochemistry[a]
Visual inspection	Tour SDA and TSA	Monthly	Results reported for any required corrective action

a. Analysis for Am-241, Pu-238, Pu-239,-240, U-235, U-238, and Sr-90.

b. Samples for radiochemical analyses usually taken during second quarter only.

c. Exact number of samples may vary, due to availability.

Direct ionizing radiation levels are monitored at the RWMC with thermoluminescent dosimeters. These measurements are used to establish exposures because of handling and disposal of LLW and to detect any trends.

Results of the monitoring program are documented annually (e.g., Tkachyk et al. 1989). Results to date indicate adherence to applicable environmental standards.

6. FURTHER STUDIES

Based on the results and analyses for this iteration of the RWMC performance assessment, seven main areas have been identified for consideration in planning future studies.

6.1 Inventory

Inventory is a critical parameter for a performance assessment. Data needs vary with the area of the RWMC considered. In general, current operational practices are superior to past practices. Specific needs are discussed below.

6.1.1 Current Inventory

Current inventory practices and documentation are adequate for the radionuclide inventory at the RWMC. However, information on nonradiological components, such as organic solvents and chelating agents, needs to be obtained in order to address future possible mixed waste issues. While this performance assessment did not address nonradiological inventory, future assessments will need to evaluate this part of the inventory.

6.1.2 Past Inventory

Past disposal practices are a continuing problem area because of inadequate recordkeeping. A thorough investigation and documentation of past waste disposal practices should be conducted. This would include interviews with employees involved with past waste disposal, packaging, and transport and a thorough search of available records.

The following two components of past inventory were not evaluated in this assessment and should be considered for future assessments: (a) the nonradiological components and (b) the TRU and intermingled LLW buried before 1964. Information on these components will need to be collected or updated.

6.2 Waste Release

The waste release from the near field is a critical parameter that affects the performance of the RWMC. Empirical values, thought to be conservative, were used to model the waste release process. A more mechanistic model, based on up-to-date data and integrating waste release, geochemical, and hydrological processes, should be developed. This model would allow full credit to be taken for the RWMC unique properties rather than making conservative assumptions.

The development of a more detailed waste release model will require data more appropriate to the near field that are not currently available. This could require field experiments that are not yet planned (e.g., lysimeters that simulate buried waste). The planning and implementation of such experiments will require the integration of modeling needs with other planning factors.

6.3 Cover

Depth of cover is an important consideration, particularly for those pathways that act to move radionuclides to the surface. Past practices have included several instances of new cover being added. Current records are not sufficient to accurately project the cumulative cover depth. In situ studies are needed to obtain best estimates of the depth of soil above the waste throughout the RMWC.

6.4 Unsaturated Zone

For this iteration of the RWMC performance assessment a simple, one-dimensional, unsaturated zone flow and transport model was used. A more detailed, site-specific, unsaturated flow and transport model (FLASH and FLAME) has been developed by the EG&G Idaho Geosciences Unit. Although undocumented, this code is more appropriate for the subsurface transport of radionuclides and may more adequately deal with flow and transport through basalt and unsaturated, arid conditions. Documentation and implementation of the code should be a part of further performance assessment efforts. In addition, use of a site-specific model will require site-specific data that are not currently available. As discussed in Section 6.2, field experiments to obtain these data should be considered.

6.5 Aquifer

A simple, one-dimensional flow and transport code was used to model ground water flow. A more complex, two-dimensional code (Magnum-2D) is available and is currently being used for other projects at the INEL. This code should be considered for use in further evaluations.

6.6 Future Environmental Conditions

One of the most difficult areas of the assessment to address was future environmental conditions. With model projections being made thousands, and in one case millions, of years in the future, the modeler should consider changes in the environment that may be caused by changes in climatic and geologic factors. For example, flooding of the RWMC by surface waters was not considered because studies of potential flooding of the INEL by a failure of the Mackay dam indicates that the RWMC would not be flooded as a result of such a failure (Koslow and Van Haaftan 1986). This, however, assumes that the spreading areas are still in existence. Climatic changes could include increased rainfall rates that would change the nature of subsurface transport. Erosion rates could also change with time. At a minimum, a literature search could be performed to project the impact of different climatic scenarios. These scenarios could be evaluated and included in the uncertainty analyses.

6.7 Sensitivity and Uncertainty Analyses

Because of the complex structure of the near-field model, which employs coupled differential equations, a differential uncertainty analysis technique may be more appropriate. This methodology was not developed to a sufficient extent to apply it to this performance assessment. However, the technique shows promise and should be considered when available.

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APPENDIX A

DETAILED METHODOLOGY

CONTENTS

APPENDIX A

DETAILED METHODOLOGY

A.1 INTRODUCTION

This appendix discusses the methods used in the performance assessment. A near-field model was developed to simulate radionuclide transport from buried waste containers within the facility boundary to media where the nuclides can be transported offsite. These media are surface soil and subsurface soil. Two main environmental transport pathways were modeled: airborne transport of resuspended contaminated soil particles and groundwater transport. In addition, inadvertent intruder scenarios were developed. Each of these topics are discussed in this appendix. The radon dose calculation methodology is also presented.

A.2 NEAR-FIELD MODEL

As discussed in Section 3.3.1, the near-field model describes the release of radionuclides from buried waste and subsequent transport within the RWMC to surface soil and subsurface media below the buried waste. Projections of radionuclides in the surface and subsurface media were then used as input into the environmental transport models.

A.2.1 Conceptual Model

The conceptual model was divided into two separate conceptual models. The new pits model addresses LLW waste buried in pits greater than 5 m deep. It represents waste emplaced, since 1975, in Pits 15 through 20. Beginning with Pit 17, in 1982, the pits were excavated deep into basalt to a depth up to 9 m. Pits 15 through 20 are situated adjacent to each other in an approximately rectangular area (see Figure 2-20). For this reason, they were treated as one large pit. The assumed profile of pits 15 through 20 is shown in Figure A-1. A total cover of 4.89 m thickness is assumed at the time of closure in 2089. The total area of these pits was estimated to be approximately 3.13 E+4 m^2.

The old pits model addresses LLW waste buried in trenches and pits between 1964 through 1974. The pits and trenches were excavated to basalt. Waste was emplaced at average depth of 3.66 m and covered with .61 m of soil (EG&G 1984). A later cover of, at a minimum, .61 m was added in 1984. A total cover of 4.87 m is assumed to be present at closure in 2089. The assumed profile of the old pits is shown in Figure A-2. The total area of the pits and trenches was estimated to be approximately 8.64 E+4 m^2.

The cover in both conceptual models was assumed to erode at a rate of 0.05 cm/yr (see Section A.2.3). At this rate, the operational cover will have eroded 6 cm by the time of closure. Thus, the cover thickness used in the models for the year 2089 was 4.8 m. The cover was further assumed

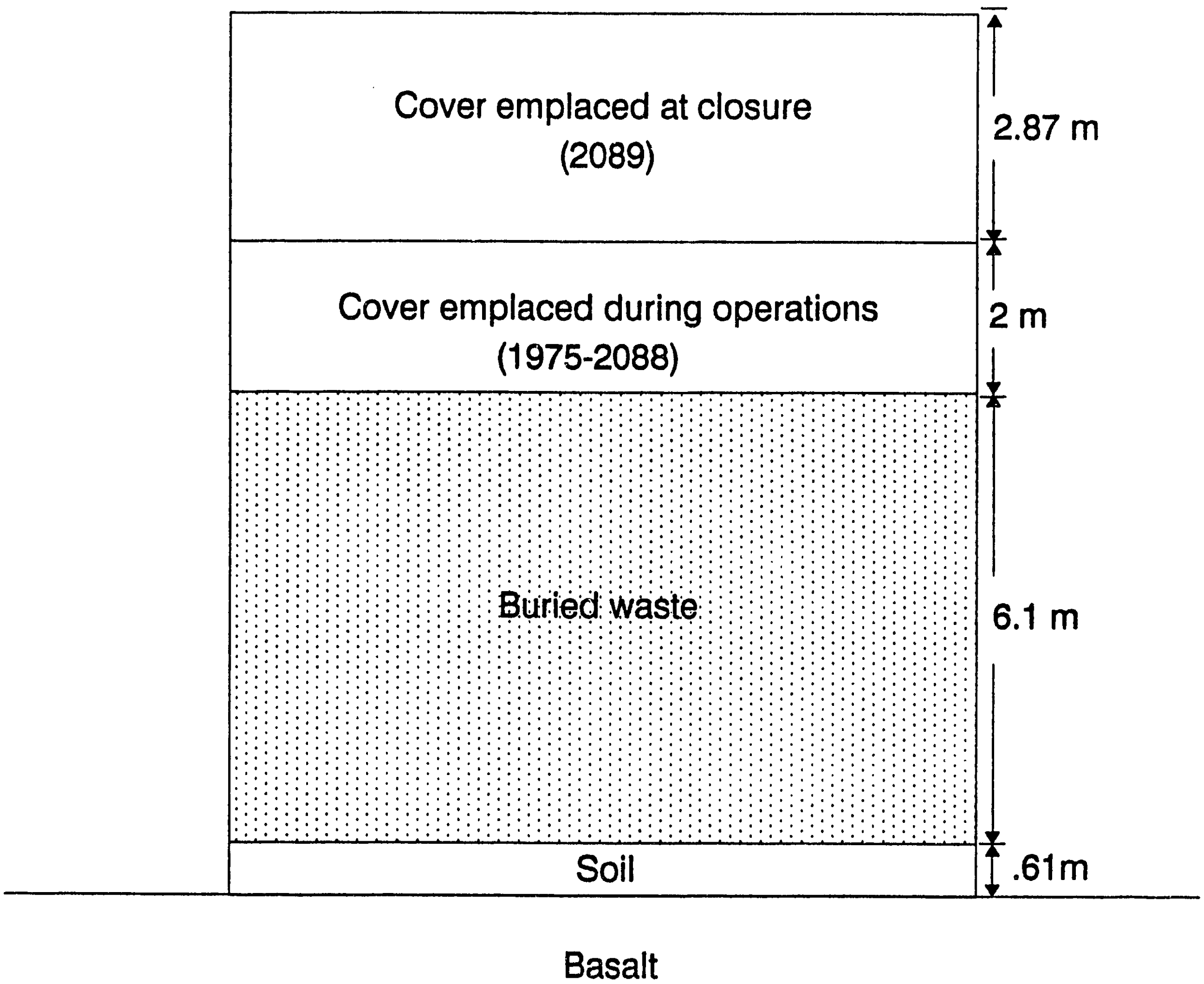


Figure A-1. Conceptual profile of new pits.

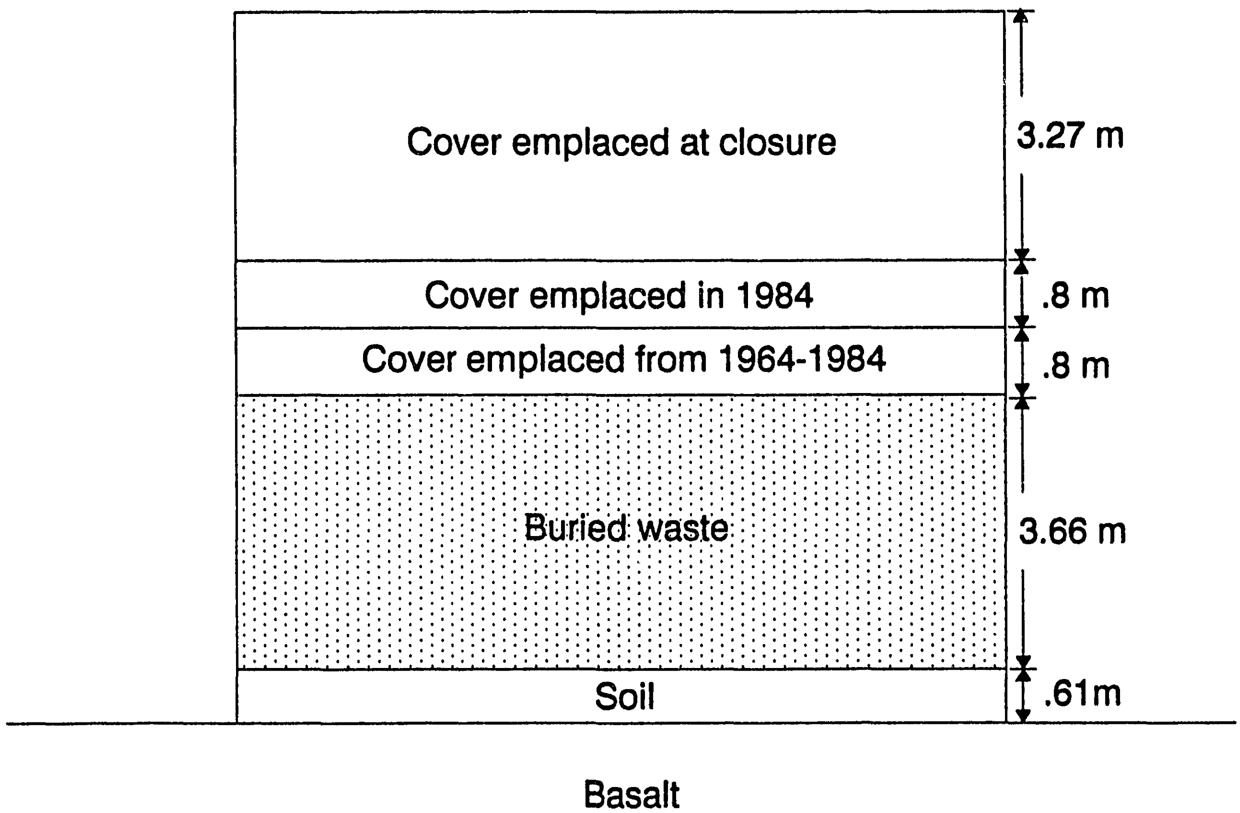


Figure A-2. Conceptual profile of old pits.

to erode to a level that is equivalent to the current surrounding elevation. The cover was estimated to erode to a final thickness of 2.4 m in the year 7069. At this point in time it was assumed that the net erosion of the cover is zero. Any loss of radionuclides was assumed to occur by resuspension of particles less than 100 μm in diameter (see Section A.2.4). The loss of soil particles was assumed to be replaced by deposition.

The conceptual model shown in Figures A-3 through A-5 represents the old pits area. The model is presented in three figures because of its complexity. Each figure corresponds to a different cover regime. The first is the original cover emplaced during operations (1964 through 1984). The second includes the cover emplaced in 1984. The third includes the final cover after erosion has decreased the depth to ambient elevation in 7069. This model addresses the cover between 2089 and 7069. It was assumed that the depth of the cover was sufficient to preclude biotic intrusion during this period. Any movement of long-lived radionuclides to the surface during this period from soils contaminated before 2089 would be minimal compared to the movement of radionuclides from buried waste compartments when biotic intrusion occurs again in 7069. In addition, the impact of short-lived radionuclides would peak well before the cover is added in 2089. Thus, it was assumed that there is no transport of radionuclides to the surface between 2089 and 7069. It should be noted that the subsurface transport of radionuclides (i.e., from waste to soil to subsurface media) was assumed to continue during the period from 2089 through 7069.

Tables A-1 and A-2 describe individual compartments and transport pathways in the old pits model. Tables A-3 and A-4 describe individual compartments and transport pathways in the new pits model. The transport pathways modeled were selected from a much larger set of potential pathways modeled previously (Shuman et al. 1985). The other pathways (e.g., small mammal ingestion and defecation) were eliminated from this model because a sensitivity analysis demonstrated them to be relatively insignificant.

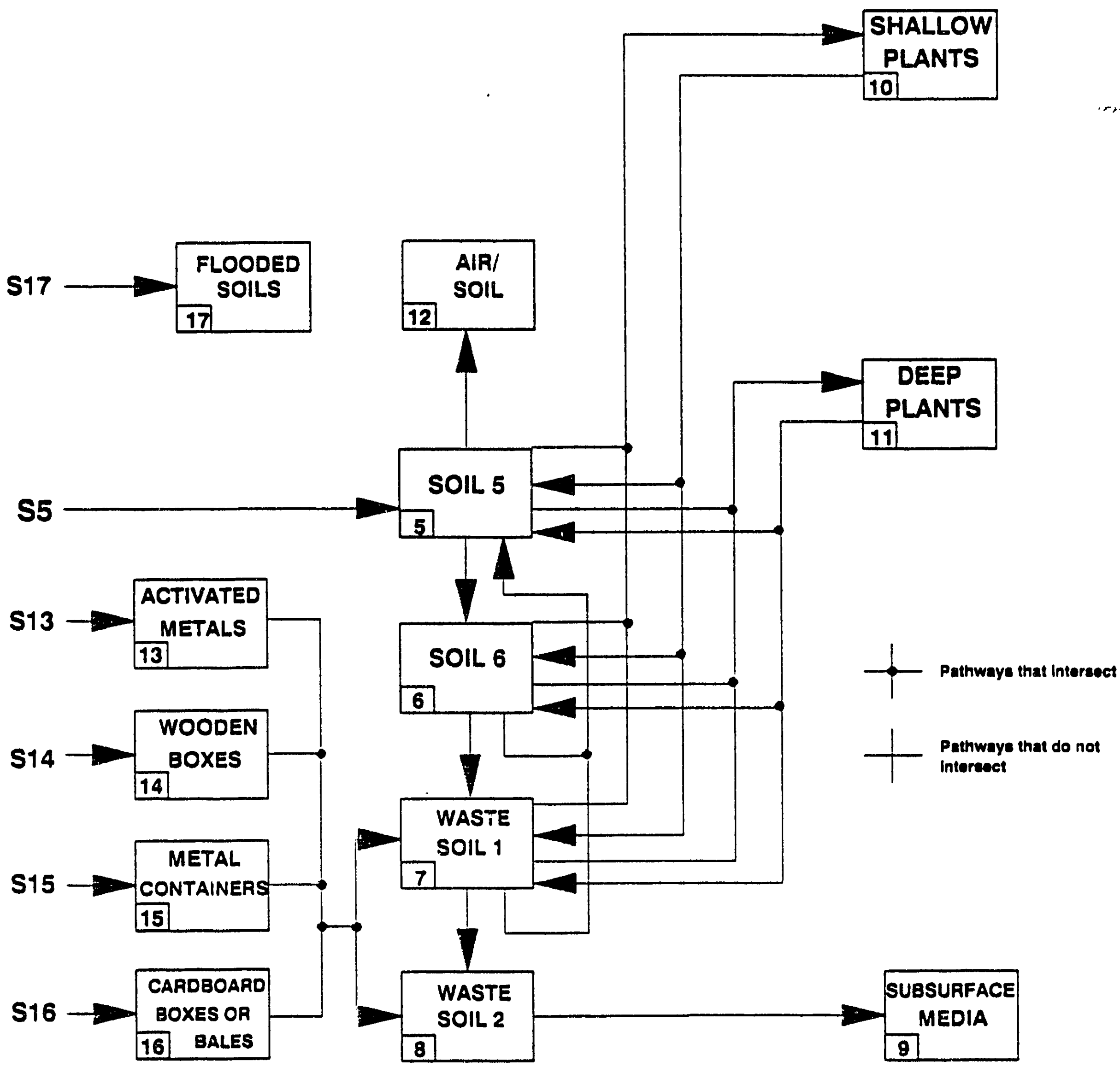


Figure A-3. Conceptual model of the transport of radionuclides in the near-field of the old pit disposal area from 1964 through 1984.

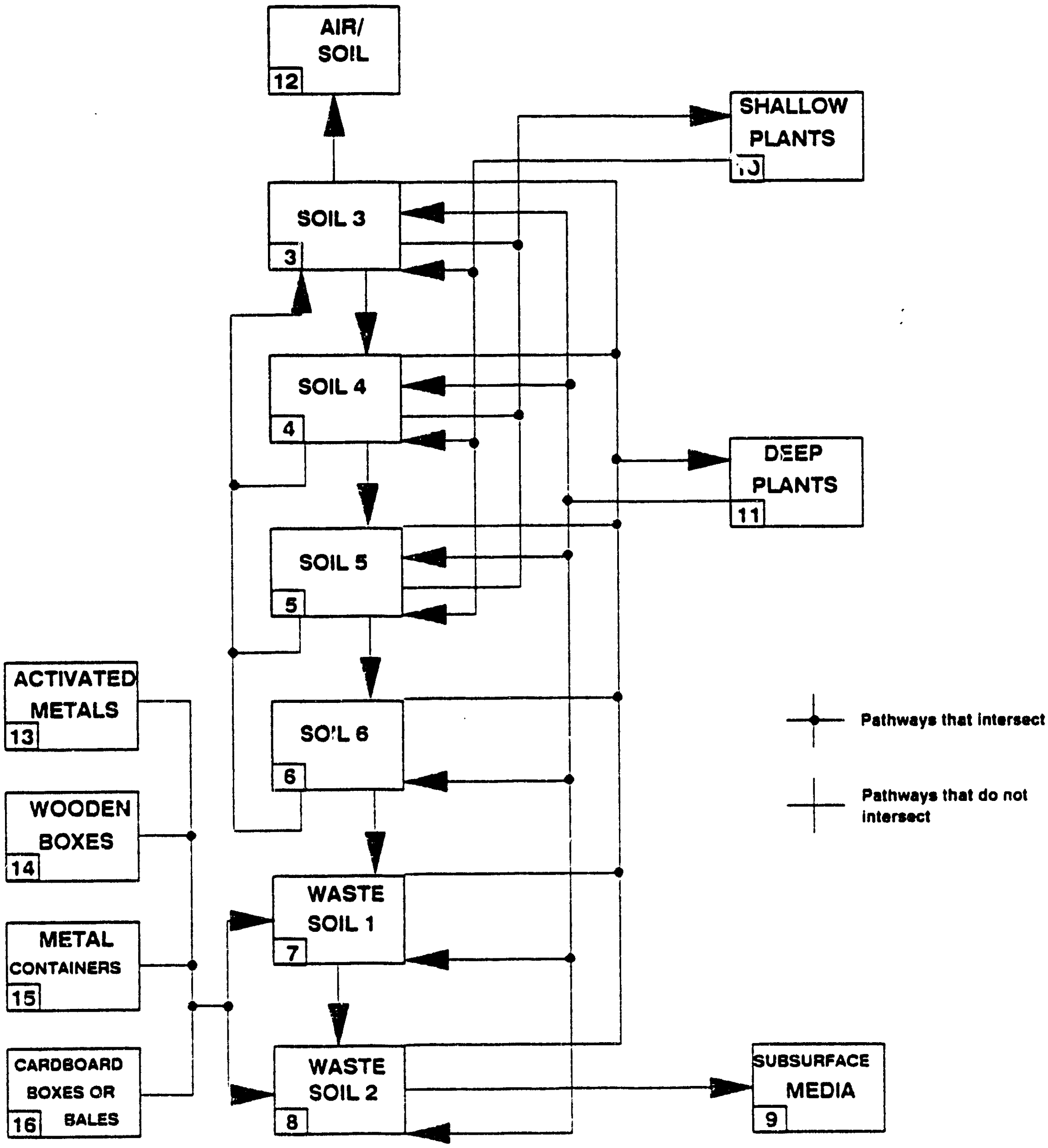


Figure A-4. Conceptual model of the transport of radionuclides in the near-field of the old pit disposal area from 1985 through 2089.

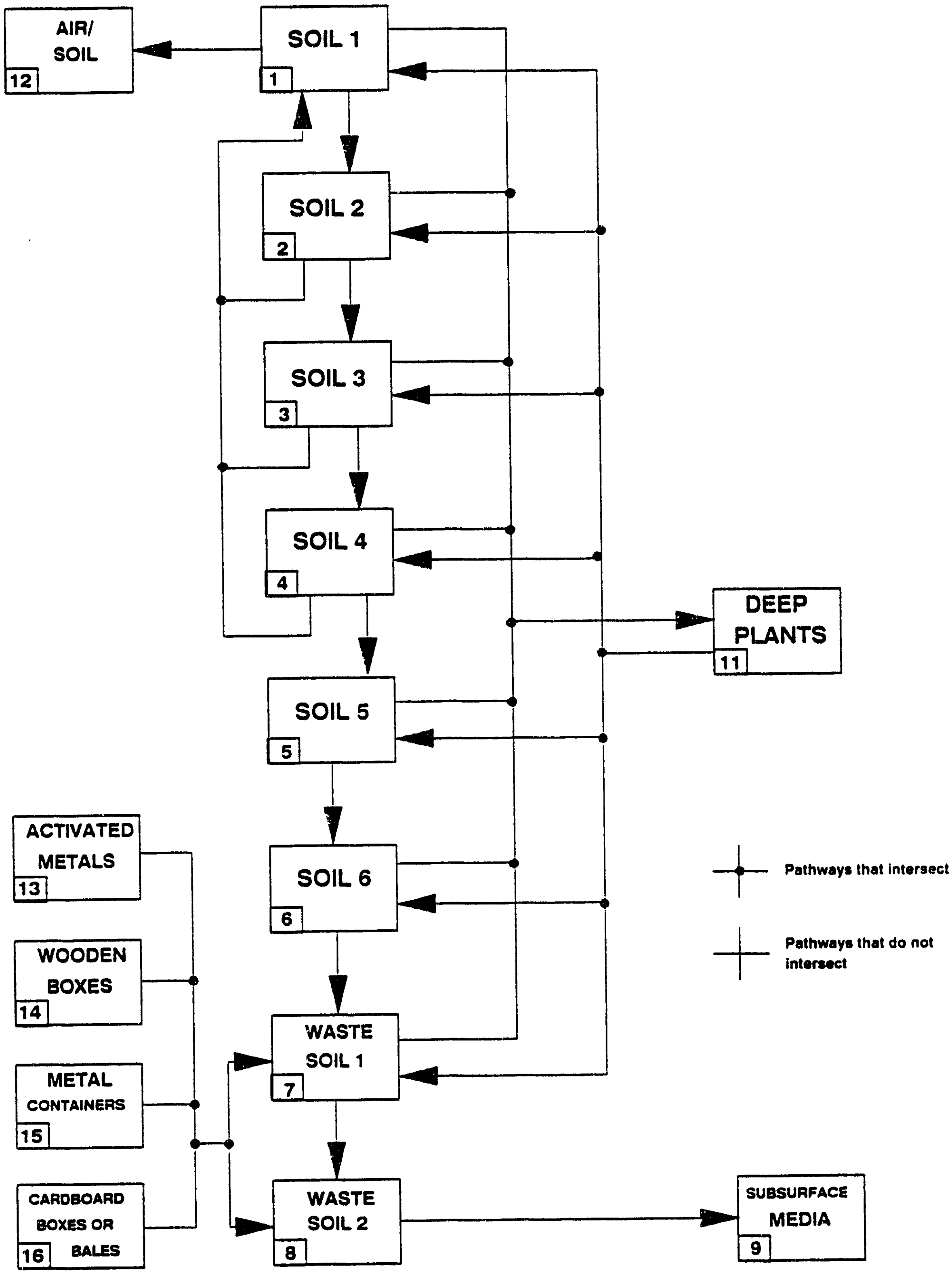


Figure A-5. Conceptual model of the transport of radionuclides in the near-field of the old pit disposal area from 7069 through 12064.

Table A-1. Definition of compartments in the old pit near-field model

Compartment Number	Compartment Name	Compartment Description
1	Surface soil	Top 40 cm of cover soil (2089-11964)
2	Upper soil	40 cm of cover soil (2089-11964)
3	Surface soil	Top 40 cm of cover soil (1985-2089)
	Upper soil	40 cm of cover soil (2089-11964)
4	Upper soil	40 cm of cover soil (1985-11964)
5	Surface soil	Top 40 cm of cover soil (1964-1984)
	Upper soil	40 cm of cover soil (1985-11964)
6	Upper soil	40 cm of cover soil (1964-2089)
7	Waste soil	183 cm of waste soil
8	Waste soil	183 cm of waste soil
9	Subsurface media	Vadose zone and aquifer beneath disposed waste
10	Shallow rooted plants	Crested Wheatgrass
11	Deep-rooted plants	Russian Thistle (1964-2089) Sagebrush (2089-11964)
12	Air/Soil	Air and offsite soil
13	Activated metals	Activated metal waste
14	Wooden boxes	LLW disposed in wooden boxes
15	Metal containers	LLW disposed in drums

Table A-1. (continued)

Compartment Number	Compartment Name	Compartment Description
16	Cardboard boxes or bales	LLW disposed in cardboard boxes or bales
17	Flooded soils	Soils outside the RWMC contaminated during spring snowmelt in 1962 and 1969.

Table A-2. Transport processes and source terms represented in old pits near-field model

Compartment Number From	To	Transport Process
1	12	Resuspension of soil
3,5	12	Erosion of soil
1,2,3,4 5,6,7,	11	Uptake of nuclides by deep-rooted plants
3,2,5,6,7	10	Uptake of nuclides by shallow-rooted plants
11	1,2,3, 4,5,6, 7	Death and decay of deep-rooted plants in soil
10	1,2,3, 4,5,6, 7	Death and decay of shallow-rooted plants in soil
2,3,4	1	Movement of soil to surface by burrowing mammals
3,4,5,6	3	Movement of soil to surface by burrowing mammals
6,7	5	Movement of soil to surface by burrowing mammals
1	2	Radionuclide transport via infiltration
2	3	Radionuclide transport via infiltration
3	4	Radionuclide transport via infiltration
4	5	Radionuclide transport via infiltration
5	6	Radionuclide transport via infiltration
6	7	Radionuclide transport via infiltration
7	8	Radionuclide transport via infiltration
8	9	Radionuclide transport via infiltration
13	7,8	Release of activation products from metal to burial soil
14	7,8	Release of radionuclides from wooden boxes to burial soil
15	7,8	Release of radionuclides from metal containers to burial soil
16	7,8	Release of radionuclides from cardboard boxes and bales to burial soil

Table A-2. (continued)

Compartment Number From	To	Source Terms
S5	5	Radionuclides deposited on RWMC surface during flooding of 1962 and 1969.
S13	13	Radionuclide inventory disposed as activated metals
S14	14	Radionuclide inventory disposed in wooden boxes
S15	15	Radionuclide inventory disposed in metal containers
S16	16	Radionuclide inventory disposed in cardboard boxes or bales
S17	17	Radionuclides deposited outside the RWMC during flooding of 1962 and 1969.

Table A-3. Definition of compartments in the new pit near-field model

Compartment Number	Compartment Name	Compartment Description
1	Surface soil	Top 40 cm of cover soil (2089-11975)
2	Surface soil	Top 40 cm of cover soil (1975-2089)
	Upper soil	40 cm of cover soil (2089-11975)
3	Upper soil	40 cm of cover soil (1985-11975)
4	Upper soil	40 cm of cover soil (1985-11975)
5	Surface soil	40 cm of cover soil (1985-11975)
6	Upper soil	40 cm of cover soil (1985-11975)
7	Waste soil	183 cm of waste soil
8	Waste soil	183 cm of waste soil
9	Subsurface media	Vadose zone and aquifer beneath disposed waste
10	Shallow rooted plants	Crested Wheatgrass (1975-2089)
11	Deep-rooted plants	Russian Thistle (1975-2089) Sagebrush (2089-11975)
12	Air/soil	Air and offsite soil
13	Activated metals	Activated metal waste
14	Wooden boxes	LLW disposed in wooden boxes
15	Metal containers	LLW disposed in drums
16	Cardboard boxes or bales	LLW disposed in cardboard boxes or bales

Table A-4. Transport processes and source terms represented in new pits near-field model

Compartment Number From	To	Transport Process
1	12	Resuspension of soil
2	12	Erosion of soil
1,2,3,4 5,6,7	11	Uptake of nuclides by deep-rooted plants
2,3,4	10	Uptake of nuclides by shallow-rooted plants
11	1,2,3, 4,5,6, 7	Death and decay of deep-rooted plants in soil
10	2,3, 4	Death and decay of shallow-rooted plants in soil
2,3,4	1	Movement of soil to surface by burrowing mammals
3,4,5,6	2	Movement of soil to surface by burrowing mammals
1	2	Radionuclide transport via infiltration
2	3	Radionuclide transport via infiltration
3	4	Radionuclide transport via infiltration
4	5	Radionuclide transport via infiltration
5	6	Radionuclide transport via infiltration
6	7	Radionuclide transport via infiltration
7	8	Radionuclide transport via infiltration
8	9	Radionuclide transport via infiltration
13	7,8	Release of activation products from metal to burial soil
14	7,8	Release of radionuclides from wooden boxes to burial soil
15	7,8	Release of radionuclides from metal containers to burial soil
16	7,8	Release of radionuclides from cardboard boxes and bales to burial soil

Table A-4. (continued)

Compartment Number From	To	Source Terms
S13	13	Radionuclide inventory disposed as activated metals
S14	14	Radionuclide inventory disposed in wooden boxes
S15	15	Radionuclide inventory disposed in metal containers
S16	16	Radionuclide inventory disposed in cardboard boxes or bales

Figure A-6 presents the new pit model. As described above, the final cover was assumed after erosion to be 2.4-m deep. This model also suppresses subsurface to surface transport during the period from 2089 to 7069, when biotic intrusion is precluded.

A.2.2 Mathematical Model

The information supplied below about the DOSTOMAN computer code is adapted from Root (1981). Additions to and refinements of the model, in adapting it for use at the INEL, have been included.

Based upon a conceptual model, appropriate data are input into DOSTOMAN, which calculates the transfer of radionuclides between model compartments. The general equation governing radionuclide movement accounts for the four factors determining the radionuclide inventory in a given compartment:

1. Transfer in from other compartments
2. Transfer out to other compartments
3. Source or sink terms
4. Radioactive decay.

These factors are incorporated into the following linear differential equation:

$$\frac{dQ_m}{dt} = \sum_{m=1}^{N} \lambda_{n,m} Q_n - \sum_{m=1}^{N} \lambda_{m,n} Q_m - \lambda_R Q_m \pm S_m \qquad \text{(A-1)}$$

where

Q_m = the quantity of radionuclide in compartment m (Ci)

Q_n = the quantity of radionuclide in compartment n (Ci)

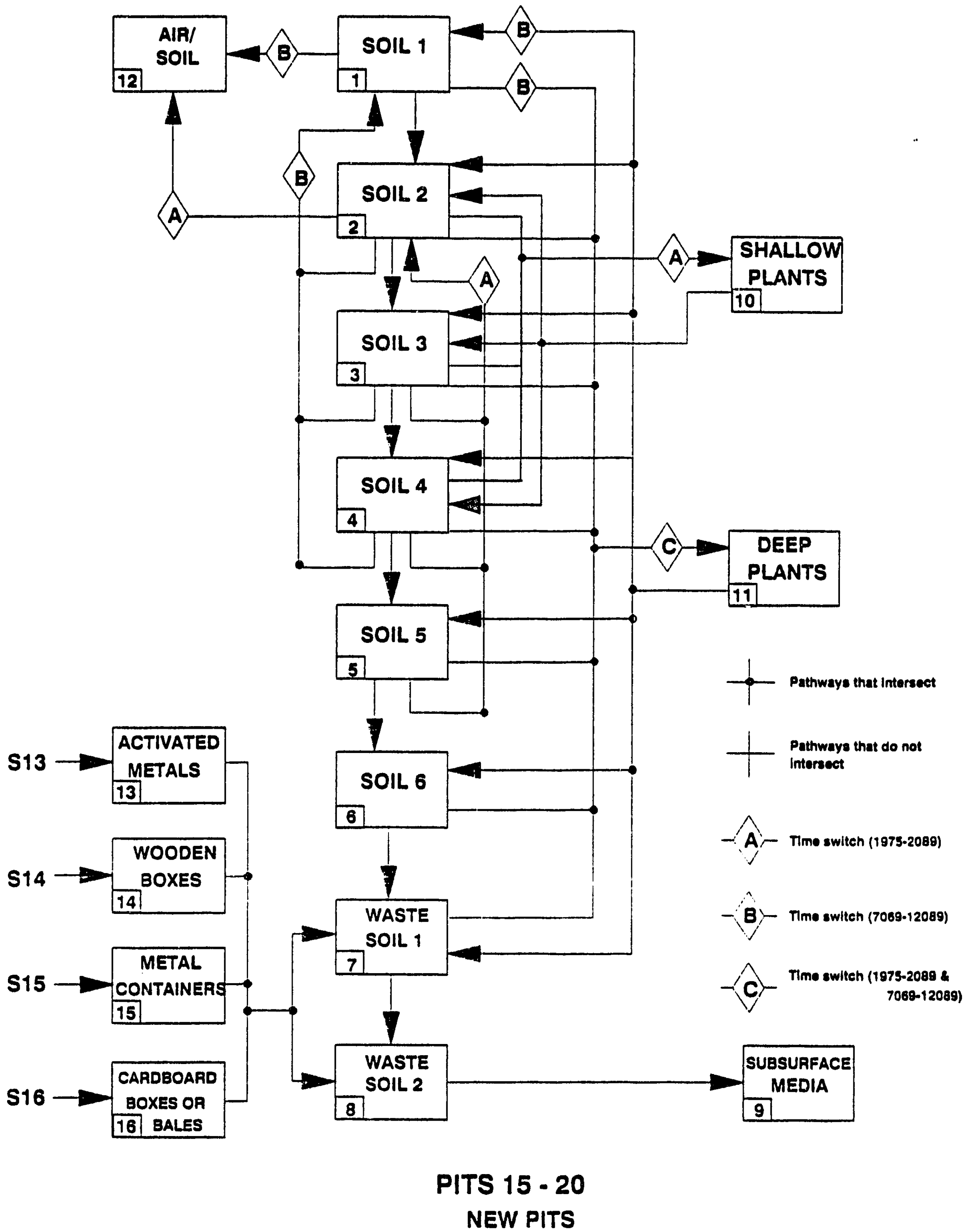


Figure A-6. Conceptual model of the transport of radionuclides in the near-field of the new pit disposal area.

$\lambda_{n,m}$ = the rate constant for the transport of radionuclides from compartment n to compartment m (yr^{-1})

$\lambda_{m,n}$ = the rate constant for the transport of radionuclides from compartment m to compartment n (yr^{-1})

λ_R = the decay constant for the radionuclide (yr^{-1})

S_m = a source or sink term in compartment m (Ci/yr)

N = the total number of compartments under consideration.

The first term to the right of the equal sign in the equation is the sum of all input rates to compartment n. The second and third terms are the sum of all loss rates from compartment n, while the fourth term is the gain or loss in compartment n because of sources or sinks.

The model is a series of simultaneous, linear differential equations that define the radionuclide inventory in compartment m with time, as a function of rate constants ($\lambda_{m,n}$ and λ_R); sources and sinks (S_n); the initial radionuclide inventory (Q°); and the time increment (Δt). This series of equations can be expressed in matrix terms as

$$A \bullet X = B \quad \text{(A-2)}$$

The solution to this equation is $X = A^{-1}B$ and is accomplished by Gauss-Jordan elimination (e.g., Burden et al. 1978). The result is the value for Q_m at time t for each compartment m. This value is the radionuclide inventory averaged for the entire compartment m. The methodology and input parameters employed in calculating the rate constants ($\lambda_{n,m}$) are discussed in the following sections.

A.2.3 Erosion of Cover

Erosion of surface soil can occur via wind and surface water runoff. Soil erosion caused by wind was evaluated using methodology described in

Isrealsen et al. (1980). The equation used was developed for determining wind erosion on highway construction sites. This is appropriate for the RWMC during active operations, but probably overestimates soil loss following closure. The formula is

$$E' = I' \bullet C' \bullet K' \bullet V' \bullet L' \quad \text{(A-3)}$$

where

E′ = soil loss by wind in tons/acre/yr (assumes an active layer of 8 cm)

I′ = soil wind erodibility factor

C′ = local wind erosion climatic factor

K′ = soil surface roughness factor

V′ = vegetative factor

L′ = length of the unshielded distance parallel to wind in the direction of the wind fetch.

The soil wind erodibility factor (I′) is the potential soil loss in ton/acre/yr from a wide unsheltered, isolated, bare and smooth crusted or noncrusted soil expanse. The I′ value is determined by dry-sieving a soil sample through a 20-mesh screen and comparing the percentage of particles larger than 20-mesh from Table A-5. No data are currently available on the mechanical composition of RWMC soils. Data on soils collected from the BORAX area (Chapin 1980), which is close to the RWMC, were thus used (see Table A-6 and Figure A-7). From Figure A-7, the percent of soil not passing through a 20-mesh screen is approximately 1%. The I′ value corresponding to this percentage is 310 ton/acre for noncrusted soil surfaces and 51.7 ton/acre for crusted soil surfaces. It was assumed, based on visual observations of the RWMC, that 75% of RWMC surface soils are crusted. Thus the weighted I′ value was calculated as follows:

Table A-5. Soil wind erodibility index I′[a]

Percent of Dry Soil Not Passing a 20 Mesh Screen	0	1%	2%	3%	4%	5%	6%	7%	8%	9%
(Units)	Non-crusted Soil Surface (tons/acre)									
0	-	310	250	220	195	180	170	160	150	140
10	134	131	128	125	121	117	113	109	106	102
20	98	95	92	90	88	86	83	81	79	76
30	74	72	71	69	67	65	63	62	60	58
40	56	54	52	51	50	48	47	45	43	41
50	38	36	33	31	29	27	25	24	23	22
60	21	20	19	18	17	16	16	15	14	13
70	12	11	10	8	7	6	4	3	3	2
80	2	-	-	-	-	-	-	-	-	-
	Fully Crusted Soil Surface (tons/acre)									
0	-	51.7	41.7	36.7	32.5	30.0	28.3	26.7	25.0	23.3
10	22.3	21.8	21.3	20.8	20.2	19.5	18.8	18.2	17.7	17.0
20	16.3	15.8	15.3	15.0	14.7	14.3	13.8	13.5	13.2	12.7
30	12.3	12.0	11.8	11.5	11.2	10.8	10.5	10.3	10.0	9.7
40	9.3	9.0	8.7	8.5	8.3	8.0	7.8	7.5	7.2	6.8
50	6.3	6.0	5.5	5.2	4.8	4.5	4.2	4.0	3.8	3.7
60	3.5	3.3	3.2	3.0	2.8	2.7	2.7	2.5	2.3	2.2
70	2.0	1.8	1.7	1.3	1.2	1.0	0.7	0.5	0.5	0.3
80	0.3	-	-	-	-	-	-	-	-	-

a. Isrealsen et al. (1980).

Table A-6. Mechanical composition of INEL soils[a]

Sample Number	Location	Depth Below Land Surface (m)	Typical Area
24	SW 1/4 SE 1/4 NE 1/4 Sec. 18, T2N, R29E	4.27 to 4.42	BORAX
25	NW 1/4 SW 1/4 Sec. 19, T3N, R30E	1.77 to 2.13	CPP, TRA
27	NW 1/4 SW 1/4 Sec. 19, T3N, R30E	1.16 to 1.58	CPP, TRA
31	SW 1/4 NE 1/4 Sec. 8, T3N, R30E	0.3 to 0.46	CPP, TRA
40	SW 1/4 SW 1/4 SE 1/4 Sec. 35, T2N, R31E	0.09 to 0.21	ARA
44	NE 1/4 NE 1/4 NE 1/4 Sec. 8, T3N, R30E	0.3 to 0.61	CPP, TRA

a. Chapin (1980).

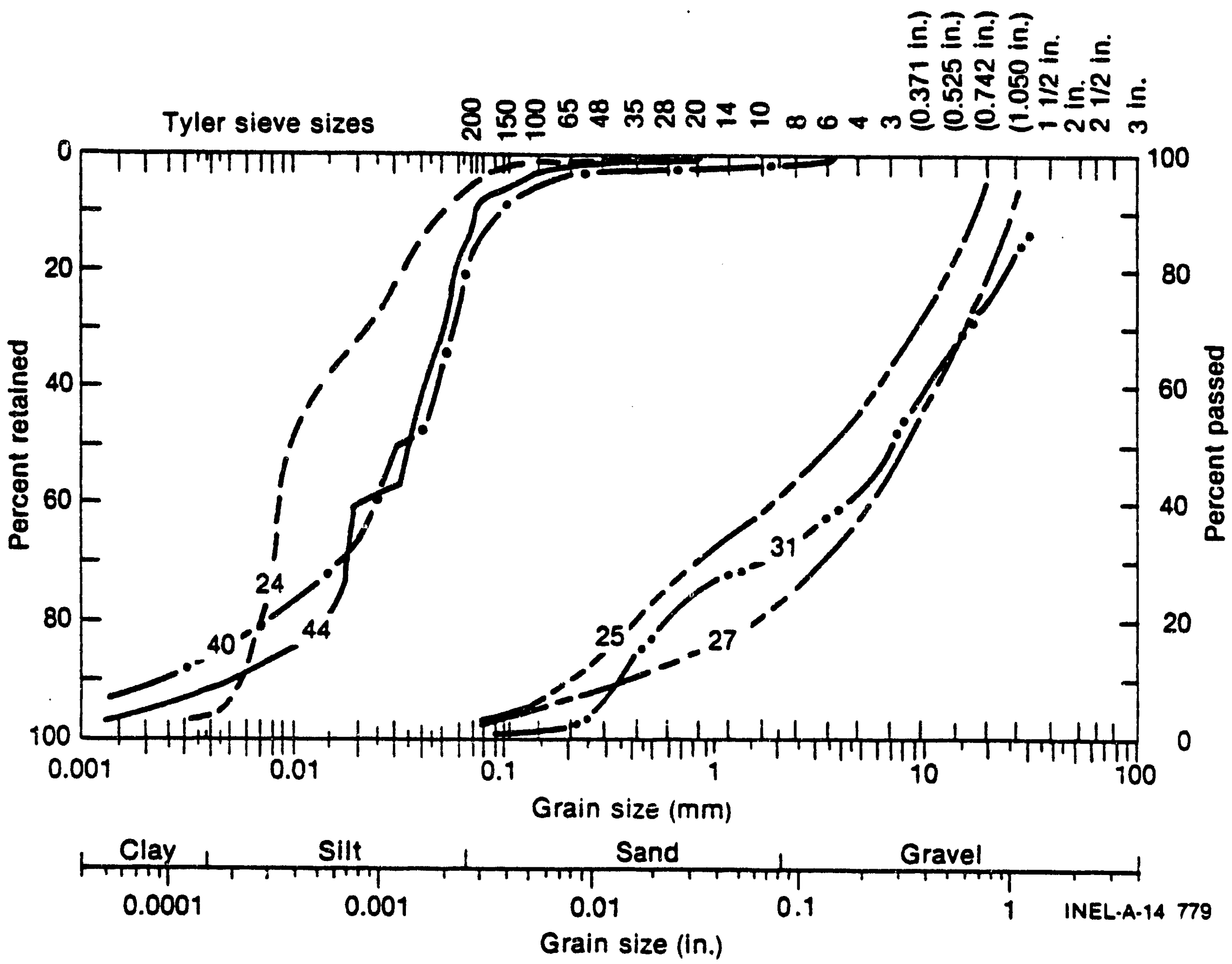


Figure A-7. Mechanical composition of INEL soils (Chapin 1980).

$$I' = (0.25 \cdot 310 + 0.75 \cdot 51.7) \text{ ton/acre} = 116.28 \text{ ton/acre} \qquad \text{(A-4)}$$

The monthly isovalues of the local wind erosion climatic factor C′ are given on maps presented in Figures A-8 through A-13. From these figures, C′ was determined for each month. The values are tabulated below:

January	= 200	July	= 225
February	= 200	August	= 80
March	= 300	September	= 200
April	= 250	October	= 125
May	= 250	November	= 30
June	= 90	December	= 200

Assuming that the RWMC surface soil is not exposed to winds during the winter months, the annual C′ value was determined by summing the monthly C′ values for the months of April through October. The sum is 1220 or 12.2%.

The soil roughness factor (K′) is a measure of the natural or artificial roughness of the soil surface in the form of ridges or small undulations. The soil at the RWMC tends to clump as it dries, forming a fairly rough surface. It was assumed, based on observation of the RWMC, that the height of the roughness elements is approximately 3 cm. From Figure A-14, a value of around 0.5 was selected for K′.

The vegetative factor (V′) represents equivalent pounds of vegetative matter as a roughness element. It is obtained, using the weight of organic material in soil, from Figure A-15. The weight of organic material, in thousands of pounds per acre, is calculated by multiplying the fraction of organic material in soil by 1 E+6. No data are currently available on the fraction of organic material in RWMC surface soils. The soils of the Snake River Plain are classified as Aridisols. The RWMC is located in an area classified as frigid Aridisol. The percent organic carbon content of a similar frigid soil, an Aridic Argiboroll from Blaine

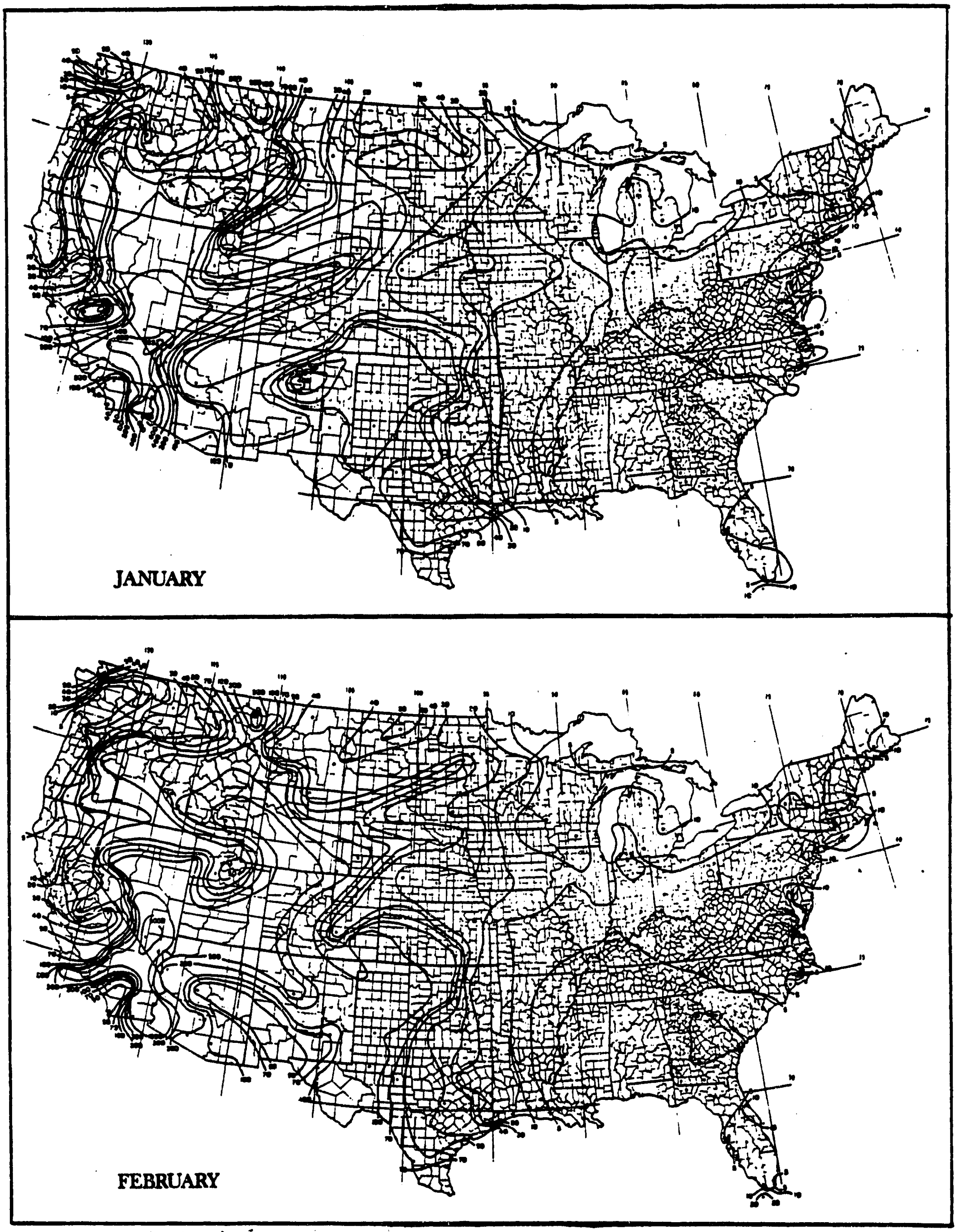


Figure A-8. Wind erosion C′ factor isomaps for the United States (January and February) (Isrealsen et al. 1980).

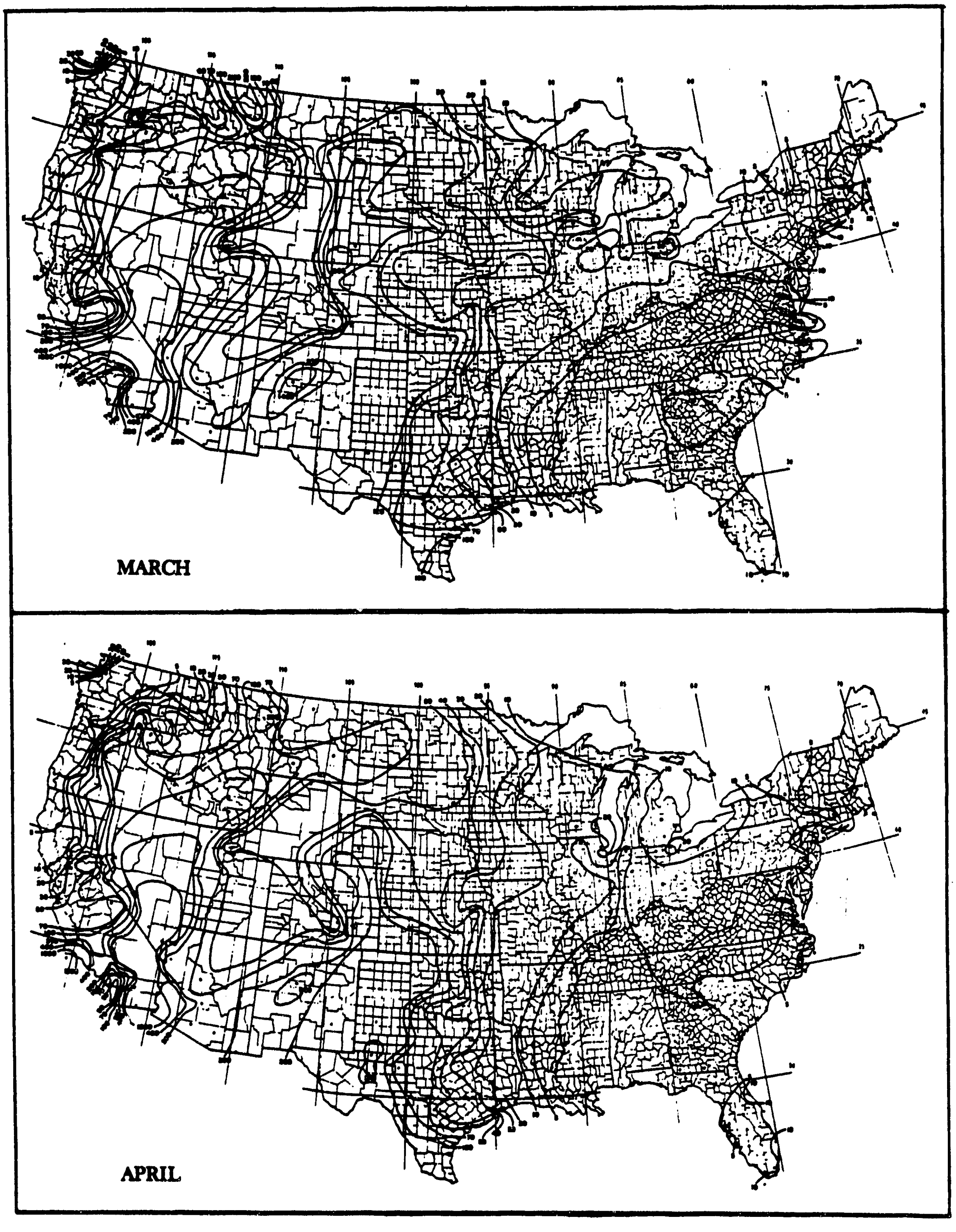


Figure A-9. Wind erosion C′ factor isomaps for the United States (March and April) (Isrealsen et al. 1980).

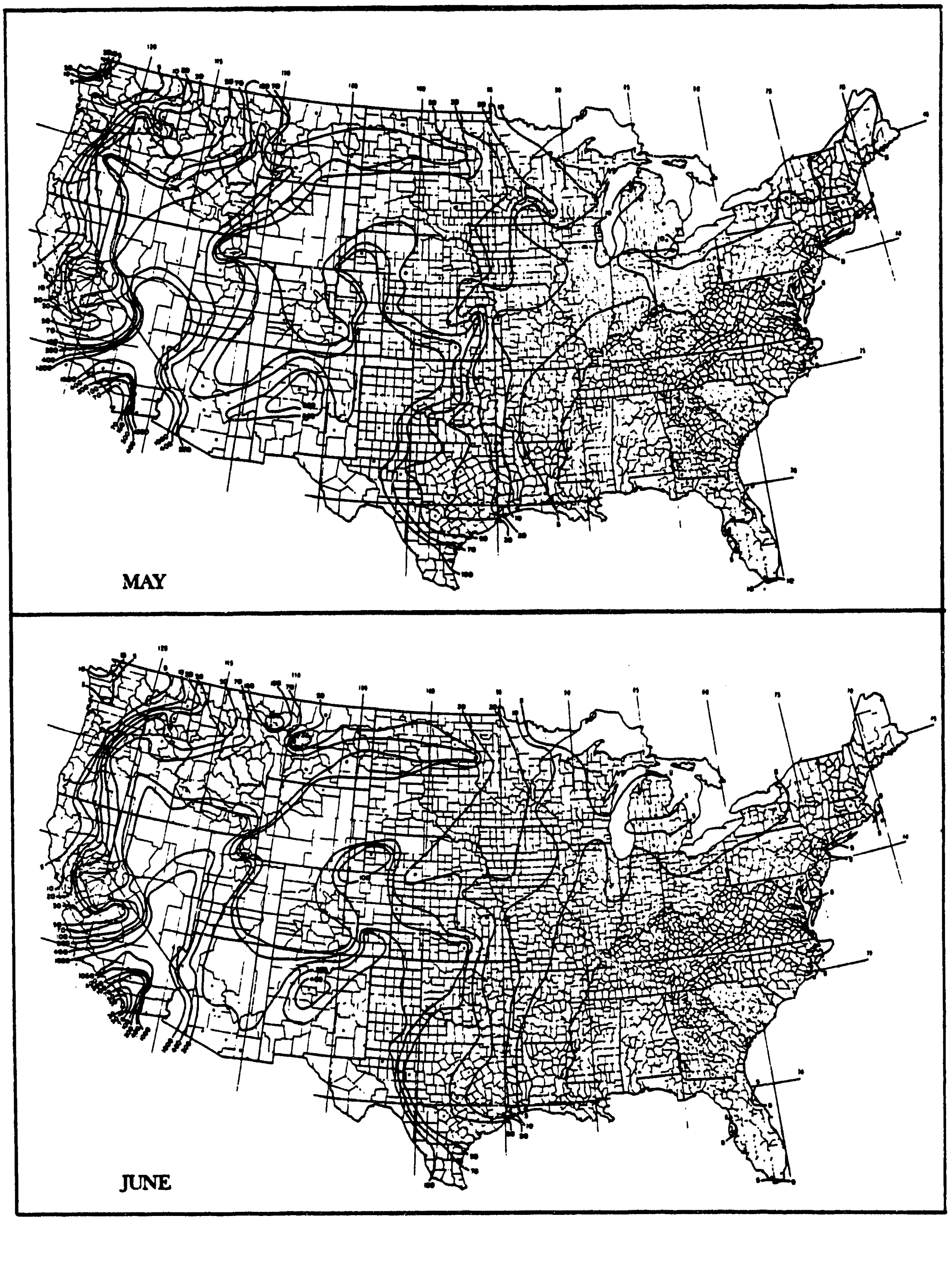


Figure A-10. Wind erosion C′ factor isomaps for the United States (May and June) (Isrealsen et al. 1980).

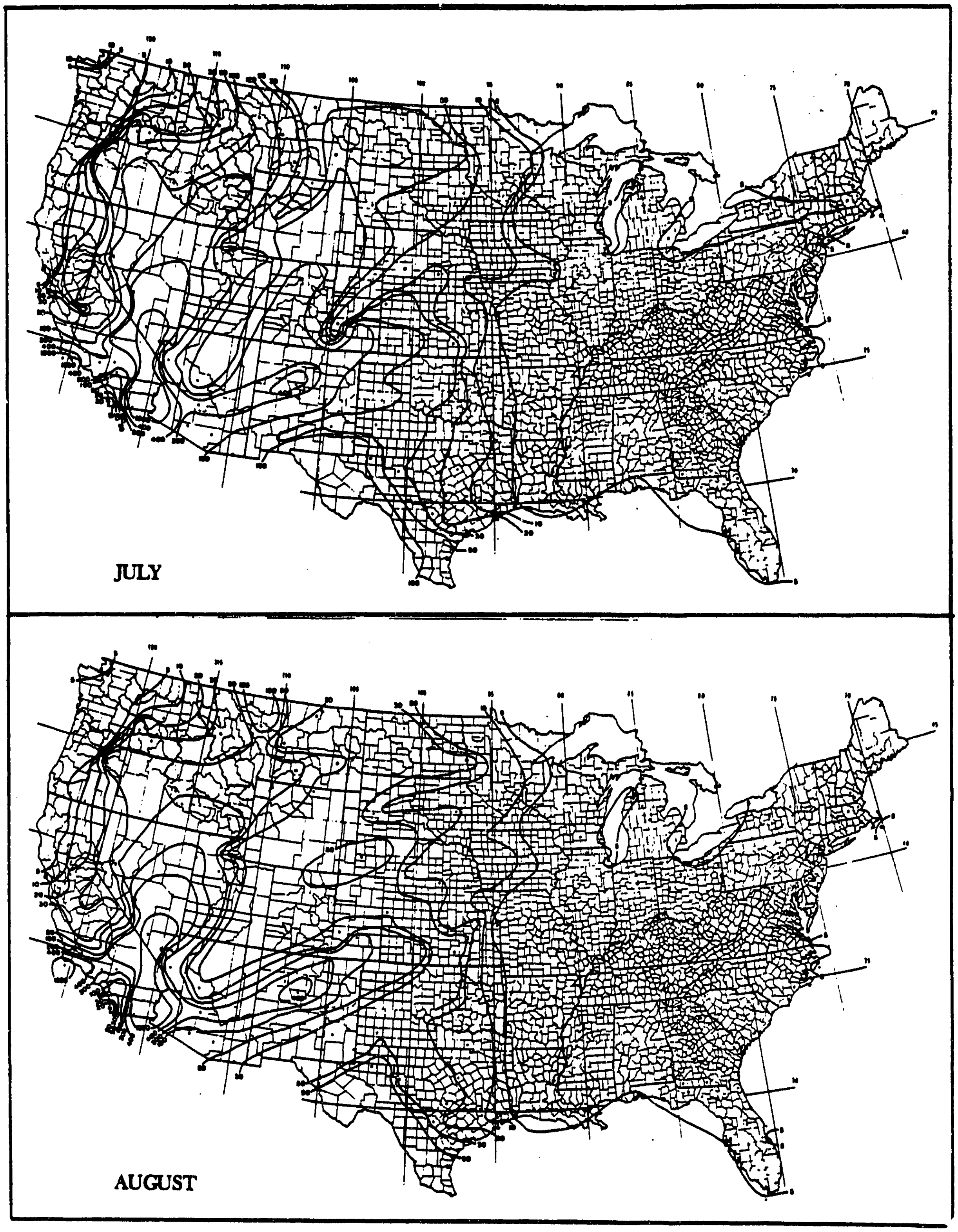


Figure A-11. Wind erosion C′ factor isomaps for the United States (July and August) (Isrealsen et al. 1980).

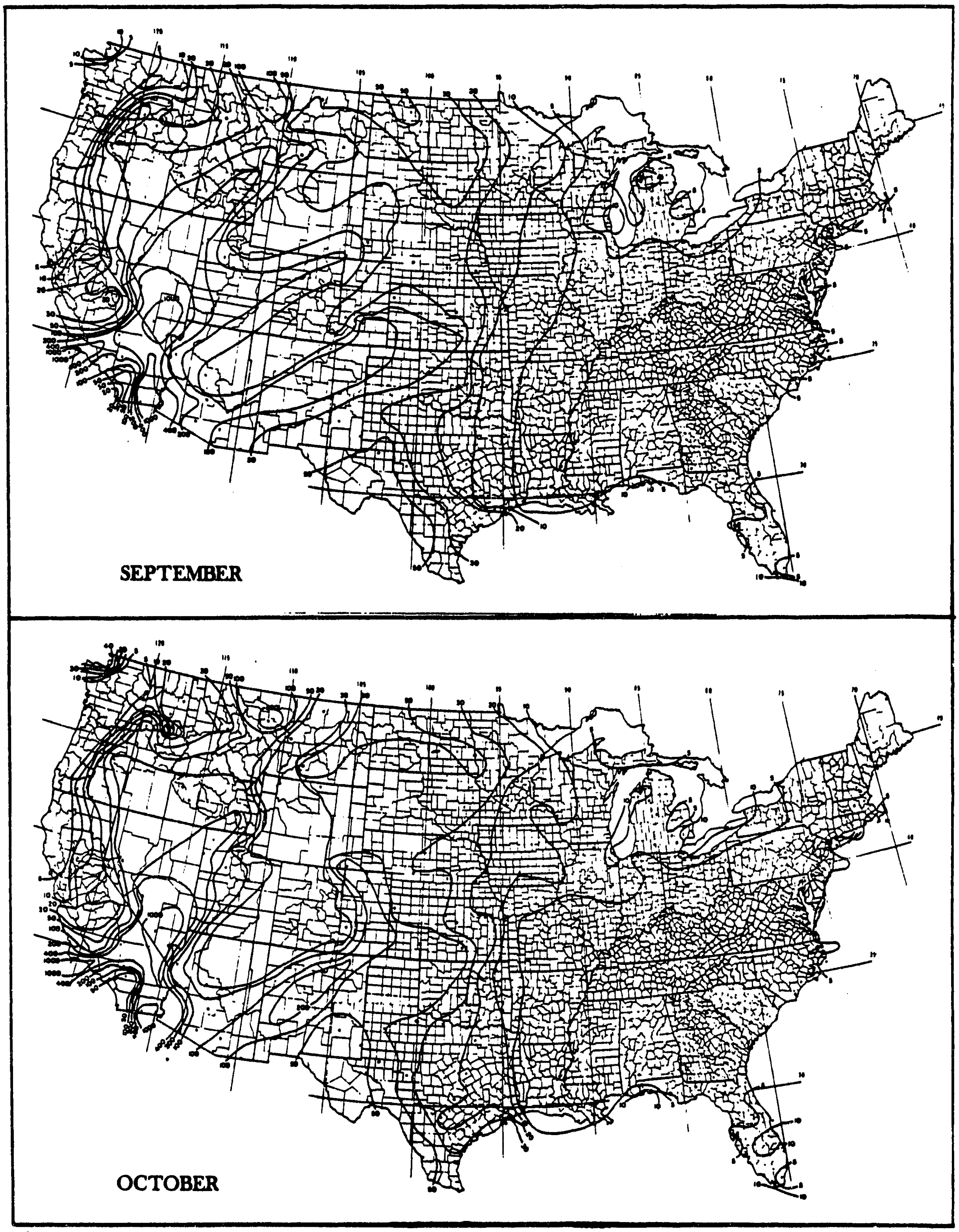


Figure A-12. Wind erosion C′ factor isomaps for the United States (September and October) (Isrealsen et al. 1980).

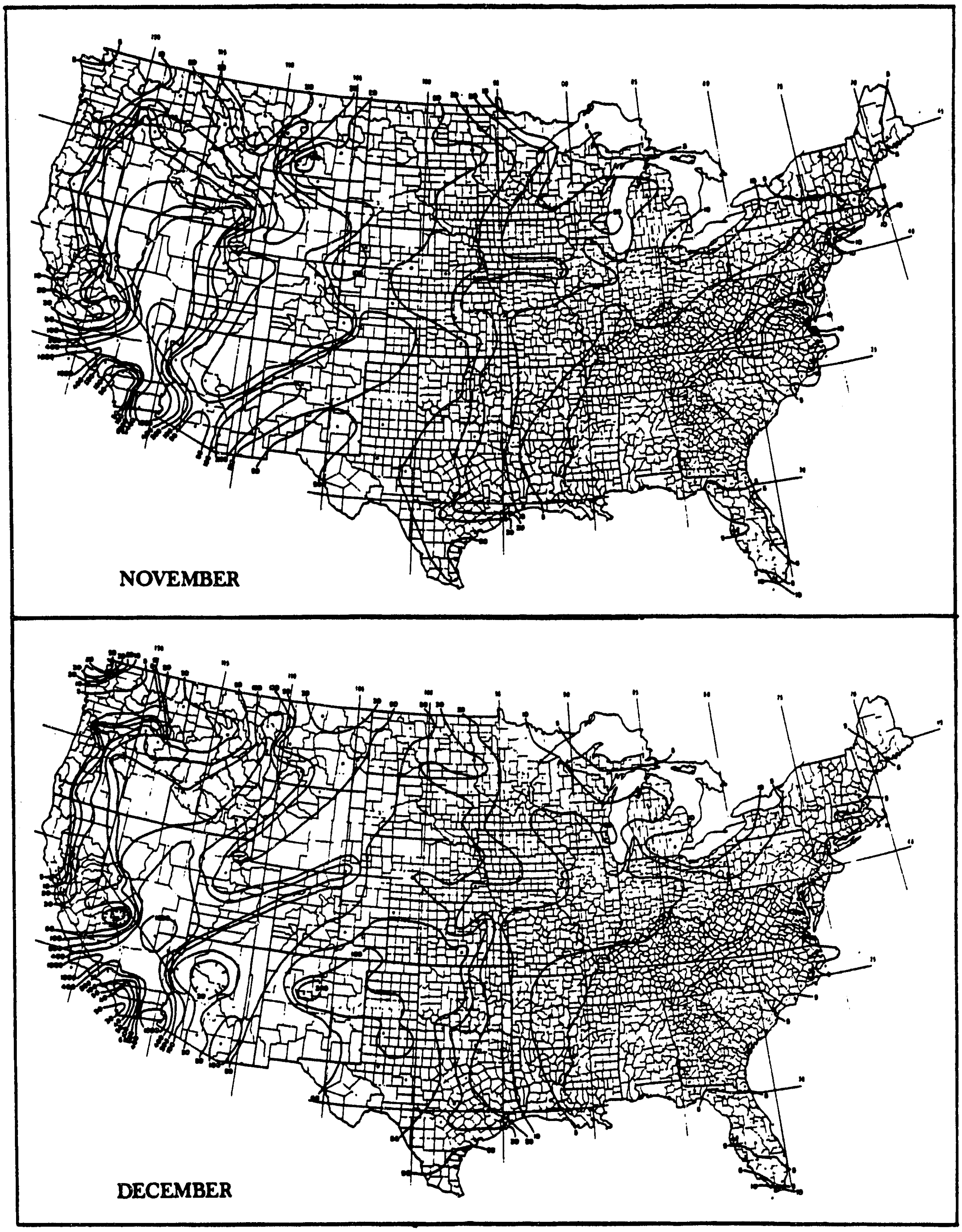


Figure A-13. Wind erosion C′ factor isomaps for the United States (November and December) (Isrealsen et al. 1980).

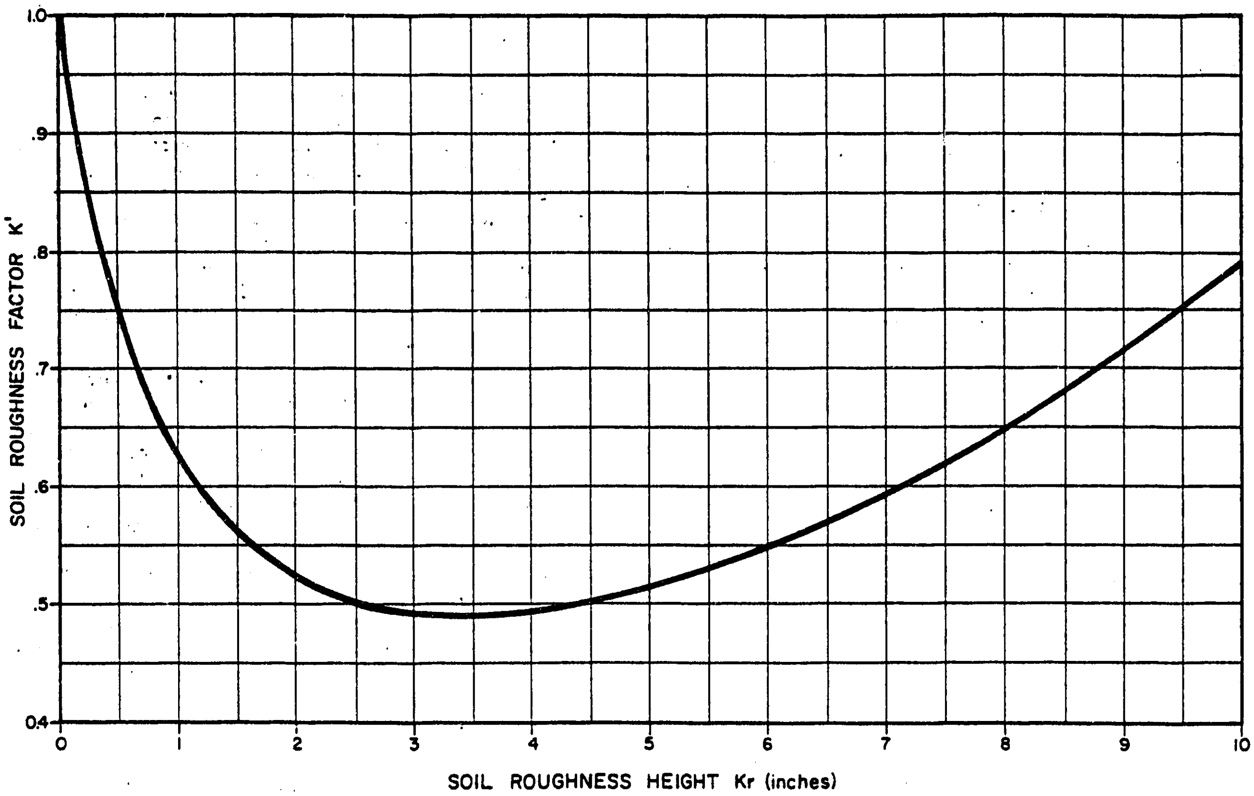


Figure A-14. Wind soil roughness factor K′ versus soil roughness height Kr (Isrealsen et al. 1980).

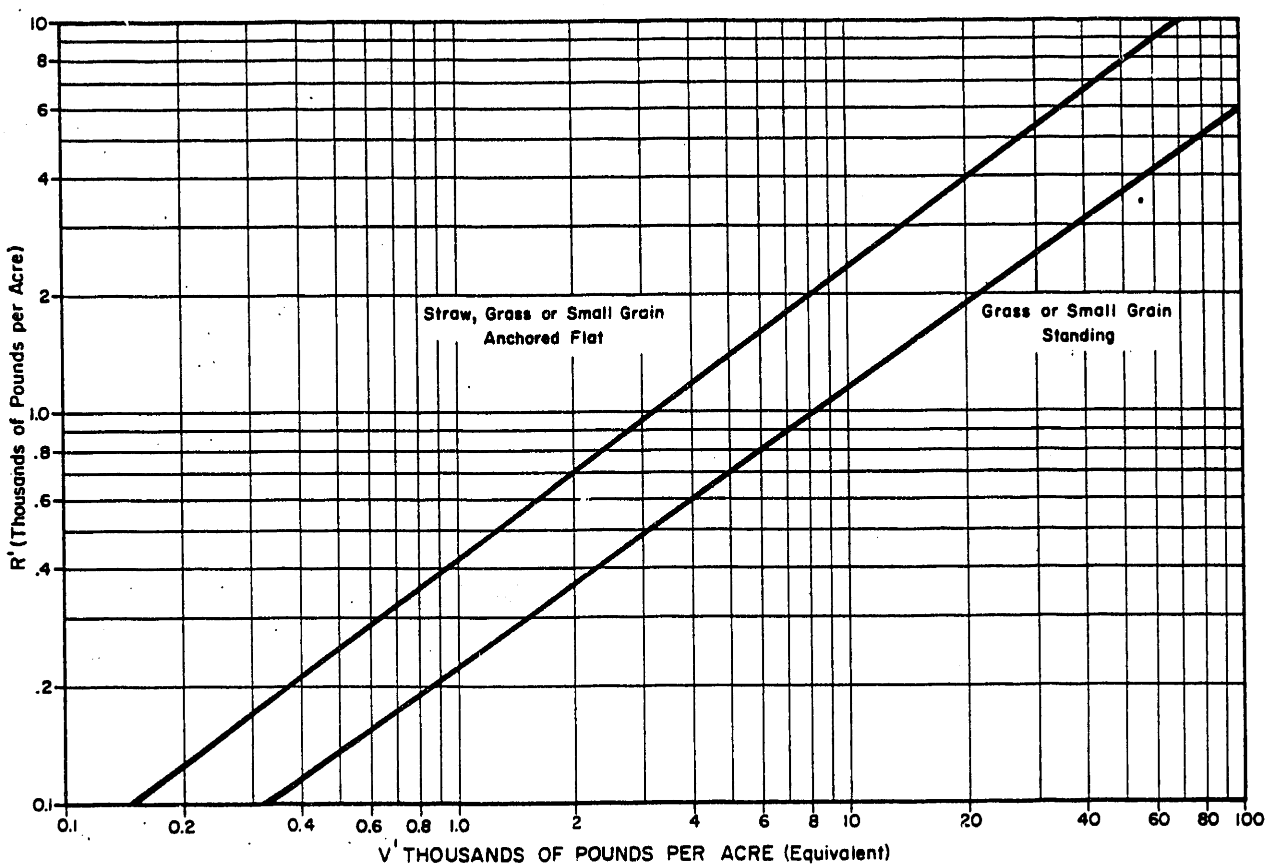


Figure A-15. Vegetative factor V′ versus R′ (Isrealsen et al. 1980).

County, Montana, is shown in Table A-7 (USDA 1975). Page et al. (1982) states that the percent of organic carbon is typically multiplied by a factor of 1.9 for surface soil and by 2.5 for subsoils to obtain the percent of organic matter. The estimated organic matter values (R′) are also shown in Table A-7 (the organic matter fractions are multiplied by 10^6 to yield R′). Using Figure A-15 and these values, V′ could range anywhere from approximately 48,000 to over 100,000 lb/acre. If one looks at the nomograph (Figure A-16) used for the solution of the soil loss equation, any value of V′ greater than 18,000 lb/acre is out of the range of the nomograph and requires extrapolation. For the sake of simplicity, and to be conservative, a V′ of 18,000 lb/acre was selected. Because the RWMC is covered with lake bed soil from the spreading areas (Figure 2-12), the low organic matter of the subsoil horizons may be appropriate.

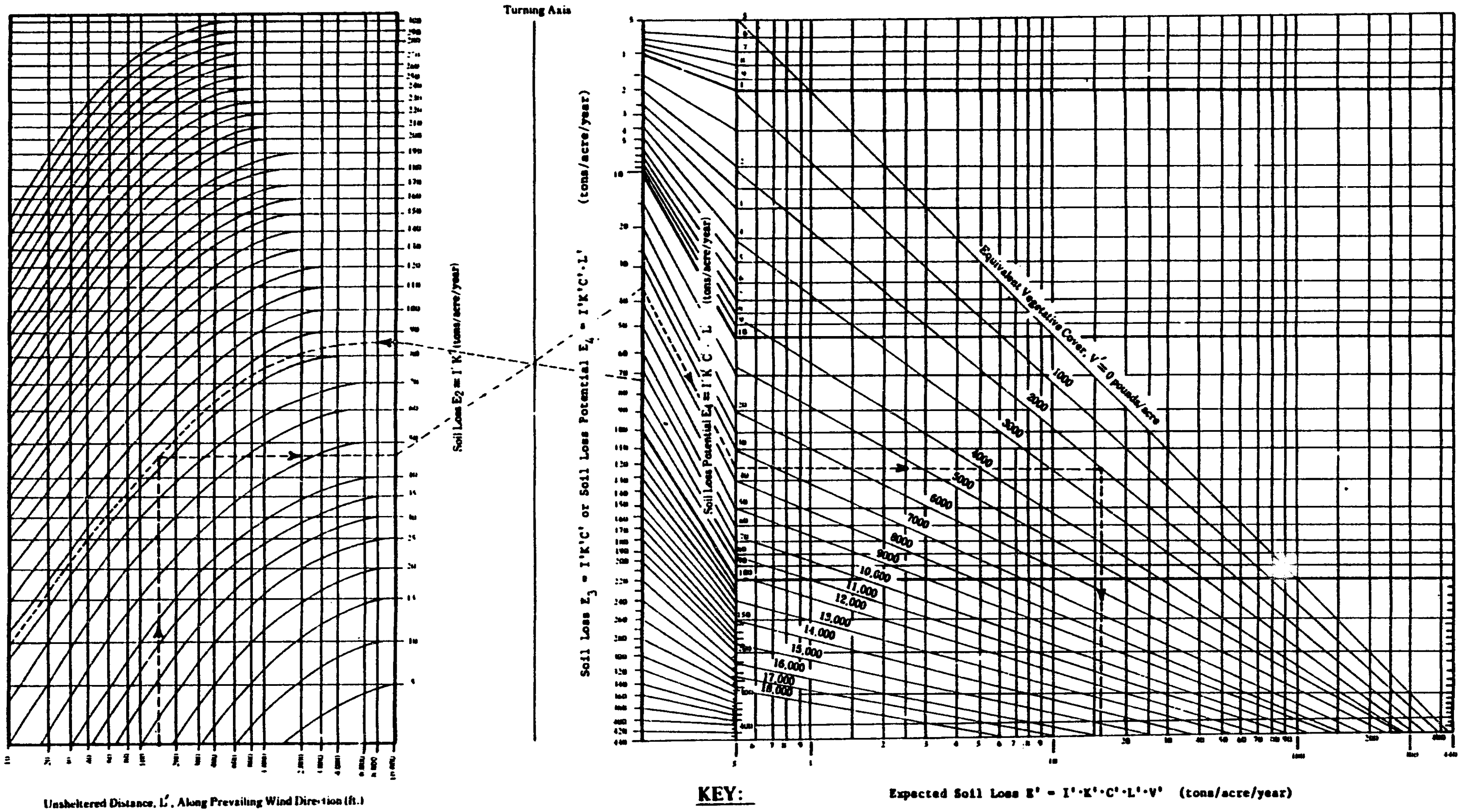
To estimate the length parallel to the preponderant wind direction (L′), it was assumed that the area of assessment is a square. The areas of the old burial ground (8.64 E+4 m^2) and the new pits (3.13 E+4 m^2) were summed (1.18 E+5 m^2). The length of one side of a square of this area is 3.43 E+2 m.

The nomographic chart for solution of the wind soil loss equation is shown in Figure A-16. Because the value of I′K′C′ (709 ton/acre) is well off the scale on the nomograph, the problem was divided into two parts. The erosion rate from April through June and from July through October were calculated separately. From the nomograph, the erosion rate during April through June is 1 ton/acre. The erosion rate during July through October is 2 ton/acre. The total erosion rate is 3 ton/acre/yr (672.27 $g/m^2/yr$). This compares well with the resuspension rate calculated in Section A.2.4. If one used an active soil layer of 8 cm, which is assumed for the soil erosion formula, the resuspension rate of 1.09 E-10 s^{-1} is equivalent to an erosion rate of 1.76 ton/acre/yr. Because resuspension affects particles <100μ, one would expect the resuspension rate to be less than the erosion rate.

Table A-7. Representative Aridisol soil series and percent organic carbon content[a]

Horizon	Depth (cm)	% Organic carbon	% Organic material	R′
A1	0-5	2.06	3.92[b]	39,200
B1	5-13	1.29	2.45[b]	24,500
B21t	13-23	0.97	2.43[c]	24,300
B22t	23-33	0.74	1.85[c]	18,500
B23t	33-48	0.76	1.90[c]	19,000
B3ca	48-64	0.67	1.68[c]	16,800
C1ca	64-95	0.50	1.25[c]	12,500
C2ca	95-135	0.35	0.88[c]	8,800
C3	135-165	0.31	0.78[c]	7,800

a. USDA (1975).
b. Calculated by multiplying the percent of organic carbon by a factor of 1.9.
c. Calculated by multiplying the percent of organic carbon by a factor of 2.5.



KEY:

Step 1. Locate I'K' value on vertical scale to the left of turning axis and construct curved dotted line as indicated.

Step 2. Move vertically upward from L' value to intercept curved line (Step 1) then horizontally to E_2 scale.

Step 3. Mark I'K'C' value on vertical scale to the right of turning axis.

Step 4. Draw line from I'K' value (Step 1) to I'K'C' value (Step 3) and mark intercept on turning axis.

Step 5. Draw line from value on E_2 scale (Step 2) through point on turning axis (Step 4) to E_4 scale, then diagonally to second E_4 scale, horizontally to intercept with appropriate V' value, and then vertically downward to read expected soil loss on E' scale.

Figure A-16. Nomographic chart for the solution of wind soil loss equation (Isrealsen et al. 1980).

The loss of soil because of entrained particles in surface water runoff was estimated using results obtained from surface runoff samples collected at the SDA pump. The water pumped from the SDA represents all surface runoff draining the SDA. Significant surface runoff typically occurs for a few days in the spring, when the snow melts. The water samples are collected in 4-l bottles and are assessed for particulate concentrations, as well as radionuclide concentrations. Results from 1983 through 1988 are presented in Table A-8. Using the probability distribution function in MINITAB (Ryan et al. 1985), it was determined that the data are lognormally distributed. The geometric mean of the particulate concentration data is 0.41 mg/mL. The 95% confidence interval is from 0.10 to 1.74 mg/mL. To be conservative, the maximum particulate concentration, 2.13 mg/mL, was used in the erosion calculations. Using an average precipitation rate of 23.03 cm/yr, the surface water erosion rate was estimated to be 49.04 $g/m^2/yr$.

The total soil erosion rate for the RWMC is the sum of the soil loss because of wind and the soil loss because of surface water runoff. The total used in the assessment is 721 $g/m^2/yr$. At this rate, the cover erodes at approximately 0.048 cm/yr. Therefore, it takes about 830 yr for a 40-cm section of cover (the size of each soil compartment in the near-field model) to erode.

To approximate the loss of radionuclides from surface soil, via erosion, in the DOSTOMAN code, the erosion rate had to be converted to an erosion rate constant that could be used in a first order differential equation (note: this assumes that radionuclides are lost in direct proportion to soil particle loss). Because the DOSTOMAN code only solves differential equations, the use of a constant fractional erosion rate (i.e., 0.0012/yr) would result in a nonlinear cover loss function. That is, the initial quantity of radionuclides lost would be the highest amount, and successive losses would become smaller and smaller. Using an erosion rate, the cover loss is a linear function. An exponential function was thus determined that would simulate a near-linear cover loss

Table A-8. Particulate concentrations in surface water samples collected at the SDA pump

Date	Weight of particulates (mg)	Particulate concentration (mg/mL)
3/10/83	7390, 8530[a]	1.85, 2.13
6/27/83	640[a]	0.16
3/14/84	7200[b]	1.80
3/21/85	800[c]	0.20
4/02/85	396[c]	0.10
2/18/86	6523[d]	1.63
4/22/88	92.2[e]	0.02

a. Blanchfield and Hoffman (1984).
b. Reyes et al. (1985).
c. Reyes et al. (1986).
d. Reyes et al. (1987).
e. Tkachyk et al. (1989).

function in the DOSTOMAN code. To accomplish this, the fraction of soil mass removed each year from a 40-cm deep section of cover was converted to a natural logarithm. A linear regression was performed on the converted data using MINITAB. The resulting formula is

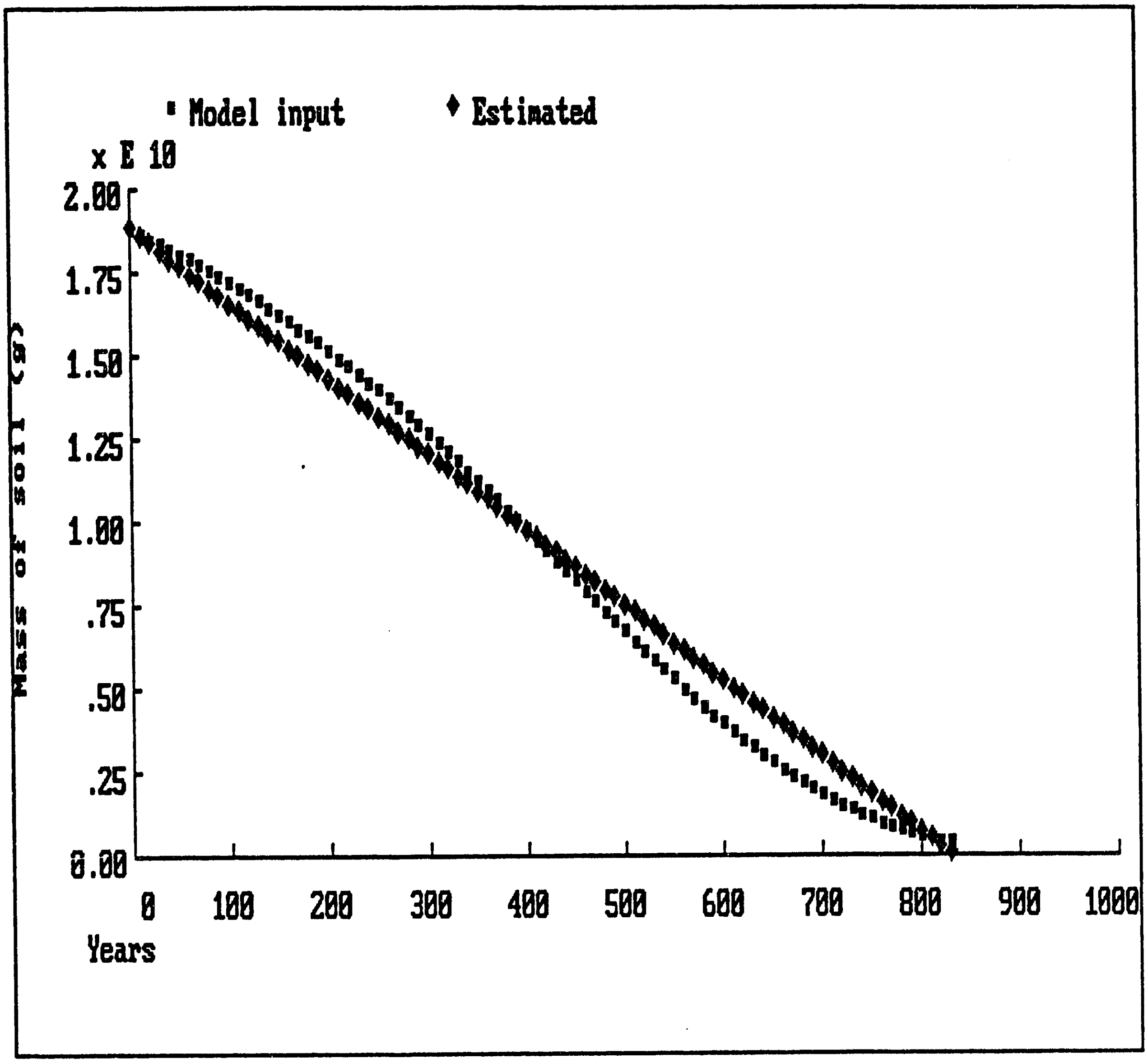
$$k = 7.318\text{E-}4 \cdot \exp(0.00359 \cdot \text{time}) \ . \qquad \text{(A-5)}$$

The variable k is the rate constant input into the DOSTOMAN code for rate constants $\lambda_{2,12}$, $\lambda_{3,12}$, and $\lambda_{5,12}$. The validity of using this rate constant was checked by modeling the erosion process with the TIME-ZERO code (Kirchner 1989). Two models were simulated using TIME-ZERO. The first model was a simple linear model that simulated the estimated loss of cover using a constant rate of 0.012 cm/yr. The second model was a first order differential equation

$$\text{Cover}(t) = -k \cdot \text{Cover} \qquad \text{(A-6)}$$

where Cover(t) is the amount of cover (mass or curies) at time t and k is the rate constant, which varies with time and was described previously. Figure A-17 shows the results of the two simulations. The figure shows that the differential equation model tracks the linear model fairly closely.

The erosion rate constant was not used in the model during the period after the year 7069. It was assumed that at this point in time that the net cover erosion is zero. The surface of the cover is level with the ambient elevation and there is no net soil loss because of erosion. That is, whatever soil loss occurs is replaced by deposition. It was further assumed that the surface soil is fairly stable and radionuclide loss occurs primarily by resuspension. See Section A.2.4 for a description of the derivation of the resuspension rate constant ($\lambda_{2,12}$).



The points labeled as "estimated" represent the model that uses a constant rate of soil erosion (i.e., a linear equation). The points labeled as "model input" represent the first order differential equation that uses a rate constant that varies with time.

Figure A-17. Results of linear and first-order differential equation erosion model simulations.

A.2.4 Resuspension Rate Constant

Transport of surface soil to air via resuspension was quantified using experimental results of Sehmel (1978). In these experiments, a submicrometer calcium molybdate tracer was deposited in a lightly vegetated area at Hanford. Resuspended particles were collected using a cowled impactor, which always faced into the wind. Measurements were made at specific wind speeds, as measured at a height of 2.1 m above the ground. Resuspension rates were calculated from a mass balance calculated from the profile. Respirable particles were separated into nominal diameters for unit-density spheres of 7, 3.3, 2.0, and 1.1 µm and smaller particles on the backup filters. Tracer resuspension rates are plotted as function of particle diameter and wind-speed increments in Figure A-18. Note that considerable uncertainty is associated with the data obtained during the winter months (January 16 through February 18, 1974), when wind intervals with wide speed intervals were used. If the winter data is excluded, the resuspension rates for all sizes increase with wind speed to the 4.8 power. For this reason, and because it is the most conservative model, the formula that was derived from the backup filter particles was used.

$$RR = 1.96\ E\text{-}13\ (\bar{U})^{4.82} \qquad \text{(A-7)}$$

where

$\bar{U}$ = mean wind speed.

In a neutral atmosphere, where temperature decrease with height is adiabatic, the friction velocity is related to wind speed by

$$\mu_{*} = (\mu_{Z} \bullet K) + \ln \frac{Z}{Z_0} \qquad \text{(A-8)}$$

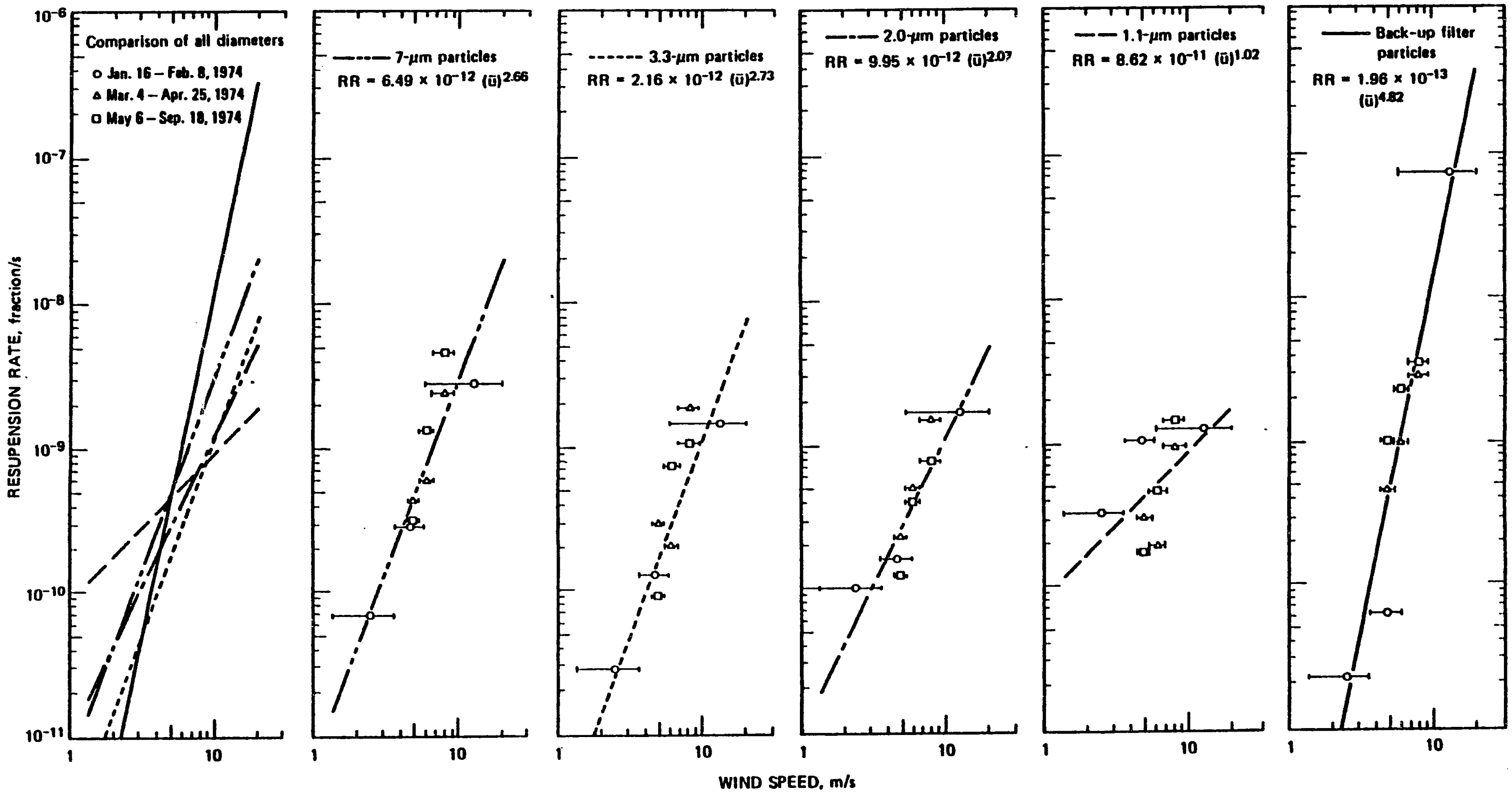


Figure A-18. Tracer resuspension rates as a function of particle diameter and wind-speed increments (Sehmel 1977).

where

μ_Z = measured wind speed at height Z (m/s)

K = von Karman constant (found by integration to be equal to 0.4)

Z = height at which wind speed measurements are taken (m)

Z_0 = height at which wind speed is zero (m).

Wind speed data used in dispersion calculations are measured by NOAA at a height of 10 m (Z). A value of 0.034 m, indicative of lightly vegetated deserts (Sehmel 1978), can be used for Z_0. Substitution of the above relationship in the Sehmel equation, thus yields the following:

$$RR = 7.04\ E\text{-}8\ \mu_*^{4.82} \quad \text{(A-9)}$$

Wind speed data used in the determination of μ_* are presented in Table A-9. The values in the table are based on meteorological data measured by NOAA during the years 1981 through 1985. To be conservative, the maximum wind speed was used to represent each wind speed class. In the case of calms, the wind speed used was 0.1 m/s. These velocities were weighted by the frequency of occurrence. Using this information, μ_Z was calculated to be 3.71 m/s and μ_* was determined to be 0.26. The resuspension rate constant was then estimated to be 1.09 E-10 s^{-1}.

The resuspension rate constant was used in the near-field model to account for loss of radionuclides from the cover soil after the year 7069 ($\lambda_{1,12}$). It was also used to estimate the source term for input into the AIRDOS-EPA code. The annual rate constant (3.44 E-3 yr^{-1}) was multiplied by the soil concentration to yield the annual release rate (Ci/yr).

Table A-9. Wind speed frequency distribution data for the RWMC.

Stability Class	Direction:	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	TOTAL
A	WSC 1*	7	7	22	31	24	15	12	10	24	34	39	45	30	11	6	12	329
	WSC 2	6	9	30	33	8	9	5	2	12	36	81	59	11	11	7	2	321
	WSC 3	1	1	19	26	6	2	0	1	5	29	89	39	7	4	2	3	234
	WSC 4	0	2	7	3	0	0	0	1	2	27	64	50	1	1	0	0	158
	WSC 5	0	0	0	0	0	0	0	0	0	2	9	24	1	0	0	0	36
	WSC 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	WSC 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B	WSC 1	98	134	106	86	59	31	28	36	56	64	120	124	124	141	68	67	1342
	WSC 2	20	138	267	138	29	16	13	14	38	123	286	175	84	55	27	27	1450
	WSC 3	5	50	150	51	7	1	6	6	12	115	358	164	26	14	11	7	983
	WSC 4	5	19	38	11	0	0	0	1	3	57	241	208	34	7	3	3	630
	WSC 5	0	3	6	1	0	0	0	1	0	11	51	96	3	0	1	0	173
	WSC 6	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	2
	WSC 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C	WSC 1	221	323	191	99	51	44	38	47	64	91	189	240	358	411	214	162	2743
	WSC 2	36	274	491	138	36	20	22	44	62	182	503	280	170	122	48	39	2467
	WSC 3	19	64	229	45	10	2	6	19	39	171	591	347	129	33	21	16	1741
	WSC 4	9	42	64	21	2	3	2	4	12	96	331	353	97	16	0	1	1053
	WSC 5	0	2	20	4	0	0	0	1	2	17	93	179	24	2	5	2	351
	WSC 6	0	1	1	0	0	0	0	0	0	0	13	16	2	0	0	0	33
	WSC 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D	WSC 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	WSC 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	WSC 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	WSC 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	WSC 5	0	2	2	1	0	0	0	0	0	6	41	104	20	0	1	0	177
	WSC 6	1	3	4	2	0	0	0	2	2	12	67	155	17	0	0	0	265
	WSC 7	0	1	0	0	1	0	0	0	0	1	2	12	0	0	0	0	17
E	WSC 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	WSC 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	WSC 3	29	104	155	66	13	2	15	32	27	431	995	431	189	43	45	28	2605
	WSC 4	6	29	84	27	4	1	5	7	9	225	460	281	86	14	7	2	1247
	WSC 5	0	18	27	2	0	0	0	0	0	45	97	101	25	2	1	0	318
	WSC 6	0	5	1	0	0	0	0	1	0	1	4	11	4	0	0	0	27
	WSC 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F	WSC 1	607	596	297	142	98	72	62	66	103	231	505	790	1535	2083	978	643	8808
	WSC 2	177	610	466	156	72	43	66	96	83	459	1294	907	704	434	170	116	5853
	WSC 3	3	21	25	13	0	1	1	4	4	33	101	50	22	13	5	6	302
	WSC 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	WSC 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	WSC 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	WSC 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	SUM OF COLUMNS	1250	2458	2702	1096	420	262	281	395	559	2499	6625	5242	3703	3417	1620	1136	33665
	CALM HRS	117	399	828	0	0	2262 (CLASSES A, B, C, D, E, AND F, RESPECTIVELY)											3606
	TOTAL HRS																	37271

*WSC = Wind speed class. Wind speed classes 1, 2, 3, 4, 5, 6, and 7 represent 0.1-1.57 mps, 1.57-3.35 mps, 3.35-5.59 mps, 5.59-8.27 mps, 8.27-10.95 mps, 10.95-15.42 mps, and 15.42-22.58 mps, respectively.

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A.2.5 Waste Source Terms

The source terms S_5 and S_{17} in the old pits conceptual model (Figure A-3) represent the movement of radionuclides from waste emplaced in open pits to surface soil, both onsite and offsite, during two separate flooding events in 1962 and 1969. The primary radionuclides affected by these events were Pu-239 and Am-241. The magnitude of these source terms, by compartment, is given in Table A-10. The total activity for each nuclide was assumed to be released in 1969 alone.

The S_5 and S_{17} source terms include radioactivity also taken into account in source terms S_{28}, S_{29}, and S_{30}. Thus, the latter source terms are inflated by the amounts of activity in S_1 and S_2 terms. However, because the magnitude of the S_1 and S_2 terms is small, the double counting was considered insignificant.

The source terms S_{13}, S_{14}, S_{15}, and S_{16} (Figures A-3 through A-6) represent the activity buried, in their respective container types, during the operational period. For the performance assessment, the wastes were assumed to be disposed in three types of containers. These were metal containers of various types, wooden boxes, and cardboard boxes or bales. The nuclides were assumed to be distributed according to the volume, rather than the number of containers. The assumed volume fractions for each year were based on disposal records for container types and average container volumes. Table A-11 shows the volume fractions assumed for the years 1964 through 1988. During this period, cardboard boxes, wooden boxes, and metal containers are estimated to have held more than 90% of the total contained waste volume entering pits at the RWMC. (The disposal volume of large uncontained items, such as trucks, was not considered in the calculation.)

For each year, the disposed activity for a particular nuclide was distributed among the container types according to the volume fractions shown in Table A-11. Similar disposal rates for a particular container were averaged to conform to the limited number of input periods allowed

Table A-10. Radionuclide source terms resulting from flooding at the RWMC

Radionuclide	Activity In Soil Compartment 5 (Ci)	Activity In Soil Compartment 17[a] (Ci)
Pu-239	3.00 E-2[b,c]	2.86 E-2
Am-241	1.49 E-3[d]	1.00 E-1

a. Adapted from Markham (1976).
b. Adapted from EG&G (1984a).
c. The precision implied is maintained to minimize rounding errors in model calculations.
d. Adapted from EG&G (1984).

Table A-11. Assumed waste volume fractions for each container type for RWMC performance assessment

Year	Cardboard Boxes or Bales	Wooden Boxes	Metal Containers
1964	0.565	0.257	0.178
1965	0.729	0.172	0.100
1966	0.627	0.228	0.145
1967	0.670	0.178	0.152
1968	0.621	0.262	0.117
1969	0.581	0.248	0.172
1970	0.484	0.380	0.135
1971	0.727	0.133	0.141
1972	0.596	0.082	0.321
1973	0.437	0.192	0.371
1974	0.322	0.163	0.515
1975	0.239	0.380	0.381
1976	0.296	0.669	0.035
1977	0.274	0.618	0.108
1978	0.024	0.903	0.073
1979	0.009	0.988	0.003
1980	0.014	0.566	0.420
1981	0.024	0.721	0.255
1982	0.023	0.686	0.291
1983	0.047	0.800	0.153
1984	0.107	0.806	0.087
1985	0.108	0.733	0.159
1986	0.016	0.858	0.126
1987	0.001	0.819	0.180
1988	0.018	0.872	0.110

for the modeling using DOSTOMAN. The input data are shown in Figures A-19 through A-46. Future disposal rates (for 1989 and beyond) were estimated by extrapolating the recent estimated average rates for each nuclide and container type.

A.2.6 Release Rates from Radioactive Waste to Burial Soil

Waste nuclides originating through the activation of metal components (e.g., Co-60), were assumed to be released at a rate dependent upon corrosion rates of stainless steel. The formula used is

$$\lambda_{m,n} = \frac{K_c A}{\rho V} \qquad \text{(A-10)}$$

where

K_c = corrosion rate of the metal ($g/cm^2 \cdot yr$)

A = surface area of the metal component (cm^2)

V = volume of the metal component (cm^3)

ρ = density of the metal component (g/cm^3).

A review of the possible component shapes led to the conclusion that the surface to volume ratio (A/V) could be approximated by $1/\Delta$, where Δ is the metal thickness (EG&G 1984a). Using a minimum thickness of 0.6 cm, a maximum corrosion rate of 6.5 E-6 $g/cm^2 \cdot yr$ for Type 304 stainless steel (Paige et al. 1972), and a metal density of 7.8 g/cm^3, the rate constant was calculated. Half of the material was assumed to enter each burial soil compartment.

The remaining radionuclides modeled (actinides and fission products) were buried in containers in the SDA. Three major container types were used: wooden boxes, cardboard boxes, and steel drums.

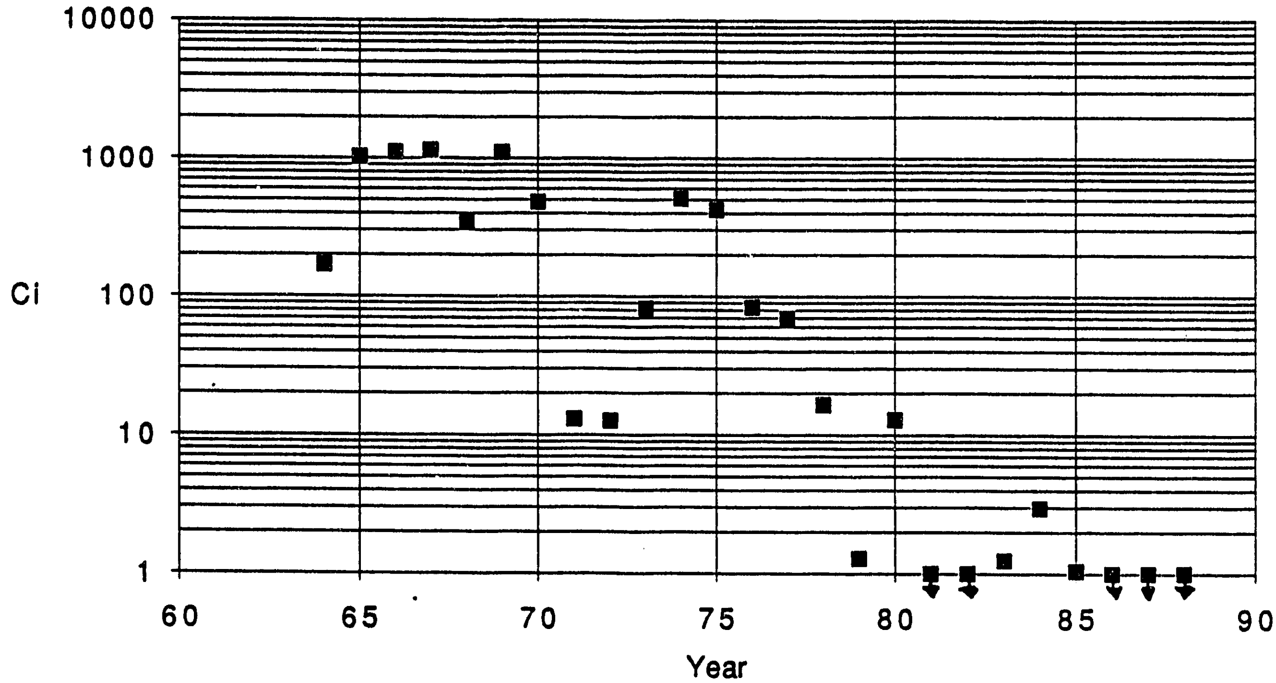

Figure A-19. Sr-90 in cardboard or bales.

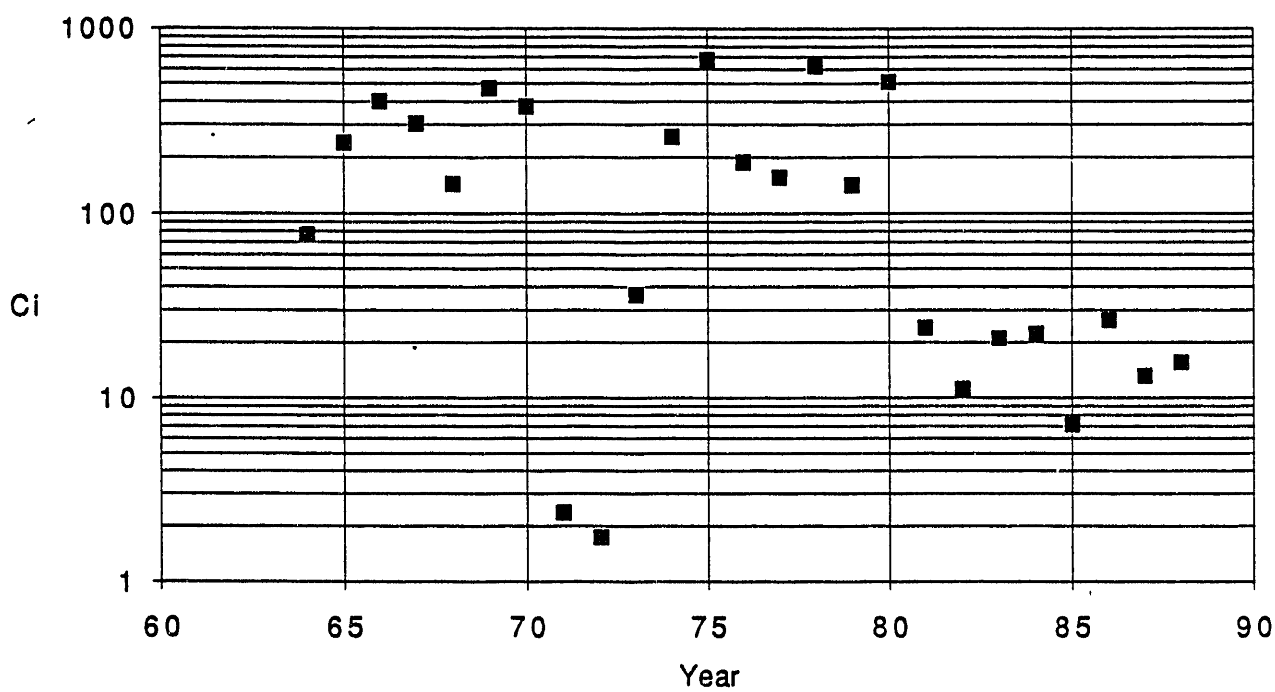

Figure A-20. Sr-90 in wooden boxes.

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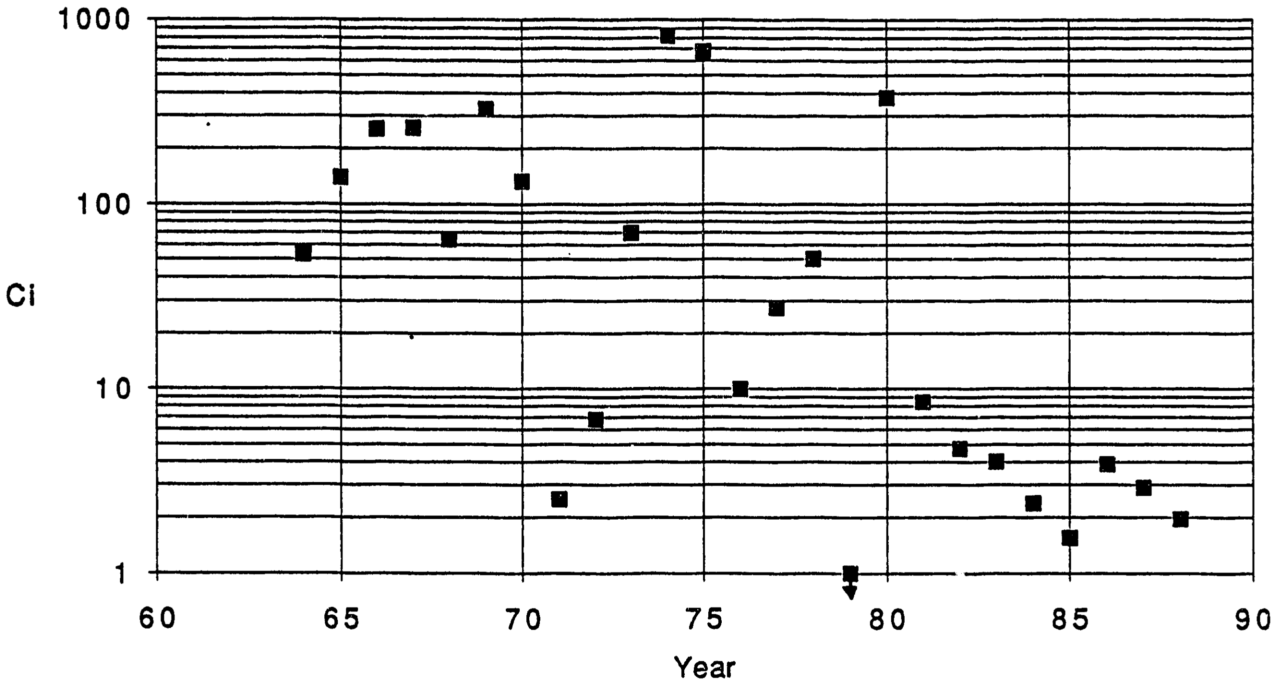

Figure A-21. Sr-90 in metal containers.

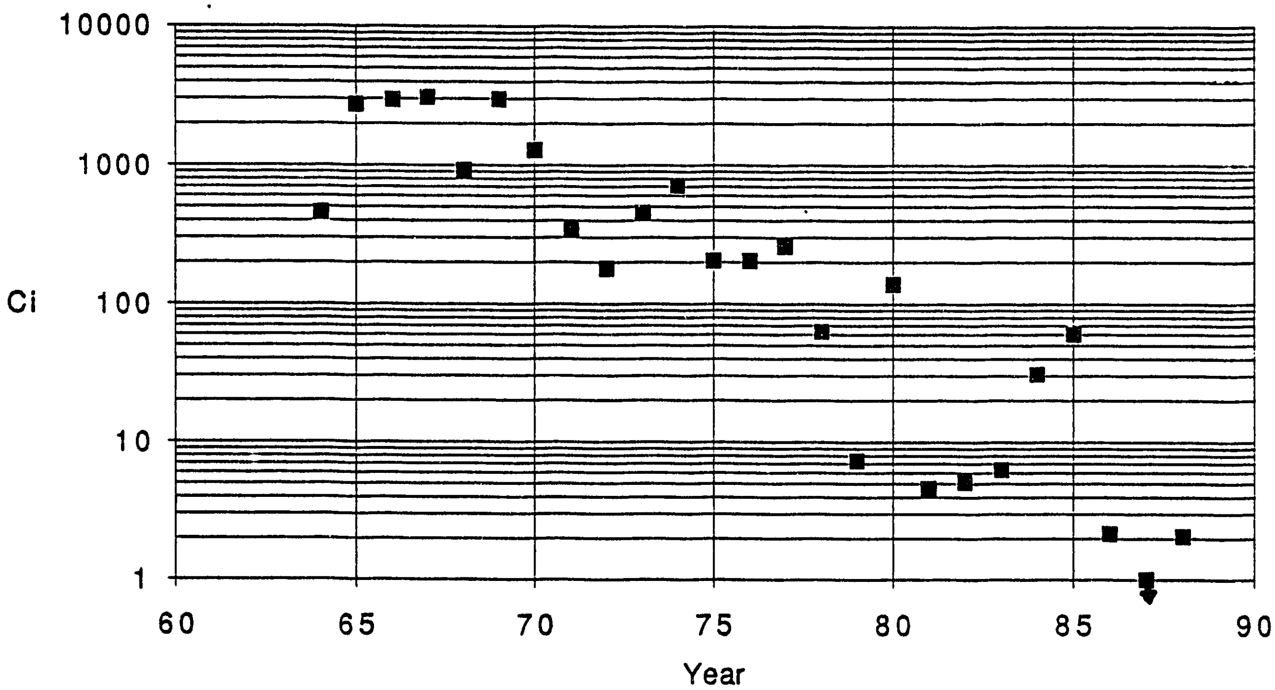

Figure A-22. Cs-137 in cardboard or bales.

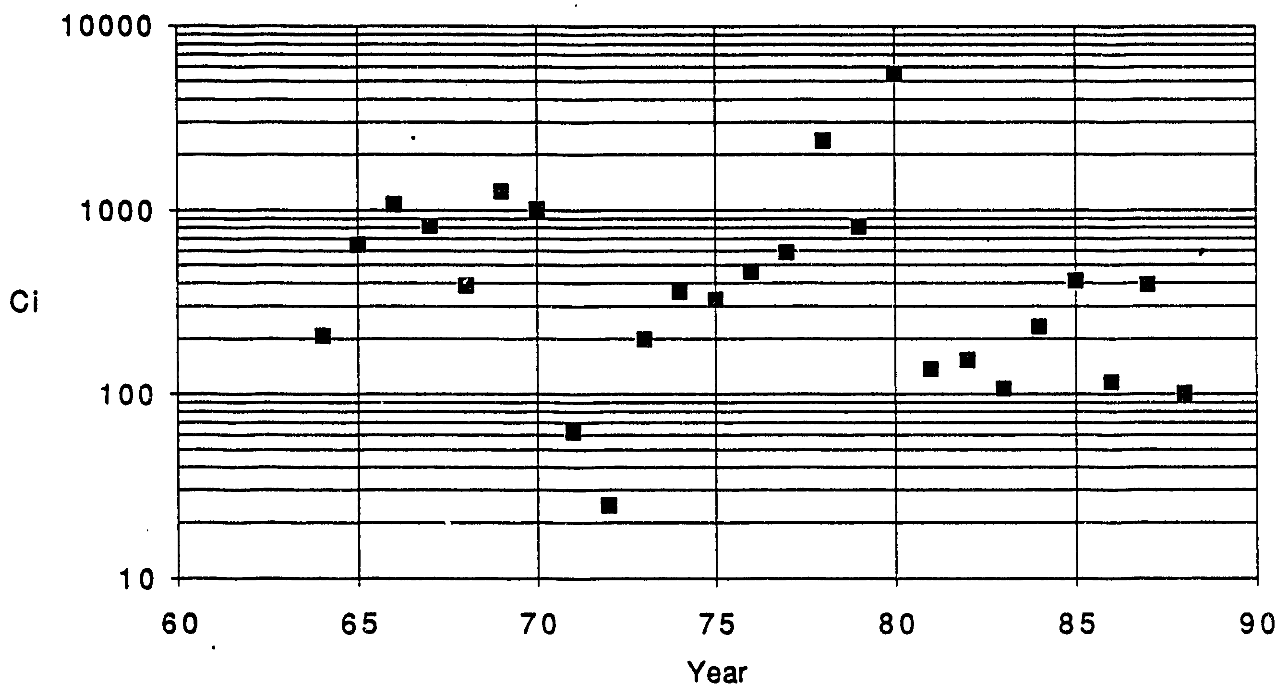

Figure A-23. Cs-137 in wooden boxes.

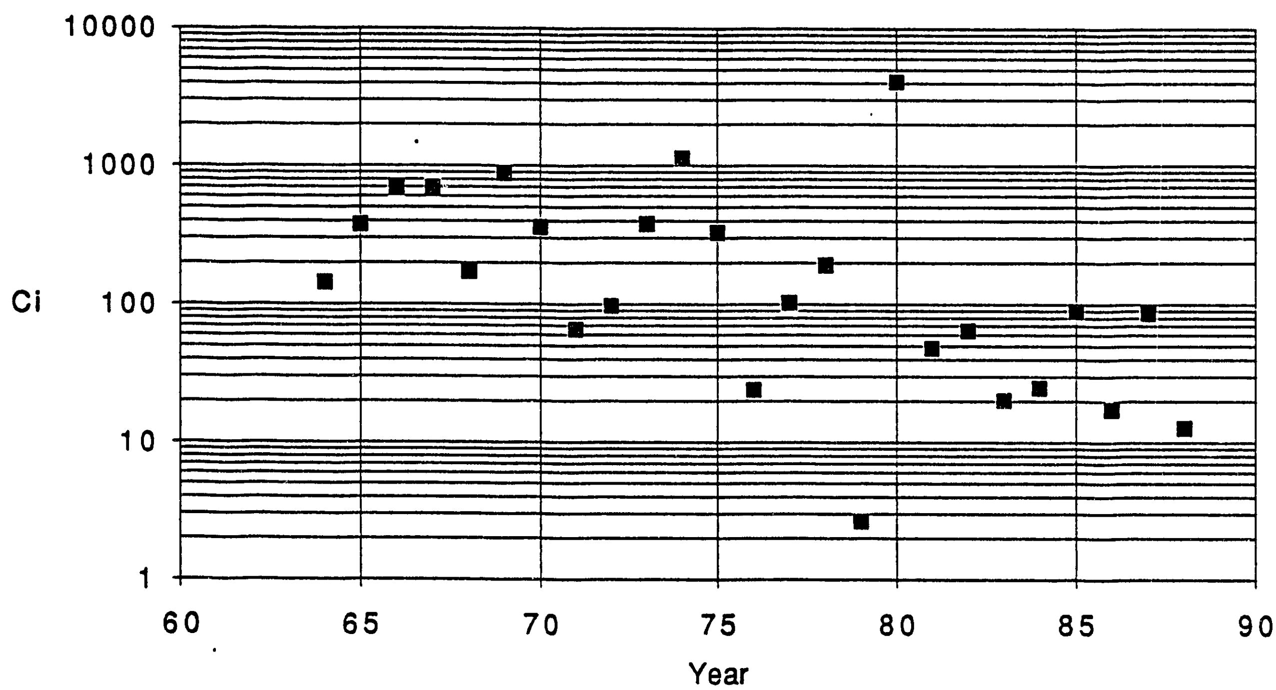

Figure A-24. Cs-137 in metal containers

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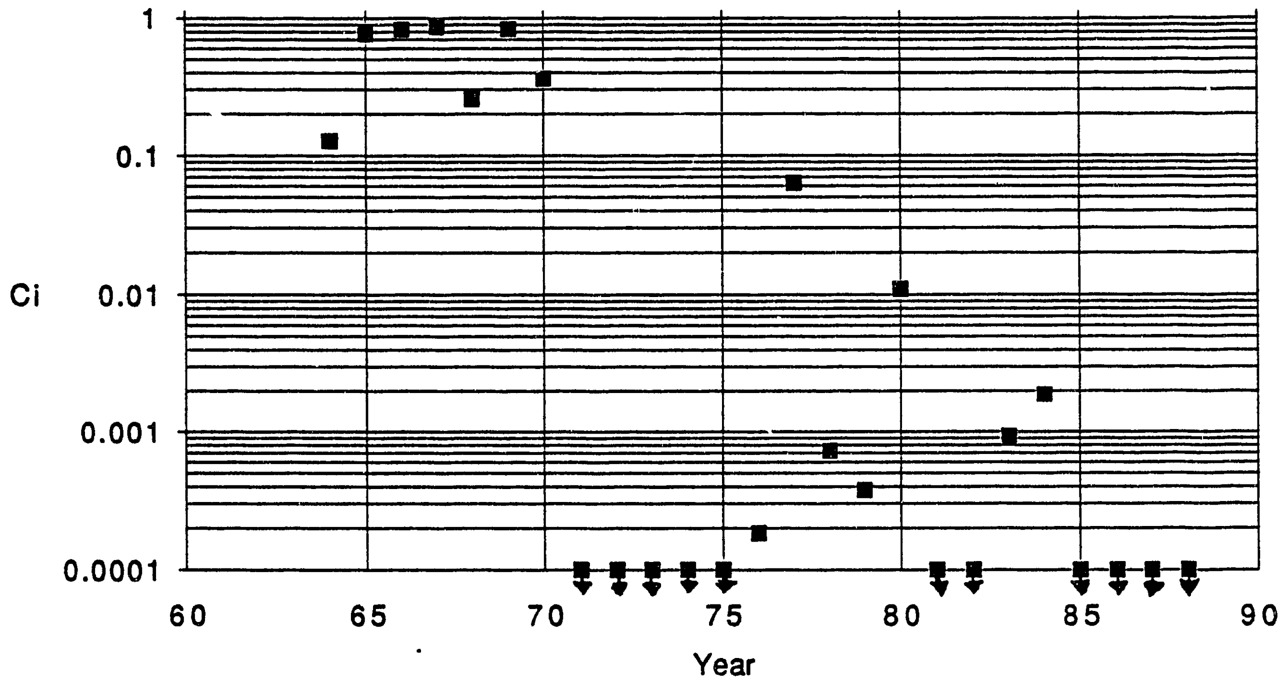

Figure A-25. Pu-238 in cardboard or bales.

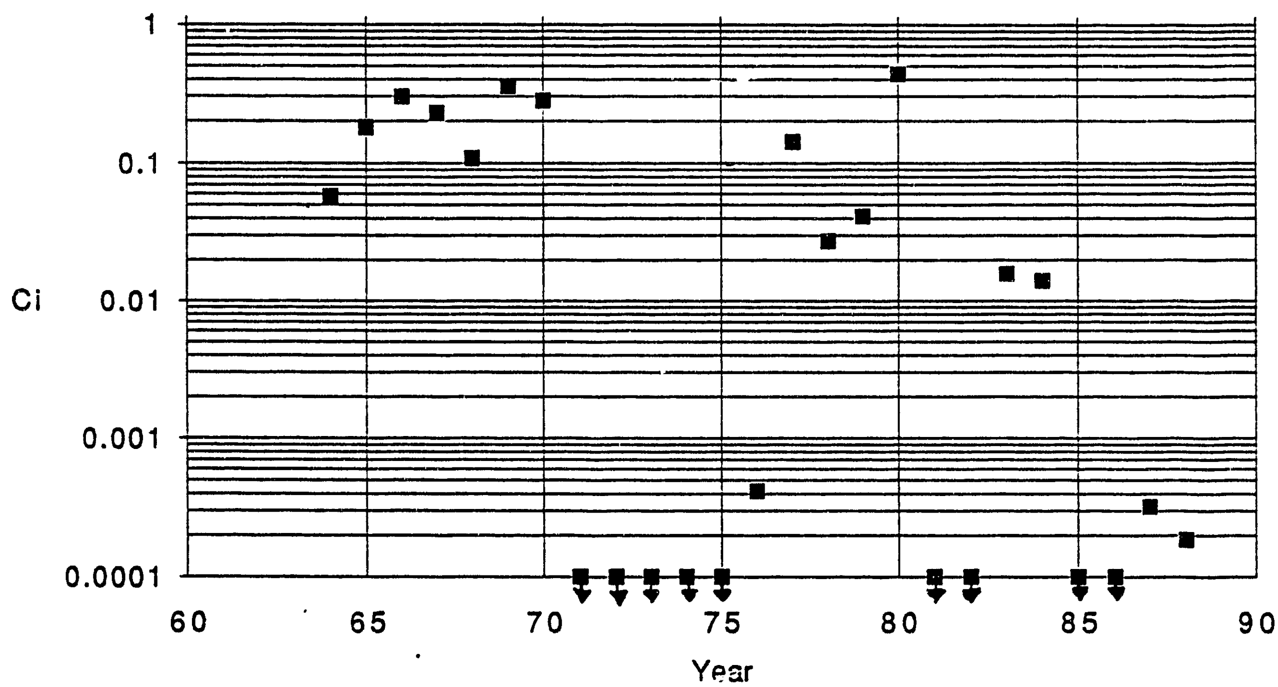

Figure A-26. Pu-238 in wooden boxes.

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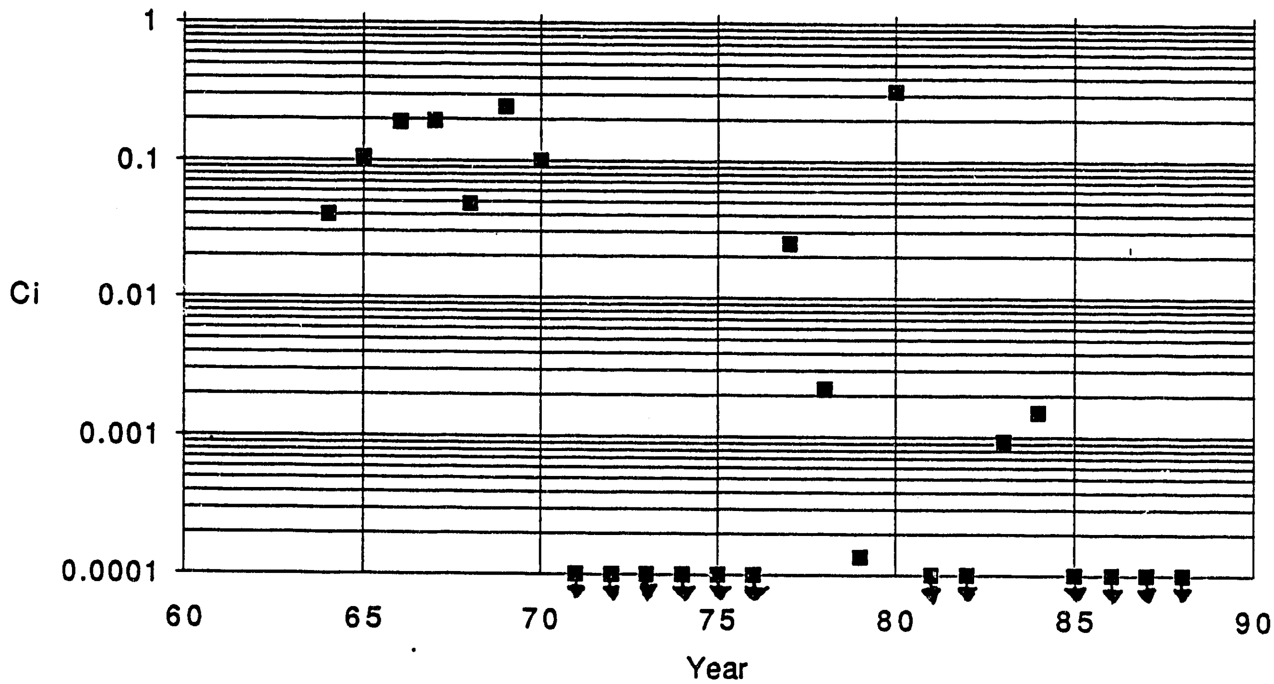

Figure A-27. Pu-238 in metal containers.

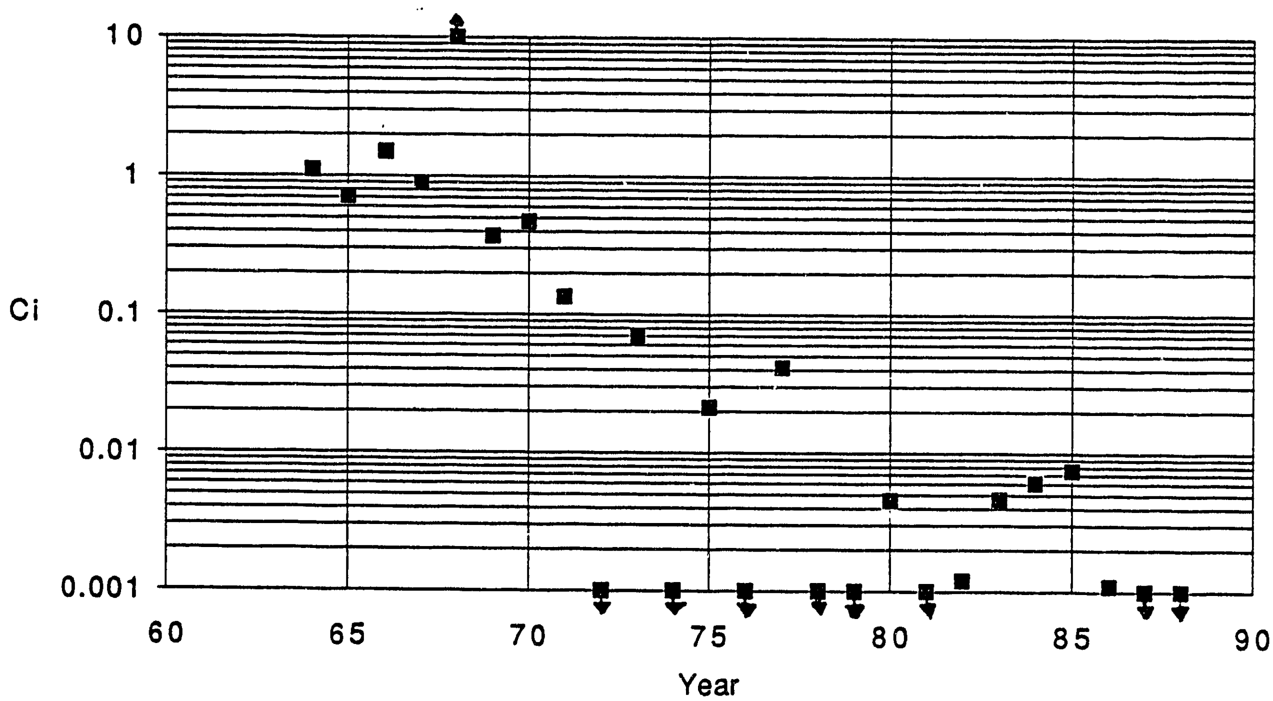

Figure A-28. Pu-239 in cardboard or bales.

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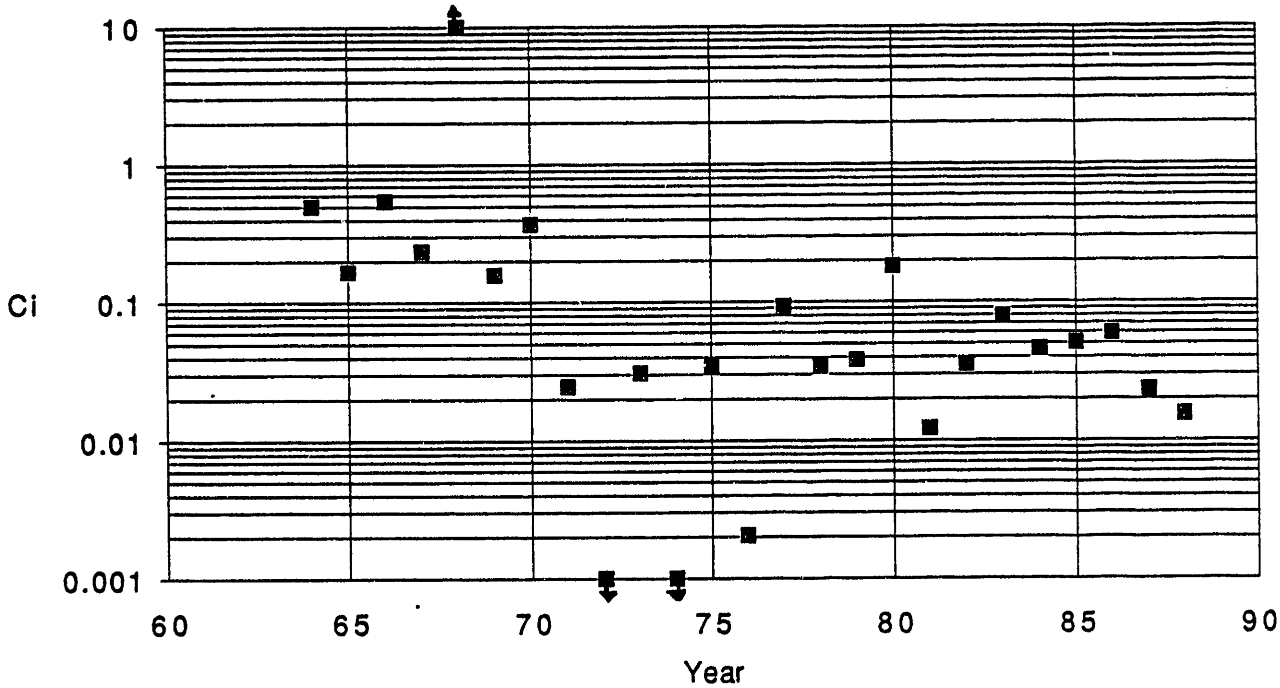

Figure A-29. Pu-239 in wooden boxes.

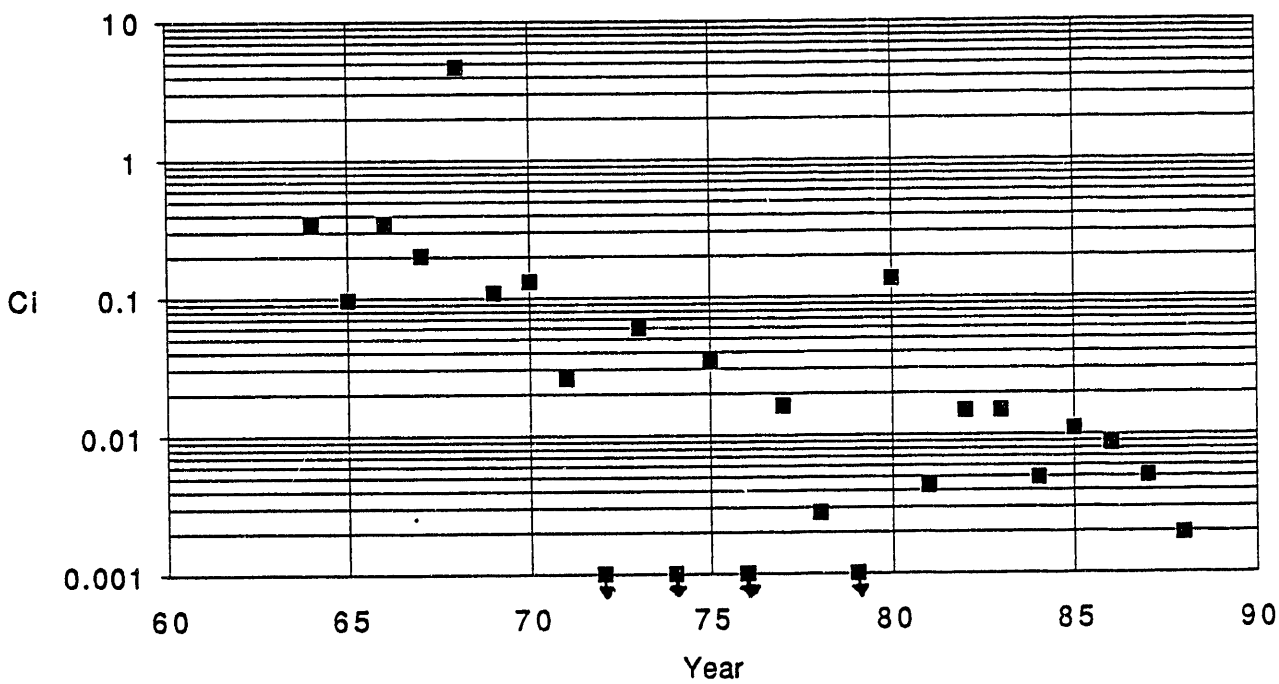

Figure A-30. Pu-239 in metal containers.

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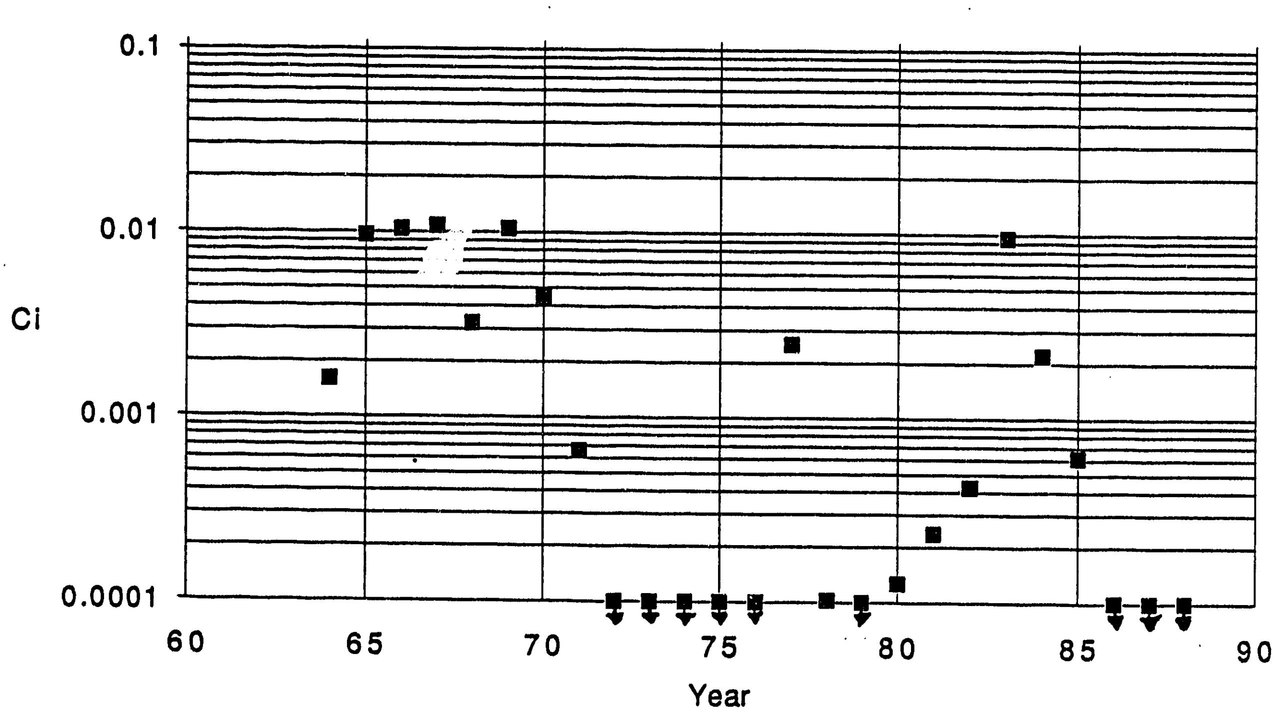

Figure A-31. Pu-240 in cardboard or bales.

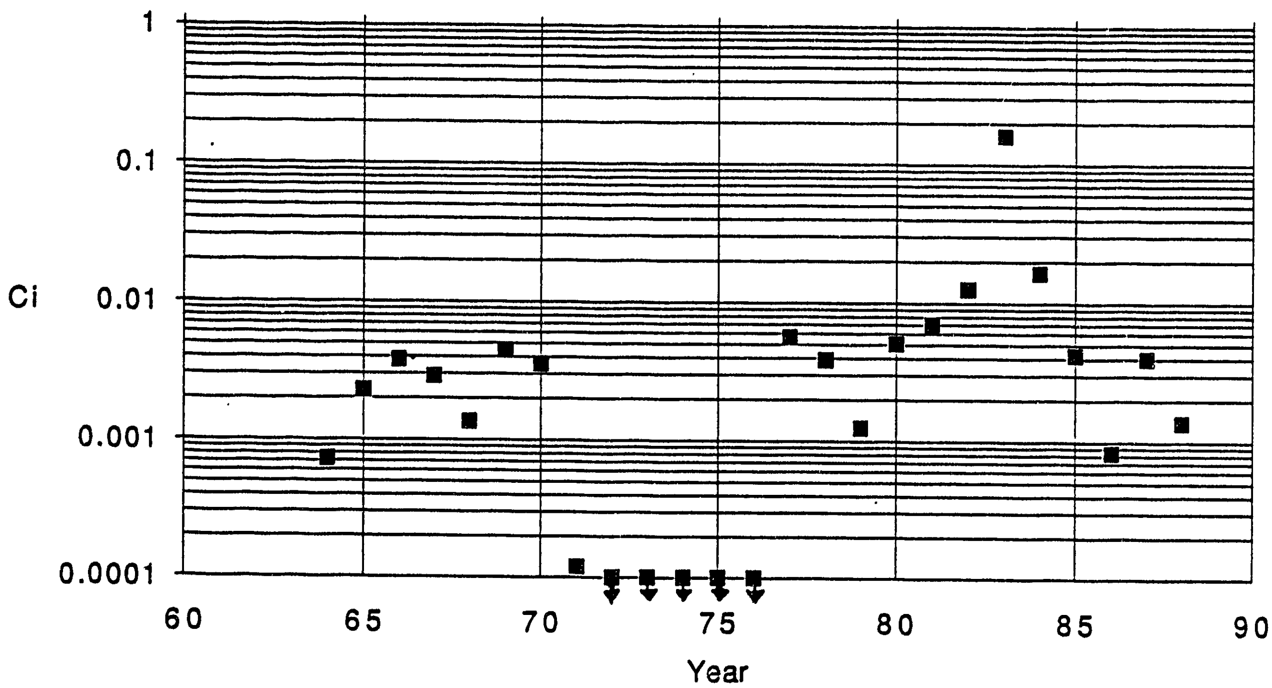

Figure A-32. Pu-240 in wooden boxes.

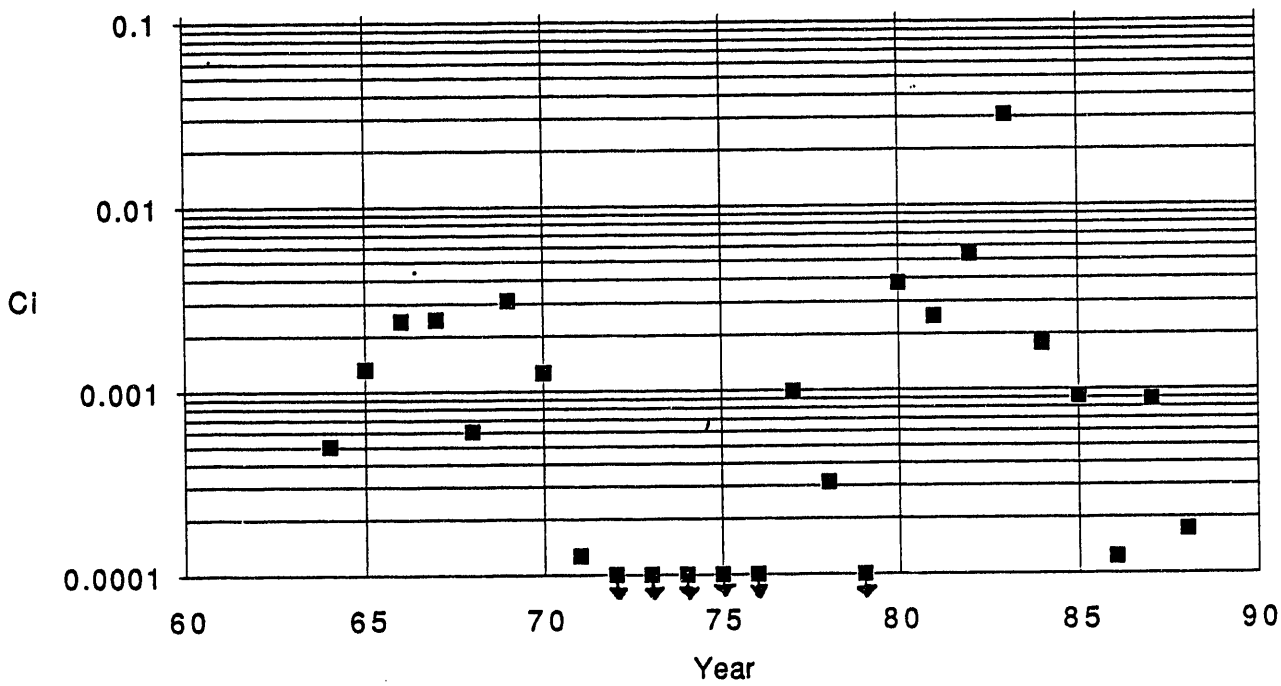

Figure A-33. Pu-240 in metal containers.

Figure A-34. Am-241 in cardboard or bales.

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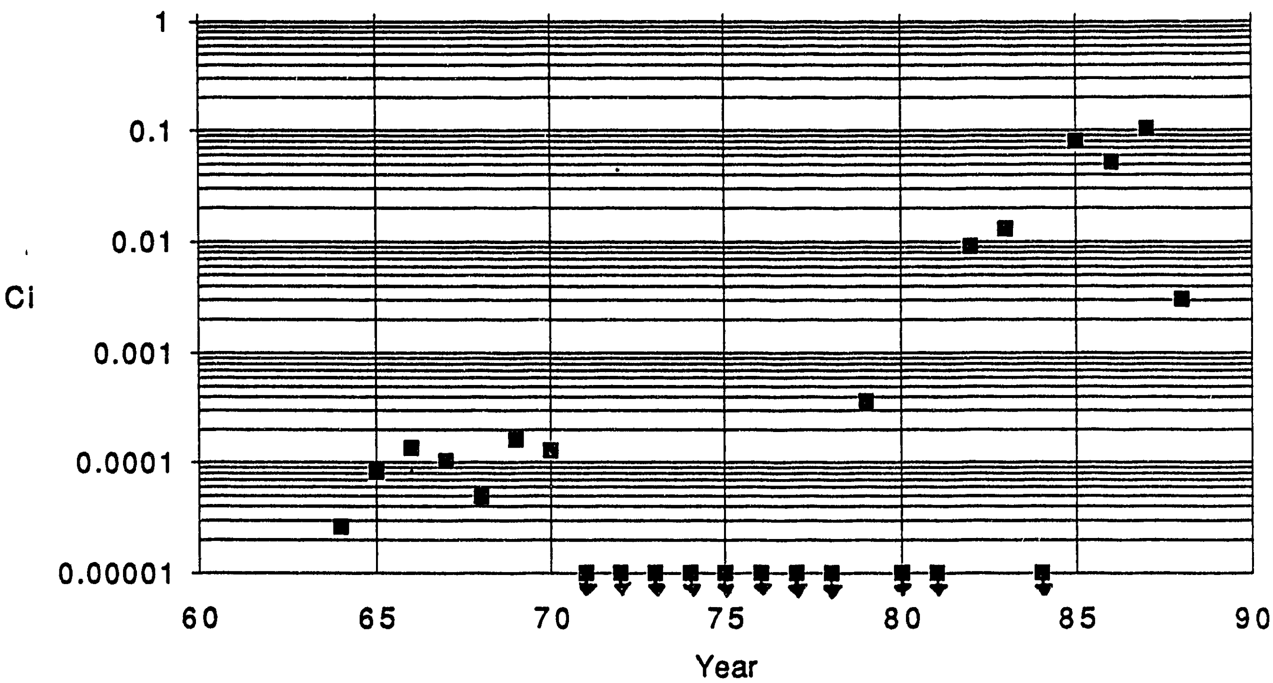

Figure A-35. Am-241 in wooden boxes.

Figure A-36. Am-241 in metal containers.

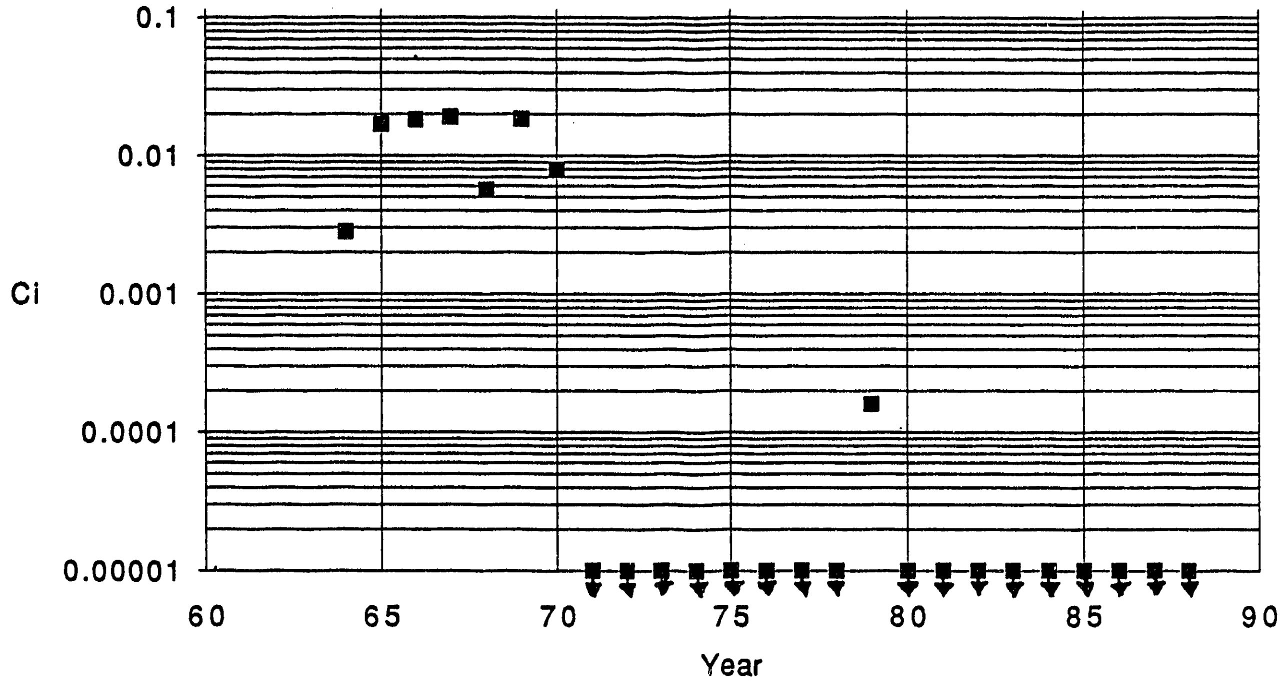

Figure A-37. Th-230 in cardboard or bales.

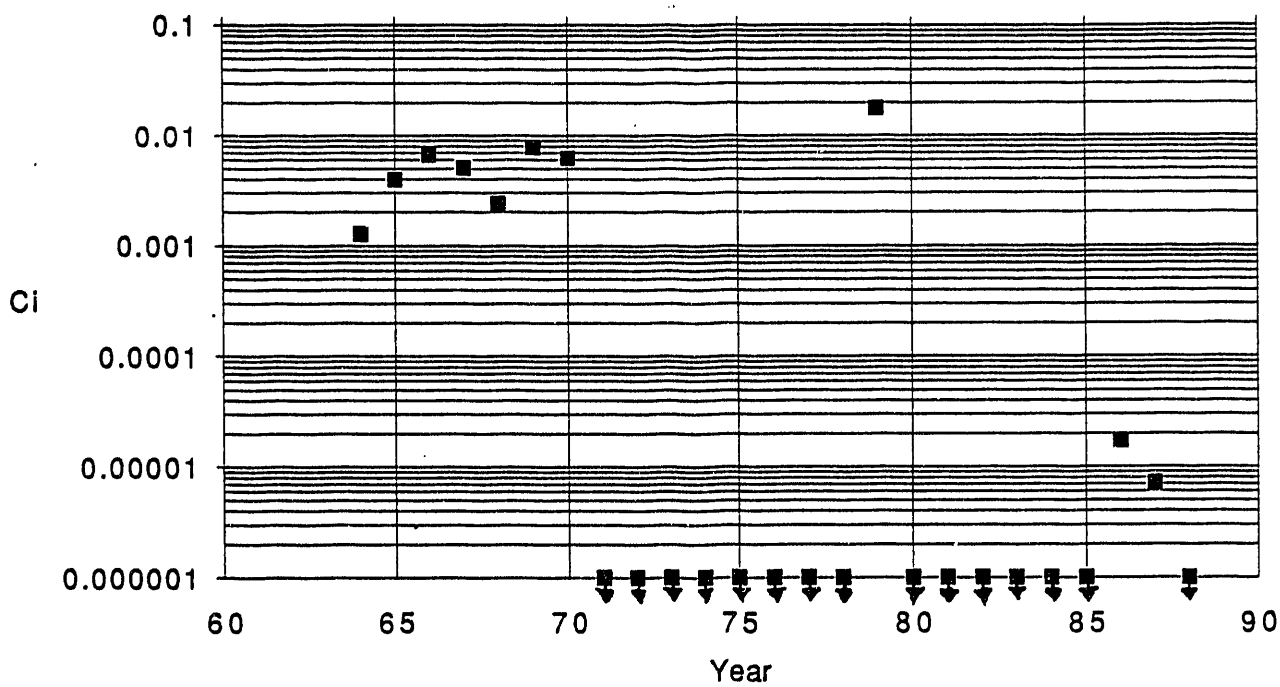

Figure A-38. Th-230 in wooden boxes.

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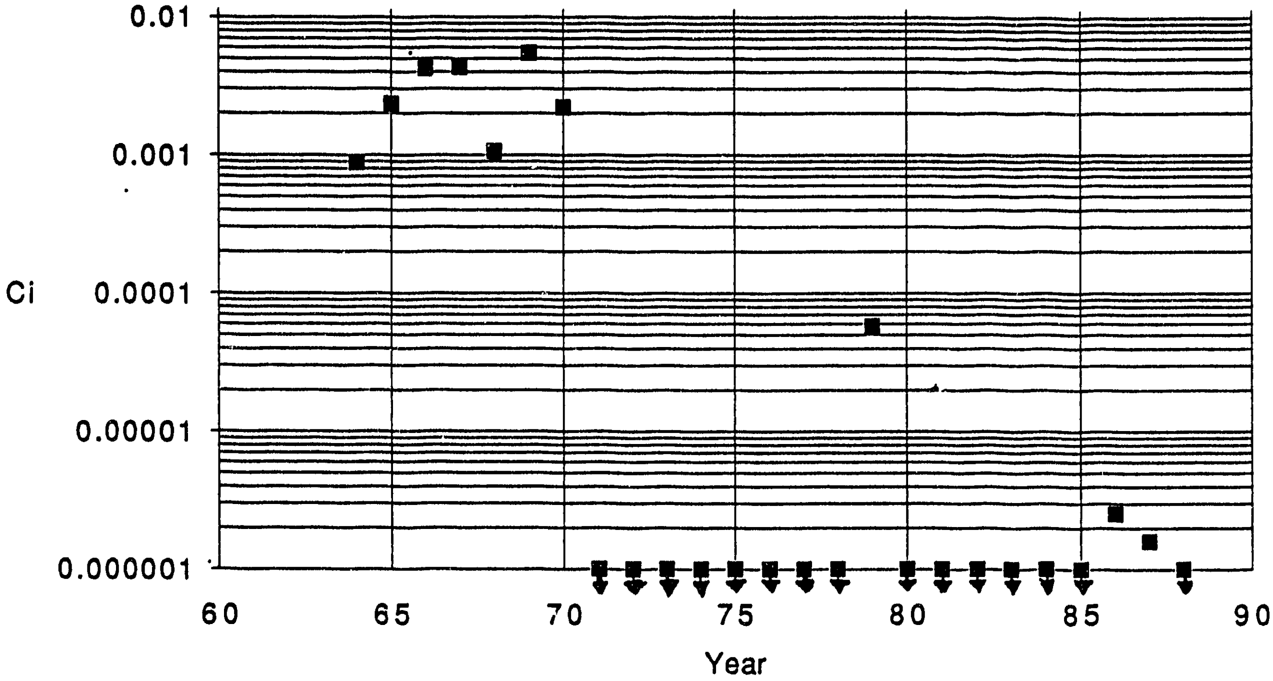

Figure A-39. Th-230 in metal containers.

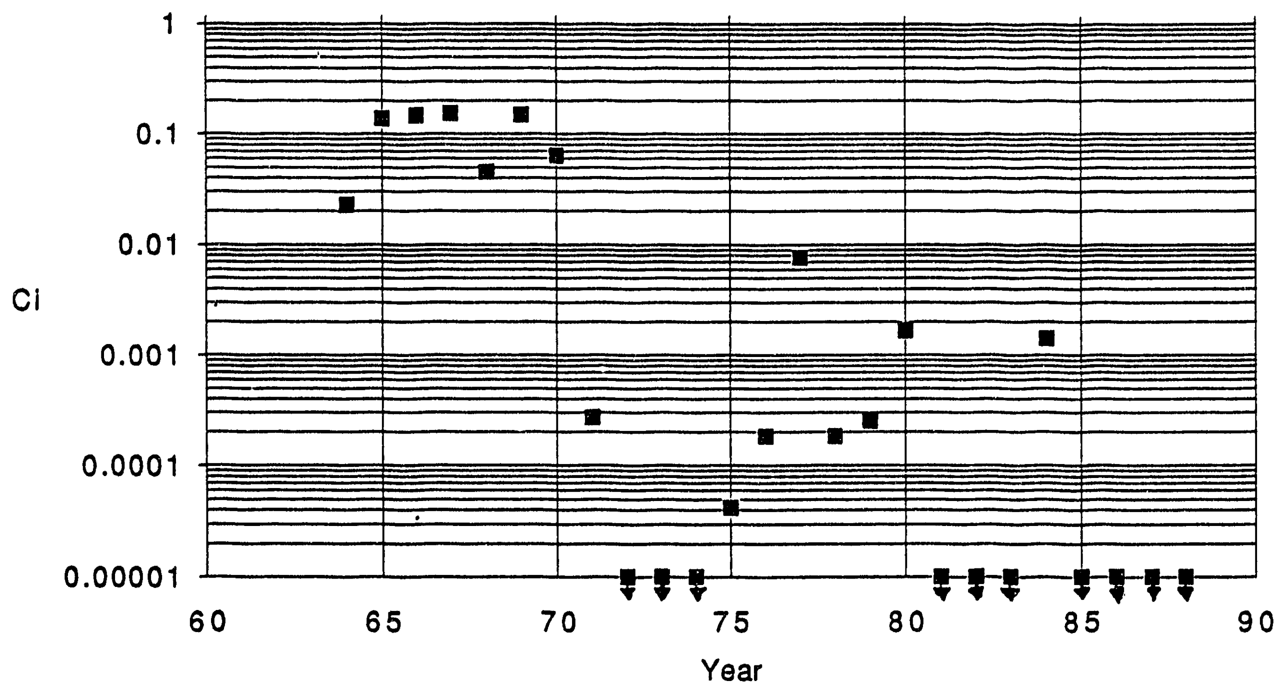

Figure A-40. U-234 in cardboard or bales.

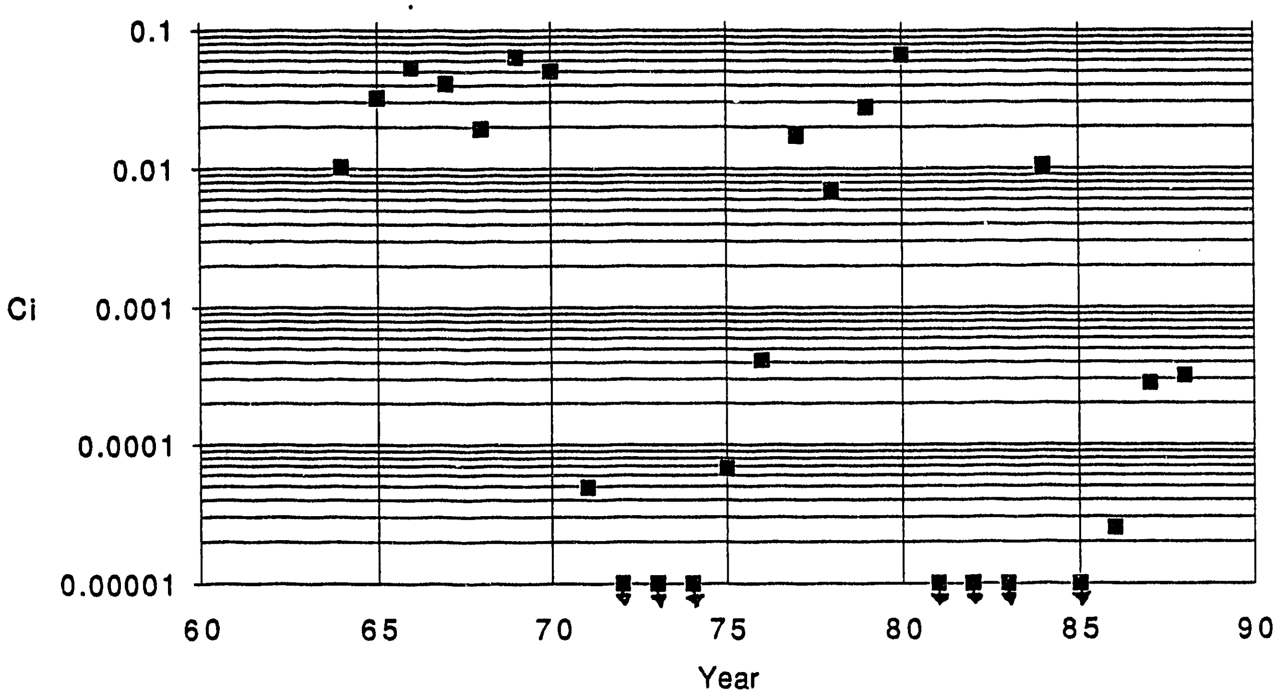

Figure A-41. U-234 in wooden boxes.

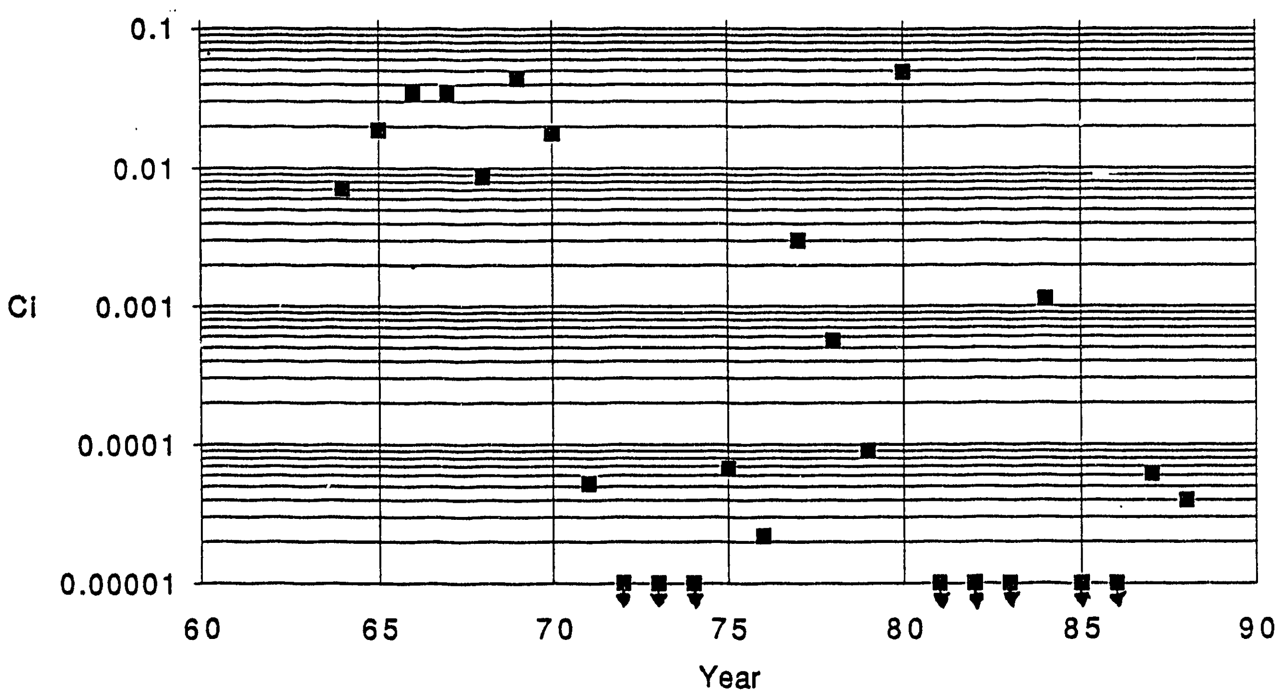

Figure A-42. U-234 in metal containers.

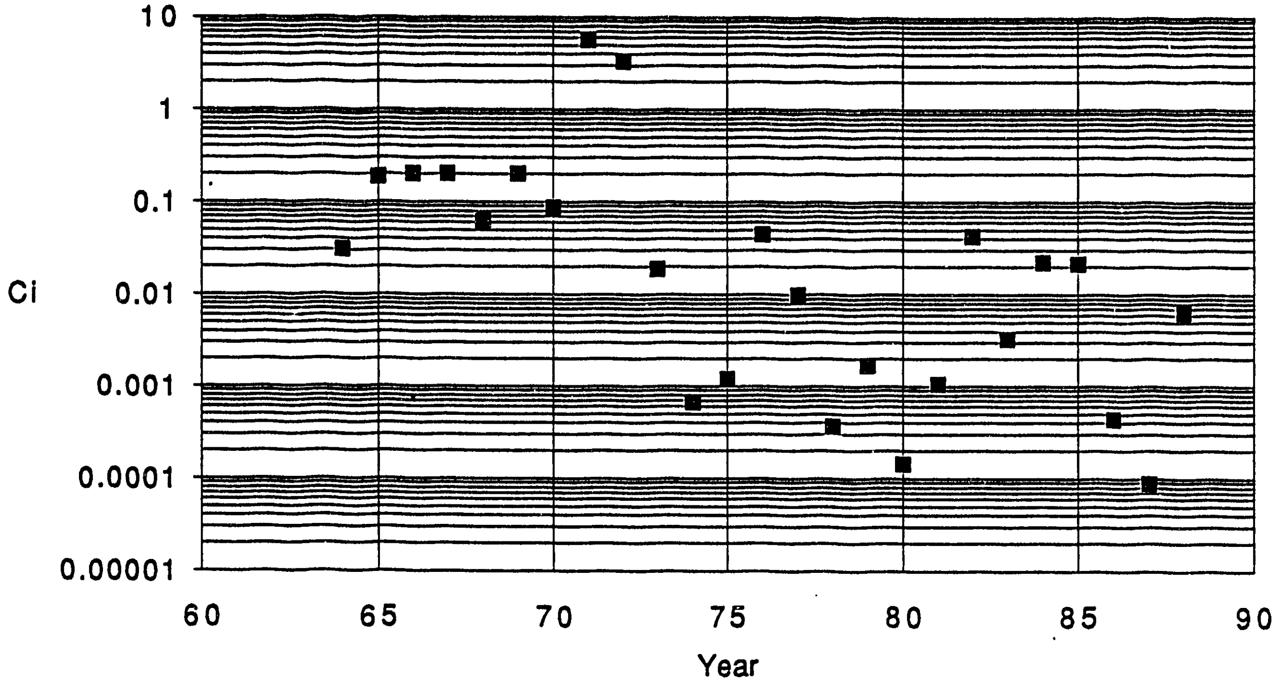

Figure A-43. U-238 in cardboard or bales.

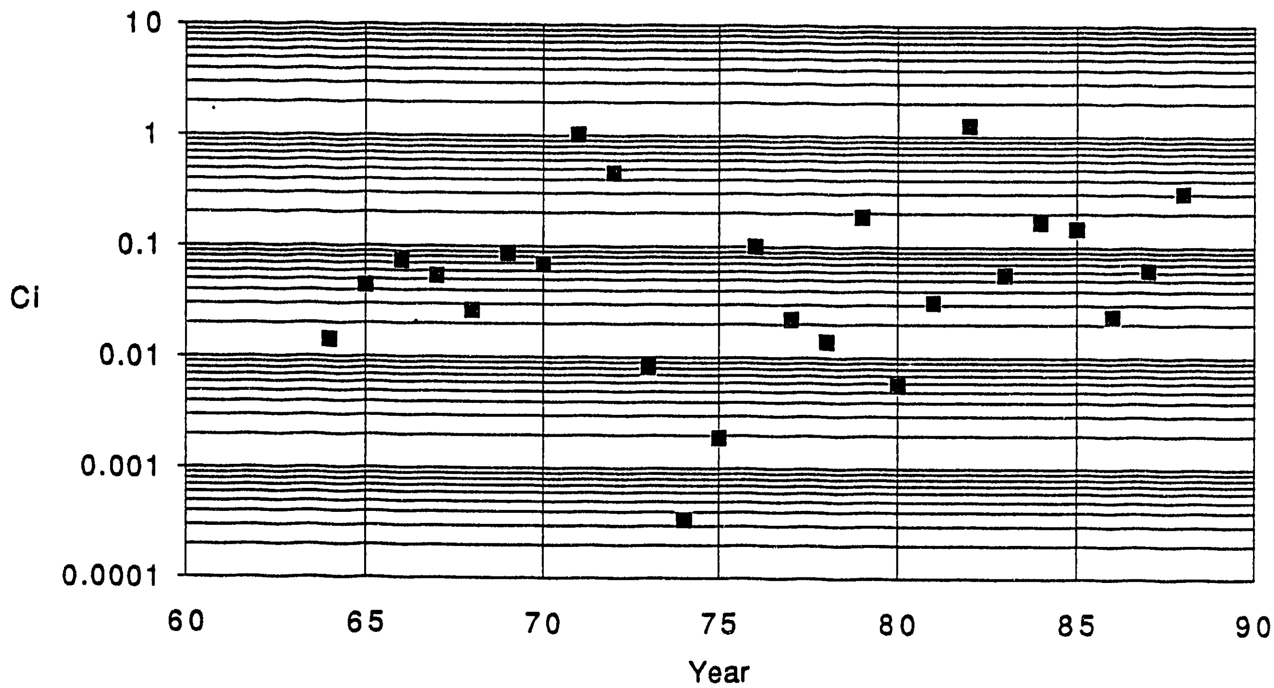

Figure A-44. U-238 in wooden boxes.

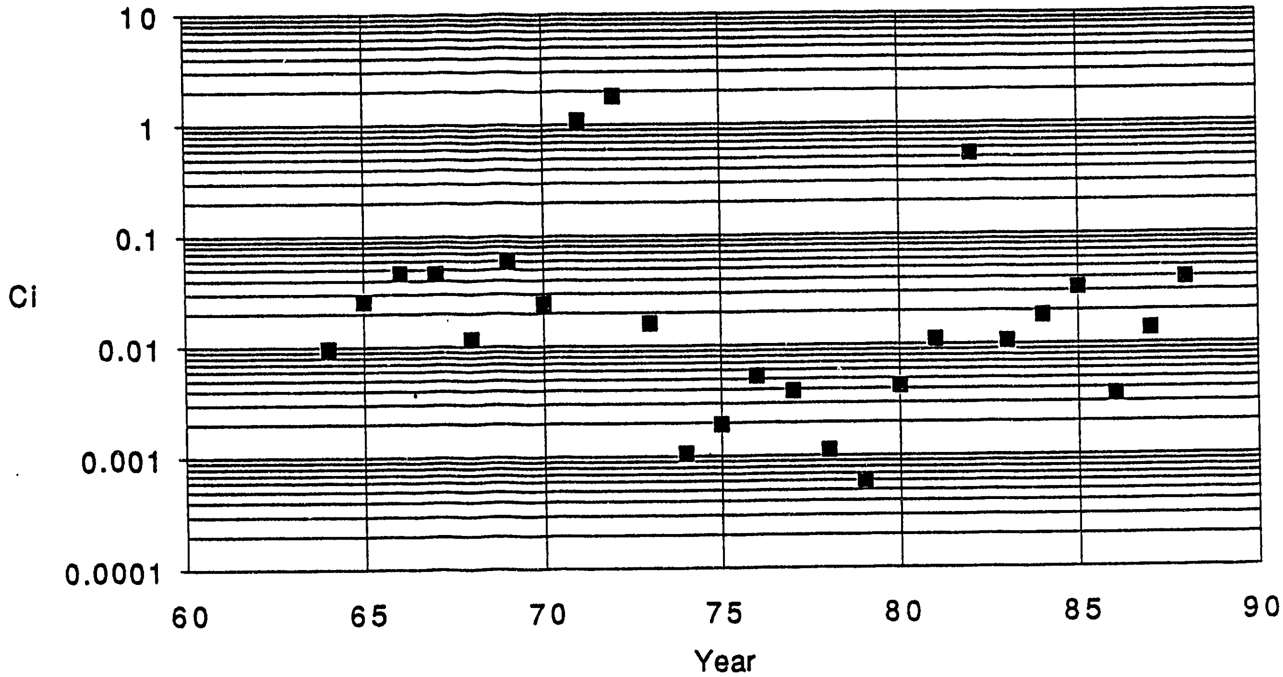

Figure A-45. U-238 in metal containers.

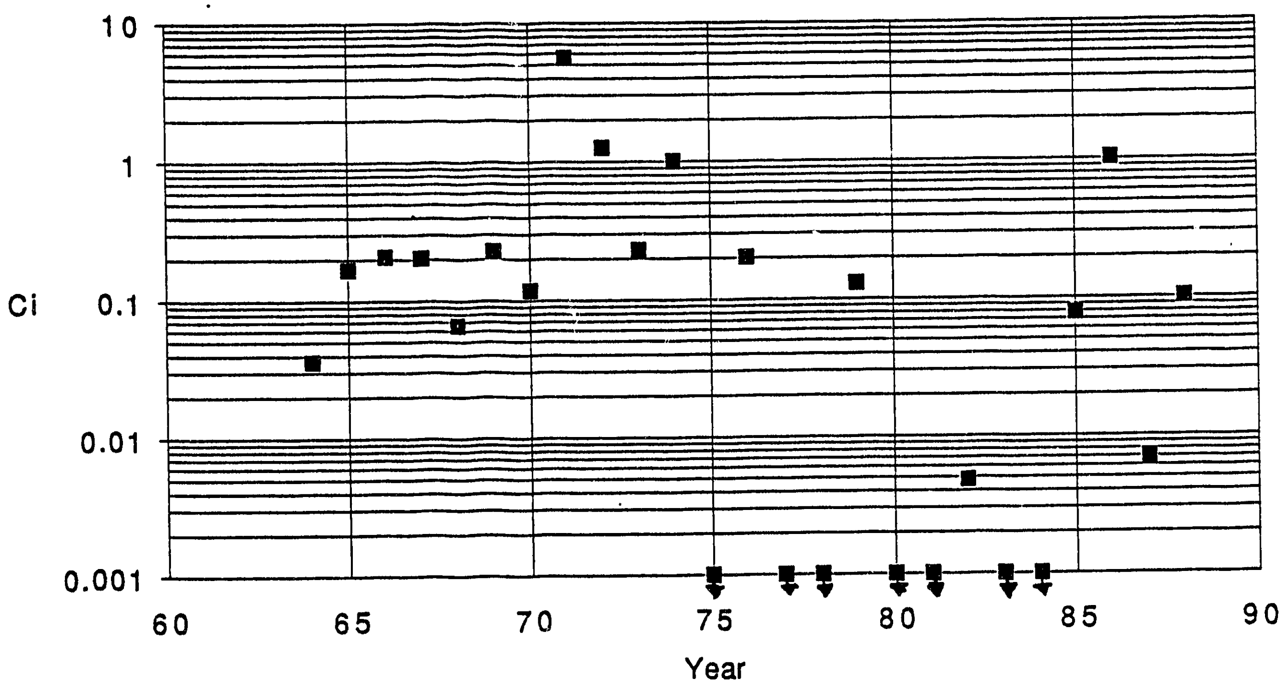

Figure A-46. Radium needles/sources.

Disposed wastes were assumed to be immobile during the lifetime of the containers and then to undergo gradual release to the burial soil. Data in Table A-12 show container lifetimes and transport rate constants used in the model. The values were estimated through comparison of observed concentrations of Pu-239/Pu-240 in subpit soil (Humphrey and Tingey 1978) with DOSTOMAN model predictions. As the measured concentrations resulted at least in part from flooding episodes, it is expected that the estimated transport parameters will lead to predicted soil concentrations higher than those that will be experienced in future operations.

A.2.7 Burial Soil to Deep Strata

Transport downward was assumed to be due to hydrologic transport alone. The rate constant is given by

$$\lambda_{m,n} = \frac{V_{nucl.}}{D_m} \qquad \text{(A-11)}$$

where

D_m = depth of soil compartment m (m)

$V_{nucl.}$ = radionuclide velocity due to hydrologic transport (m/yr).

The nuclide velocity is given by (Wilhite 1978):

$$V_{nucl.} = \frac{V_{water}}{(1 + K_d R)} \qquad \text{(A-12)}$$

where

V_{water} = ground water velocity (m/yr)

K_d = distribution coefficient (ml/g)

Table A-12. Estimated container lifetimes and container-to-soil transfer coefficients[a]

Container Type	Container Lifetime (yr)	Rate Constant $(yr^{-1})^b$
Wooden boxes	5	0.03
Cardboard boxes	0.1	0.05
Steel drums	15	0.01

a. Adapted from Humphrey and Tingey (1978).
b. Total rate constant; half of the material was assumed to enter each burial soil compartment.

R = ratio of soil mineral weight per unit volume of soil column to water volume per unit volume of soil column (g/mL).

It is assumed that the ground water velocity in the unsaturated zone is proportional to the rate of recharge of water at the surface and inversely proportional to the mean volumetric moisture content (NCRP 1984).

$$V_{water} = \frac{S_r}{MC_v} \qquad \text{(A-13)}$$

where

S_r = rate of recharge of water at the surface (cm/yr)

MC_v = mean volumetric moisture content.

A paucity of data exists on ground water recharge by annual precipitation. Walton (1970) cites a number of studies in the arid and semiarid western U.S. in which the annual recharge rate was 5 to 7% of the annual precipitation. A value of 5% was applied to an annual precipitation rate of 23.03 cm/yr (EG&G 1984b).

The mean volumetric moisture content can be conservatively assumed to be equal to the field capacity, the water content at which moisture can no longer be held against gravity (NCRP 1984). The field capacity may be estimated assuming that 50% of the pore space is occupied by water (Foth 1978). The field capacity was calculated using a porosity of 0.35 (Robertson 1977) for sediments.

This formula for nuclide velocity was also used to describe movement between cover, surface, and burial soil compartments. Distribution coefficients used in these calculations are listed in Table A-13. A value of 8.6 g/mL was used for R, based on bulk density and moisture content data from the INEL (Barraclough et al. 1976).

A.2.8. Burial Soil to Surface Soils

Transport between compartments may be in a downward direction, because of hydrologic transport, and upward, because of plant uptake and subsequent death and animal excavation. Soil brought to the surface by animals may be expected to subside over time.

The incorporation of radionuclides into surface soil Compartments 1 through 6, because of plant root death, was determined using

$$\lambda_{m,n} = (1 - FAB_i) \cdot FD_i \cdot FP_{i,n} \qquad \text{(A-14)}$$

where

FAB_i = fraction of total biomass of plant species i that is aboveground

Table A-13. Distribution coefficients used in hydrologic transport calculations in the near-field model[a]

Element	Distribution Coefficient (mL/g)
Co	1000
Sr	20
Cs	200
Ra	1000
Th	50
U	1000
Pu	2000
Am	700

a. DOE (1982) and EG&G (1984a).

FD_i = fraction of belowground biomass of plant species i that dies annually (yr^{-1})

$FP_{i,n}$ = fraction of root mass of plant species i in soil compartment n.

Assumed values for FD_i were 1.0 yr^{-1} for Russian thistle, an annual, and 0.5 yr^{-1} for crested wheatgrass and for sagebrush (EG&G 1984a). Values for FAB_i and $FP_{i,m}$ are included in Table A-14.

The root depths measured by Reynolds (1989) did not exceed 120 cm. To make the model more conservative, the rooting depths and distributions below 120 cm assumed in McKenzie et al. (1982) for the "final community" were used. The fractional root distributions in Reynolds (1989) were adjusted to accommodate the additional depth.

The aboveground biomass was assumed to enter the uppermost surface soil layer at a rate equal to the annual death rate. The foliage of

Table A-14. Data for plant uptake and death calculations

Parameter	Crested Wheatgrass	Russian Thistle	Sagebrush
Fraction of aboveground biomass	0.32[a]	0.42[b]	0.50[c]
Fractional root distribution (cm):			
0-40	0.344[d]	0.25[e]	0.269[e]
40-80	0.313	0.26	0.27
80-120	0.343	0.31	0.281
120-160		0.09	0.09
160-200		0.04	0.04
200-240		0.04	0.04
>240		0.01	0.01

a. EG&G (1984a).
b. Adapted from Cline et al. (1982).
c. Adapted from McKenzie et al. (1982).
d. Adapted from Reynolds (1989).
e. Adapted from Reynolds (1989) and McKenzie et al. (1982).

Russian Thistle and crested wheatgrass dies at an annual rate of 1.0 yr^{-1}. It was conservatively assumed that 50% of the sagebrush aboveground biomass dies annually.

The RWMC was modeled as a crested wheatgrass community, which includes Russian thistle, before closure. After closure, it was assumed that a sagebrush community invades and becomes dominant. The plant densities used are discussed in Section A.2.9.

Soil transport due to burrowing animals was calculated using

$$\lambda_{m,n} = \frac{\sum_{i=1}^{4} N_i \cdot MB_i \cdot FNB_i \cdot FB_{i,m}}{MS_m} \quad \text{(A-15)}$$

where

N_i = number of individuals of species i

MB_i = mass of soil moved to surface, per individual, by species i (g)

FNB_i = fraction of new burrows per year for species i (yr^{-1})

$FB_{i,m}$ = fraction of burrows of species i in soil compartment m

MS_m = mass of soil compartment m (g).

Four species (deer mice, montane voles, kangaroo rats, and ground squirrels) comprise the majority of the small mammal biomass at the SDA (Groves and Keller 1983). Burrow depth distribution data are included in Table A-15. Population, soil movement, and burrow renewal rate data are listed in Table A-16. The mass of each 40-cm soil compartment (using a density of 1.5 g/mL) is 1.88 E+10 g for the new pit model and 5.18 E+10 g for the old pit model.

A.2.9 Plant Uptake

Soil nuclide movement rates because of plant uptake are calculated as follows:

$$\lambda_{m,n} = \frac{CR \cdot PP_i \cdot FP_{i,m}}{MS_m} \quad \text{(A-16)}$$

Table A-15. Fraction of soils removed per burrow from 40-cm depth increments for small mammals[a]

Depth (cm)	Species: Deer Mouse	Montane Vole	Kangaroo Rat	Ground Squirrel
EDS model w/cover soil layers 1 and 2:				
0-40	.983	1.0	0.571	0.620
40-80	.017		0.406	0.223
80-120	--	--	0.023	0.149
120-160	--	--	--	0.006

a. T. D. Reynolds, U.S. Department of Energy Radiological and Environmental Sciences Laboratory, to M. J. Case, EG&G Idaho, Inc., "Effect of soil disturbance on burrow characteristics of five small mammal species," January 30, 1989. Original percentage data added up to 90%. These data were adjusted so that the sum of the fractions equal 1.0.

Table A-16. Burrowing mammal population numbers and soil transport data

Parameter	Dear Mice	Montane Voles	Kangaroo Rats	Ground Squirrels
Estimated number of animals on SDA:[a]				
New pit model:				
1975-2089	626	432	138	85
7069-11975	532	41	103	91
Old pit model:				
1964-2089	1728	1192	380	233
7069-11964	1469	112	285	250
Mass of soil moved to surface annually, per individual burrow (g)[b]	2.55 E+3	1.65 E+3	1.08 E+4	4.19 E+4
Fraction of new burrows per year[c]	0.875	0.875	0.875	0.750

a. Adapted from Groves and Keller (1983).
b. Adapted from Reynolds and Wakkinen (1987).
c. Adpated from McKenzie et al. (1982).

where

CR = concentration ratio

PP_i = net primary productivity for plant species i (g/yr)

$FP_{i,m}$ = fraction of root mass of plant species i in soil compartment m

MS_m = mass of soil compartment m (g).

Rate constants were calculated for crested wheatgrass and Russian thistle for soil Compartments 1 through 6.

Plant concentration factors used are listed in Table A-17. Aboveground biomass data for each plant species are listed in Table A-18. Applying root:shoot ratios, total biomass was calculated. For Russian thistle, the total biomass was assumed to represent annual production. A similar assumption was made for the aboveground portion of crested wheatgrass; annual crested wheatgrass root production was assumed to be 50% of the root biomass. The sum of these two components yields annual plant productivity. Root:shoot ratios and the calculated plant productivities are listed in Table A-18.

Root distribution data are included in Table A-14. The soil compartment mass was calculated using a soil density of 1.5 g/cm^3 as 1.88 E+10 g for the new pit model and 5.18 E+10 g for the old pit model.

Table A-17. Plant uptake concentration factors used for the SDA

Radionuclide	Russian Thistle	Crested Wheatgrass	Sagebrush
Co[a]	2.4 E-1	2.4 E-1	2.4 E-1
Sr[a]	3.5	3.5	3.5
Cs[a]	5.2	5.2	5.2
Pu[b]	4.6 E-5	1.7 E-5	4.6 E-5
Am[b]	1.4 E-3	6.0 E-4	1.4 E-3
Ra[c]	1.4 E-3	1.4 E-3	1.4 E-3
Th[c]	4.2 E-3	4.2 E-3	4.2 E-3
U[c]	2.5 E-3	2.5 E-3	2.5 E-3

a. Ng et al. (1982).
b. Price (1972).
c. McKenzie et al. (1982)

Table A-18. Plant species data for plant uptake rate constant calculations

Parameter	Plant Species		
	Crested Wheatgrass	Russian Thistle	Sagebrush
Biomass (kg/m^2)			
Shoot[a]	1.10 E-1	3.27 E-2	4.6 E-2
Root:shoot ratio	2.1[b]	1.38[c]	1[d]
Total biomass (kg)			
New pit model	10,673	2,436	1,440
Old pit model	29,462	6,727	3,974
Annual plant productivity (kg/yr)			
New pit model	3,443	1,023	1,440
Old pit model	9,504	2,825	3,974

a. Adapted from Arthur (1982).
b. EG&G (1984a).
c. Cline et al. (1982).
d. Adapted from McKenzie et al. (1982).

A.3. AIRBORNE TRANSPORT

The resuspension rate constant (see Section A.2.4) was used to estimate the source term for input into the AIRDOS-EPA code for all radionuclides except radon (see Section A.7). The annual rate constant (3.44 E-03 yr^{-1}) was multiplied by the surface soil concentration projected by the DOSTOMAN code to yield the annual release rate (Ci/yr).

The source term was modeled as a ground-level release. The area of the release was assumed to be a circle with a diameter of 200 m for the new pit model and 332 m for the old pit model.

The wind data used are shown in Table A-9. The ingestion and agriculture parameters used are those presented in the Environmental Assessment of the Fuel Processing Restoration (FPR EA) (DOE 1987). For those nuclides not included in the FPR EA, default parameters in the AIRDOS-EPA code were used. In order to compare the results with 40 CFR 61 criteria, the dose conversion factors in the EPA-RADRISK library were used.

The maximum airborne radionuclide concentration at the INEL Site boundary was determined, using the AIRDOS-EPA code, to be approximately 6 km south-southwest of the RWMC. The maximally exposed individual was assumed to reside at this location year-round. The doses received by this individual from airborne releases from the RWMC were projected during the periods of operations and institutional control.

The population dose was determined during the same time periods using the projected population within a 80-km radius. The population distribution shown in Figure 2-16 was increased using growth rates in the FPR EA. These growth rates are as follows: 1980-85, 1.87%; 1985-90, 1.22%; 1990-2000, 1.12%; 2000-2030, 0.56%; and 2030-3000, 1.00%.

A.4 GROUND WATER AND FOOD CHAIN TRANSPORT

A.4.1 Introduction

The PATHRAE-EPA computer code (Rogers and Hung 1987) was used to model the transport of radionuclides in the vadose zone and aquifer at the 'WMC. The scenario that was modeled included

- Leaching of radionuclides from the waste
- Transport of radionuclides in the vadose zone to the aquifer
- Transport of radionuclides in the aquifer to a well
- Transport of radionuclides in well water through the food chain to humans.

It was assumed that a hypothetical individual occupied a family farm adjacent to the well. During the operational and institutional control periods, this person was assumed to reside at the INEL Site boundary, 4800 m from the RWMC. During the post-institutional control period, this person was assumed to reside at the RWMC boundary. In either case, this hypothetical person was assumed to be the maximally exposed individual.

The water from the well was assumed to be used for human consumption, watering of stock, and irrigation. Therefore, the maximally exposed individual may be exposed to radionuclides through a variety of exposure pathways. The following exposure pathways were considered in this analysis:

- Water-human
- Water-plant-human
- Water-animal-human
- Water-animal-animal product-human
- Water-plant-animal-human
- Water-plant-animal-animal product-human.

A.4.2 Leaching and Release from the Waste

Leaching and the resulting release rate of radionuclides from the buried waste was determined by the equation

$$\text{Release rate} = Q\ \lambda_L\ . \qquad \text{(A-17)}$$

The leach rate, λ_L, and inventory available for release, Q, were determined using the DOSTOMAN computer code (see Section A.2). The maximum inventory contained in Compartments 7 and 8 of the DOSTOMAN near-field model was used to calculate the inventory for release. Because old pits, new pits, and soil vaults were modeled separately, each area had a different inventory available for release (see Table A-19). Leach rates were element-specific and are contained in Table A-20.

A.4.3 Transport in the Vadose Zone

PATHRAE-EPA has the capability to calculate the vertical water velocity in the vadose zone. This capability was not used in this analysis because of the complex hydrogeology of the RWMC. Instead, the computer code FLASH was used to determine the vertical water velocity (V_w), which was then used as input to PATHRAE-EPA (see Section A.5). However, PATHRAE-EPA was used to model radionuclide transport in the vadose zone. This was accomplished by first determining the retardation, R, in the vadose zone

$$R = 1 + \frac{d_s\ K_d}{p_s\ S} \qquad \text{(A-18)}$$

where

p_s = the effective soil porosity

S = the fraction of saturation

Table A-19. Maximum inventory available for ground water transport from the RWMC[a]

Radionuclide	New Pits (Ci)	Old Pits (Ci)	Soil Vaults (Ci)
Pu-238	0.49	3.5	--
Pu-239	5.9	48	1.1
Pu-240	0.58	0.079	0.14
Am-241	5.7	0.0023	--
Ra-226	26	7.1	--
Th-230	0.18	0.15	--
U-234	0.22	1.1	--
U-238	19	15	--

a. DOSTOMAN (see Section A.2).

Table A-20. Radionuclide distribution coefficients and leach rates[a]

Element	Leach Rate (1/yr)	Vertical K_d (mL/g)	Aquifer K_d (mL/g)
Po	2.48 E-4	1.0	1.0
Bi	2.51 E-5	10	10
Pb	2.51 E-5	10	10
Ra	5.02 E-5	5.0	5.0
Th	2.51 E-6	100	100
Pa	2.51 E-6	100	100
U	2.51 E-6	100	100
Pu	1.26 E-6	200	200
Am	3.59 E-6	70	70
Ac	2.51 E-6	100	100
Np	5.02 E-5	5.0	5.0

a. EG&G (1984a) and DOSTOMAN (see Section A.2).

d_s = the bulk density of the soil

K_d = the distribution coefficient for the radionuclide of interest.

The K_ds are element-specific and are contained in Table A-20. The other parameters are contained in Table A-21.

After the retardation is determined, the radionuclide velocity (V_r) is determined

$$V_r = \frac{V_w}{R} \ . \qquad \text{(A-19)}$$

A.4.3 Transport in the Aquifer

The concentration of each radionuclide in the well water at time t is determined by first calculating the fraction of the inventory (f_o) that arrives at the well at time t

$$f_o = \frac{1}{N} \sum_{j=1}^{N} [F_j(t) - F_j(t-1/\lambda_L)] \qquad \text{(A-20)}$$

where

N = number of spatial integration mesh points over waste source

t = calendar time (yr)

$F_j(t)$ = 0.5 U(t) [erfc (z-) + exp (d_j) erfc (z+)]

erf(z) = error function of z

erfc(z) = complementary error function of z

U(t) = unit step function:

Table A-21. Miscellaneous parameters used in PATHRAE-EPA

Parameter	Value	Reference
Density of aquifer	1900 kg/m^3	EGG-WM-6523
Density of waste	1500 kg/m^3	EGG-WM-6523
Longitudinal dispersivity	91 m	EGG-WM-6523
Vertical water velocity	0.18 m/yr	Section A.4
Ground water velocity	570 m/yr	This study
Porosity of aquifer	0.10	EGG-WM-6523
Saturation	0.50	Section A.4
Percolation rate	0.011 m/yr	Section A.4
Distance from aquifer to waste	176 m	Section A.1.1
Thickness of aquifer	76 m	Section A.1.1
Erosion rate	8.6 E-4 m/yr	This study
Fraction of food grown onsite	0.50	DOE/EA-0306
Time-weighted average dust loading	5.53 E-8 kg/m^3	EGG-WM-6523
Adult breathing rate	8030 m^3/yr	DOE/EA-0306
Agricultural productivity for pasture grass	0.04 kg/m^2	EPA 520/1-87-012-1
Agricultural productivity for vegetation	0.76 kg/m^2	EPA 520/1-87-012-1
Weathering rate constant	0.0021 h^{-1}	DOE/EA-0306
Irrigation time - pasture grass	720 h	EPA 520/1-87-012-1
Irrigation time - other vegetation	1440 h	EPA 520/1-87-012-1
Delay time - pasture grass	0 h	EPA 520/1-87-012-1
Delay time - stored feed	2160 h	EPA 520/1-87-012-1
Delay time - leafy vegetables	24 h	EPA 520/1-87-012-1
Delay time - produce	1440 h	EPA 520/1-87-012-1
Delay time - milk	48 h	EPA 520/1-87-012-1
Delay time - meat	480 h	EPA 520/1-87-012-1
Fraction of year animals graze on pasture grass	0.47	EPA 520/1-87-012-1
Fraction of animal feed that is pasture grass	1.0	EPA 520/1-87-012-1
Amount of feed consumed by cattle	50 kg/d	EPA 520/1-87-012-1
Amount of water consumed by milk cows	60 L/d	EPA 520/1-87-012-1
Amount of water consumed by beef cattle	50 L/d	EPA 520/1-87-012-1
Fraction of year crops irrigated	0.114	This study
Irrigation rate	0.24 L/m^2-h	This study
Human uptake - leafy vegetables	16.5 kg/yr	EPA 520/1-87-012-1
Human uptake - produce	94.2 kg/yr	EPA 520/1-87-012-1
Human uptake - milk	122.7 L/yr	EPA 520/1-87-012-1
Human uptake - meat	61.6 kg/yr	EPA 520/1-87-012-1
Human uptake - water	467.9 L/yr	EPA 520/1-87-012-1

$$z^{\pm} = \frac{\sqrt{d_j}\,[1 \pm t/(Rt_{wj})]}{2\sqrt{t/(Rt_{wj})}}$$

R = retardation in the aquifer = $1 + d/p\ K_d$

K_d = distribution coefficient in the aquifer

d = aquifer density

p = aquifer porosity

d_j = distance from sector center to access location, divided by the dispersivity

t_{wj} = water travel time from sector center to access location (yr).

The quantity f_o accounts for retardation in the aquifer. The aquifer K_ds are contained in Table A-20.

The aquifer dilution flow rate (q_w) is then determined

$$q_w = W\ L\ V_a\ P \qquad \text{(A-21)}$$

where

W = width of waste pit perpendicular to aquifer flow (m)

L = thickness of aquifer (m)

V_a = interstitial horizontal aquifer velocity (m/yr)

P = porosity of the aquifer.

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The radionuclide concentration (with units of Ci/m^3) is given by:

$$\frac{Q \lambda_L f_o}{q_w} . \qquad \text{(A-22)}$$

Additional detail on this methodology may be found in the PATHRAE-EPA model documentation (Rogers and Hung 1987).

A.4.5 Food Chain Transport

Radionuclides contained in well water were assumed to be transferred through the food chain to human receptors. This transfer can occur through the following means:

- Human consumption of contaminated well water
- Watering of stock using contaminated well water
- Irrigation of plants using contaminated well water.

A.4.5.1 Direct Human Consumption.

Given that the concentration of a radionuclide in well water (C_w) is known, the quantity of the radionuclide ingested through the drinking of contaminated well water is given by

$$C_w U_{water} . \qquad \text{(A-23)}$$

In this equation, U_{water} represents the human consumption rate of water (see Table A-21).

A.4.5.2 Watering of Stock.

If the concentration of a radionuclide in well water is known, the quantity of the radionuclide ingested by an animal through the drinking of contaminated water is given by

$$C_w \, Q_w \, . \tag{A-24}$$

In this equation, Q_w represents the amount of water consumed by either beef cattle or milk cows (see Table A-21).

To determine the quantity of a radionuclide transferred from the animal's feed (in this case, water) to an animal product, a transfer coefficient is typically used. Transfer to two animal products was modeled: transfer to meat and transfer to milk. The quantity of transferred to meat is given by

$$C_w \, Q_w \, F_f \, . \tag{A-25}$$

The quantity transferred to milk is given by

$$C_w \, Q_w \, F_m \, . \tag{A-26}$$

The quantity of a radionuclide consumed by humans through ingestion of meat and milk is given by

$$C_w \, Q_w \, F_f \, U_{meat} \tag{A-27}$$

and

$$C_w \, Q_w \, F_m \, U_{milk} \, . \tag{A-28}$$

The terms F_f and F_m are the meat and milk transfer coefficients, respectively. Values for F_f and F_m are element-specific and are given in Table A-22. U_{meat} and U_{milk} are the human meat and milk consumption rates, respectively (see Table A-21).

A.4.5.3 Irrigation of Plants.

If contaminated well water is used for the irrigation of plants, the rate at which radionuclides are sprayed on to plants is given by

$$I_r = C_w W_I \tag{A-29}$$

where

I_r = radionuclide application rate (pCi/m^2-h)

W_I = irrigation rate 1/m^2-h)

C_w = radionuclide concentration in irrigation water (pCi/1

Table A-22. Radionuclide transfer coefficients[a]

Element	Ingestion-to-Milk (d/1)	Ingestion-to-Beef (d/kg)
Po	3.5E-4	9.5E-5
Bi	5.0E-4	4.0E-4
Pb	2.5E-4	3.0E-4
Ra	4.5E-4	2.5E-4
Th	5.0E-6	6.0E-6
Pa	5.0E-6	1.0E-5
U	6.0E-4	2.0E-4
Pu	1.0E-7	5.0E-7
Am	4.0E-7	3.5E-6
Ac	2.0E-5	2.5E-5
Np	5.0E-6	5.5E-5

a. Baes et al. (1984).

The radionuclide concentration (C_v) in and on vegetation that has been contaminated by this irrigation water is given by

$$C_v = \left[\frac{I_r \;\; f_R \,[1 - \exp(-\lambda_e t_w)]}{Y_v \, \lambda_e} + \frac{B \; CSP \; f_I}{P} \right] \exp(-\lambda t_h) \qquad \text{(A-30)}$$

where

f_R = fraction of deposited activity retained on vegetation

λ_e = weathering rate constant

t_w = irrigation time

Y_v = agricultural productivity [kg(dry weight)/m^2]

B = concentration ratio for soil-to-plant uptake (dry weight basis)

CSP = time average value of soil radionuclide concentration assuming a steady deposition rate

P = surface density of soil [kg(dry weight)/m^2]

f_I = fraction of year irrigation occurs

t_h = time interval between harvest and consumption of food.

Values for B are element-specific and are found in Table A-23. The values for most of the other parameters are found in Table A-21.

Table A-23. Concentration ratios for soil-to-plant uptake[a]

Element	Concentration Ratio for Vegetative Portions of Plants (Dry Weight)	Concentration Ratio for Nonvegetative Portions of Plants (Dry Weight)
Po	0.0025	4.0E-4
Bi	0.035	0.0050
Pb	0.045	0.0090
Ra	0.015	0.0015
Th	8.5E-4	8.5E-5
Pa	0.0025	2.5E-4
U	0.0085	0.0040
Pu	4.5E-4	4.5E-5
Am	0.0055	2.5E-4
Ac	0.0035	3.5E-4
Np	0.10	0.010

a. Baes et al. (1984).

This equation is used to estimate the radionuclide concentrations of produce and leafy vegetables consumed by humans and in pasture grass (C_p) and stored feed (C_s) consumed by milk cows and beef cattle.

The amount of a radionuclide ingested by a human as a result of eating contaminated produce or leafy vegetables is given by

$$C_v \, U_{leafy\ vegetables} \qquad \text{(A-31)}$$

and

$$C_v \, U_{produce} \,. \qquad \text{(A-32)}$$

$U_{leafy\ vegetables}$ and $U_{produce}$ are the human leafy vegetable and produce consumption rates, respectively (see Table A-21).

The concentration of each radionuclide in animal forage or feed (C_f) is given by

$$C_f = f_p f_s C_p + (1 - f_p f_s) C_s \qquad \text{(A-33)}$$

where

C_p = radionuclide concentration on pasture grass

C_s = radionuclide concentration on stored feed

f_p = fraction of the year that animals graze on pasture

f_s fraction of daily feed that is pasture grass when the animals graze on pasture.

The radionuclide concentration in meat (C_F) and milk (C_M) is again estimated using transfer coefficients

$$C_F = C_f \, Q_f \, F_f \exp(-\lambda t_s) \qquad \text{(A-34)}$$

and

$$C_M = C_f \, Q_f \, F_m \exp(-\lambda t_f) \qquad \text{(A-35)}$$

where

t_s = the time interval between slaughter and consumption of meat

t_f = the time between milking and the consumption of milk (see Table A-21).

The quantity of a radionuclide consumed by humans through the ingestion of meat and milk is given by

$$C_F \, U_{meat} \tag{A-36}$$

and

$$C_M \, U_{milk} \, . \tag{A-37}$$

To arrive at the total quantity of material ingested, the contribution from all contaminated food stuffs must be considered. For example, the total human consumption of a particular radionuclide would be the sum of the amount consumed through direct human consumption, watering of stock, and irrigation of plants.

A.5 TRANSPORT IN THE VERTICAL UNSATURATED ZONE

A.5.1 Introduction

Understanding the physics of moisture movement in the vadose zone is a basic prerequisite for making rational assessments of contaminant migration from disposal sites at INEL (Baca and Walton 1988). Recent field studies (Laney et al. 1988) at the RWMC have provided some insight to the rates and directions of moisture movement in the surficial sediments. However, relatively little is presently known about the patterns and mechanics of moisture movement in the fractured-porous basalt. Consequently, any attempts to model water flow in the vadose zone will be highly theoretical in nature.

The objective of this preliminary unsaturated flow analysis is to estimate the average pore water velocity in the vadose zone. The pore water velocity is an important quantity because it determines the water travel time through the vadose zone, the advective mass flux of dissolved contaminants and solute arrival times at the underlying aquifer. Thus, the pore water velocity is a basic hydrologic parameter that is important to performance assessment calculations.

A one-dimensional, steady-state simulation of water flow through the vadose zone was performed. The simulation provided estimates of the soil moisture profile, hydraulic gradients, and fluid flux. In turn, the simulation results were used to obtain a representative estimate of the pore water velocity in the deep basalt. This preliminary estimate is likely to be updated in the near-term, as additional field and laboratory data become available.

A.5.2 Modeling Approach

The movement of moisture through the RWMC vadose zone was performed using a traditional continuum formulation for unsaturated flow expressed as Richard's equation (Kirkham and Powers 1972). The mathematical formulation for a one-dimensional system is given by

$$C(\psi)\frac{\partial\psi}{\partial t}=\frac{\partial}{\partial z}\left[K(\psi)\left(\frac{\partial\psi}{\partial z}-1\right)\right] \tag{A-38}$$

where ψ is the pressure head, $K(\psi)$ is the unsaturated hydraulic conductivity, and z is the vertical coordinate (cm). The water capacity $C(\psi)$ is given by

$$C(\psi)=\frac{\partial\theta}{\partial\psi} \tag{A-39}$$

where θ is the volumetric moisture content. This parameter is determined directly from the so-called "characteristics curve." The pressure head, ψ, is a negative quantity in unsaturated soils and positive in fully saturated soils. Because this analysis deals strictly with "unsaturated" conditions, it is convenient to drop the negative sign in the numerical and graphical results.

In using Richard's equation, the following basic assumptions have been made:

- The geologic medium exhibits a hydraulic behavior analogous to that of a porous continuum.
- Fluid flow is isothermal, single phase, and independent of air flow.
- The hydraulic properties of the medium are nonhysteretic.

Richard's equation has been used by soil physicists to model unsaturated flow in soils. The validity of this equation has been shown with comparisons to laboratory and field data.

The FLASH computer code was developed to solve the one- or two-dimensional formulation of Richard's equation. The FLASH computer code uses a finite element solution technique to solve the governing flow equation. This computer code is designed to handle

- Heterogeneous and anisotropic media
- Liquid and vapor phase water flow
- Isothermal or nonisothermal conditions
- Flow in porous media and/or discrete fractures.

For the one-dimensional case, the FLASH code computes the pressure head and moisture content profiles as a function of the infiltration rate at the surface, the geometry and hydraulic properties of the strata, and drainage conditions at the bottom of the vadose zone.

The FLASH computer code has been extensively verified and benchmark tested. The code has been verified using analytical solutions for boundary value problems and benchmarked against other unsaturated flow codes (Baca and Magnuson 1990). In addition, the FLASH computer code is maintained under a formalized software change control procedures. Thus, considerable confidence exists regarding its computational reliability.

A.5.3 Data and Assumptions

A relatively simple conceptual framework was used to represent the geologic setting at the RWMC. This simple conceptual model was based on a multilayer idealization composed of (a) thin layer of surficial sediments (3.5 m); (b) thick basalt layer (30.5 m); (c) sedimentary interbed (4 m); and (d) thick basalt layer (35.5 m). Only a portion of the vadose zone was considered in the physical representation; the upper 73.5 m of the vadose zone was modeled. Some of the important assumptions made in this conceptual framework are (a) fluid flow is through the rock matrix and not in the discrete fractures, (b) there are no perched water zones, and (c) the basalt layers exhibit a vesicular character.

Hydraulic properties such as saturated hydraulic conductivity, porosity, characteristic and relative permeability curves were obtained from the technical literature. For example, the hydraulic properties for the sediment layers were based on laboratory test data for sediment core samples from the RWMC reported by Laney et al. (1988) and Borghese (1988). Hydraulic properties for the basalt layers were taken from core test data reported by TerraTek (1988) and Johnson (1960) for INEL basalt; however, these data required an analysis using the theory of van Genuchten (1980) to estimate the characteristic and relative permeability curves. The primary hydraulic data used in the simulation is summarized in Table A-24.

The simulation of unsaturated flow was performed using (a) a constant surface flux of 1.15 cm/yr and (b) free drainage flux at the bottom of the system. The surface flux was estimated by assuming the drainage rate to be 5% (Walton 1970) of the annual average precipitation of 23 cm/yr (EG&G 1984a). A finite element grid was setup to represent the 73.5 m portion of the geologic section. The FLASH computer code was run in a time-dependent mode until the results converged to steady-state.

A.5.4 Summary of Results

The steady-state pore water velocity is a function of the Darcy flux and moisture content. For this case, the velocity (V_p) can be computed directly from the equation

Table A-24. Saturated hydraulic conductivity and porosity

Strata	Saturated Hydraulic K (cm/s)	Porosity
Sediment	3.0 E-4	0.28
Basalt	4.3 E-3	0.12

$$v_p = \frac{q}{\theta} \qquad \text{(A-40)}$$

where

q = Darcy fluid flux

θ = volumetric moisture content.

At steady-state, the Darcy flux is exactly equal to the infiltration rate. In the unsaturated flow simulation, the infiltration rate was 1.15 cm/yr and saturation level (computed by FLASH) for the basalt was approximately 0.50. Using the fact that volumetric moisture content is equal to the saturation times the porosity, the pore water velocity is calculated as

$$v_p = \frac{1.15}{0.50 x 0.12} \doteq 19 cm/yr \qquad \text{(A-41)}$$

This calculation represents a best estimate for the pore water velocity. Using this velocity as average value for the vadose zone, it suggests a water travel time to the aquifer of about 950 yr. The pore water velocity is used as input to the PATHRAE-EPA computer code.

A.6 DOSES TO INTRUDERS

A.6.1 Introduction

Three types of inadvertent intruder scenarios were evaluated in this analysis:

- Intruder-drilling
- Intruder-construction
- Intruder-agriculture.

The intruder-drilling and intruder-construction scenarios were used to evaluate compliance with the 500 mrem acute exposure criterion in DOE Order 5820.2A. The intruder-agriculture scenario was used to evaluate compliance with the 100 mrem/yr continuous exposure criterion in DOE Order 5820.2A. These scenarios were comparable to the scenarios developed and used by the U.S. Nuclear Regulatory Commission in 10 CFR 61 to evaluate the land disposal of radioactive waste (NRC 1981, NRC 1982, Oztunali and Roles 1986, Kennedy and Peloquin 1988).

For the new pits and old pits, the intruder-construction and intruder-agriculture scenarios were evaluated. For the soil vaults, the intruder-drilling and intruder-agriculture scenarios were evaluated. The entire inventory in each area was assumed to be available for intrusion, no depletion because of leaching was assumed (see Table A-25). In all cases, the doses resulting from intrusion include the contributions from the decay and ingrowth of radioactive progeny.

A.6.2 Intruder-Drilling

The intruder-drilling scenario assumes that an inadvertent intruder drills a well into the contents of a soil vault. The intruder was assumed to be exposed to contaminated drill cuttings in a mud pit for a period of 6 h. After this, the mud pit was assumed to be filled with soil and the intruder was exposed to the buried cuttings for an additional period of 494 h. The total exposure time for this scenario was 500 h.

Table A-25. Maximum inventory available for intrusion of the RWMC[a]

Radionuclide	New Pits (Ci)	Old Pits (Ci)	Soil Vaults (Ci)
Pu-238	1.1	6.4	--
Pu-239	5.9	48	1.1
Pu-240	0.60	0.079	0.14
Am-241	7.6	0.0023	--
Ra-226	32	8.6	--
Th-230	0.18	0.15	--
U-234	0.22	1.1	--
U-238	19	15	--
Co-60	2.0 E+5	9.1 E+5	b
Sr-90	6.4 E+3	1.0 E+4	3.4 E+4
Cs-137	4.4 E+4	2.7 E+4	2.6 E+5

a. DOSTOMAN (see Section A.2).
b. By the time intrusion can occur in year 2189, all Co-60 has decayed.

The diameter of the well was assumed to be 11 cm and the soil vault was assumed to be 3.05-m in thickness. The well was drilled to the aquifer, 176-m in depth. Therefore, 1.69 m^3 of clean cuttings and 2.93 E-2 m^3 of contaminated cuttings were brought to the surface. The mud pit was 2.4 x 2.7 m, the depth of contaminated cuttings was assumed to be 0.30 m. The total volume of contaminated cuttings in the bottom of the mud pit was 2.04 m^3. The total depth of the mud pit was 1.2 m, water filled an additional 0.61 m of the pit, overlying the contaminated cuttings. The exposed individual was assumed to stand adjacent to the pit for 6 h. After drilling, the pit was filled with 0.91 m of clean soil. The exposed individual was assumed to stand on the pit for 494 h.

Intrusion was assumed to take place 100 yr after site closure, which yields the maximum intruder dose. A total of 0.14 Ci of Sr-90, 1.2 Ci of Cs-137, 5.0 E-5 Ci of Pu-239, and 6.3 E-6 Ci of Pu-240 were assumed to be brought to the surface, along with associated radioactive progeny. External exposure was the only pathway used in this scenario. The external dose rate was calculated using the computer code MICROSHIELD.

A.6.3 Intruder-Construction

The intruder-construction scenario assumes that an inadvertent intruder excavates a basement in the waste. The intruder was assumed to be exposed to contaminated dust and contaminated waste in the bottom of the pit. No ingestion doses were postulated for this scenario. This scenario was applicable to new pits and old pits but not to soil vaults. Soil vaults have extra cover, which precludes intrusion by digging a basement. It should be noted that an "intruder-potato cellar" scenario was evaluated. Because potato cellars are relatively shallow, approximately 1 m, the intruder was able to contact more waste via basement excavation, assumed to be 3-m deep. Therefore, the "intruder-potato cellar" acute scenario was bounded by the "intruder-basement excavation" acute scenario.

The exposure time was assumed to be 500 h. For the inhalation pathway, the dust loading was 1.0 E-6 kg/m^3, representative of construction activities. For the external exposure pathway, the intruder was assumed to stand directly on the exposed waste. Therefore, no shielding, except for the self-shielding provided by the waste, was assumed. The excavation was assumed to be 10 x 10 m in area and 3-m in depth. Intrusion was assumed to take place at 3000 yr after site closure, which corresponds to the time when the cover is eroded to the maximum extent.

PATHRAE-EPA was used to model the inhalation pathway and MICROSHIELD was used to the external exposure pathway. The inventory was decayed and ingrown for a period of 3000 yr; therefore, the resulting doses reflect exposure to radioactive progeny.

A.6.4 Intruder-Agriculture

The intruder-agriculture scenario assumes that an inadvertent intruder first constructs a basement in the waste. The waste from the excavation was then assumed to be spread around the site and food grown in it. It was also assumed that a well is drilled onsite, which may result in contaminated water being used for direct human consumption, watering of stock, and irrigation. The intruder is exposed to contaminated dust, contaminated food stuffs, and from direct exposure to contaminated ground surfaces. The scenario was applicable to new pits, old pits, and soil vaults.

The exposure time was assumed to be 1 yr. For the dust inhalation pathway, the intruder was assumed to spend 24 h plowing and cultivating (1 mg/m^3 dust loading), 1200 h conducting other farm activities (0.07 mg/m^3 dust loading), and 7536 h conducting other activities, which result in a dust loading of 0.05 mg/m^3. This results in a time-weighted average dust loading of 5.53 E-8 kg/m^3.

Food was assumed to be grown onsite in a family garden that contains contaminated soil. Section A.4.5 provides details on the food chain transfer methodology used in PATHRAE-EPA and on parameters used in this analysis. This scenario accounts for food chain chain transfer via contaminated soil and contaminated irrigation water. The contaminated soil was assumed to be mixed and diluted with uncontaminated excavated soil and surface soil (Rogers et al. 1982). One half of the intruder's food was assumed to come from this onsite garden.

External exposures were calculated using the computer code MICROSHIELD. The intruder was assumed to be exposed to waste excavated from the basement and spread around a home site (2300 m^2). However, the excavated waste was diluted and mixed with uncontaminated soil during the excavation process. The intruder was assumed to be exposed to the contaminated soil for 2500 h/yr.

A.7 RADON FLUX CALCULATIONS

To calculate the release of radon, for input into the AIRDOS-EPA code, the radon flux methodology in DOE (1982) was used. The following description was obtained from that reference. The radon flux is first calculated assuming no cover over the buried waste (bare waste). Then the flux is calculated taking into account the soil covers.

For calculating the radon flux from bare waste, the flux equation given by Sears et al. (1975) was used.

$$J_o = 10{,}000\ D_e C_{Rn}\ (\lambda V/D_e)^{1/2} \qquad \text{(A-42)}$$

where

J_o = radon flux from bare waste ($pCi/m^2/s$)

10,000 = conversion factor (cm^2/m^2)

D_e = effective diffusion coefficient, defined below (cm^2/s)

C_{Rn} = concentration of radon-222 in the void spaces of the waste (pCi/cm^3)

λ = decay constant for radon-222 (2.097 E-6/s)

V = void fraction (fraction of total buried waste volume that is void).

The equation used to calculate the radon concentration C_{Rn} is as follows (Sears et al. 1975):

$$C_{Rn} = \frac{EC_{Ra}}{V} \qquad \text{(A-43)}$$

where

E = emanating power

C_{Ra} = radium-226 concentration in the waste (pCi/cm^3).

For calculations of C_{Rn} by Equation (A-43), the value of E was taken to be 0.03, which is close to the high-range value found for mill tailings (Rogers et al. 1980). The value of V was taken to be 0.4, also based on mill tailings values (Sears et al. 1975).

Some values of the diffusion coefficient D of radon in the air spaces of various media are shown in Table A-26. The diffusion coefficient is often expressed as an effective diffusion coefficient D_e as in Equation (A-42), by correcting for the fraction of the unit volume that is void, V. Thus, $D_e = VD$. It was assumed that the deteriorated buried waste would be similar in diffusion properties to the detrital granite deposits and the Yucca Flats soil shown in Table A-26. Thus, a diffusion coefficient D_e/V of 0.03 cm^2/s was used in Equation (A-42) for calculating the flux from the bare waste.

To calculate the radon flux through the soil cover, the equation of Nielsen and Rogers (1980) and Rogers et al. (1980) was used.

$$J = J_o f_s \exp(-\alpha_s x_s) \qquad (A\text{-}44)$$

where

J = flux from the covered waste ($pCi/m^2/s$)

J_o = flux from bare waste ($pCi/m^2/s$)

f_s = correction factors for the soil cover (f_s = 0.86) (Nielsen and Rogers 1980)

Table A-26. Diffusion coefficients for radon in air spaces of various media

Medium	Diffusion Coefficient, D cm^2/s
Building sand	0.054[a]
Eluvial-detrital deposits of granite	0.015[a]
Alluvium virgin soil at Yucca Flats	0.036[b]
Topsoil	0.036[c]
Loams	0.008[a]
Clay	0.001[c]

a. Tanner (1964).
b. Kraner et al. (1964).
c. Nielsen and Rogers (1980).

α_s = $(\lambda V/D_e)_s^{1/2}$ for soil (s), where λ, V, and D_e have been previously defined (/cm)

x_s = thicknesses of soil (x_s) covers (cm).

Values of D_e/V for soil and clay were taken to be 0.025 and 0.001 cm/s, respectively (Nielsen and Rogers 1980).

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APPENDIX B

DESCRIPTION OF COMPUTER CODES USED IN THE RWMC PERFORMANCE ASSESSMENT ANALYSES

CONTENTS

APPENDIX B

DESCRIPTION OF COMPUTER CODES USED IN THE RWMC PERFORMANCE ASSESSMENT ANALYSES

This Appendix provides a brief description of computer codes used for the analyses supporting the RWMC performance assessment.

B.1 DOSTOMAN

This code (Root 1981) was used to implement the conceptual model of radionuclide transport at the RWMC site. DOSTOMAN was developed at Savannah River Laboratory for estimating radiological doses from operation of a burial ground for solid radioactive waste. It has been verified and partially validated by the Savannah River Laboratory. It was selected for use at the RWMC after an extensive technical review of several codes, conducted in 1982 (Shuman et al. 1985). It is a simple compartmental model code. Using site-specific data to calculate appropriate transfer rate constants, DOSTOMAN calculates the transfer of radionuclides between environmental compartments. Data required to run the code include all factors that influence the rate of movement of radionuclides in the environment. Such factors are accounted for through the use of transfer coefficients. DOSTOMAN output values from were input to AIRDOS-EPA for the calculation of offsite doses; DOSTOMAN output was used directly in the calculation of the intruder doses.

B.2 AIRDOS-EPA

This code (Moore et al. 1979) was designed to estimate air dispersion of radionuclides and radiological doses to man via inhalation, ingestion of meat, milk, and vegetables, and external irradiation (cloud immersion and exposure to contaminated ground surfaces). It is approved by the EPA for use in demonstrating compliance with 40 CFR 61. DOE requires that an EPA-approved code be used to demonstrate compliance with 40 CFR 61 (DOE Order 5400.5). The code uses a modified Gaussian plume equation to estimate horizontal and vertical dispersion of released radionuclides. Radionuclide concentrations in meat, milk, and fresh produce consumed by humans are estimated by coupling the output of the atmospheric transport models with Regulatory Guide 1.109 food chain models. The code may be run to estimate the highest individual dose in the assessment area or the collective population dose, using the RADRISK data base of dose-conversion factors (Dunning et al. 1980). Alternately, the user may input other dose conversion factors. For the calculation of doses because of the RWMC, output from DOSTOMAN (radionuclide concentrations in various environmental compartments) was input to the AIRDOS-EPA code for the maximum individual dose and the population dose.

B.3 PATHRAE-EPA

The PATHRAE-EPA code can be used for the calculation of the multiple pathway transport of radionuclides and the resulting potential impact to humans as a result of land disposal of radioactive wastes. PATHRAE-EPA can be used to calculate maximum annual EDE to a critical population group and to an offsite individual at risk. Maximum annual doses are calculated to workers during disposal operations, to offsite personnel after site closure, and to reclaimers and inadvertent intruders after site closure. The offsite pathways include ground water transport to a river and to a well, surface erosion, disposal facility overflow, and atmospheric transport. The onsite pathways of concern arise principally from worker doses during operations and from postclosure site reclamation and intruder activities such as living growing edible vegetation onsite and drilling wells for irrigation and/or drinking water.

B.4 MICROSHIELD 3.0

MICORSHIELD 3.0 is a PC version of ISOSHLD, which is a computer code that performs gamma ray shielding calculations for radioactive sources with a wide variety of source and shield configurations. Attenuation calculations are performed by point kernel integration; i.e., the dose at the exposure point is the contribution from a large number of point sources. A numerical integration is carried out over the source volume to obtain the total dose. Buildup factors are used and are calculated by the code based on the number of mean free paths of material between the source and exposure point locations, the effective atomic number of a particular shield region, and the point isotropic NDA buildup data available as Taylor coefficients in the effective atomic number range of 4 to 82. For most problems the user need only supply (a) the geometry and material composition of the source and of the shields and (b) the thicknesses and distances involved. Other data needed to complete the calculations are contained in data libraries used by the code.

B.5 FLASH

The vertical one-dimensional flow and contaminant transport modeling for the subsurface environment at the RWMC was performed using a general two-dimensional model called FLASH. This code was developed at the INEL, specifically for the RWMC subsurface environment. The code was used to calculate the steady state matric potential distribution and moisture flow velocities given the appropriate material type geometries and boundary conditions. FLASH uses a Petrov-Galerkin finite element method for solving Richard's equations for unsaturated flow in porous media. The specific input requirements of the user are the material types and depths, flux rates, and contaminant concentrations. Values for two RWMC material types are available; different material types can also be used. The output from FLASH, moisture content level and Darcian velocity, was used as input to the PATHRAE-EPA code.

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APPENDIX C

DATA QUALITY

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DATA QUALITY

In 1970, drilling was started to characterize the subsurface hydrology at the RWMC. Data quality was consistent with the state of the art at the time, but because of the pioneering nature of the work, detailed procedures and data quality standards were not available. At this time, data collection procedures did not use extensive contamination control technology.

In 1975, a task force was formed to review drilling procedures. Emphasis was placed on developing procedures that minimized external contamination during drilling and sample collection. This resulted in improved drilling and sample collection techniques.

Since 1985, data quality has increased because of more stringent quality control procedures, the use of more modern analytical techniques, refining of data collection methods, and the use of extensive contamination control technology. Detailed study plans and procedures are now in place to aid in current and future investigations.

The quality of the inventory data that has been collected over the years at the RWMC has continuously improved. Initially, records were collected, but individual radionuclides were not identified and the curie content was estimated, not measured. Improved radionuclide identification procedures have been put into place, which result in reasonably accurate estimates of container activity. In addition, data on physical and chemical characteristics are now collected. Waste management records have been computerized and incorporated into the RWMIS.

The burial records for the old pits are thought to exhibit a range of uncertainty of ±100%. The data for the new pits, having been collected on a container by container basis, are thought to exhibit a range of uncertainty of ±30%.

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