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Laboratory

Addendum to Radioactive Waste Management Complex Low-Level Waste Radiological Performance Assessment (EGG-WM-8773)

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EXECUTIVE SUMMARY

This report documents the projected impacts associated with the disposal of radioactive low-level radioactive waste (LLW) at the Idaho National Engineering Laboratory (INEL) Radioactive Waste Management Complex (RWMC). The impacts were compared with applicable U.S. Department of Energy (DOE) and U.S. Environmental Protection Agency (EPA) standards.

The LLW radiological performance assessment for the RWMC presents a comprehensive, systematic analysis of the long-term impacts of LLW disposal in an arid, near-surface environment. Occupational radiological doses and impacts of nonradioactive hazardous constituents are beyond the scope of this radiological performance assessment and will be considered in other assessments.

For the purpose of assessing the performance of LLW disposed of at the RWMC, three time periods are of concern:

1. The operational period, 1984 through 2020, during which radioactive waste is actively disposed of at the facility.

2. The institutional control period, 2021 through 2120, which follows site closure and during which periodic maintenance and monitoring activities are conducted. The facility is assumed to be closed, stabilized, and maintained but is still part of the INEL reservation and is fenced and patrolled.

3. The post-institutional control period, beginning in 2120, during which the facility is no longer maintained by the DOE and may be accessible to the public. Radiological impacts are presented for a period of 1000 years, the maximum time of compliance for DOE LLW performance assessments. Analyses were also carried out to the time of maximum potential impact.

Two receptor types were assessed. The first was a member of the public. During the operational and institutional control periods this individual resided at the INEL Site boundary. During the post-institutional control period, the member of the public resided 100 m from the RWMC Subsurface Disposal Area (SDA) boundary.

The second type of receptor evaluated was an intruder. This hypothetical receptor was assumed to inadvertently intrude onto the RWMC SDA during the post-institutional control period. Two general kinds of intruder scenarios were evaluated: chronic and acute. The chronic scenarios included a well-drilling scenario, a basement excavation scenario, a biointrusion scenario, and a radon scenario. These scenarios included the doses from ingestion of contaminated food, inhalation of contaminated air, and external exposure. The acute scenarios included a construction scenario and a well-drilling scenario. These scenarios included the doses from inhalation of contaminated air and external exposure. In both the acute and chronic scenarios, the inhalation and ingestion doses were evaluated using the GENII computer code and the external doses were evaluated using the MICROSHIELD computer code.

The performance assessment process consists of conceptual models that link radionuclide inventory, release (or source term), environmental transfer, and impact assessment (see Figure ES-1) and culminate in radiological doses to receptors. The waste inventory used in the performance assessment was derived from the Radioactive Waste Management Information System (RWMIS) and consists of the LLW buried since 1984 and LLW projected for future disposal through 2020. Transuranic (TRU) waste and LLW intermixed with TRU waste that was buried before 1984 were not included because they are planned for assessment by the Environmental Restoration Program. Where possible, site-specific data and parameters were used in the analyses.

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 near-surface soil particles from biointrusion and groundwater transport of radionuclides leached from buried waste. For this

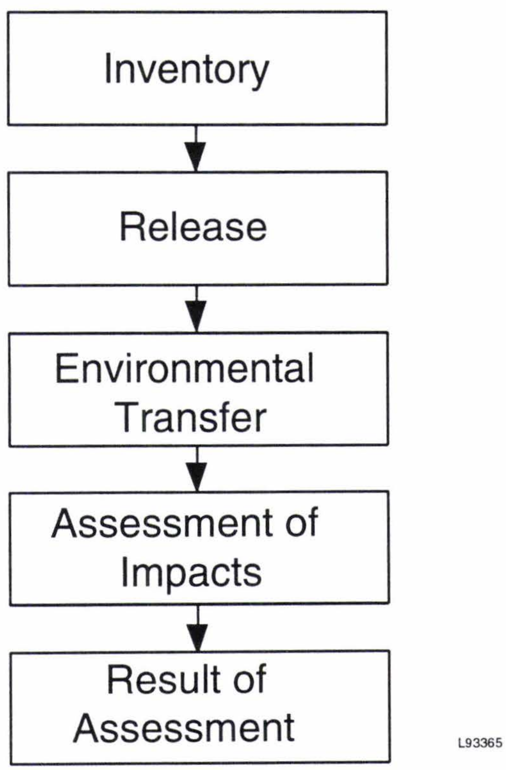

Figure ES-1. Performance assessment process.

reason, the performance assessment focuses on these two transport pathways for members of the public.

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

The source of radionuclides for airborne transport was biointrusion by plant roots and harvester ants. Radioactivity was brought to the surface by plant roots and harvester ants and dispersed downwind to a receptor. The GENII computer code was used to calculate the dose to the offsite receptor using annual average atmospheric dispersion conditions. Radioactive progeny were included in the calculations.

Impacts from the subsurface migration of radionuclides dissolved in groundwater were estimated using computer models that described release of radionuclides from the RWMC pits and soil vaults and transport in the unsaturated zone and aquifer. A site-specific source term model that accounted for the time-dependent waste emplacement rate, waste form type, container integrity, and variable infiltration rate, was coupled to the GWSCREEN code. For the purposes of simplifying the transport calculations, the RWMC was assumed to be an area source of uniform thickness. Radionuclides were assumed to be uniformly distributed throughout the volume, and the radionuclide release rate was assumed to be a first-order process. The GWSCREEN code was used to calculate transport in the unsaturated zone and aquifer. Concentrations were estimated in the aquifer at a hypothetical receptor well located 100 m downgradient from the edge of the RWMC active pits and at the INEL Site boundary. Decay and sorption were included throughout the model and reduced or slowed the migration of radionuclides in the subsurface.

This representation of subsurface transport is undoubtedly greatly simplified over the true processes that occur, reflecting the lack of definitive understanding of water movement in the subsurface beneath the RWMC. As a result, the predictive concentrations used in this radiological performance assessment are affected by the uncertainties regarding these processes. Site-specific data were used where available, and conservative assumptions were made where the processes were uncertain, such as the use of a constant infiltration rate that maximizes waste release and a relatively instantaneous water travel time through fractured basalt. The assumptions represent our best current professional opinion and are used as such. The results of this radiological performance assessment analyses are, thus, more likely to overestimate rather than underestimate doses. Periodic review and revision of this radiological performance assessment is planned to incorporate new data from future studies concerning subsurface water movement.

The results of the atmospheric, all-pathways, inadvertent intruder, and groundwater protection analyses are shown in Table ES-1, based on a maximum time of compliance of 1000 years. These results indicate that the atmospheric, all-pathways, chronic intrusion, and acute intrusion performance objectives will be met. However, the results also indicate that the 4 mrem/yr groundwater protection performance objective will be exceeded during the post-institutional control period. This is due primarily to C-14. For this reason, total inventory limits for C-14 and other important radionuclides were determined. These total inventory limits will help to ensure that the groundwater protection performance objectives are met.

Waste concentration limits were also determined for radionuclides that were found to be important in the inadvertent intruder analyses. These waste concentration limits will help to ensure that the chronic and acute intruder performance objectives are met. The combination of total inventory limits and waste concentration limits provides reasonable assurance that public health and safety will be protected.

If the time of compliance were extended past 1000 years to the time of maximum impact, the conclusions of the RWMC performance assessment would not be altered. In conjunction with the total inventory limits derived based on the 1000 year time of compliance, the performance objectives for the atmospheric, all-pathways, inadvertent intruder, and groundwater protection scenarios would still be met. This provides further assurance that public health and safety will be protected.

Table ES-1. Comparison of performance objectives and RWMC performance assessment results.

Performance objective	Standard	RWMC performance assessment result
Atmospheric (40 CFR 61 Subpart H)	10 mrem/yr EDE	0.0026 mrem/yr during operational and institutional control periods (entire INEL) 1.3 mrem/yr during post-institutional control period (entire INEL)
Atmospheric (40 CFR 61 Subpart Q)	20 pCi/m^2-s radon flux	0.059 pCi/m^2-s
All-pathways (DOE Order 5820.2A)	25 mrem/yr	0.57 mrem/yr during operational and institutional control periods 17 mrem/yr during post-institutional control period 7.3 mrem/yr (at 270,000 years)
Chronic inadvertent intrusion (DOE Order 5820.2A)	100 mrem/yr	Soil vaults (1000 year time of compliance) 66 mrem/yr (drilling) 5.2 mrem/yr (biointrusion) 0.087 mrem/yr (radon) 71 mrem/yr total Soil vaults (maximum impact) 66 mrem/yr (drilling) 5.2 mrem/yr (biointrusion) 13 mrem/yr (radon) 84 mrem/yr total Pits (1000 year time of compliance) 1.5 mrem/yr (drilling) 1.4 mrem/yr (biointrusion) 21 mrem/yr (radon) 24 mrem/yr total Pits (maximum impact) 35 mrem/yr (basement excavation) 1.4 mrem/yr (biointrusion) 35 mrem/yr (radon) 71 mrem/yr total

Table ES-1. (continued).

Performance objective	Standard	RWMC performance assessment result
Acute inadvertent intrusion (DOE Order 5820.2A)	500 mrem	1000 year time of compliance
		190 mrem (soil vaults)
		8.3 mrem (pits)
		Maximum impact
		190 mrem (soil vaults)
		11 mrem (pits)
Groundwater protection	4 mrem/yr EDE	0.19 mrem/yr during operational and institutional control periods
		5.6 mrem/yr during post-institutional control period
		Reduced to 4.0 mrem/yr during post-institutional control period using inventory limits
	20,000 pCi/L H-3	2,300 pCi/L during operational and institutional control periods
		980 pCi/L during post-institutional control period
	8 pCi/L Sr-90	1.7E-4 pCi/L during operational and institutional control periods
		6.7E-2 pCi/L during post-institutional control period
	5 pCi/L Ra-226 and Ra-228	4.9 pCi/L (at 270,000 years)
	15 pCi/L gross alpha	7.7 pCi/L (at 270,000 years)
	20 µg/L uranium	1.9 µg/L (at 270,000 years)

CONTENTS

FIGURES

TABLES

1. INTRODUCTION

1.1 Purpose and Scope

This report documents the projected radiological impacts associated with the disposal of low-level radioactive waste (LLW) at the Radioactive Waste Management Complex (RWMC) at the Idaho National Engineering Laboratory (INEL). The projected impacts are used to demonstrate compliance with applicable radiological dose criteria of the U.S. Department of Energy (DOE) and the U.S. Environmental Protection Agency (EPA) for protection of the public and the environment. The radiological performance assessment is being conducted to fulfill the requirements of DOE Order 5820.2A, "Radioactive Waste Management" (DOE 1988a).

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). Performance objectives include public and intruder radiological dose limits and drinking water radiological dose limits established by DOE orders and EPA requirements. In the context of this radiological performance assessment, the waste management system consists of the disposed LLW, the LLW disposal facility, and its environs. This radiological performance assessment is a tool used to predict the potential environmental consequences of the LLW disposal facility; its intent is to determine whether waste management activities will accomplish the goal of effectively containing LLW. This goal is accomplished if compliance with performance objectives is demonstrated in the performance assessment.

The LLW radiological performance assessment for the RWMC presents a comprehensive, systematic analysis of the long-term impacts of LLW disposal in an arid near-surface environment. Related assessment activities (e.g., safety assessments, risk 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 assessed in this document. Although occupational doses to workers are an important area of concern for facility operations, they are addressed by regulations and guidance different than those covering performance assessments. Furthermore, compliance with occupational criteria is not necessarily demonstrated by the type of calculations performed for radiological performance assessments. Additionally, this document excludes the potential impacts of chemical toxicity of radiological constituents and nonradiological hazardous constituents that may be in the waste.

Waste has been buried in the Subsurface Disposal Area (SDA) since 1952 in trenches, pits, and soil vault rows. LLW buried since 1984 and projected for the future is assessed in this report. Buried transuranic (TRU) waste, stored TRU waste, and buried commingled TRU waste and LLW are not included in the report. Although DOE Order 5820.2A applies only to LLW disposed of after September 26, 1988, LLW disposed of before this date was included in this radiological performance assessment. The Environmental Restoration Program at the INEL will assess waste buried in the SDA from 1952 through 1983 in accordance with the National Contingency Plan under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). The year 1983 was selected as the cutoff date for waste to be assessed under CERCLA because waste containing the hazardous materials mercury and cadmium was disposed of in the SDA as late as June 1983. Therefore, the trenches, pits, and soil vault rows that were open before this date could potentially contain mixed waste, which falls under the domain of the Environmental Restoration Program, and will be assessed under CERCLA.

Because it is impractical to remediate only part of a pit or soil vault row, all waste buried in Pit 16 and Soil Vault Row 13 will be assessed under CERCLA even though Pit 16 closed October 25, 1984, and Soil Vault Row 13 closed on December 21, 1984. Soil Vault Row 14 opened on October 16, 1984, and Pit 17 opened on May 5, 1984; they should only contain LLW, not the mixed waste described previously. Therefore, the inventory analyzed in the performance assessment will begin with Soil Vault Row 14 and Pit 17. This provides an effective point of interface with the Environmental Restoration Program. This will ensure that all waste is accounted for either in the radiological performance assessment performed under DOE Order 5820.2A or in the baseline risk assessments performed under CERCLA.

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

1.2 General Description of the RWMC

The INEL is a DOE facility occupying approximately 2,315 km^2 of land in southeastern Idaho (see Figure 1-1). 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 for solid radioactive wastes at the INEL.

The RWMC provides a near surface disposal site for solid LLW generated almost exclusively by INEL activities. The RWMC opened in 1952 near the southwestern corner of the INEL Site (see Figure 1-1). The initial tract of land used as a burial ground for radioactive waste was 13 acres. This tract became the SDA and was later expanded to 97 acres. In 1970, the 58-acre 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 at the RWMC diverts runoff away from the facility.

Most of the LLW arrives at the RWMC packed in containers such as large wooden boxes with plastic liners. Incineration, compaction, melting, and sizing activities have been conducted on portions of the waste. Waste is buried in large pits that are excavated to a depth of 9 m. After

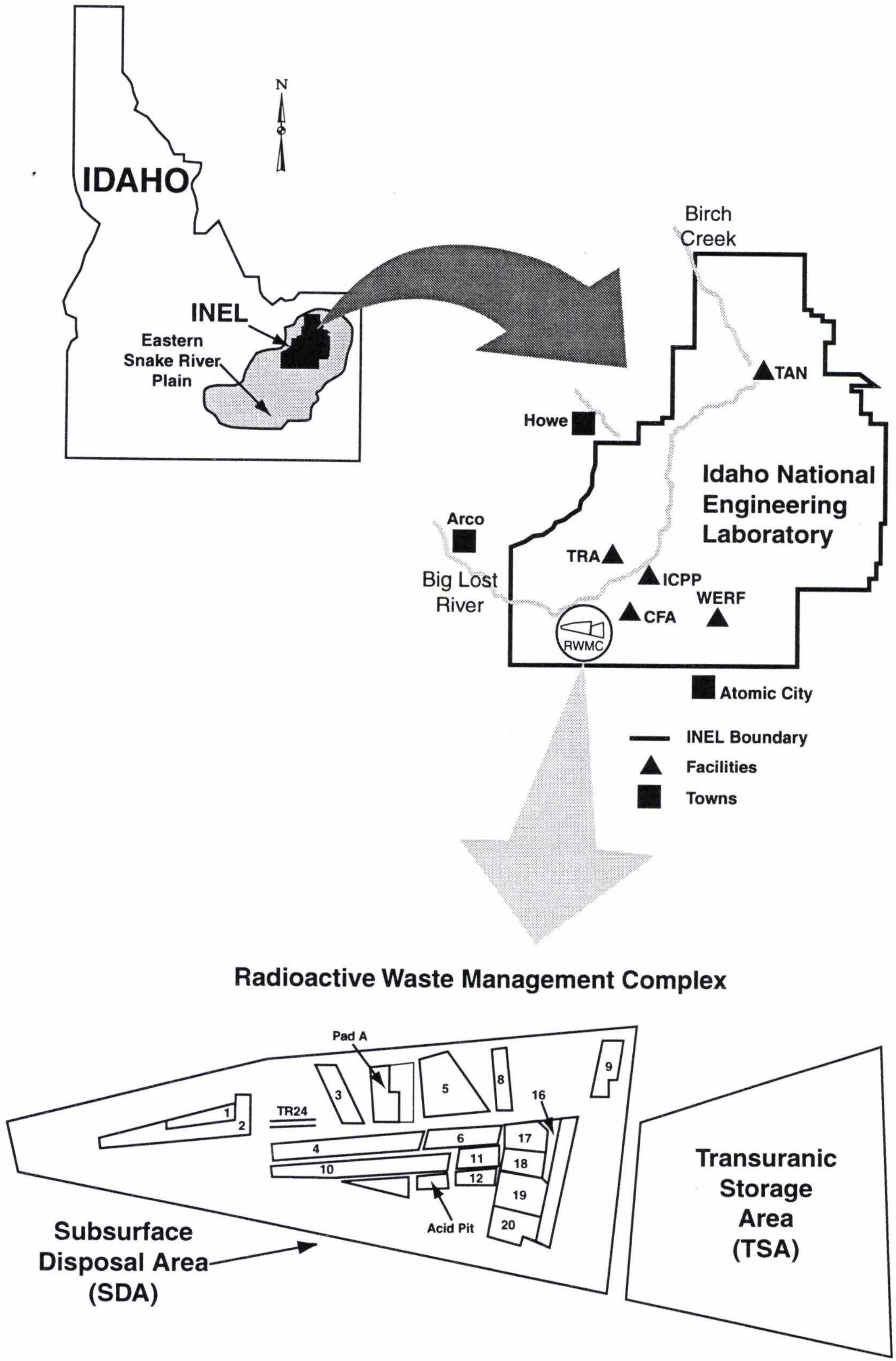

Figure 1-1. Overview of the INEL, RWMC, and SDA.

the waste is emplaced, it is covered with 1 to 2 m of soil. Small quantities of LLW with higher radiation levels are placed in cylindrical soil vaults.

LLW generated at the INEL primarily consists of contaminated or potentially contaminated protective clothing, paper, rags, packing material, glassware, tubing, and other general use items. Also included is contaminated equipment (such as gloveboxes and ventilation ducts) and process waste (such as filter cartridges and sludges). These materials are either surface contaminated with radionuclides 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 LLW has an external exposure rate <500 mR/h at 0.9 m from the container surface.

Environmental surveillance programs are conducted onsite and offsite to monitor for any inadvertent release of radioactivity from the RWMC and the INEL.

1.3 Performance Objectives

For the purposes of determining which performance objectives are applicable for the LLW analyzed in the RWMC radiological performance assessment, it should be noted that the LLW does not contain nonradiological hazardous constituents and is not mixed LLW, TRU waste, high-level waste, or spent nuclear fuel.

The specific performance objectives for LLW disposal at the RWMC are contained in DOE Order 5820.2A:

- Protect public health and safety in accordance with standards specified in applicable EH orders and other DOE orders.

- Assure that external exposure to the waste and concentrations of radioactive material that may be released into surface water, groundwater, 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 which limits the EDE to 10 mrem/yr. Reasonable effort should be made to maintain releases of radioactivity in effluents to the general environment to levels as low as reasonably achievable (ALARA).

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

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

This section discusses (a) the performance objective for releases to the atmosphere, (b) the impacts of sole source aquifer designation on the performance objectives, (c) the INEL Federal Facility Agreement and Consent Order, (d) the performance objective for groundwater protection, and (e) community water systems.

1.3.1 Releases to the Atmosphere

Subpart H of 40 CFR 61, "National Emission Standards for Emissions of Radionuclides Other Than Radon From Department of Energy Facilities," contains radiation dose standards for members of the public resulting from airborne effluents from DOE facilities. The performance objective contained in 40 CFR 61 Subpart H is an EDE of 10 mrem/yr through the atmospheric pathway for radionuclides other than radon. For radon, Subpart Q of 40 CFR 61, "National Emission Standards for Radon Emissions From Department of Energy Facilities," contains a radon flux standard of 20 pCi/m^2-s.

It is not clear whether the performance objective contained in 40 CFR 61 Subpart H as implemented in DOE Order 5820.2A applies just to the LLW disposal facility or to the entire INEL. The EPA, Region 10 approach to 40 CFR 61 Subpart H compliance considers the entire INEL in the 10 mrem/yr compliance determination. However, in *Clarification of Requirements of DOE Order 5820.2A*,[a] it is specifically stated that "the performance objectives are intended to apply to each LLW facility on a reservation rather than to the reservation as a whole." Because of these inconsistent positions, it was decided to evaluate atmospheric emissions on a single facility basis and on an INEL-wide basis, using the present levels of INEL emissions as a baseline, and a performance objective of 10 mrem/yr. No attempt was made to derive emission estimates for new facilities that may be built at the INEL or for projects that may take place in the future.

1.3.2 Sole Source Aquifer Designation

The Eastern Snake River Plain Aquifer has been designated by the EPA as a sole source aquifer (EPA 1991a). After sole source designation, any Federal financial assistance projects are subject to EPA to ensure that these projects do not contaminate the aquifer as to create a significant hazard to public health. However, the INEL is operated by direct Federal funding and it is not funded through Federal financial assistance projects. Therefore, the designation of the Eastern Snake River Plain Aquifer as a sole source aquifer has no regulatory impact on the performance objectives used in the RWMC performance assessment.

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a. Letter from T. B. Hindman to Distribution, February 28, 1989, and letter from T. B. Hindman to P. Saxman et al., March 28, 1989. These letters are contained in Dodge et al. (1989).

1.3.3 Federal Facility Agreement and Consent Order

In 1989, the INEL was added to the EPA National Priorities List of Superfund sites. In 1991, a Federal Facility Agreement and Consent Order (FFA/CO) was signed by the DOE Idaho Operations Office (DOE-ID), the EPA, and the Idaho Department of Health and Welfare (IDHW).

The Action Plan for the FFA/CO organized the INEL into 10 Waste Area Groups (WAGs). The RWMC was designated as WAG-7; the RWMC contains 14 Operable Units (OUs). A comprehensive Remedial Investigation/Feasibility Study (RI/FS) is planned for the waste disposed in the RWMC from 1952 through 1993 (Becker et al. 1996). Forecast waste from 1994 through 2003 will be assessed as a sensitivity case. The work plan for the RI/FS (Becker et al. 1996) initially identifies applicable or relevant and appropriate requirements (ARARs) for the RWMC. Maximum contaminant levels (MCLs) for radionuclides from 40 CFR 141, "National Primary Drinking Water Regulations," are identified as potential ARARs.

In previous risk assessments conducted at the INEL as part of the FFA/CO, MCLs for radionuclides have also been used as ARARs for man-made beta particle and photon radioactivity, using a 2 L/d water consumption rate and the dose conversion factors in either DOE (1988b) or Federal Guidance Report No. 11 (Eckerman et al. 1988) (i.e., based on EDE, not total body dose). It should be noted that previous risk assessments have concentrated on OUs contaminated predominately with fission and activation products, not on OUs with significant actinide (i.e., uranium and plutonium) contamination. The ARARs for alpha emitting radionuclides at the RWMC will be determined as part of a phased process as remedial action alternatives appropriate for the site are identified.

1.3.4 Groundwater Protection

DOE Order 5820.2A does not specify what constitutes protection of groundwater resources and does not specify radiation dose or concentration limits that would constitute performance objectives for protection of groundwater. In the absence of specific performance objectives from DOE Order 5820.2A, guidance from DOE-HQ[b] was used to develop a site-specific groundwater protection performance objective. This guidance states that the performance objective should be based on (a) a legally applicable State or local law, regulation, or other legally applicable requirement for groundwater protection, or (b) a formal agreement with appropriate State or local officials applicable to groundwater protection. Six different options for the groundwater protection performance objective were evaluated.

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b. Letter from S. P. Cowan to J. T. Case, June 20, 1996, "Groundwater Compliance for the Low-Level Waste Radiological Performance Assessment for the Radioactive Waste Management Complex at the Idaho National Engineering Laboratory."

1.3.4.1 Option 1. In the first option, protection of groundwater would be defined by the performance objective specified in IDHW Rules, IDAPA 16.01.02, "Water Quality Standards and Wastewater Treatment Requirements." IDAPA 16.01.02.299, "Ground Water Quality Standards," states that the concentration of radioactive materials or radioactivity in potable water supplies shall not exceed the values listed in the 10 CFR Part 20, Appendix B, Table 2, Column 2 "Effluent Concentrations." These concentrations are equivalent to a radiation dose of 50 mrem/yr (EDE) based on a water consumption rate of 2 L/d.

1.3.4.2 Option 2. In the second option, protection of groundwater would be defined as compliance with the 25 mrem/yr (EDE) standard contained in DOE Order 5820.2A. Instead of being based solely on the consumption of drinking water, the evaluation of compliance would be based on all applicable exposure pathways (i.e., an "all-pathways" analysis).

1.3.4.3 Option 3. In the third option, the MCLs for radionuclides specified in 40 CFR 141 would be used as the performance objective for the protection of groundwater resources. The current standards, promulgated in 1976, include (a) a limit on concentration of 5 pCi/L for Ra-226 and Ra-228 combined, (b) a limit on concentration of 15 pCi/L for gross alpha particle activity, including Ra-226, but excluding radon and uranium, and (c) a limit on dose equivalent to the total body or any organ of 4 mrem/yr from beta particle and photon radioactivity from man-made radionuclides. The definition of man-made radionuclides excludes the beta-emitting progeny of Th-232, U-235, and U-238. In addition, the definition of gross alpha activity in 40 CFR 141 specifies that the gross alpha activity is to be inferred from measurements made from a dry sample. Therefore, any gaseous Rn-222 originally present in the sample would not be present when the sample was counted. Consequently, the short-lived alpha-emitting Rn-222 progeny Po-218 ($T½ = 3.05$ min) and Po-214 ($T½ = 164$ μsec) would also not be present and were excluded from the gross alpha activity. 40 CFR 141 also specifies that the concentrations that yield 4 mrem/yr should be calculated based on a water intake of 2 L/d and the 168-hour data listed in *Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and in Water for Occupational Exposure* (USDC 1963), except for H-3 and Sr-90, where the concentrations that yield 4 mrem/yr total body dose are specified to be 20,000 pCi/L and 8 pCi/L, respectively.

1.3.4.4 Option 4. In option 4, the current MCLs specified in 40 CFR 141 of 5 pCi/L for Ra-226 and Ra-228 (combined) and 15 pCi/L for gross alpha particle activity, including Ra-226, but excluding radon and uranium, would be retained. The 4 mrem/yr dose limit for beta particle and photon radioactivity from man-made radionuclides would also be retained, but the 4 mrem/yr would now be an EDE, not a total body dose. The EDE would be calculated using a water intake of 2 L/d and ICRP-30 dosimetry, as implemented in DOE (1988b), not using the ICRP-2 dosimetry that served as the basis for the data listed in Department of Commerce (1963). The concentrations that yield 4 mrem/yr total body dose specified in 40 CFR 141 of 20,000 pCi/L for H-3 and 8 pCi/L for Sr-90 would be retained.

1.3.4.5 Option 5. In the fifth option, the MCLs for radionuclides specified in the proposed revision to 40 CFR 141 (EPA 1991b) would be used as the performance objective for the protection of groundwater resources. The proposed standards include (a) separate concentration limits of 20 pCi/L for Ra-226 and Ra-228, (b) a limit on concentration of 20 μg/L for uranium, (c) a limit of 15 pCi/L for adjusted gross alpha particle activity, excluding Ra-226, uranium, and Rn-222, and (d) a dose limit of 4 mrem/yr (EDE) for beta particle and photon-emitting radionuclides, excluding Ra-228. Based on the Advance Notice of Proposed Rulemaking (EPA 1986), the definition of beta particle and photon emitting radionuclides would continue to exclude the beta-emitting progeny of Th-232, U-235, and U-238. ICRP-30 dosimetry, as implemented in DOE (1988b), would be used to calculate the EDE.[c] In the current MCLs, uranium is unregulated. The proposed concentration limit for uranium is based on the chemical toxicity in the kidney, not on the radiotoxicity, and corresponds to an activity concentration of 30 pCi/L for naturally occurring uranium with its normal isotopic abundances. The proposed standards also include a concentration limit of 300 pCi/L for Rn-222, but the Energy Policy Act of 1992 directs the EPA not to issue a standard for radon in drinking water at the present time.

1.3.4.6 Option 6. In option six, a dose limit of 4 mrem/yr (EDE) for all radionuclides would be used as the performance objective for the protection of groundwater resources. A water intake of 2 L/d and ICRP-30 dosimetry, as implemented in DOE (1988b), would be used to calculate the EDE.

1.3.4.7 Summary. The various groundwater protection performance objectives are summarized in Table 1-1. The selection of a site-specific groundwater protection performance objective for use in the RWMC performance assessment was based on guidance from DOE-HQ.[d] This guidance states that the performance objective should be based on (a) a legally applicable State or local law, regulation, or other legally applicable requirement for groundwater protection, or (b) a formal agreement with appropriate State or local officials applicable to groundwater protection. Although the INEL FFA/CO does not specifically address the issue of groundwater protection for LLW, risk assessments done as part of the FFA/CO have used MCLs as ARARs. Therefore, in the RWMC performance assessment, option 4 will be used as the groundwater protection performance objective (see Table 1-1); for uranium, a performance objective of 20 μg/L from option 5 will be used. This approach is consistent with the approach used in risk assessments done at the INEL as part of the FFA/CO, where MCLs are used as ARARs. It should be noted that for receptors near the RWMC after the end of institutional control, MCLs would be considered relevant and appropriate and would, therefore, apply before treatment, not after treatment at the point of use (EPA 1988).

c. In the Proposed Rule, ICRP-30 dosimetry as implemented in RADRISK was used.

d. Letter from S. P. Cowan to J. T. Case, June 20, 1996, "Groundwater Compliance for the Low-Level Waste Radiological Performance Assessment for the Radioactive Waste Management Complex at the Idaho National Engineering Laboratory."

Table 1-1. Summary of groundwater protection performance objective options.

Option	Total dose (mrem/yr)	Man-made beta-gamma dose (mrem/yr)	Gross alpha concentration (pCi/L)	Ra-226 and Ra-228 concentration (pCi/L)	Uranium concentration (μg/L)
1	50[a]	a,b	a,b	a,b	a,b
2	25[a]	a,b	a,b	a,b	a,b
3	--	4[c,h]	15[e,i]	5[d]	--
4	--	4[a,h]	15[e,i]	5[d]	--
5	--	4[a]	15[g,i]	20[f]	20
6	4[a]	a,b	a,b	a,b	a,b
Selection	--	4[a,h]	15[e]	5[d]	20

a. Based on ICRP-30 dosimetry.
b. Incorporated into total dose (EDE).
c. Based on ICRP-2 dosimetry.
d. Ra-226 and Ra-228, combined.
e. Excluding uranium and radon isotopes.
f. Ra-226 and Ra-228, separate.
g. Excluding Ra-226, uranium isotopes, and Rn-222.
h. For H-3 and Sr-90, the concentrations that yield 4 mrem/yr total body dose are specified to be 20,000 pCi/L and 8 pCi/L, respectively.
i. Excludes beta-gamma progeny of U-238, U-235, and Th-232.

The use of MCLs as the performance objective for groundwater protection is also consistent with the designation of the Eastern Snake River Plain Aquifer as a sole source aquifer. After designation as a sole source aquifer, Federal financial assistance projects are reviewed to ensure that the sole source aquifer is not contaminated as to create a significant hazard to public health. Using MCLs as the performance objective is consistent with not creating a significant hazard to public health.

1.3.5 Community Water Systems

The closest onsite community water system originates at the RWMC production wells, just to the north but upgradient of the RWMC. The closest offsite community water system is in Atomic City, which is about 21 km southeast of the RWMC, but offgradient. There are no community water system wells in the vicinity of the nearest INEL Site boundary, 5500 m downgradient.

The "National Primary Drinking Water Regulations" in 40 CFR 141 contain regulations that apply to radioactivity in community water systems (see §141.15 and §141.16). Public water systems provide piped water for human consumption and have at least 15 connections or regularly serve at least 25 people (§141.2); the category public water system is composed of community water systems and noncommunity water systems. Community water systems are public water systems that provide piped water for human consumption and have at least 15 connections used by year-round residents or regularly serve 25 year-round residents (§141.2). The regulations in §141.15 and §141.16 apply at the point of human consumption (i.e., at the tap, not in the groundwater). The IDHW Rules, IDAPA 16.01.08, "Idaho Rules for Public Drinking Water Systems," incorporate 40 CFR 141.15 and 141.16 by reference.

In the RWMC performance assessment, the groundwater protection performance objectives (see the discussion in Section 1.3.4.7) will also be used as the performance objective for radionuclides in community drinking water systems. This approach is consistent with the approach used in risk assessments done at the INEL as part of the FFA/CO. In addition, the groundwater protection analysis bounds the community water system analysis because (a) the performance objectives for groundwater protection and community water systems are identical, (b) the downgradient receptor locations for groundwater protection are closer to the RWMC than downgradient existing community water systems, and (c) the groundwater performance objectives apply before treatment, not after treatment at the point of use (i.e., at the tap).

1.4 Time Periods of Concern

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

- The operational period was assumed to last from 1984 to 2020, at which time the RWMC would be closed. Anticipated disposals of LLW through CY 2020 were included in the RWMC performance assessment to provide future flexibility because of uncertain funding levels needed to support developing a new disposal facility. The waste inventory includes the amount accumulated from 1984 through 1993 plus the amount projected to accumulate from 1994 through 2020.

- The period of institutional control was assumed to last for 100 years, from 2021 through 2120, during which time maintenance and surveillance monitoring of the RWMC would continue and no additional waste would be disposed. During this time, the INEL Site boundary would be maintained, restricting public access to the RWMC. A 100-year period of institutional control is consistent with the INEL *Comprehensive*

Facility and Land Use Plan (DOE 1996) and risk assessments done at the INEL as part of the FFA/CO.

- The post-institutional control period, beginning in the year 2120, is the period during which no maintenance or surveillance monitoring would occur. The INEL Site boundary would cease to exist, and the area near the RWMC would be available for unrestricted access and use by the public. The maximum time of compliance was 1000 years; however, analyses were made to the time of maximum potential impact.

1.5 Receptors

Two receptor types were assessed in this radiological performance assessment: (1) members of the public and (2) intruders. During the operational and institutional control periods, the member of the public resided at the INEL Site boundary, 5500 m downgradient from the RWMC. This receptor would be exposed to atmospheric releases from the RWMC and other INEL facilities, which have a performance objective of 10 mrem/yr. This receptor also would be exposed to radionuclides in contaminated groundwater through all applicable exposure pathways; the appropriate performance objective for this analysis is 25 mrem/yr. The groundwater protection performance objective would also apply at the INEL Site boundary during this time period. This approach is consistent with risk assessments done at the INEL as part of the FFA/CO, which evaluate residential scenarios only at the INEL Site boundary during the operational and institutional control periods.[e] During the operational and post-operational periods, the only onsite scenarios evaluated in risk assessments done as part of the FFA/CO are for workers; worker scenarios are beyond the scope of a performance assessment. For the groundwater scenarios at the INEL Site boundary, the contamination was mixed over 76 m, the effective thickness of the aquifer; more recent data indicate that the thickness of the aquifer may be greater, which would increase the mixing depth.

During the post-institutional control period, the member of the public resided 100 m from the edge of the LLW disposal pits. This receptor would be exposed to atmospheric releases from the RWMC and other INEL facilities, which have a performance objective of 10 mrem/yr. This receptor also would be exposed to radionuclides in contaminated groundwater through all applicable exposure pathways; the appropriate performance objective for this analysis is 25 mrem/yr. The groundwater protection performance objective (see Section 1.3.4.7) would now apply at 100 m from the edge of the LLW disposal pits during the post-institutional control time period. This approach is consistent with risk assessments done at the INEL as part of the FFA/CO, which evaluate residential scenarios near the RWMC boundary during the

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e. FFA/CO risk assessments at the INEL use the term post-operational period instead of institutional control period.

post-institutional control period.[f] For the groundwater scenarios at 100 m from the edge of the LLW disposal pits, the contamination was mixed over 12 m, based on the average well screen depth for drinking water wells drilled into the Snake River Plain Aquifer. This approach is also consistent with risk assessments done at the INEL as part of the FFA/CO.

The application of the all-pathways and groundwater protection performance objectives at the INEL Site boundary during the operational and institutional control periods and at 100 m from the edge of the waste during post-institutional control was based on guidance from DOE-HQ.[g] This guidance states that the performance objective should be based on (a) a legally applicable State or local law, regulation, or other legally applicable requirement for groundwater protection, or (b) a formal agreement with appropriate State or local officials applicable to groundwater protection. As stated previously, risk assessments done as part of the FFA/CO, an agreement between DOE-ID, the EPA, and the Idaho Department of Health and Welfare, evaluate residential scenarios at the INEL Site boundary during the operational and institutional control periods. The risk assessments do not evaluate onsite residential scenarios and do not apply MCLs as ARARs for onsite residents during the operational and institutional control periods. During post-institutional control, residential scenarios near the RWMC boundary are evaluated in risk assessments done as part of the FFA/CO; therefore, the receptor location was moved to 100 m from the edge of the waste during the post-institutional control period.

Intruder scenarios do not apply during the operational or institutional control periods because access to the RWMC would be restricted. During the post-institutional control period, the intruder was assumed to inadvertently intrude onto the LLW. Two general kinds of intruder scenarios were evaluated: (1) a chronic exposure scenario and (2) an acute exposure scenario. These scenarios were based on a maximum time of compliance of 1000 years. At 1000 years after closure, about 4 m of cover remains over the pits and soil vaults based on site-specific waste configurations and a site-specific erosion rate, so intrusion by a 3-m deep basement is not possible. Therefore, the acute and chronic intruder analyses are based on drilling a well through the waste, and an acute construction scenario and a chronic basement excavation scenario were not used to demonstrate compliance. In the acute well drilling scenario, the receptor was exposed to contaminated drill cuttings spread over the ground. In the chronic well drilling scenario, the receptor was exposed to contaminated drill cuttings spread over the ground and also obtained a portion of his food from farming at the RWMC. The intruder also was exposed to radon and its short-lived progeny that diffused through a basement foundation.

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f. FFA/CO risk assessments at the INEL use the term post 100-year institutional control period instead of post-institutional control period.

g. Letter from S. P. Cowan to J. T. Case, June 20, 1996, "Groundwater Compliance for the Low-Level Waste Radiological Performance Assessment for the Radioactive Waste Management Complex at the Idaho National Engineering Laboratory."

3.4 Pathways and Scenarios

Exposure pathways are the link between contaminated environmental media and the exposure of a receptor. Figure 3-20 summarizes the exposure pathways from LLW disposed of in the RWMC SDA. This diagram does not include processes that recycle radionuclides, such as plant senescence, because these processes tend to dilute the amount of radioactive material available for uptake when compared to direct uptake pathways.

Environmental monitoring has been performed at the RWMC since 1960, and special studies are also periodically conducted. The Radiological and Environmental Sciences Laboratory (RESL) conducts radioecological studies at and around the RWMC. Many of the RESL studies have focused on radionuclide transport via biota. The results of the monitoring and special studies indicate that the greatest potential for the transport of radionuclides to a member of the public is via atmospheric transport of resuspended soil and groundwater transport of radionuclides leached from buried waste. Therefore, this performance assessment focuses on these two routes of exposure for dose assessments for members of the public. For intruders, direct exposure to the waste is assumed, either through excavation or drilling. For excavation and drilling, pathways are evaluated and doses are calculated from ingestion, inhalation, and external exposure to radioactive material.

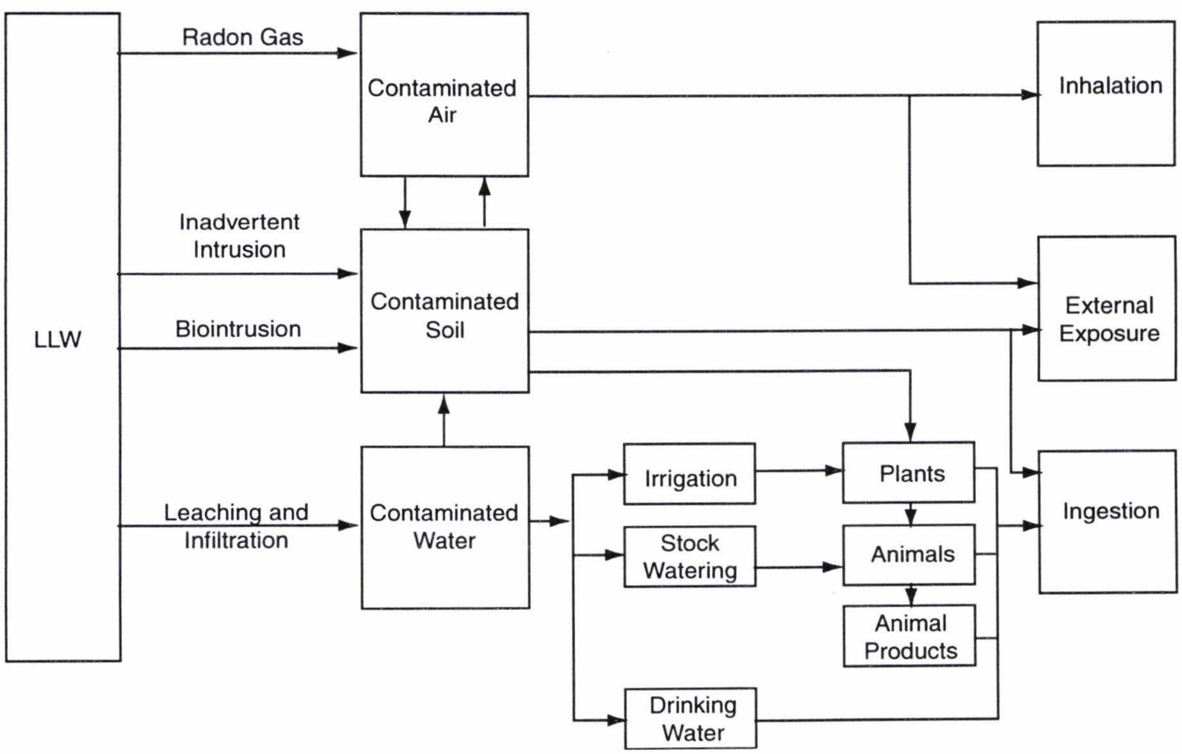

Figure 3-20. Exposure pathways at the RWMC.

Two general types of scenarios are evaluated in this performance assessment: (1) doses to members of the public, and (2) doses to inadvertent intruders (see Figure 3-21). Doses to members of the public are evaluated for two scenarios: atmospheric transport and groundwater transport. To meet the requirements in DOE Order 5820.2A, doses to intruders are also evaluated for two scenarios: acute exposures and chronic exposures. The receptors for the member of the public dose assessments are located at the INEL Site boundary during operations and institutional control and at 100 m from the RWMC boundary during post-institutional control. The intruder is assumed to reside on the RWMC SDA. The following sections describe the atmospheric, all-pathways, intruder, and groundwater protection scenarios used to evaluate impacts.

3.4.1 Atmospheric Scenario

3.4.1.1 Operational and Institutional Control Periods. This section describes the methodology and data used to calculate doses from atmospheric emissions from the RWMC during the operational and institutional control periods. These doses are based on the diffuse emissions dose assessments performed for the INEL National Emission Standard for Hazardous Air Pollutants (NESHAP) Annual Report (DOE 1993).

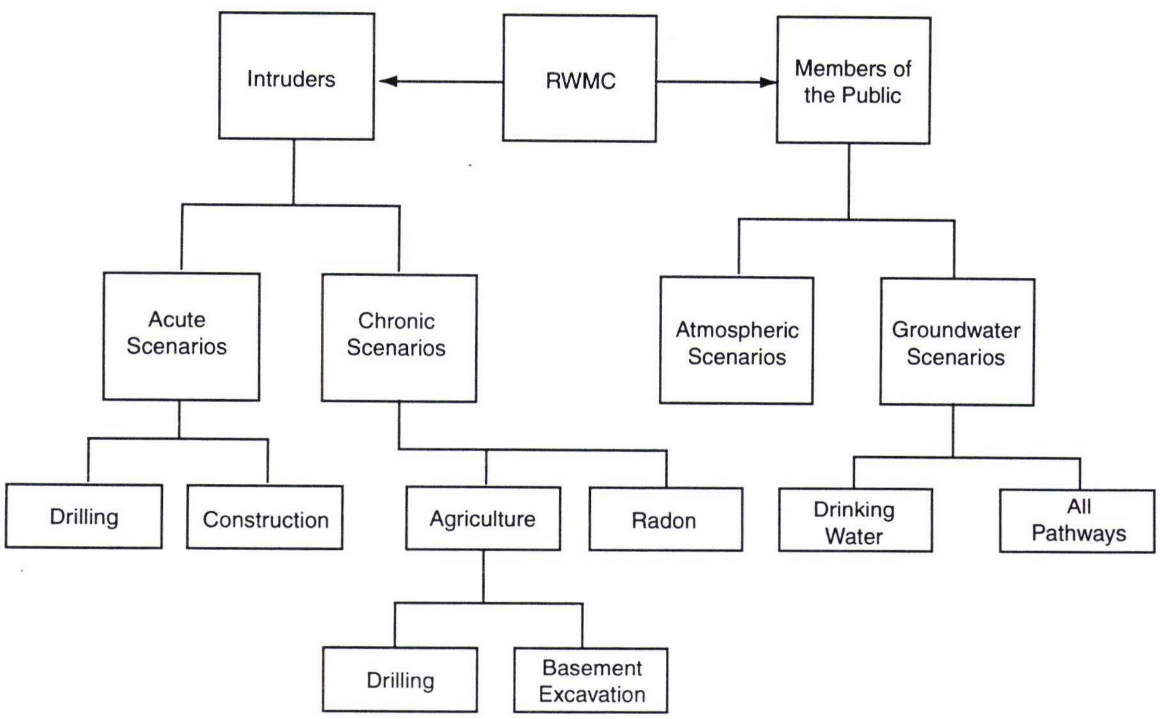

Figure 3-21. Scenarios at the RWMC.

During the operational and institutional control periods, the RWMC will be actively maintained and monitored. Therefore, it is reasonable to postulate that soil contamination levels will not be higher than current levels. In reality, soil contamination will decrease because of environmental remediation activities at the RWMC. DOE (1993) describes the existing soil contamination levels at the RWMC and the areal extent of this contamination. The radionuclide soil concentrations at contaminated areas were estimated based on sampling studies or field survey measurements. The areal extent of each area was also estimated based on field observations and measurements. These data were used to estimate an annual release rate for each radionuclide in units of curies per year. The resuspension rate constant used in this analysis was based on the mass loading model. Appendix B contains additional information on the resuspension rate constant.

As required for NESHAP compliance dose assessments, the receptor location for the operational and institutional control periods was an actual residence located near the INEL Site boundary, 8 km south-southwest of the RWMC (DOE 1993). The atmospheric data, environmental data, and the computer code used in the analyses are also discussed in DOE (1993).

3.4.1.2 Post-Institutional Control Period. This section describes the methodology used to calculate doses from atmospheric emissions of radionuclides from the RWMC SDA after institutional control. The scenario was based on biointrusion contaminating the surface soil at the RWMC SDA. This contaminated surface soil was blown offsite to a member of the public 100 m from the boundary of the RWMC SDA. This hypothetical receptor ate contaminated food, was immersed in contaminated air, breathed contaminated air, and was exposed to contaminated ground surfaces.

The scenario used for this analysis started with the LLW inventory disposed of in the RWMC LLW disposal locations from 1984 to 1993 and was augmented with the forecasted additions for 1994 to 2020 (see Appendix A). A portion of the inventory was brought to the surface through biointrusion and distributed over the RWMC, forming a large area source of radioactive material that could be resuspended by wind.

The contaminated material was then blown offsite to a hypothetical member of the public located 100 m from the RWMC. The receptor was located in the east-northeast sector, the sector that yielded the largest annual average sector-averaged air concentration at 100 m from the RWMC, using a ground-level release and meteorological data collected from 1987 to 1991 at the Central Facilities Area (CFA) (Leonard 1992). The sector with the highest air concentration will also yield the highest dose. The sector was determined by calculating air concentrations in all 16 sectors and choosing the sector with the largest value.

For this analysis, the GENII computer code (Version 1.485) (Napier et al. 1988) was used to model the doses resulting from RWMC releases. Although GENII may model both acute and chronic releases to the atmosphere, only the chronic option was exercised in this analysis. The output from GENII is the EDE, which includes the 50-year committed effective dose equivalent (CEDE) from internal exposure through the ingestion and inhalation pathways and the external EDE from ground deposition and air immersion. Napier et al. (1988) completely describes the GENII computer code. The assessments done for operational and institutional control periods (DOE 1993) and GENII use the same pathways.

Inhalation doses were calculated based on exposure to contaminated air for 1 year (8760 hours). Two inhalation rates were evaluated: 8030 and 5840 m^3/yr. ICRP-23 presents 8030 m^3/yr as the inhalation rate for Reference Man (ICRP 1975). Data presented in Konz et al. (1989) were used to derive an inhalation rate of 5840 m^3/yr, based on a person spending 11.2 h/day at rest, 11.2 h/day at light activity, 1.4 h/day at moderate activity, and 0.22 h/day at heavy activity. The corresponding inhalation rates for average adults are 0.5, 0.6, 2.1, and 3.9 m^3/h. This yields a time-weighted inhalation rate of 16 m^3/day or 5,840 m^3/yr.

Ground surface doses were calculated assuming 100 years of buildup of radionuclides in the surface soil because of atmospheric deposition. Two shielding factors were evaluated: 0.7 and 0.36. The 0.7 shielding factor is from NRC (1977) and corresponds to the shielding factor used for the maximally exposed individual. The 0.36 shielding factor was calculated using data presented in Konz et al. (1989), based on a person spending 16.75 h/day at home and indoors and 0.23 h/day at home and outdoors. The corresponding reduction factors for these activities are 0.5 and 1.0. The remaining 7.02 h/day was associated with activities conducted at work and indoors, at work and outdoors, in transit, and activities classified as "other" in Konz et al. (1989). These activities were assigned a reduction factor of 0.0.

Air immersion doses were calculated based on exposure to contaminated air for 1 year, using shielding factors of 0.7 and 0.36, as in the ground surface analyses (see NRC 1977).

Ingestion doses were calculated based on the consumption of contaminated produce, leafy vegetables, milk, and meat. The conceptual model for ingestion doses begins with radionuclides that are deposited on forage, soil, produce, and leafy vegetables. Radionuclides deposited on forage are subsequently transferred through the food chain to meat and milk and then to humans. Radionuclides deposited on produce and leafy vegetables are also consumed by humans. Radionuclides deposited on soil are transferred to forage, produce, and leafy vegetables through the mechanism of root uptake and then transferred to humans through ingestion of contaminated meat, milk, produce, and leafy vegetables. The parameters used to calculate food chain doses are contained in Napier et al. (1988). The values for the concentration ratios for forage and crops and the transfer coefficients for milk and meat are contained in Figures B-1 through B-4 of Appendix B. The concentration ratios for forage and crops are in terms of dry weight.

Two diets were evaluated: (1) a diet developed by Rupp (1980) and based on a 1965 U.S Department of Agriculture (USDA) survey and (2) a diet developed by Yang and Nelson (1984,

1986) and based on a 1977 to 1978 USDA survey (see Table 3-13). The Rupp diet was the default diet used in the EPA's NESHAPs Environmental Impact Statement (EPA 1989). The Yang and Nelson diet represents a more realistic diet than the Rupp diet because it is based on a later dietary survey. Dietary fractions representative of rural agricultural areas were used (EPA 1989). Based on the data in EPA (1989), 70% of the receptor's vegetables and produce, 40% of the milk, and 44% of the meat were produced locally.

The dose conversion factors used in this analysis are from the GENII library, which uses the most conservative dose conversion factors contained in DOE (1988b and 1988c).

Two biointrusion mechanisms were examined as potential ways to bring contaminated material to the surface: intrusion by burrowing animals and intrusion by plant roots. Groves and Keller (1983) identified 10 species of small mammals nesting on or near the RWMC. Four species were the most numerous: deer mice (*Peromyscus maniculatus*), montane voles (*Microtus montanus*), Ord's kangaroo rats (*Dipodomys ordii*), and Townsend's ground squirrels (*Spermophilus townsendii*). Reynolds and Wakkinen (1987) studied the burrow depths of these four species in undisturbed soils and the maximum reported burrow depth for undisturbed soil was 138 cm for a Townsend's ground squirrel. A 1988 study by Reynolds and Laundre examined the burrow depths of the same species in both disturbed and undisturbed soils on the INEL. The maximum burrow depth in disturbed soils documented in Reynolds and Laundre (1988) was 140 cm was for a Townsend's ground squirrel. None of the deer mice burrows extended past 60 cm, none of the montane vole burrows extended past 70 cm, and none of the Ord's kangaroo rat burrows extended past 100 cm.

At maximum erosion, there is 240 cm of cover left over the pits and trenches and 330 cm of cover left over the soil vaults. Based on the site-specific studies in Reynolds and Wakkinen (1987) and Reynolds and Laundre (1988) that report burrow depths are not observed in undisturbed or disturbed soils at the INEL greater than 140 cm deep, intrusion by burrowing

Table 3-13. Alternative human diets.

Food product	Rupp diet	Yang and Nelson diet
Produce (kg/yr)	176	94
Leafy vegetables (kg/yr)	18	17
Milk (L/yr)	112	89
Meat (kg/yr)	85	55

small mammals is highly unlikely and was removed from further consideration. The authors acknowledge that investigators at other sites have observed different results for other species of small mammals (e.g., McKenzie et al. 1982). These other studies were considered in evaluating intrusion by the burrowing small mammal pathway; however, preference was given to the site-specific studies based on the guidance provided in Dodge et al. (1991).

In contrast to burrowing mammals, harvester ants (*Pogonomyrmex salinus*) burrow deep enough to encounter the waste. For example, Blom et al. (1991) states that harvester ants have been found as deep as 2.7 m in Wyoming and at the Hanford Site. To account for the intrusion of harvester ants into the waste, a model similar to that in Kennedy et al. (1985) was constructed. In contrast to burrowing small mammals, no site-specific data for harvester ant burrow depths exist; therefore, data from Kennedy et al. (1985) were used in the model.

The model was based on harvester ants burrowing into the waste and bringing contaminated material to the surface. The volume of contaminated material that a single harvester ant colony brought to the surface was calculated using the burrow volume and the fraction of the burrow that was deep enough to encounter the waste. Because the waste was at depths greater than 2 m below the surface at maximum erosion, 5% of the burrow volume was estimated to encounter the waste (see Kennedy et al. 1985). An average burrow volume per colony of 0.002 m^3 was also obtained from Kennedy et al. (1985). The resulting volume of contaminated material was multiplied by the radionuclide concentration in the waste to yield the activity that a single harvester ant colony could bring to the surface. This result was multiplied by the average harvester ant colony density and the surface area of the pits and soil vaults to yield the total activity brought to the surface:

$$\begin{aligned} &\textit{Activity on the surface } (Ci) = \textit{waste concentration } (Ci/m^3) \times \\ &\textit{burrow volume } (m^3/colony) \times \textit{fraction of burrow in waste} \times \\ &\quad \textit{colony density } (colonies/m^2) \times \textit{surface area } (m^2). \end{aligned} \tag{3-33}$$

Based on data for harvester ant colony densities in big sagebrush (*Artemisia tridentata*) communities on the INEL (Blom et al. 1991), a density of 35.6 colonies/10,000 m^2 was used. This represents the mean density over five locations on the INEL. For pits[a] and soil vaults,[b] surface areas of 12,000 and 890 m^2 were calculated, respectively.

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a. The volume of waste in the pits was 75,600 m^3 and the waste thickness was 6.1 m, which yielded a surface area of 12,000 m^2.

b. The volume of waste in the soil vaults was 2,700 m^3 and the waste thickness was 3.05 m, which yielded a surface area of 890 m^2.

The total activity brought to the surface through harvester ant burrowing was then dispersed in the environment and blown to a hypothetical receptor located 100 m from the RWMC. While this is a conservative assumption, it puts an upper bound on the material that a receptor could be exposed to through the atmospheric pathway.

The potential for biointrusion by plant roots was also evaluated. Elevated concentrations of radionuclides in plant species growing on the RWMC have been observed (Arthur 1982). These elevated concentrations were observed in areas where 0.6 to 1.8 m of cover was present over the waste. Reynolds and Fraley (1989) studied root profiles near the RWMC and determined the maximum rooting depth for big sagebrush (*Artemisia tridentata*) was 225 cm, for green rabbitbrush (*Chrysothamnus vicidiflorus*) was 190 cm, and for Great Basin wild rye (*Leymus cinereus*) was 200 cm.

Based on the site-specific data in Reynolds and Fraley (1989), biointrusion by plant roots of pits and soil vaults may be possible. However, biointrusion by plant roots of soil vaults is less likely because of increased cover depth.

To estimate the amount of radioactive material that plant roots could bring to the surface, a model similar to those used in GENII (Napier et al. 1988) and Kennedy et al. (1985) was constructed. First, the dominant plant species in terms of absolute cover were determined. Anderson and Inouye (1988) found that big sagebrush has an absolute cover of 13%, green rabbitbrush has an absolute cover of 4.3%, and Great Basin wild rye has an absolute cover of 0.013% at the INEL. Russian thistle, another potentially deep rooted species, had an absolute cover of 0.005%. Because big sagebrush is the dominant plant species, estimates of biointrusion were based on big sagebrush data.

The aboveground biomass of big sagebrush was estimated to be 46 g/m^2 using INEL-specific data from Fraley (1978). Because the waste is at depths greater than 2 m below the surface at maximum erosion, 5% of the plant roots were estimated to encounter the waste (see Kennedy et al. 1985). The activity brought to the surface by plants was estimated by multiplying the radionuclide concentration in the waste by the concentration ratio (CR), the fraction of the roots that can encounter the waste, the biomass, and the area of the pits or soil vaults.

$$\begin{aligned} &Activity\,on\,the\,surface\,(Ci) = waste\ \ concentration\,(Ci/m^3) \times \\ &\frac{1}{soil\ \ bulk\ \ density\,(g/m^3)} \times fraction\ \ of\ \ roots\ \ in\ \ waste\ \times \\ &\quad CR\left[\frac{Ci/g(plants)}{Ci/g(waste)}\right] \times biomass\,(g/m^2) \times area\,(m^2). \end{aligned} \tag{3-34}$$

Dry weight CRs for pasture from Baes et al. (1984) were used (see Figure B-2). CRs for uptake by cheatgrass and tumbleweed (Russian thistle) of neptunium, plutonium, americium, and curium were also examined and found to be in reasonable agreement (i.e., within an order of magnitude) of the CRs from Baes et al. (1984) (see Price 1972).

The total activity brought to the surface through plant uptake was then dispersed in the environment and blown to a hypothetical receptor 100 m from the RWMC. This implies that the entire big sagebrush aboveground biomass was converted to a dispersible form. While this is a conservative assumption, it puts an upper bound on the material that a receptor could be exposed to through the atmospheric pathway.

Doses because of harvester ant burrowing and plant uptake were calculated at various points in time after site closure, beginning in 2120 and continuing to 1,000,000 years after site closure. The year 2120 corresponds to the beginning of the post-institutional control period and is the earliest time that biointrusion could occur during the post-institutional control period. This is also the time when the maximum fission product and activation product inventory is available for biointrusion because fission and activation products do not contain long-lived decay series with substantial progeny ingrowth. Doses were also calculated at the year 12,000 and 1,000,000 years after site closure. These times were chosen to determine if there were any long-lived actinide decay series that could yield large doses because of progeny ingrowth over long time frames. One million years corresponds to the time when most long-lived decay series have achieved a substantial fraction of secular equilibrium; therefore, it represents a reasonable time to calculate doses.

The fraction of the root or burrow system that contacted the waste did not change as the amount of cover over the waste changed because of erosion. This fraction was held constant over time because the data in Kennedy et al. (1985) do not permit further refinement of the depth profile at depths greater than 2 m. Because the minimum depth to waste at maximum erosion was 2.4 m, the data for the fraction of the root or burrow system at 2 m were applied to all depths greater than 2 m. This approach is conservative because there is undoubtedly a depth-dependent root or burrow profile at depths greater than 2 m that would result in less biointrusion as the depth to the waste increases. However, this approach eliminates the need to consider the erosion rate in the calculations, and maximum dose can be calculated by performing a few representative assessments. In addition, every burrow system or plant over the pits was assumed to contact the waste; this is also a conservative approach.

3.4.1.3 Gaseous Releases of Tritium and Carbon-14. The purpose of this analysis was to estimate the doses from gaseous releases of H-3 and C-14. The H-3 and C-14 release rates were calculated by the hydrological model used to estimate groundwater impacts. Instead of H-3 and C-14 moving downward with water, H-3 and C-14 were assumed to move upward as gases and were transported to receptors downwind of the RWMC. Doses were evaluated for two time periods: (1) the operational and institutional control periods, where the receptor was an actual residence located 8000 m south-southwest from the RWMC at the INEL Site boundary and (2) the post-institutional control period, where the receptor was located 100 m from the RWMC. During each of these periods, the peak release rates for H-3 and C-14 were used.

During the operational and institutional control time periods, the peak release rate for C-14 was 0.37 Ci/yr, and the peak release rate for H-3 was 90 Ci/yr. During the post-institutional control period, the peak release rate for C-14 was 0.35 Ci/yr, and the peak release rate for H-3 was 0.34 Ci/yr. The methodology and data used to evaluate H-3 and C-14 doses are the same used for the biointrusion analyses. The H-3 and C-14 dose assessments were performed using the GENII computer code (Napier et al. 1988), which also describes the H-3 and C-14 models.

3.4.1.4 Radon Flux. The purpose of this analysis was to estimate the radon flux from the surface of the RWMC to demonstrate compliance with the 20 pCi/m^2-s standard contained in Subpart Q of 40 CFR 61. As with the chronic intruder radon scenario, the RESRAD computer code (Gilbert et al. 1989) was used to estimate the surface radon flux. The methods and data used to estimate the radon flux were identical to the methods and data used to estimate the chronic intruder radon doses. These methods and data are presented in Section 3.4.3.4.

3.4.2 All-Pathways Scenario

The all-pathways scenario was used to evaluate compliance with the requirement in DOE Order 5820.2A that the annual EDE received by a member of the public must not exceed 25 mrem from exposure to RWMC effluents. The methodology used to calculate the all-pathways dose was based on the methodology presented in NRC (1977) and Peterson (1983). This all-pathways scenario assumed that a receptor drank contaminated groundwater, ate leafy vegetables and produce that were irrigated with contaminated groundwater, and consumed milk and meat from animals that consumed contaminated water and pasture grass irrigated with contaminated groundwater. The scenario assumed that groundwater was used for drinking, watering beef and milk cattle, and irrigating crops and pasture. Radionuclide concentrations as a function of time at the receptor well that were calculated using the hydrological transport model described in Section 3.3 were used as input to this model. The receptor was located at the INEL Site boundary during the operational and institutional control periods, based on guidance from DOE-HQ.[c] During this time, the INEL Site boundary is maintained, and access by the public is not allowed. During post-institutional control, the receptor was located 100 m downgradient of the RWMC facility boundary. Table 3-14 contains the parameter values used in the all pathways dose calculation.

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c. Letter from S. P. Cowan to J. T. Case, June 20, 1996, "Groundwater Compliance for the Low-Level Waste Radiological Performance Assessment for the Radioactive Waste Management Complex at the Idaho National Engineering Laboratory."

Table 3-14. Parameter values used in the all pathway dose calculation.

Parameter	Value	Reference
U_W	258 L/yr	Yang and Nelson (1984)
Q_W (beef cattle)	50 L/day	NRC (1977)
Q_W (milk cattle)	60 L/day	NRC (1977)
Q_F (beef cattle, dry weight)	12 kg/day	NCRP (1984)
Q_F (milk cattle, dry weight)	16 kg/day	NCRP (1984)
U_B	85 kg/yr	Rupp (1980)
U_M	112 L/yr	Rupp (1980)
U_P	176 kg/yr	Rupp (1980)
U_{LV}	18 kg/yr	Rupp (1980)
I	8.47 L/m^2-day	Site specific
k	0.025 mm^{-1}	Peterson (1983)
r/Y_v (leafy veg, wet weight)	0.076 m^2/kg	Calculated from Baes and Orton (1979) and Baes et al. (1984)
r/Y_v (produce, wet weight)	0.032 m^2/kg	Calculated from Baes and Orton (1979) and Baes et al. (1984)
r/Y_v (pasture, dry weight)	2.0 m^2/kg	Calculated from Baes and Orton (1979) and Baes et al. (1984)
P (dry weight)	225 kg/m^2	DOE (1987)
t_i	90 day	Site specific
t_b	365 day	Site specific
f_I	0.25	Site specific
T (leafy veg)	1.0	Ng et al. (1978)
T (produce)	0.1	Ng et al. (1978)
DF (leafy veg)	0.5	Ng et al. (1978)
DF (produce)	1.0	Ng et al. (1978)
FV	0.7	EPA (1989)
FB	0.442	EPA (1989)
FM	0.399	EPA (1989)

The dose from human consumption of drinking water was calculated using

$$D = C_{GW} \times U_W \times DCF \times \frac{10^{-6}\ \mu Ci}{pCi} \times \frac{1{,}000\, mrem}{rem} \tag{3-35}$$

where

D = dose (CEDE) from one year's consumption of contaminated media, in this case groundwater (mrem/yr)

C_{GW} = radionuclide concentration in groundwater (pCi/L)

U_W = human consumption rate of water (L/yr)

DCF = ingestion dose conversion factor (rem/μCi).

The dose through water ingestion by beef and milk cattle assumes that cattle drink contaminated water. The receptor is then assumed to drink milk and eat meat from the cattle that drank the contaminated water. Meat and milk were treated separately. The dose was calculated using

Meat:

$$D = C_{GW} \times Q_W \times F_f \times U_B \times DCF \times \frac{10^{-6}\mu Ci}{pCi} \times \frac{1{,}000\, mrem}{rem} \times FB \tag{3-36}$$

Milk:

$$D = C_{GW} \times Q_W \times F_m \times U_M \times DCF \times \frac{10^{-6}\mu Ci}{pCi} \times \frac{1{,}000\, mrem}{rem} \times FM \tag{3-37}$$

where

Q_W = consumption rate of water by beef or milk cattle (L/day)

F_f = meat transfer coefficient (day/kg)

U_B = human consumption rate of meat (kg/yr)

FB = fraction of beef produced locally (unitless)

F_m = milk transfer coefficient (day/L)

U_M = human consumption rate of milk (L/yr)

FM = fraction of milk produced locally (unitless).

The dose to humans from ingestion of contaminated leafy vegetables and produce was calculated assuming two contamination routes: direct deposition of contaminated irrigation water on plants and deposition of contaminated irrigation water on soil followed by root uptake by plants. Leafy vegetables and produce were treated separately. The dose through direct deposition was calculated using

Leafy Vegetables - Direct Deposition:

$$D = \frac{C_{GW} \times I \times r}{Y_v} \times \frac{1 - e^{-(\lambda_r + kI)t_i}}{\lambda_r + kI} \times U_{LV} \times \frac{10^{-6} \mu Ci}{pCi} \times DCF \times \times \frac{1{,}000\, mrem}{rem} \times DF \times T \times FV \qquad (3\text{-}38)$$

Produce - Direct Deposition:

$$D = \frac{C_{GW} \times I \times r}{Y_v} \times \frac{1 - e^{-(\lambda_r + kI)t_i}}{\lambda_r + kI} \times U_P \times \frac{10^{-6} \mu Ci}{pCi} \times DCF \times \times \frac{1{,}000\, mrem}{rem} \times DF \times T \times FV \qquad (3\text{-}39)$$

where

I = irrigation rate (L/m^2-day)

r = interception fraction (unitless)

Y_v = agricultural yield (kg/m^2, wet weight)

λ_r = radioactive decay constant (per day)

k = washoff constant (mm^{-1})

t_i = irrigation time (day).

U_{LV} = human consumption rate of leafy vegetables (kg/yr)

DF = fraction of activity remaining after preparation and processing (unitless)

T = translocation factor (unitless)

FV = fraction of leafy vegetables and produce produced locally (unitless)

U_P = human consumption rate of produce (kg/yr).

The product kI is also known as the weathering rate constant because of washoff (Peterson 1983). This quantity describes the rate at which material is removed from plant surfaces by water and is analogous to λ_e, the weathering rate constant used in nonirrigation situations. The value of kI was calculated using

$$kI = 0.025\,mm^{-1} \times \frac{8.47\,L}{m^2\text{-}day} \times \frac{1\,m^3}{1{,}000\,L} \times \frac{1{,}000\,mm}{1\,m} = 0.212/day \tag{3-40}$$

The dose from deposition of contaminated irrigation water on soil followed by root uptake by plants and human consumption of plants was calculated using the following equations. Credit was not taken for leaching of radionuclides from the root zone of plants.

Leafy Vegetables - Root Uptake:

$$D = \frac{C_{GW} \times I \times f_I}{P} \times \frac{1 - e^{-\lambda_r t_b}}{\lambda_r} \times CR \times U_{LV} \times \frac{10^{-6}\mu Ci}{pCi} \times \\ \times DCF \times \frac{1{,}000\,mrem}{rem} \times FV \tag{3-41}$$

Produce - Root Uptake:

$$D = \frac{C_{GW} \times I \times f_I}{P} \times \frac{1 - e^{-\lambda_r t_b}}{\lambda_r} \times CR \times U_P \times \frac{10^{-6}\mu Ci}{pCi} \times \\ \times DCF \times \frac{1{,}000\,mrem}{rem} \times FV \tag{3-42}$$

where

f_I = fraction of the year that crops are irrigated (unitless)

P = areal density [kg (dry weight soil)/m^2]

CR = concentration ratio [pCi/kg (wet weight plant) ÷ pCi/kg (dry weight soil)]

t_b = build-up time for radionuclides in soil (day).

The dose to humans from ingestion of contaminated animal products was also calculated assuming two contamination routes: direct deposition and root uptake; meat and milk were treated separately. All food (pasture or stored feed) eaten by cattle was assumed to be contaminated. The dose through direct deposition was calculated using

Meat - Direct Deposition:

$$D = \frac{C_{GW} \times I \times r}{Y_v} \times \frac{1 - e^{-(\lambda_r + kI)t_i}}{\lambda_r + kI} \times Q_F \times F_f \times U_B \times \times \frac{10^{-6} \mu Ci}{pCi} \times DCF \times \frac{1{,}000\, mrem}{rem} \times FB \tag{3-43}$$

Milk - Direct Deposition:

$$D = \frac{C_{GW} \times I \times r}{Y_v} \times \frac{1 - e^{-(\lambda_r + kI)t_i}}{\lambda_r + kI} \times Q_F \times F_m \times U_M \times \times \frac{10^{-6} \mu Ci}{pCi} \times DCF \times \frac{1{,}000\, mrem}{rem} \times FM \tag{3-44}$$

where

Y_v = agricultural yield (kg/m^2, dry weight)

Q_F = animal consumption rate of pasture and feed [kg (dry)/day].

The dose through deposition on soil followed by root uptake was calculated using the following equations. As with produce and leafy vegetables, credit was not taken for leaching of radionuclides from the root zone of plants.

Meat - Root Uptake:

$$D = \frac{C_{GW} \times I \times f_I}{P} \times \frac{1 - e^{-\lambda_r t_b}}{\lambda_r} \times CR \times Q_F \times F_f \times U_B \times$$
$$\times \frac{10^{-6} \mu Ci}{pCi} \times DCF \times \frac{1{,}000\, mrem}{rem} \times FB \tag{3-45}$$

Milk - Root Uptake:

$$D = \frac{C_{GW} \times I \times f_I}{P} \times \frac{1 - e^{-\lambda_r t_b}}{\lambda_r} \times CR \times Q_F \times F_m \times U_M \times$$
$$\times \frac{10^{-6} \mu Ci}{pCi} \times DCF \times \frac{1{,}000\, mrem}{rem} \times FM \tag{3-46}$$

where

CR = concentration ratio [pCi/kg (dry weight plant) ÷ pCi/kg (dry weight soil)].

Equivalent water intake rates for all pathways were calculated using the above methodology and a spreadsheet. These rates were then input into GWSCREEN to perform all-pathways dose calculations.

Secondary and indirect pathways, such as inhalation of contaminated irrigation water, inhalation of contaminated dust, or external exposure from radionuclides deposited on the soil, were omitted from this scenario. These pathways were either not viewed as credible (e.g., a farmer standing under a center pivot irrigator while it was running and inhaling contaminated irrigation water) or would contribute relatively minor amounts when compared to direct pathways such as direct ingestion of contaminated water.

3.4.3 Intruder Scenarios

The following six types of inadvertent intruder scenarios were evaluated in this analysis and are summarized in this section:

1. Acute intruder drilling
2. Acute intruder construction
3. Chronic intruder drilling
4. Chronic intruder basement excavation
5. Chronic intruder radon
6. Chronic biointrusion.

The results from the acute drilling and acute construction scenarios were compared to the 500 mrem acute exposure standard in DOE Order 5820.2A. The results from the chronic drilling, chronic basement excavation, chronic radon, and chronic biointrusion scenarios were compared to the 100 mrem/yr continuous exposure standard in DOE Order 5820.2A. These scenarios were based on the scenarios developed and used by the NRC in 10 CFR 61 to evaluate the land disposal of radioactive waste (NRC 1981; NRC 1982; Oztunali and Roles 1986; Kennedy and Peloquin 1988).

The acute drilling, acute construction, chronic drilling, chronic basement excavation, chronic radon, and chronic biointrusion scenarios were evaluated for pits. For the soil vaults, the acute drilling, chronic drilling, chronic radon, and chronic biointrusion scenarios were evaluated. The acute construction scenario and the chronic basement excavation scenario were not evaluated for the soil vaults because a basement excavation would not contact the waste. The entire inventory in the pits and soil vaults was available for intrusion, no depletion because of leaching was assumed. Although leaching will occur over time, this conservative assumption was made for excavation cases; during the drilling cases both the inventory still in the waste and the leached inventory would be contacted during intrusion. Therefore, leaching has no impact on the drilling intruder assessments.

Appendix A contains the inventory used in the intruder assessments. Appendix C provides the radionuclide concentrations in the waste and on the surface for pits and soil vault rows. In all cases, the doses resulting from intrusion include the contributions from the decay and ingrowth of radioactive progeny. Detailed computer runs for intruder analyses are contained in Maheras (1993a, 1995a, 1995b, 1997a). Figure 3-22 summarizes the pathways evaluated for each intruder scenario.

3.4.3.1 Acute Intruder Drilling Scenario. The acute drilling scenario assumed that an inadvertent intruder drilled a well into the contents of a soil vault or pit (see Figure 3-23). As in the NRC drilling scenario, the intruder was exposed to contaminated drill cuttings spread over the ground and to contaminated airborne dust. In the NRC drilling scenario, the intruder was exposed to contaminated drill cuttings in a mud pit. Interviews with local well drilling contractors in the Idaho Falls area indicated that drillers spread the cuttings over the ground and do not use mud pits (Seitz 1991); therefore, this site-specific deviation of the NRC drilling scenario was incorporated into the analyses. In addition, spreading the cuttings over the ground yields higher doses than putting the cuttings in a mud pit because of decreased shielding. These cuttings were spread out over a 2,200 m^2 lot (Rogers and Hung 1987). This lot corresponds to about one-half of an acre; lots located outside the city limits of Idaho Falls are typically 1 to 3 acres. Therefore, a 2200 m^2 lot size is conservative for the local area surrounding Idaho Falls. The intruder was exposed to the contaminated cuttings for 160 hours (Seitz 1991), the time local Idaho Falls well drilling contractors state it would take to drill and develop a 22-in. diameter irrigation well.

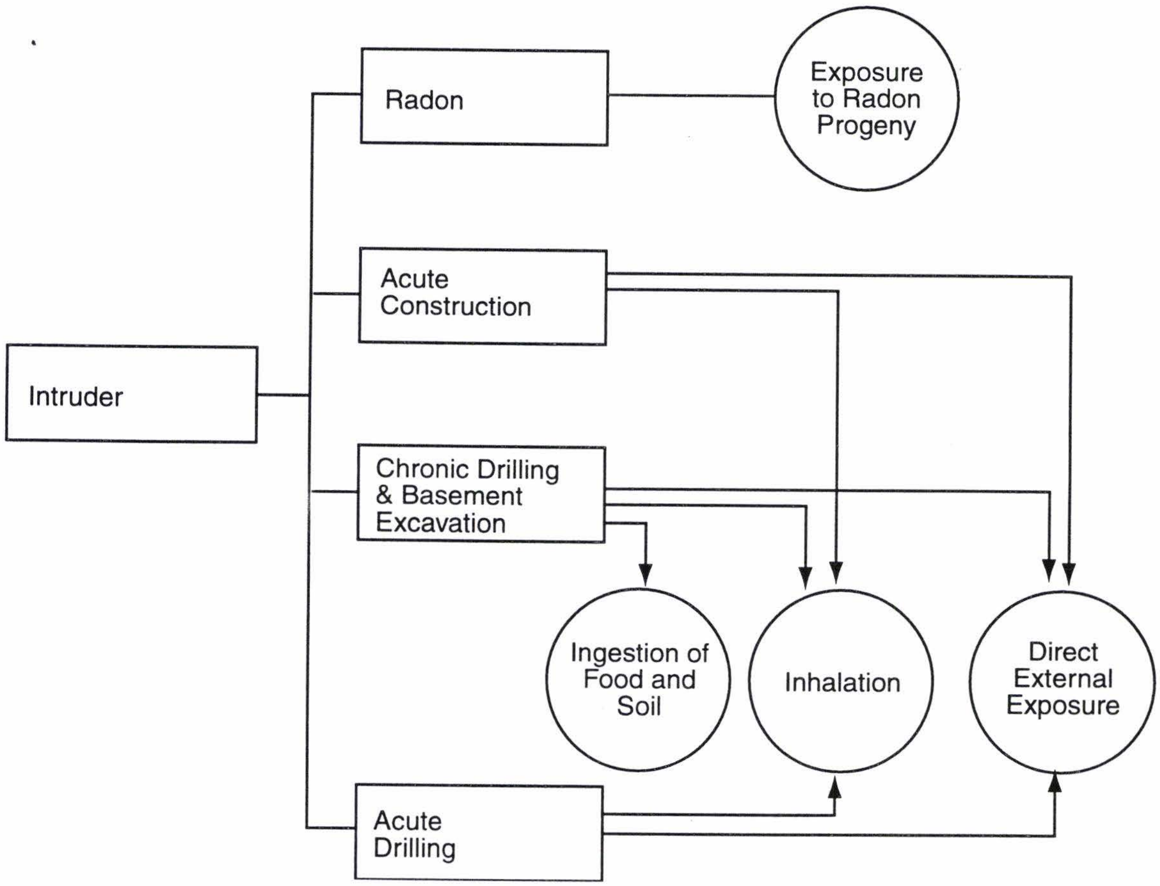

Figure 3-22. RWMC performance assessment intruder pathways.

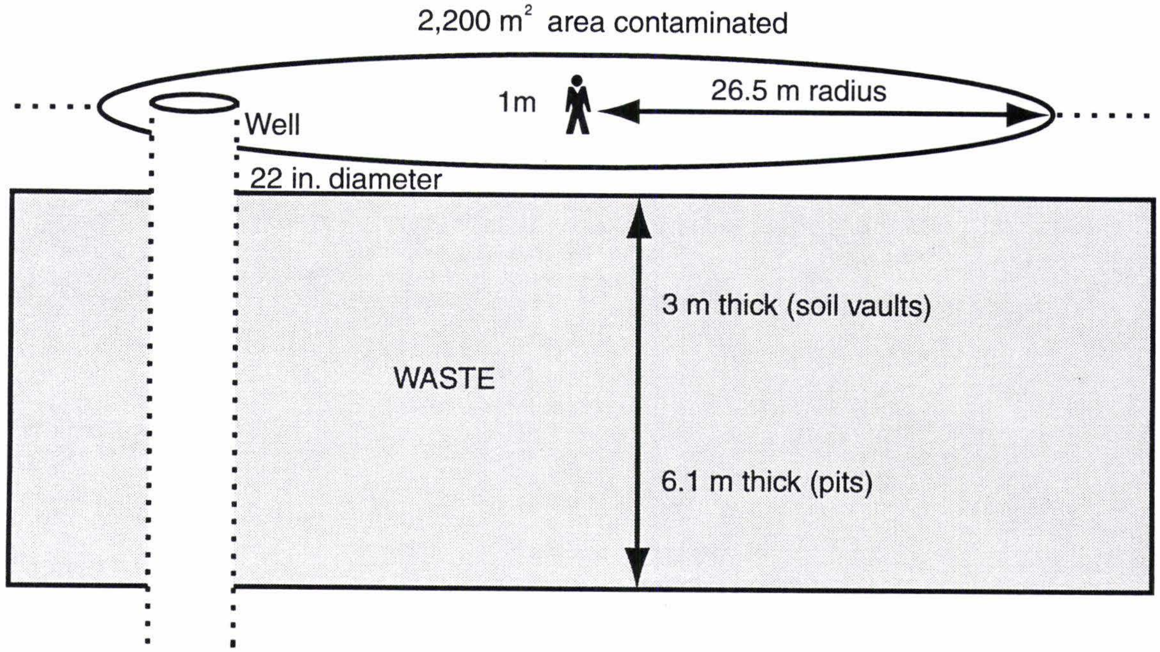

Figure 3-23. Acute intruder drilling scenario.

Well drilling contractors in the Idaho Falls area reported that two types of wells are typically drilled: small diameter residential wells and large diameter irrigation wells. The small residential wells are typically 6 to 8 in. in diameter, serve a single residence, and also may provide enough water for a family garden and several cows. The large diameter irrigation wells are drilled to serve systems that irrigate hundreds of acres; the wells are located in the middle of farm fields, not near the farmer's residence. Therefore, a farmer would not drill an irrigation well to acquire water for his residence. Large diameter irrigation wells are currently drilled 18-in. in diameter, but drilling contractors thought 22-in. diameter irrigation wells would be drilled in the near future.

Based on the information obtained from Idaho Falls area drilling contractors, an acute drilling exposure could result from drilling either an 8-in. diameter residential well or a 22-in. diameter irrigation well. Because the doses for this scenario are directly proportional to the volume of contaminated cuttings brought to the surface, to provide bounding doses a 22-in. diameter irrigation well was evaluated. The time required to drill and develop a well (160 hours for a large irrigation well and 48 hours for a residential well) also provided bounding doses when an irrigation well was evaluated.

Based on a waste thickness of 6.1 m for pits, the 22-in. well results in 1.5 m^3 of contaminated cuttings being brought to the surface during the acute drilling scenario. Based on a waste thickness of 3 m, for soil vault rows, the 22-in. well results in 0.75 m^3 of contaminated cuttings being brought to the surface.

Intruder doses were calculated at various points in time after site closure. For pits and soil vaults, these times were 2120 (100 years after site closure), 2520, 3020, 5020, 7020, 12020, and at 1,000,000 years after site closure. One million years corresponds to the time when most long-lived decay series have achieved a substantial fraction of secular equilibrium, and was analyzed to determine if there were any long-lived decay series that could yield large doses because of progeny ingrowth over long time frames. Inhalation doses were calculated using the GENII computer code and were based on a dust loading of 1 mg/m^3 (EG&G Idaho 1984), representative of construction activities. The external dose rate was calculated using the MICROSHIELD computer code. The source configuration was modeled as a 26.5-m radius plane, the radius of a circular 2,200 m^2 lot, with a receptor point 1 m above the plane at approximately waist height. The doses include exposure to radioactive progeny. No shielding factors were incorporated into the analyses.

3.4.3.2 Acute Intruder Construction Scenario. The acute construction scenario assumes that an inadvertent intruder moves onto the RWMC SDA and excavates a basement in the waste (see Figure 3-24). The intruder is exposed to contaminated dust and contaminated waste in the bottom of the pit. No ingestion doses are postulated for this scenario. This scenario is applicable to pits but not to soil vaults. Soil vaults have extra cover, which precludes intrusion into the waste by digging a basement. Because potatoes are a large cash crop in southeastern Idaho, the potential for an inadvertent intruder to dig a potato cellar was also considered. This scenario was

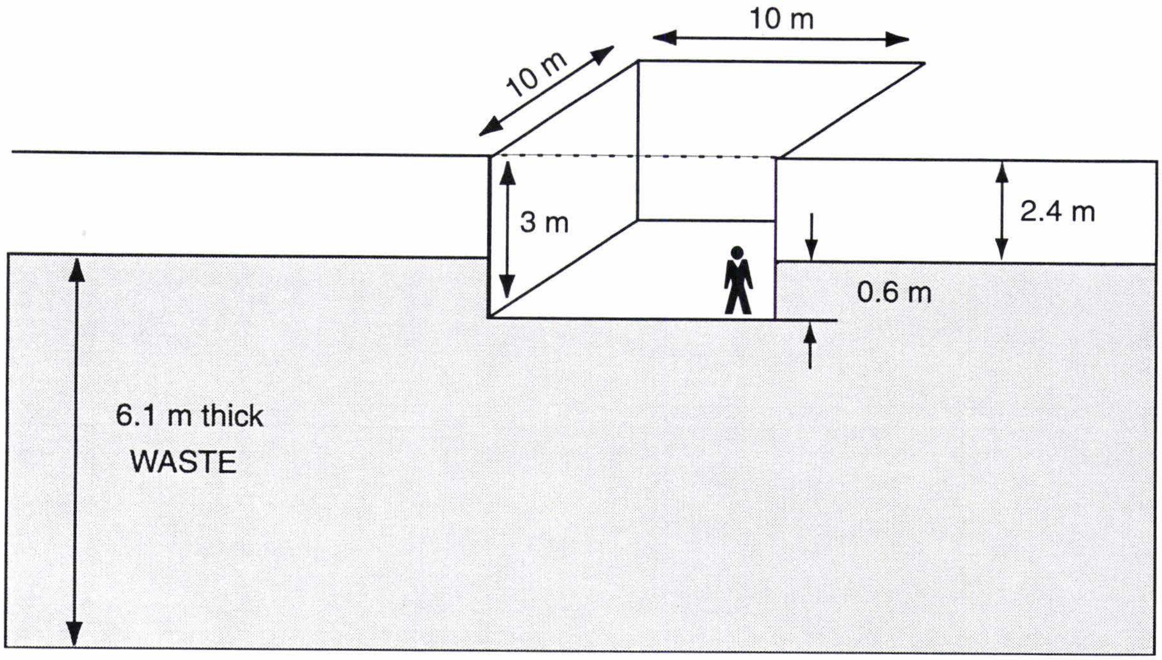

Figure 3-24. Acute intruder construction scenario.

dismissed because potato cellars are relatively shallow, approximately 1 m deep, and the intruder is unable to contact the waste during excavation. Because a basement excavation, which is 3 m deep, contacts the waste, the acute potato cellar construction scenario is bounded by the acute basement construction scenario.

Based on an interview with an Idaho Falls construction contractor, the exposure time for this scenario was 64 hours (Sussman 1993). This exposure time includes the time required to excavate the basement, pour the footings, form the basement walls, remove the forms, and backfill and grade the area around the basement. For the inhalation pathway, the dust loading was 1 mg/m^3 (EG&G Idaho 1984), representative of construction activities. For the external exposure pathway, the intruder stood directly on the exposed waste. This is conservative because an intruder would spend only a part of the time down inside the excavation. Shielding was not considered except for the self-shielding provided by the waste. The excavation was an 10 × 10-m area and 3-m deep (Rogers and Hung 1987). At the time of maximum erosion (the year 5020), 2.4 m of cover remains over the waste and the 3-m basement protrudes into the waste a distance of 0.6 m. The area of the basement corresponds to 1,100 ft^2, a reasonably-sized home in southeastern Idaho. The sides of the excavation will undoubtedly slope, but because of the small depth that the excavation penetrates the waste (0.6 m or less than 2 ft), sloping sides were not considered. Intruder doses were calculated at various points in time after site closure. Because of cover thickness, intrusion into the waste was not possible until about 3000 years after closure. To maximize doses, intrusion was postulated to start in 5020, which corresponds to the time of maximum erosion. Intruder doses were also calculated in 7020, 12020, and at 1,000,000 years after site closure. One million years corresponds to the time when most long-lived decay series have achieved a substantial fraction of secular equilibrium and was analyzed to determine if there were any long-lived decay series that could yield large doses because of progeny ingrowth over long time frames.

GENII was used to model the inhalation pathway, and MICROSHIELD was used to model the external exposure pathway. The source configuration was modeled as a volume source with infinite lateral extent with a receptor point 1 m above the source. In this configuration, the top of the volume source is the floor of the basement. This configuration does not account for the four 0.6-m vertical walls that surround the receptor. An evaluation of the doses from these walls found the doses to be two orders of magnitude less than the doses from the floor of the basement, and the doses from the walls were omitted from further calculations.

3.4.3.3 Chronic Intruder Drilling and Chronic Intruder Basement Excavation Scenarios. The chronic drilling scenario assumes that an inadvertent intruder moves onto the RWMC SDA and drills a residential well into the waste (see Figures 3-25 and 3-26). This scenario is applicable to both pits and soil vaults. The chronic basement excavation scenario assumes that an inadvertent intruder drills a residential well through the waste and also excavates a basement in the waste (see Figure 3-25). This scenario is applicable to pits, but not to soil vaults, because a basement excavation would not contact the waste in soil vaults.

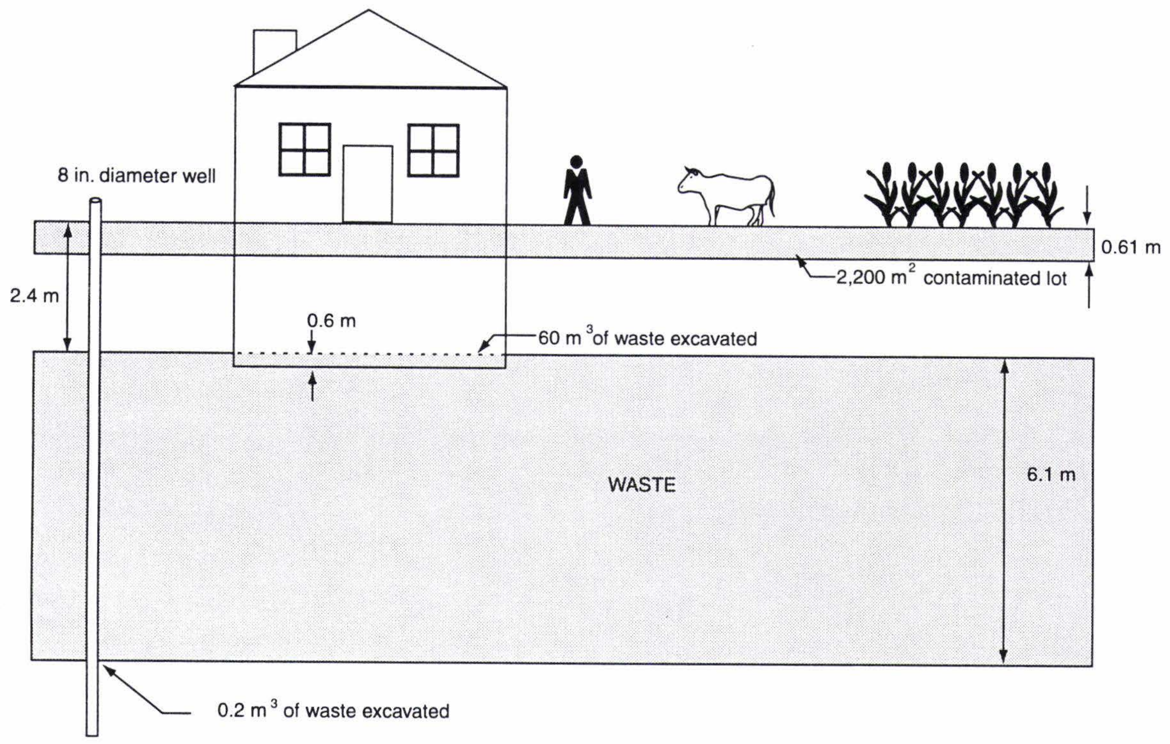

Figure 3-25. Chronic intruder drilling and chronic intruder basement excavation scenarios for pits.

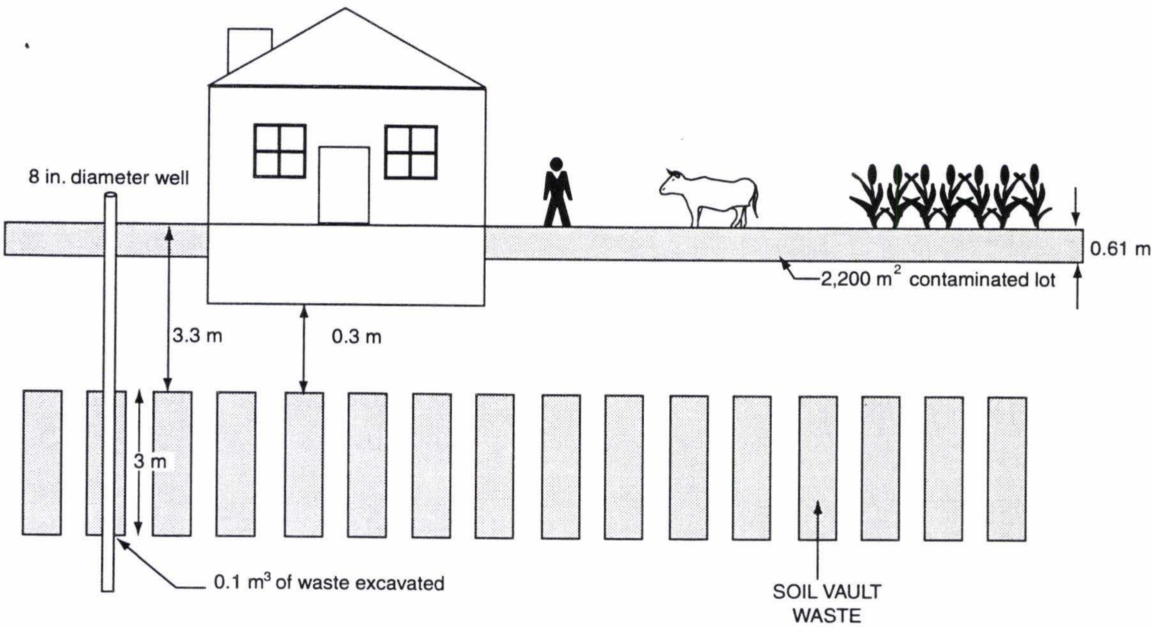

Figure 3-26. Chronic intruder drilling scenario for soil vaults.

In both the chronic drilling and chronic basement excavation scenarios, the contaminated material brought to the surface is spread around the site and mixed in the top 0.61 m of soil where crops are grown. The intruder breathes contaminated dust, eats contaminated food stuffs, inadvertently eats soil, and is directly exposed to contaminated ground surfaces.

The drilling portion of the scenarios evaluates an 8-in. residential well. This type of well serves a single residence and provides enough additional water for a family garden and several cows. As described in the acute drilling scenario, large diameter irrigation wells are drilled to serve large irrigation systems (hundreds of acres) that are located in the middle of farm fields, not near a farmer's residence. Therefore, in this residence/home garden scenario it is appropriate to evaluate a case where a farmer drills a small diameter residential well near his residence, not a large diameter irrigation well.

As discussed in the acute construction scenario, the basement excavation was 10 × 10 m in area and 3 m deep (Rogers and Hung 1987). As is the case in the acute construction scenario, the potential for an inadvertent intruder digging a potato cellar was considered. This scenario was dismissed because potato cellars are relatively shallow, approximately 1 m deep, and the intruder is able to contact more waste during basement excavation, approximately 3 m deep. Therefore, the amount of contaminated material brought to the surface through basement excavation exceeds the amount of contaminated material brought to the surface during potato cellar construction. Therefore, the doses from the chronic basement excavation scenario bound the doses from the chronic potato cellar construction scenario.

For the pits, drilling an 8-in. diameter residential well through the waste would bring 0.2 m^3 of waste to the surface, based on a 6.1-m waste thickness. For the pits at minimum cover thickness (maximum waste penetration), 2.4 m of cover is present over the waste, and 60 m^3 of contaminated waste could be brought to the surface[d] through basement excavation. Because an 8-in. diameter residential well is also drilled through the waste, an additional 0.2 m^3 of waste is brought to the surface, for a total of 60.2 m^3 of contaminated material on the surface.

For the soil vaults, intrusion by basement excavation is precluded by increased cover thickness (greater than 3 m). Well drilling was calculated to bring 0.1 m^3 of contaminated material to the surface based on a 3-m waste thickness and an 8-in. diameter residential well.

The exposure time was 1 year (8760 hours). For the dust inhalation pathway, the intruder spent 24 hours plowing and cultivating (1 mg/m^3 dust loading), 1200 hours conducting other farm activities (0.07 mg/m^3 dust loading), and 7536 hours conducting other activities, which result in a dust loading of 0.05 mg/m^3 (EG&G Idaho 1984). This results in a time-weighted average dust loading of 5.53E-8 kg/m^3. The waste was spread out over a 2,200 m^2 lot (Rogers and Hung 1987). The 2,200-m^2 (0.5-acre) lot is conservative because lots outside of Idaho Falls

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d. A 3-m excavation depth and a 2.4-m cover thickness results in a 0.6 m penetration of the waste. Based on an area of 10 × 10 m, the volume brought to the surface is 60 m^3 (0.6 × 10 × 10 m).

are typically 1 to 3 acres. The waste was mixed to a depth of 0.61 m. The mixing depth of 0.61 m was based on using a deep tilling plow to increase the depth of the root zone and to break up soil compaction. These plows are also used in areas of southeast Idaho with highly erodible soils to minimize erosion. Deep tilling plows have shanks that till to a depth of 24 inches (0.61 m) and are sold at Idaho Falls implement dealers.

The GENII computer code was used to model the inhalation and food chain doses. Crops were grown onsite in a family garden that contained contaminated soil. Appendix B provides details on parameters used in this analysis, and Napier et al. (1988) provides details on the food chain pathway methodology used in GENII. The contaminated soil was mixed and diluted with uncontaminated excavated soil and surface soil (Rogers et al. 1982). Dietary fractions representative of rural agriculture areas were used (EPA 1989). Based on the data in EPA (1989), 70% of the intruder's vegetables and produce, 40% of the intruder's milk, and 44% of the intruder's meat were assumed to be produced locally. Because 2200 m^2 is a relatively small lot that cannot fully support beef cattle or milk cows, the consumption rate of contaminated pasture was adjusted to reflect the maximum amount of feed that could be produced on the lot, assuming three cuttings of hay per year and a yield of 0.7 kg/m^2 (wet weight). Stored feed was assumed to be uncontaminated. Based on a total consumption rate of 12 kg/day (dry weight) for beef cattle and 16 kg/day (dry weight) for milk cows and a dry to wet weight conversion factor of 0.2, 9% of the total pasture eaten by the animal was contaminated. The consumption rate for contaminated pasture was 5.4 kg/day (wet weight) for beef cattle and 7.2 kg/day (wet weight) for milk cows.

$$\begin{aligned} 0.7\,kg/m^2\ (wet\ wt.) \times 3\ cuttings\ hay/yr \times 2{,}200 m^2 \\ = 4{,}620\ kg/yr\ (wet\ wt.) \end{aligned} \tag{3-47}$$

$$\frac{12\ kg/d}{0.2}\ x\ 365\ d/yr = 21{,}900\ kg/yr\ (beef\ cattle,\ wet\ wt.) \tag{3-48}$$

$$\frac{16\ kg/d}{0.2}\ x\ 365\ d/yr = 29{,}200\ kg/yr\ (milk\ cattle,\ wet\ wt.) \tag{3-49}$$

$$Total = 21{,}900\ kg/yr + 29{,}200\ kg/yr = 51{,}100\ kg/yr\ (wet\ wt.) \tag{3-50}$$

$$\frac{4{,}620\ kg/yr}{51{,}100\ kg/yr} = 0.090 \tag{3-51}$$

$$\frac{12\ kg/d}{0.2}\ x\ 0.090 = 5.4\ kg/d\ (beef\ cattle,\ wet\ wt.) \tag{3-52}$$

$$\frac{16\ kg/d}{0.2}\ x\ 0.090 = 7.2\ kg/d\ (milk\ cattle,\ wet\ wt.) \tag{3-53}$$

Two sets of human consumption rates were evaluated: (1) a diet developed in Rupp (1980) and based on a 1965 USDA survey and (2) a diet developed in Yang and Nelson (1984, 1986) and based on a 1977–1978 USDA survey. The Rupp diet was the default diet used in the EPA's NESHAPs Environmental Impact Statement (EPA 1989). The Yang and Nelson diet represents a more realistic diet than the Rupp diet because it is based on a later dietary survey (see Table 3-13). As in the atmospheric transport analyses, two inhalation rates were evaluated: 8030 and 5840 m^3/yr (see Section 3.4.1). Consumption of contaminated soil by adults was incorporated into the scenario using a consumption rate of 10 mg/day (Konz et al. 1989).

External exposures were calculated using the computer code MICROSHIELD. The intruder was exposed to waste excavated from the basement and spread around a home site (2,200 m^2) to a depth of 0.61 m. The source configuration was modeled as a 26.5-m radius plane and a thickness of 0.61 m. The receptor point was 1 m above the plane (see Figures 3-25 and 3-26).

The excavated waste was diluted and mixed with uncontaminated soil during excavation. The exposure time was 1 year (8760 hours). Two shielding factors were evaluated: 0.7 and 0.36. The 0.7 shielding factor is from NRC (1977) and corresponds to the shielding factor used for the maximally exposed individual. The 0.36 shielding factor was calculated using data presented in Konz et al. (1989) (See Section 3.4.1).

For pits and soil vaults, the chronic drilling scenario was evaluated at 2120, 2520, 3020, 5020, 7020, 12020, and at 1,000,000 years after site closure. For pits, the chronic basement excavation scenario was postulated to start in 5020, which corresponds to the time of maximum erosion. The chronic basement excavation scenario was also evaluated at 7020, 12020, and at 1,000,000 years after site closure. One million years corresponds to the time when most long-lived decay series have achieved a substantial fraction of secular equilibrium, and was analyzed to determine if there were any long-lived decay series that could yield large doses because of progeny ingrowth over long time frames.

3.4.3.4 Chronic Intruder Radon Scenario. Two scenarios were considered for calculating chronic radon doses: excavation over pits and excavation over soil vaults. The scenarios were based on an intruder excavating a 10 × 10 × 3-m basement over the waste and constructing a 10 × 10 × 3-m house over the basement. The intruder was exposed to Rn-222 and its short-lived progeny (Po-218, Pb-214, Bi-214, and Po-214) while in the basement and house. The data in Konz et al. (1989) were used to estimate that an individual spent 115 h/week or 68% of their time indoors. This represents the time spent at home and indoors.

The RESRAD computer code (Gilbert et al. 1989) was used to perform the dose assessments. The RESRAD output also provides the radon flux from the surface, which was compared to the 20 pCi/m^2-s standard contained in 40 CFR 61 Subpart Q. Site-specific geometry parameters (such as waste layer thickness and cover thickness) were used in the analyses. The data for the properties of the concrete used in the basement foundation were obtained from two instrumented basement structures located at Colorado State University in Fort Collins, Colorado (Gadd 1993).

The Colorado State University structures were constructed and instrumented for research into the transport, entry, and accumulation of radon in residential structures (Ward et al. 1993). The structures were built using standard residential construction techniques and concrete. For example, the concrete was selected from three Fort Collins-area concrete distributors, based on the lowest cost. The concrete aggregate was surveyed to ensure that it did not contain excessive quantities of Ra-226, which would confound soil radon entry measurements.

Although the outside of a foundation is typically water proofed in the Western United States, water proofing was not applied to the basement structure. The walls and floor were constructed slightly thinner than standard because the structural support for a full upper story was not required and to increase the diffusion of radon into the basement from the surrounding soil to minimize radon measurement problems. The basement structures were instrumented to measure indoor-soil pressure differentials; soil gas Rn-222 concentrations; air permeability; soil moisture; and indoor, outdoor, and subslab Rn-222 concentrations (Gadd 1993).

The Colorado State University data (see Table 3-15) were used because they represent residential concrete and construction techniques used in the Western United States, and they were collected under rigorous and known conditions. RESRAD does not model basement and first floor radon exposures separately. Therefore, a total room height of 6 m was used to account for first floor and basement exposures.

Table 3-15 lists the U-238, U-234, Th-230, and Ra-226 concentrations in the year 2020 (site closure). Radon doses were evaluated at 100, 300, 500, 700, 900, 950, and 1000 years after site closure. Doses were also evaluated at the time of maximum dose, taking into account the changing geometry of the scenario because of erosion, radioactive decay and ingrowth, and leaching. For the pits, the peak dose occurred 2,200 years after the site closure, at the time when the floor of the basement just comes into contact with the waste (Figure 3-27). At later times, even though the basement excavation penetrates the waste, the decrease in Ra-226 concentration because of radioactive decay and leaching yields lower doses. At 2,200 years after site closure, almost 100% of the Ra-226 is from disposed Ra-226, not from Ra-226 that ingrew from U-238, U-234, or Th-230.

For soil vaults, the peak dose occurred 53,000 years after site closure because of ingrowth of Ra-226 from U-238. At this time, there was 3.3 m of cover over the waste, and the bottom of the basement and the top of the waste were separated by 0.3 m of soil (Figure 3-28). The analysis was based on excavating a basement over a row of five soil vaults, each with the diameter of 2 m, separated by 0.6 m of clean soil. This is the maximum number of 2-m diameter soil vaults that can fit in the foot print of a 10 × 10-m basement.

Table 3-15. Data used in the chronic intruder-radon scenario.

Parameter	Pits	Soil vaults
Basement depth	3 m	3 m
First floor height[a]	3 m	3 m
Total porosity	0.487	0.487
Volumetric water content	0.33	0.33
Soil density	1.5 g/cm^3	1.5 g/cm^3
U-238 concentration in 2020	65.7 pCi/g	136 pCi/g
U-234 concentration in 2020	2.46E-1 pCi/g	128 pCi/g
Th-230 concentration in 2020	5.85E-4 pCi/g	1.62E-2 pCi/g
Ra-226 concentration in 2020	13.5 pCi/g	6.40E-5 pCi/g
Ra-226 concentration at time of maximum dose	3.71 pCi/g	12.7 pCi/g
Waste area	12,400 m^2	15.7 m^2 [b]
Waste thickness	6.1 m	3.05 m
Cover thickness	3 m	3.3 m
Uranium leach rate	7.6E-6/yr[c]	1.5E-5/yr[c]
Thorium leach rate	7.6E-6/yr[c]	1.5E-5/yr[c]
Radium leach rate	1.5E-4/yr[d]	3.1E-4/yr[d]

	Colorado State University value[e]
Diffusion coefficient	2.5E-8 m^2/s
Emanation fraction	0.17
Thickness of building foundation	0.10 m
Density of building foundation	2.1 g/cm^3
Total porosity of building foundation	0.13
Volumetric water content of building foundation	0.13[f]

a. A total room height of 6 m was used.

b. Based on five 2-m diameter soil vaults.

c. Based on a K_d of 1,000 mL/g and an infiltration rate of 0.070 m/yr.

d. Based on a K_d of 50 mL/g and an infiltration rate of 0.070 m/yr.

e. Source: Gadd (1993).

f. Calculated based on 100% saturation of concrete. Because a diffusion coefficient was entered, this parameter is not used by RESRAD.

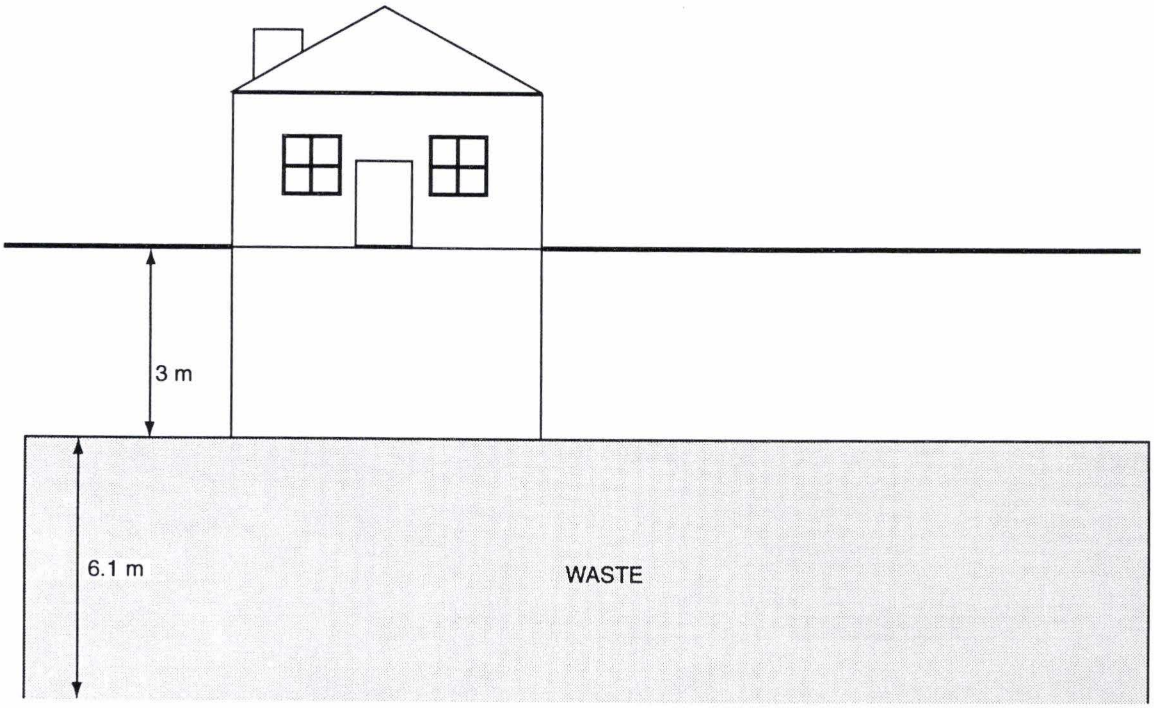

Figure 3-27. Chronic radon scenario for pits.

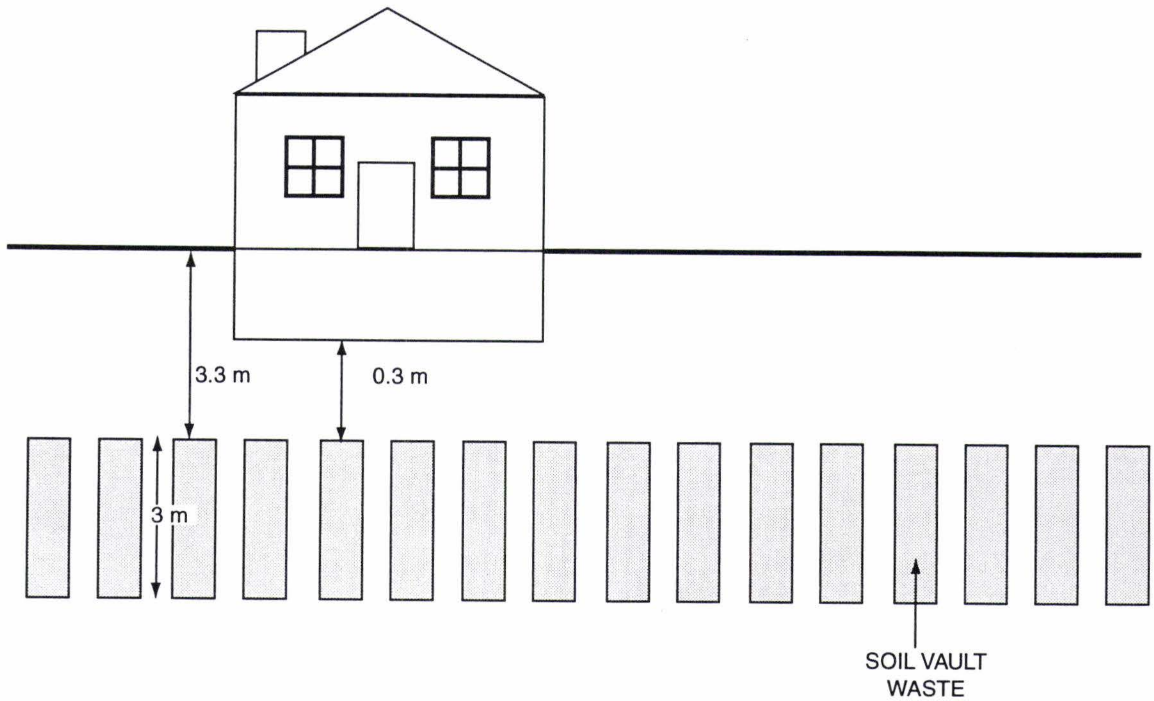

Figure 3-28. Chronic radon scenario for soil vaults.

3.4.3.5 Chronic Biointrusion Scenario. The chronic biointrusion scenario assumes that an inadvertent intruder moves onto the RWMC SDA but does not excavate into the waste and does not contact the waste directly. Rather, radioactivity was brought to the surface by plants and ants. Instead of being blown downwind as in the atmospheric scenario, the radioactivity was assumed to remain at the RWMC, exposing the intruder. In addition, H-3 and C-14 could also diffuse upward as gases and expose the inadvertent intruder.

The models and data used to estimate the quantity of radioactive material brought to the surface by plants and ants were identical to the models and data used to evaluate biointrusion in Section 3.4.1. The models and data used to estimate the doses to the intruder were identical to the models and data used to estimate the doses in the chronic drilling and chronic basement excavation scenarios in Section 3.4.3.3, except that the radioactivity brought to the surface was mixed in the top 15 cm of soil.

Chronic biointrusion doses were evaluated separately for pits and soil vaults. Based on the atmospheric biointrusion analyses, biointrusion in the year 2120 yields higher doses than at other times. Therefore, the chronic biointrusion intruder scenario was evaluated only in the year 2120.

The doses from gaseous releases of H-3 and C-14 were estimated using the peak H-3 and C-14 release rates that were calculated by the hydrological model used to estimate groundwater impacts. Instead of H-3 and C-14 moving downward with water, H-3 and C-14 were assumed to move upward as gases and expose the intruder occupying the RWMC SDA during the post-institutional control period. During the post-institutional control period, the peak release rate for H-3 was 0.34 Ci/yr and the peak release rate for C-14 was 0.35 Ci/yr.

3.4.4 Groundwater Protection Scenario

The groundwater protection scenario was used to evaluate compliance with the groundwater protection performance objective presented in Section 1.3.4. Receptor locations for this analysis were chosen based on guidance from DOE-HQ.[e] During the operational and institutional control periods, the receptor was located at the nearest INEL Site boundary in the direction of groundwater flow, 5500 m south-southwest from the RWMC. During this time, the INEL Site boundary is maintained, and access by the public is not allowed. During post-institutional control, the receptor was located 100 m downgradient of the RWMC facility boundary. Radionuclide concentrations as a function of time at the receptor wells were calculated using the hydrological transport model described in Section 3.3, and were used as input to the groundwater protection analysis.

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e. Letter from S. P. Cowan to J. T. Case, June 20, 1996, "Groundwater Compliance for the Low-Level Waste Radiological Performance Assessment for the Radioactive Waste Management Complex at the Idaho National Engineering Laboratory."

4. Results of Analyses

This chapter presents the projected impacts for each pathway, the sensitivity and uncertainty related to the impacts, and an integration and interpretation of the results.

4.1 Projected Impacts

Section 4.1 presents projected impacts for the atmospheric, all pathways, intruder, and groundwater protection analyses. The impacts are presented based on a time of compliance of 1000 years. However, if the peak impacts occur beyond 1000 years they are also presented.

4.1.1 Atmospheric

Based on the dose assessments in the *1992 INEL National Emission Standard for Hazardous Air Pollutants Annual Report* (DOE 1993), the emissions from contaminated soil areas at the RWMC yielded a dose of 5.7E-6 mrem/yr during the operational and institutional control periods. Gaseous emissions of H-3 and C-14 during the operational and institutional control periods yielded a dose of 0.0011 mrem/yr. When these doses were combined with the dose from existing monitored and unmonitored emission points at the INEL and existing diffuse sources at other areas of the INEL (DOE 1993), a dose of 0.0026 mrem/yr was calculated (see Table 4-1). This dose was well below the 40 CFR 61 Subpart H standard of 10 mrem/yr.

Post-institutional control doses represent the doses through the ingestion, inhalation, and external exposure pathways. During the post-institutional control period, biointrusion by plant roots and harvester ants was used as the mechanism to move radioactive material to the surface, which was then transported to a receptor via the atmosphere. For both pits and soil vaults, the maximum doses occurred in the year 2120, at the end of institutional control. The doses for pits ranged from 0.026 to 0.039 mrem/yr, and the doses for soil vaults ranged from 0.079 to 0.13 mrem/yr. The dominant dose contributor for the pits was Cs-137, and the dominant dose contributors for the soil vaults were Cs-137 and Ni-63.

Gaseous emissions of H-3 and C-14 during the post-institutional control period yielded a dose of 1.1 mrem/yr. When these doses were combined with the dose from existing monitored and unmonitored emission points at the INEL and existing diffuse sources at other areas of the INEL (DOE 1993), doses that ranged from 1.2 to 1.3 mrem/yr resulted (see Table 4-1). These doses were well below the 40 CFR 61 Subpart H standard of 10 mrem/yr.

Based on a time of compliance of 1000 years, the peak radon flux was 0.057 pCi/m^2-s for pits and 0.0015 pCi/m^2-s for soil vaults. The combined radon flux, 0.059 pCi/m^2-s, was well below the 40 CFR 61 Subpart Q standard of 20 pCi/m^2-s and occurred 1000 years after closure in the year 3020. If the time of compliance were extended, the peak radon flux for pits was 0.090 pCi/m^2-s in the year 4220, 2200 years after closure. The peak radon flux for soil vaults

Table 4-1. Atmospheric impacts.

Time period	EDE (mrem/yr)
Operational and institutional control	
INEL baseline[a]	0.0015
Contaminated soil areas at the RWMC	5.7E-6
Gaseous H-3 and C-14	0.0011
Total	0.0026
Post-institutional control	
INEL baseline[a]	0.0015
Pits	0.026–0.039
Soil vaults	0.079–0.13
Gaseous H-3 and C-14	1.1
Total	1.2–1.3
Radon Flux	
Pits	0.057 pCi/m^2-s
Soil vaults	0.0015 pCi/m^2-s
Total	0.059 pCi/m^2-s

a. The INEL baseline consists of monitored and unmonitored emission points at the INEL and existing diffuse sources at other areas of the INEL.

was 0.23 pCi/m^2-s, 53,000 years after closure. These fluxes are also well below the 20 pCi/m^2-s standard.

4.1.2 All-Pathways

For members of the public, groundwater was the primary pathway of concern. During the operational and institutional control periods, 1984 through 2120, the member of the public was located at the INEL Site boundary, 5500 m south of the RWMC facility boundary. The all-pathways dose through groundwater for this member of the public was estimated to be 0.57 mrem/yr in the year 2060, less than 3% of the 25 mrem/yr standard (see Figure 4-1). This dose was estimated using a groundwater intake rate of 258 L/yr. If a groundwater intake rate of 730 L/yr (2 L/d) were used in the assessment, a dose of 0.69 mrem/yr was estimated, still less than 3% of the 25 mrem/yr standard. For these analyses, H-3, C-14, I-129, K-40, Tc-99, Sr-90, and Ni-59 were the primary radionuclides of concern.

During the operational period, 1984 through 2020, a 7 cm/yr infiltration rate was used to calculate the release rate from the waste. During the institutional control period, 2021 through 2120, the infiltration rate was reduced to 1 cm/yr to account for the presence and maintenance of an engineered cover, and the release rate from the waste decreased. At the end of institutional control, in 2120, the infiltration rate was increased to 7 cm/yr. The reduced release rate during the institutional control period results in lower radionuclide flux to the aquifer. The water travel time in the unsaturated zone was estimated to be 30 years for all time periods including institutional control. The travel time was assumed to remain at 30 years for the period of institutional control and while the cover remained intact. Presence of the cover reduced infiltration, but water travel time in the unsaturated zone is driven by the presence of perched water above the interbeds. This perched water originates from sources other than the SDA and was not assumed to be affected by the presence of a cover. This 30-year travel time in the unsaturated zone and approximately 10-year travel time to the INEL Site boundary causes the sharp decline in dose at the INEL Site boundary at 2060 (Figure 4-1). The I-129 peak is offset from the H-3 and C-14 peak because it is slightly retarded. Therefore, the peak occurs at a later time. The sensitivity to reduced infiltration associated with the placement of an engineered cover is discussed in Section 4.2.

During the post-institutional control period, the member of the public was located 100 m from the edge of the waste. Two impact peaks were observed: (1) a near term peak 140 years after closure due to mobile fission and activation products and (2) a long term peak 270,000 years after closure due to long-lived actinides. In the near term, the all-pathways dose through groundwater was estimated to be 17 mrem/yr , 68% of the 25 mrem/yr standard. This dose occurred in the year 2160 (see Figure 4-2). If a groundwater intake rate of 730 L/yr (2 L/d) were used in the assessment, a dose of 20 mrem/yr was estimated, 80% of the 25 mrem/yr standard. Iodine-129, K-40, and C-14 were significant dose contributors during this time period. Tritium doses after institutional control are insignificant because of decay during institutional control. The lag times between the K-40 and C-14 peaks are due to the K-40 retardation and result in slower transit times of K-40. Strontium-90 and Ni-59 doses were insignificant compared to the other fission/activation products. The maximum Sr-90 dose was 3.9×10^{-3} mrem at 589 years, and the maximum Ni-59 dose was 4.3×10^{-1} mrem at 33,000 years.

In the long term, all actinide doses occurred at times greater than 10,000 years. The all-pathways dose through groundwater was estimated to be 7.3 mrem/yr, which is 29% of the 25 mrem/yr standard. This dose occurred 270,000 years after the end of institutional control and

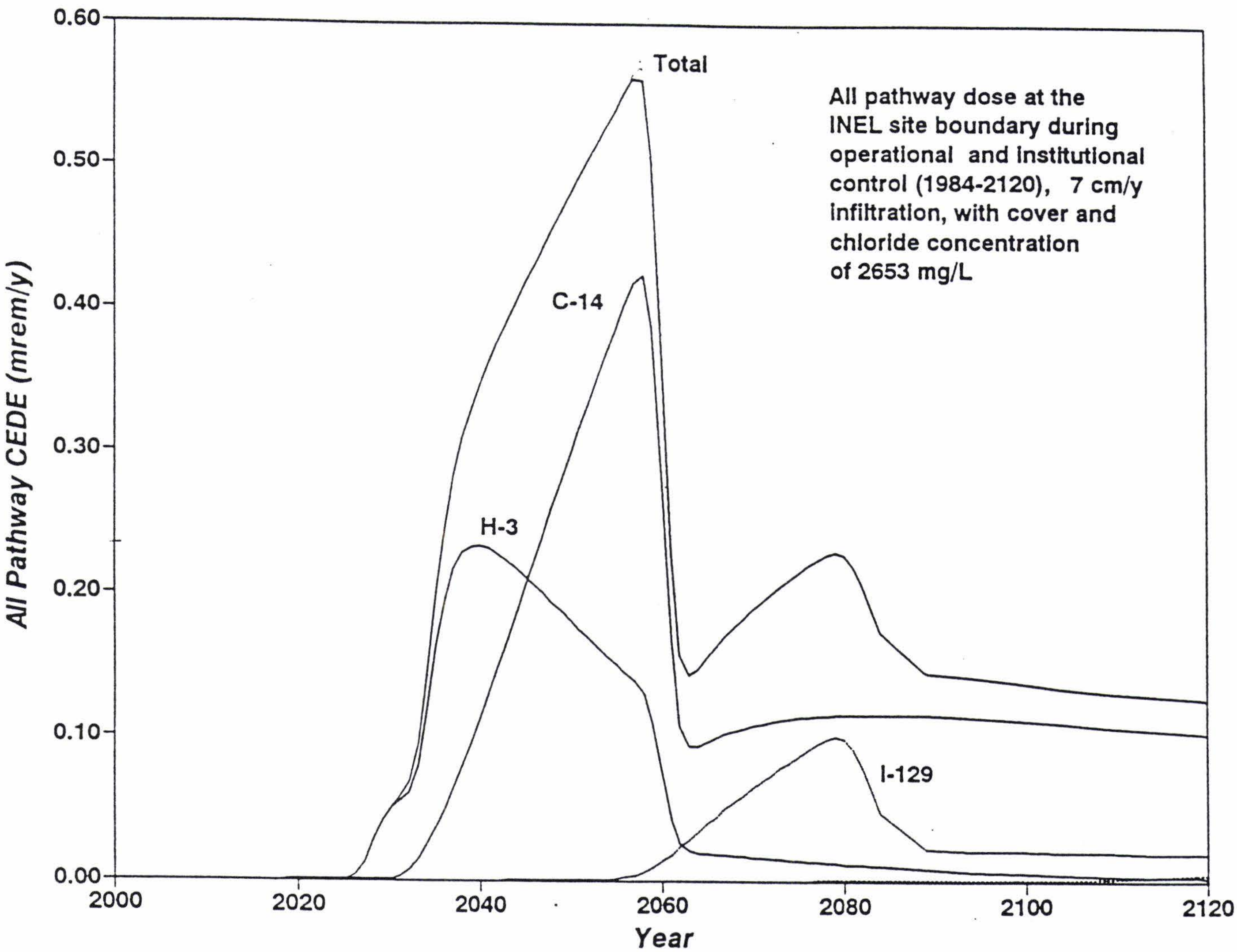

Figure 4-1. All pathway dose for fission and activation products at the INEL Site boundary during the operational and institutional control periods for the base case at 7 cm/yr infiltration and an engineered cover in place at closure.

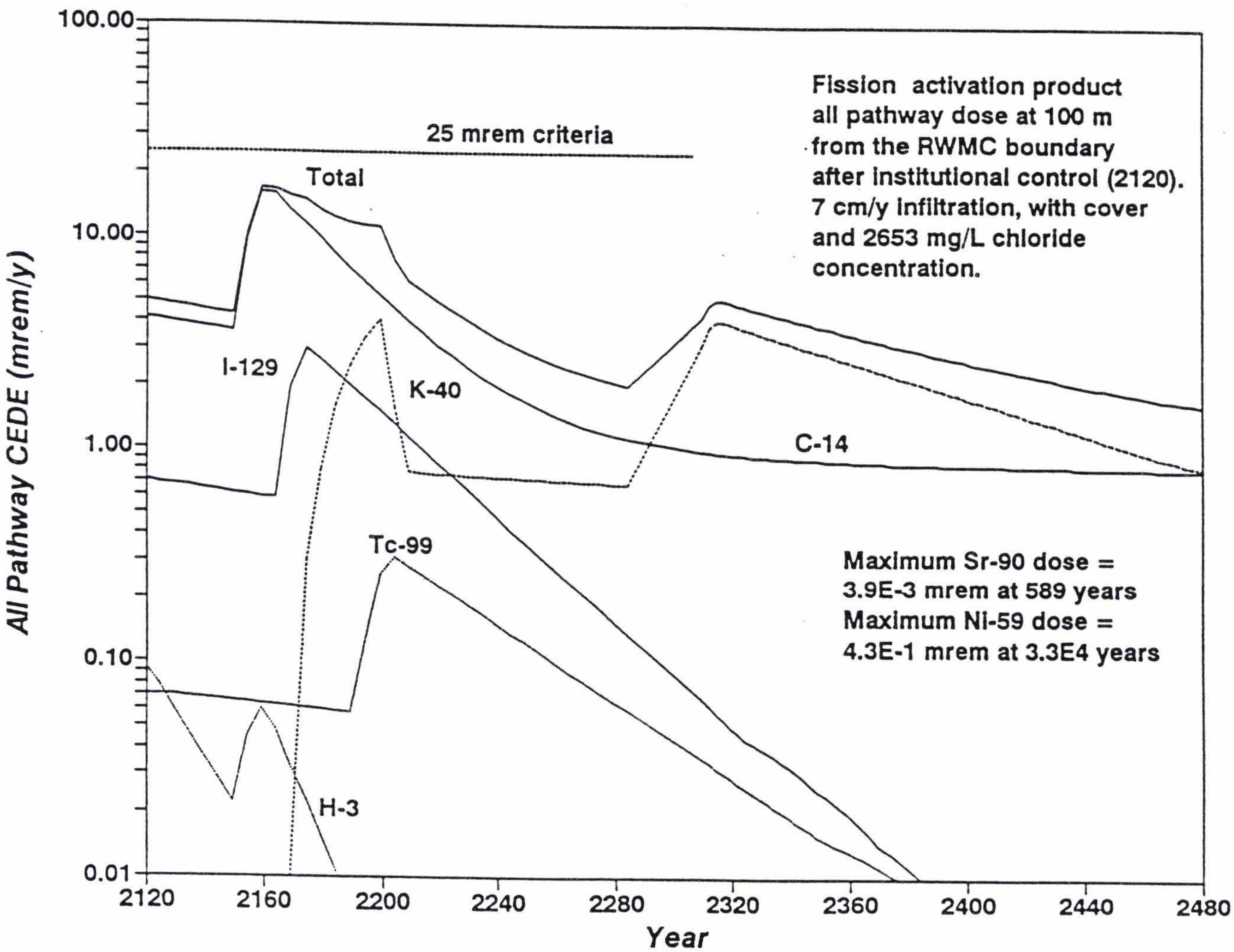

Figure 4-2. All pathway dose for fission and activation products at 100 m from the RWMC facility boundary after the institutional control period for the base case of 7 cm/yr infiltration and an engineered cover in place at closure.

was due primarily to U-238 and its progeny (see Table 4-2). If a groundwater intake rate of 730 L/yr (2 L/d) were used in the assessment, a dose of 18 mrem/yr was estimated, which is 72% of the 25 mrem/yr standard.

4.1.3 Intruders

This section presents the doses to inadvertent intruders for acute and chronic scenarios, based on a maximum time of compliance of 1000 years. At 1000 years after closure, about 4 m of cover remains over the pits and soil vaults based on site-specific waste configurations and a site-specific erosion rate, so intrusion by a 3-m deep basement is not possible. Therefore, the acute and chronic intruder analyses are based on drilling a well through the waste, and an acute construction scenario and a chronic basement excavation scenario were not used to demonstrate compliance. However, results for these scenarios are presented.

4.1.3.1 Acute Intruder Drilling Scenario. For the pits, the acute intruder drilling scenario yielded a peak dose of 8.3 mrem in 2120, the end of institutional control (see Table 4-3). Inhalation accounted for the majority of the dose; U-232 was the dominant radionuclide. The dominant radionuclide for the external exposure pathway was Cs-137.

Table 4-2. All pathways dose for actinides at 100 m from the RWMC facility boundary for the base case of 7 cm/yr infiltration and an engineered cover in place at closure.

Radionuclide	Maximum dose[b] (mrem)	Maximum times (yr)
U-238	6.5	270,000
U-235	0.090	270,000
U-234	0.68	270,000
Pu-239	1.2E-5	550,000
Ra-226	0.0092	14,000
Np-237	0.11	14,000
Th-232	0.0015	270,000
Th-230	1.2E-05	270,000
Maximum[a]	7.3	270,000

a. The maximum total dose calculated for all radionuclides for all time periods.
b. All doses include radioactive progeny.

For the soil vaults, the acute intruder drilling scenario yielded a peak dose of 190 mrem in the year 2120, the end of institutional control (see Table 4-3). Inhalation and external exposure accounted for approximately equal portions of the dose. Nickel-63 was the dominant radionuclide for inhalation, and Cs-137 was the dominant radionuclide for external exposures.

For both pits and soil vaults, the doses were below the DOE Order 5820.2A acute exposure standard of 500 mrem. If the maximum time of compliance were extended past 1000 years, the peak doses from the acute drilling scenario would be unaffected because the peak doses occurred before to 1000 years.

Table 4-3. Acute and chronic intruder doses.

	Dose				
Scenario	100 years	500 years	1000 years	3000 years	5000 years
SVR acute drilling	1.9e+02 mrem	1.9e+01 mrem	1.6e+01 mrem	1.5e+01 mrem	1.5e+01 mrem
BGP acute drilling	8.3e+00 mrem	2.0e+00 mrem	1.8e+00 mrem	1.7e+00 mrem	1.8e+00 mrem
Acute construction	na	na	na	1.4e+00 mrem	1.1e+00 mrem
SVR chronic drilling (a)	6.6e+01 mrem/yr	7.1e-01 mrem/yr	1.4e-01 mrem/yr	1.3e-01 mrem/yr	1.3e-01 mrem/yr
SVR chronic drilling (b)	3.4e+01 mrem/yr	3.9e-01 mrem/yr	7.9e-02 mrem/yr	7.1e-02 mrem/yr	6.9e-02 mrem/yr
BGP chronic drilling (a)	1.5e+00 mrem/yr	2.5e-02 mrem/yr	2.0e-02 mrem/yr	1.1e-02 mrem/yr	7.0e-03 mrem/yr
BGP chronic drilling (b)	7.8e-01 mrem/yr	1.3e-02 mrem/yr	1.1e-02 mrem/yr	5.9e-03 mrem/yr	3.9e-03 mrem/yr
Basement excavation (a)	na	na	na	3.2e+00 mrem/yr	2.1e+00 mrem/yr
Basement excavation (b)	na	na	na	1.8e+00 mrem/yr	1.2e+00 mrem/yr

Scenario	Dose 10,000 years	Dose 1E6 years	Maximum dose 100 to 1000 years	Maximum dose 100 to 1E6 years	DOE 5820.2A Standard
SVR acute drilling	1.5e+01 mrem	1.2e+01 mrem	1.9e+02 mrem	1.9e+02 mrem	500 mrem
BGP acute drilling	1.9e+00 mrem	7.6e+00 mrem	8.3 mrem	8.3 mrem	500 mrem
Acute construction	1.0e+00 mrem	1.1e+01 mrem	na	1.1e+01 mrem	500 mrem
SVR chronic drilling (a)	1.3e-01 mrem/yr	1.5e-01 mrem/yr	6.6e+01 mrem/yr	6.6e+01 mrem/yr	100 mrem/yr
SVR chronic drilling (b)	6.7e-02 mrem/yr	8.0e-02 mrem/yr	3.4e+01 mrem/yr	3.4e+01 mrem/yr	100 mrem/yr
BGP chronic drilling (a)	4.8e-03 mrem/yr	1.2e-01 mrem/yr	1.5 mrem/yr	1.5 mrem/yr	100 mrem/yr
BGP chronic drilling (b)	2.7e-03 mrem/yr	6.3e-02 mrem/yr	7.8e-01 mrem/yr	7.8e-01 mrem/yr	100 mrem/yr
Basement excavation (a)	1.4e+00 mrem/yr	3.5e+01 mrem/yr	na	3.5e+01 mrem/yr	100 mrem/yr
Basement excavation (b)	8.2e-01 mrem/yr	1.9e+01 mrem/yr	na	1.9e+01 mrem/yr	100 mrem/yr

a. 8030 m^3/yr inhalation rate, Rupp diet, and 0.70 shielding factor.
b. 5840 m^3/yr inhalation rate, Yang and Nelson diet, and 0.36 shielding factor.

4.1.3.2 Chronic Intruder Drilling Scenario. The maximum chronic intruder drilling dose for pits ranged from 0.78 to 1.5 mrem/yr (see Table 4-3) and occurred in the year 2120 (100 years after closure of the RWMC). For soil vaults, the maximum chronic intruder drilling dose ranged from 34 to 66 mrem/yr (see Table 4-3) and also occurred in the year 2120.

Fission and activation products such as Sr-90, Cs-137, and Ni-63 dominated the doses for both pits and soil vaults, and the doses were well below the DOE Order 5820.2A chronic exposure standard of 100 mrem/yr. If the maximum time of compliance were extended past 1000 years, the peak doses from the chronic drilling scenario would be unaffected because the peak doses occurred before 1000 years.

4.1.3.3 Acute Intruder Construction Scenario. The impacts from the acute construction scenario do not occur until the year 5020, 3000 years after closure of the RWMC (see Table 4-3). Therefore, this scenario was not used to demonstrate compliance with DOE Order 5820.2A. However, the peak impacts from the acute construction scenario were 11 mrem at 1,000,000 years after closure of the RWMC. Inhalation accounted for 30% of the dose, and external exposure accounted for 70% of the dose. Uranium-238, U-234, and Th-230 were the dominant radionuclides. The 11 mrem dose was well below the DOE Order 5820.2A 500 mrem acute exposure standard.

4.1.3.4 Chronic Intruder Basement Excavation Scenario. The impacts from the chronic basement excavation scenario do not occur until the year 5020, 3000 years after closure of the RWMC (see Table 4-3). Therefore, this scenario was not used to demonstrate compliance with DOE Order 5820.2A. However, the peak impacts from the chronic basement excavation scenario ranged from 19 to 35 mrem/yr at 1,000,000 years after closure of the RWMC. Actinides (such as U-238) and their progeny dominated the doses. The doses of 19 to 35 mrem/yr were well below the DOE Order 5820.2A 100 mrem/yr chronic exposure standard.

4.1.3.5 Chronic Intruder Radon Scenario. Based on a maximum time of compliance of 1000 years, the peak radon doses were 21 mrem/yr for pits and 0.087 mrem/yr for soil vaults. These doses occurred in the year 3020, 1000 years after closure of the RWMC. For pits, almost all of the dose was due to disposed Ra-226; for soil vaults, almost all of the dose was due to ingrowth of Ra-226 from disposed U-234. These doses were well below the DOE Order 5820.2A 100 mrem/yr chronic exposure standard.

If the time of compliance was extended past 1000 years, the peak radon doses were 35 mrem/yr for pits and 13 mrem/yr for soil vaults. For the pits, the peak dose occurred in the year 4320, 2200 years after RWMC closure. Almost 100% of the dose was from disposed Ra-226. For the soil vaults, the peak dose occurred almost 53,000 years after RWMC closure because of ingrowth of Ra-226 from U-238. These doses were also well below the DOE Order 5820.2A 100 mrem/yr chronic exposure standard.

4.1.3.6 Chronic Biointrusion Scenario. The chronic biointrusion doses were 1.4 mrem/yr for pits and 5.2 mrem/yr for soil vaults. These doses occurred in the year 2120 and included the doses from upward migration of gaseous H-3 and C-14. These doses were well below the DOE Order 5820.2A chronic exposure standard of 100 mrem/yr. If the maximum time of compliance was extended past 1000 years, the peak doses from the chronic biointrusion scenario would be unaffected because the peak doses occurred before 1000 years.

4.1.3.7 Summary of Intruder Scenarios. Table 4-3 summarizes the doses from the acute drilling, acute construction, chronic drilling, and basement excavation scenarios. For both pits and soil vaults, the doses were well below the DOE Order 5820.2A exposure standards, even if the maximum time of compliance were extended past 1000 years.

Table 4-4 summarizes the total doses from the chronic intruder scenarios based on an intruder being exposed to the peak impacts from all the chronic scenarios concurrently. This is an extremely conservative method of summing intruder doses because many of the scenarios do not yield peak doses at the same time.

Based on a maximum time of compliance of 1000 years, the total dose through the chronic drilling, radon, and biointrusion scenarios ranged from 23 to 24 mrem/yr for pits and were dominated by radon doses. If radon were excluded, the doses would range from 2.2 to 2.9 mrem/yr. In either case, the doses were well below the DOE Order 5820.2A 100 mrem/yr chronic exposure standard. If the time of compliance were extended past 1000 years, the doses for pits would range from 55 to 71 mrem/yr and would be dominated by chronic basement excavation doses and radon doses. The doses would still be below the DOE Order 5820.2A 100 mrem/yr chronic exposure standard.

For soil vaults, the total doses based on a maximum time of compliance of 1000 years ranged from 39 to 71 mrem/yr and were dominated by the chronic intruder drilling scenario. Radon contributes an extremely small fraction of the dose, ranging from 0.12 to 0.22%. As with the pits, the doses were well below the DOE Order 5820.2A 100 mrem/yr chronic exposure standard. If the time of compliance were extended past 1000 years, the doses for soil vaults would range from 52 to 84 mrem/yr and would be dominated by chronic drilling doses and radon doses. The doses would still be below the DOE Order 5820.2A 100 mrem/yr chronic exposure standard.

4.1.4 Groundwater Protection

During the operational and institutional control periods, the point of compliance was located at the INEL Site boundary. During these time periods, only beta-gamma emitting radionuclides reached the INEL Site boundary. The drinking water dose was estimated to be 0.19 mrem/yr, less than 5% of the groundwater protection standard of 4 mrem/yr. The peak Sr-90 and H-3 activity concentrations were estimated to be 1.7E-4 pCi/L and 2300 pCi/L, respectively. These

Table 4-4. Summary of chronic intruder doses.

Case	1000 year time of compliance EDE (mrem/yr)	Year	Unlimited time of compliance EDE (mrem/yr)	Year
Pits				
Peak chronic scenario[a]	1.5[c]	2120	35[d]	1,000,000 years after closure
Peak chronic scenario[b]	0.78[c]	2120	19[d]	1,000,000 years after closure
Biointrusion	1.4	2120	1.4	2120
Radon	21	3020	35	4320
Total	23-24		55-71	
Soil vaults				
Peak chronic scenario[a]	66[c]	2120	66[c]	2120
Peak chronic scenario[b]	34[c]	2120	34[c]	2120
Biointrusion	5.2	2120	5.2	2120
Radon	0.087	3020	13	53,000 years after closure
Total	39-71		52-84	

a. 8030 m^3/yr inhalation rate, Rupp diet, and 0.70 shielding factor.
b. 5840 m^3/yr inhalation rate, Yang and Nelson diet, and 0.36 shielding factor.
c. Chronic drilling scenario.
d. Chronic basement excavation scenario.

activity concentrations were well below the concentrations that yield 4 mrem/yr total body dose, 8 pCi/L for Sr-90 and 20,000 pCi/L for H-3. When the drinking water doses and the H-3 and Sr-90 activity concentrations were combined in a sum of fractions calculation, the maximum time-dependent sum of fractions was 0.13.

The dose from the consumption of groundwater at the INEL Site boundary (Figure 4-3) for fission and activation products was dominated by C-14, H-3, and I-129. Tritium played a lesser role in the total dose because of decay during transit. The two prominent peaks in Figure 4-3 (about year 2060 and 2160) that are separated by a valley are a result of cover emplacement. The first peak is a result of releases that are postulated to occur before emplacement of a cover, and the second peak is a result of releases that are postulated to occur following the loss of institutional control and degradation of the cover.

During the post-institutional control period, the point of compliance was located 100 m from the edge of the waste. Two impact peaks were observed: (1) a near term peak 140 years after closure because of mobile fission and activation products and (2) a long term peak 270,000 years after closure because of long-lived actinides.

For the near term peak consisting of fission and activation products, the groundwater protection performance objective was 4 mrem/yr because of man-made beta-gamma emitting radionuclides. The drinking water dose was estimated to be 5.6 mrem/yr, which exceeded the 4 mrem/yr standard. This dose occurred in the year 2170 and was due primarily to C-14. The peak Sr-90 and H-3 activity concentrations were estimated to be 6.7E-2 pCi/L and 980 pCi/L, respectively. These activity concentrations were well below the concentrations that yield 4 mrem/yr total body dose, 8 pCi/L for Sr-90 and 20,000 pCi/L for H-3. When the drinking water doses and the H-3 and Sr-90 activity concentrations were combined in a sum of fractions calculation, the maximum time-dependent sum of fractions was 1.4.

For the long term peak consisting of long-lived actinides, the groundwater protection performance objective was (a) a limit on concentration of 5 pCi/L for Ra-226 and Ra-228 combined, (b) a limit on concentration of 15 pCi/L for gross alpha particle activity, including Ra-226, but excluding radon and uranium, and (c) a limit on concentration of 20 μg/L for uranium. Based on the results in Rood (1997) and presented in Table 4-5, at the time of peak impact 270,000 years after the end of institutional control, the uranium concentration was 1.9 μg/L, about 9.5% of the 20 μg/L standard. The Ra-226 concentration was 4.9 pCi/L, 98% of the 5 pCi/L standard. The Ra-228 concentration was 0.0016 pCi/L, 0.03% of the 5 pCi/L standard. The gross alpha concentration was 7.7 pCi/L, 51% of the 15 pCi/L standard. These concentrations were primarily due to U-238, U-234, and their progeny.

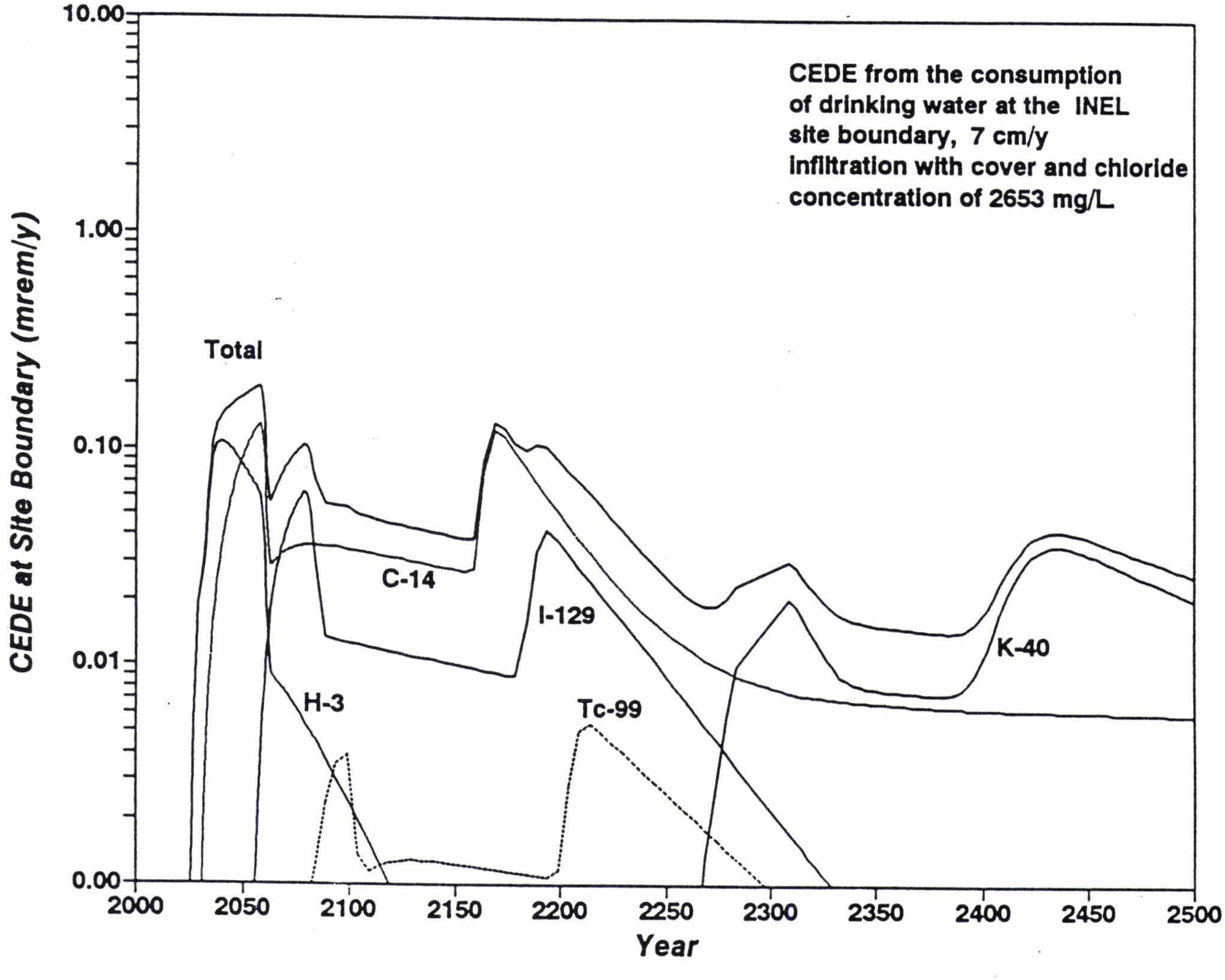

Figure 4-3. Drinking water dose for fission and activation products at the INEL Site boundary for the base case of 7 cm/yr infiltration and an engineered cover in place.

Table 4-5. Groundwater impacts at 100 m from the RWMC for actinides for the base case of 7 cm/yr infiltration and an engineered cover in place.

Radionuclides	Maximum gross alpha activity concentration (pCi/L)	Maximum Ra-226/Ra-228 concentration (pCi/L)	Maximum uranium mass concentration (μg/L)	Time of maximum alpha activity (yr)
U-238	6.8	4.4 (Ra-226)	1.8	270,000
U-234	0.72	0.46 (Ra-226)	3.2E-6	270,000
U-235	0.058	na	5.4E-3	270,000
Np-237	0.094	na	2.8E-8	14,000
Pu-239	7.8E-6	na	7.2E-7	550,000
Ra-226	9.6E-3	6.3E-3 (Ra-226)	na	14,000
Th-230	1.3E-5	8.3E-6 (Ra-226)	na	270,000
Th-232	4.0E-3	1.6E-3 (Ra-228)	na	270,000
Maximum[a]	7.7	4.9	1.9	270,000

a. The maximum impacts calculated for all radionuclides for all time periods

4.2 Uncertainty and Sensitivity Analysis

Models[a] are used in many areas of radiological performance assessments to quantify the behavior of complex systems and processes. Typically, the models are deterministic, with a set of parameters used as input and a resulting output value. In reality input parameters are not single values; they exhibit stochastic variability. There is uncertainty in the input data used in a model; therefore, there is uncertainty in the output estimated by the model. This type of uncertainty is known as parameter uncertainty. The objective of a parameter uncertainty analysis is to quantify the uncertainty in the output from a model based on the uncertainty in the input data.

There is also uncertainty in formulating the model used to quantify the behavior of the system or process; this is referred to as structural uncertainty. Structural uncertainty results from incomplete knowledge of the system or process and includes the uncertainty in the choice and specification of scenarios. The objective of a structural uncertainty analysis is to quantify the uncertainty in the output data based on the uncertainty in formulating the conceptual model of the system or process. Sensitivity analysis identifies the components of a model that have the most affect on model output.

The approach used in the radiological performance assessment to determine uncertainties relies on the results obtained using the nominal data. These results were used to remove unimportant scenarios, pathways, and radionuclides from further consideration. After they were removed from consideration, a quantitative uncertainty analysis was performed using a variety of techniques depending on the individual analysis. The techniques used were (a) assigning generic estimates of uncertainty to the results based on similar published analyses, (b) performing simple parameter perturbation analyses, or (c) performing Monte Carlo analyses.

After the uncertainty analyses were performed, sensitivity analyses were used to identify the important contributors to the uncertainty. As with the uncertainty analyses, various techniques were used to estimate sensitivity, such as (a) generic estimates using published sensitivity analyses, (b) simple perturbation analyses, or (c) correlation coefficients calculated from Monte Carlo analyses.

Uncertainty and sensitivity analyses in this radiological performance assessment were divided into four categories: inventory, groundwater, atmospheric, and intruder. Within each one of these categories, dose to receptor was the end point evaluated. Unimportant scenarios, pathways, and radionuclides were removed from further analyses based on the results obtained using the nominal data, allowing the analyses to focus on the important scenarios, pathways, and radionuclides.

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a. In this context, the term model refers to the conceptual model of a system or process rather than the term computer code, which refers to a specific computer implementation of a model.

4.2.1 Inventory

There are four components to the uncertainty in the radionuclide inventory used in this radiological performance assessment. The first component is the uncertainty in the activity reported to the Radioactive Waste Management Information System (RWMIS) for each radionuclide. The activity is usually determined by sampling and analyses of the waste for radionuclides that are readily measured, by using scaling factors for those radionuclides that are not readily measured, or based on knowledge of facility operations. The uncertainty in the activity for a specific radionuclide will be dependent on a number of factors, such as the decay mode of the radionuclide, the measurement system, the accuracy of scaling factors, and the waste form and container. An added dimension to measurement system uncertainty is present at the INEL because not all measurement systems or procedures are identical at each INEL facility, and they have changed over time.

At the present time, insufficient data exist to provide a meaningful estimate of uncertainty for the activity reported for individual radionuclides in the RWMIS. Because meaningful uncertainty estimates are not available, the results from a sensitivity analysis would also be highly speculative. For example, insufficient data exist to even establish a range over which the radionuclide inventory might vary. Based on these considerations, sensitivity analysis was not attempted. However, important radionuclides were identified throughout the performance assessment. Radionuclide uncertainty and sensitivity should be examined in future research.

The second component is uncertainty in the identity of the radionuclides reported to the inventory data base. Historically, waste generators have reported readily measured gamma-emitting radionuclides, but they have sometimes neglected to report harder to measure beta-emitting radionuclides. The uncertainty in the identity of radionuclides based on scaling factors or process knowledge is also included in this component of inventory uncertainty. As inventory estimates have become more refined, omissions such as these have become apparent and the inventory has been revised to incorporate previously unreported radionuclides. This process will continue as the performance assessment is revised in the future.

A third component is uncertainty in the radionuclide forecasts. For example, radionuclide forecasts sometimes do not reflect historical data with respect to the radionuclides identified or radionuclide activities. While there may be good reasons for these forecasts, such as the uncertainty in the future mission of the INEL and Decontamination and Decommissioning and Environmental Restoration activities, in some cases they are based on incorrect assumptions or compounded conservative assumptions that do not reflect reality. In the performance assessment, a weighted average of historical and forecast data has been used to minimize this uncertainty. In addition, because of the iterative performance assessment process, this uncertainty will be reduced as time progresses and forecast inventory becomes better defined and as forecast inventory becomes disposal inventory.

A fourth component is the uncertainty in the identity of radioactivity reported to the RWMIS as mixed activation products (MAPs), mixed fission products (MFPs), and unidentified beta-gamma activity. In the performance assessment, unidentified activity accounts for only 0.12% of the activity disposed of in the pits and 0.033% of the activity disposed of in the soil vault rows. All unidentified activity was assigned to be 50% Sr-90 and 50% Cs-137. As an alternative to this assignment, the unidentified activity was assigned to various radionuclides based on historical data for 1984 to 1993. These calculations are discussed in Section 4.2.1.1, and their use in atmospheric, intruder, and groundwater all-pathways scenarios is described in Sections 4.2.1.2 and 4.2.1.3. The problem of unidentified activity for future waste has been eliminated because the RWMC waste acceptance criteria does not allow activity to be reported as unidentified.

4.2.1.1 Alternative Inventory Assignment. As an alternative to assigning 50% Sr-90 and 50% Cs-137 to unidentified activity, the historical data for 1984 to 1993 were used to develop a distribution of radionuclides assigned to unidentified activity. This distribution was developed by adding the disposal activity of each radionuclide for 1984 through 1993 to arrive at a total for each radionuclide (see Tables A-1 and A-2). Inventory already identified as MFP, MAP, or unidentified beta-gamma was not included. In addition, H-3 associated with beryllium blocks was not included because MFP, MAP, and unidentified beta-gamma activity is not associated with the blocks.

The radionuclide totals were then normalized by dividing the inventory for each radionuclide by the total activity (summed over all radionuclides). MFP, MAP, unidentified beta-gamma activity, and the H-3 associated with beryllium blocks were also not included in the total activity. The normalized radionuclide distribution was then multiplied by the total unidentified activity to arrive at the radionuclide inventory used in the analyses (see Table 4-6). Radioactive decay was not considered at any point in this process.

4.2.1.2 Scenarios Involving Direct Contact with Waste. As a first step in the uncertainty analysis for scenarios involving direct contact with the waste, the intruder and atmospheric scenarios were examined to identify dominant scenarios, pathways, and radionuclides to limit the scope of the uncertainty analysis. Based on the results obtained using nominal parameter values, the atmospheric scenario yielded a dose that was 11% of the 10 mrem/yr dose standard. The intruder scenarios related to direct contact with waste yielded doses that were up to 66% of the 100 mrem/yr dose standard. The intruder scenarios were identified as the dominant scenarios, and the atmospheric scenario was not considered further in the inventory uncertainty analysis. The groundwater all-pathways analyses are evaluated in the following section.

Table 4-6. Unidentified activity distribution.

Soil vault row unidentified activity distribution		Pit unidentified activity distribution		Soil vault row and pit unidentified activity distribution	
Nuclide	Ci	Nuclide	Ci	Nuclide	Ci
		Ac-227	6.894E-03	Ac-227	6.894E-03
		Ag-108m	4.259E-05	Ag-108m	4.259E-05
		Ag-110	3.186E-03	Ag-110	3.186E-03
Ag-110m	4.727E-06	Ag-110m	8.151E-02	Ag-110m	8.151E-02
Am-241	1.039E-06	Am-241	1.676E-02	Am-241	1.676E-02
		Am-243	7.428E-05	Am-243	7.428E-05
		Ba-140	4.258E-02	Ba-140	4.258E-02
		Ba-133	4.258E-08	Ba-133	4.258E-08
		Ba-140	5.652E-02	Ba-140	5.652E-02
		Be-7	2.803E-05	Be-7	2.803E-05
		Bk-249	7.238E-04	Bk-249	7.238E-04
		Br-82	4.258E-05	Br-82	4.258E-05
C-14	2.799E-02	C-14	2.746E-03	C-14	3.074E-02
		Ca-45	4.322E-05	Ca-45	4.322E-05
		Cd-109	5.608E-04	Cd-109	5.608E-04
		Ce-139	1.277E-05	Ce-139	1.277E-05
		Ce-141	9.883E-02	Ce-141	9.883E-02
Ce-144	6.572E-01	Ce-144	1.207E+01	Ce-144	1.273E+01
		Cf-249	8.924E-06	Cf-249	8.924E-06
		Cf-250	4.598E-06	Cf-250	4.598E-06
		Cf-252	1.936E-05	Cf-252	1.936E-05
Cm-242	2.935E-14	Cm-242	4.221E-09	Cm-242	4.221E-09
		Cm-243	2.129E-08	Cm-243	2.129E-08
Cm-244	1.421E-08	Cm-244	9.676E-05	Cm-244	9.678E-05
		Co-56	3.330E-07	Co-56	3.330E-07
		Co-57	1.995E-03	Co-57	1.995E-03
Co-58	1.070E+03	Co-58	2.635E+00	Co-58	1.073E+03
Co-60	2.288E+03	Co-60	3.503E+02	Co-60	2.638E+03
Cr-51	8.412E+01	Cr-51	1.734E+02	Cr-51	2.575E+02
Cs-134	3.351E-01	Cs-134	2.807E+00	Cs-134	3.142E+00
Cs-137	8.150E+00	Cs-137	4.202E+01	Cs-137	5.017E+01
Eu-152	1.093E-02	Eu-152	2.817E-01	Eu-152	2.927E-01
Eu-154	1.640E-03	Eu-154	2.285E-01	Eu-154	2.302E-01
Eu-155	1.079E-03	Eu-155	6.815E-02	Eu-155	6.923E-02
Fe-55	2.623E+02	Fe-55	1.691E+02	Fe-55	4.314E+02
Fe-59	9.292E+00	Fe-59	1.836E-02	Fe-59	9.310E+00
H-3	5.437E-02	H-3	1.265E+02	H-3	1.266E+02
Hf-175	6.786E+00	Hf-175	1.763E-03	Hf-175	6.788E+00
Hf-181	1.077E+01	Hf-181	1.996E-01	Hf-181	1.097E+01
		Hg-203	4.258E-08	Hg-203	4.258E-08
		I-125	4.918E-05	I-125	4.918E-05
I-129	1.506E-06	I-129	5.980E-09	I-129	1.512E-06
		I-131	2.929E-03	I-131	2.929E-03
		I-132	4.293E-02	I-132	4.293E-02
		I-133	6.386E-05	I-133	6.386E-05
Ir-192	1.822E-03	Ir-192	1.150E-04	Ir-192	1.937E-03
		K-40	7.201E-03	K-40	7.201E-03
		La-140	6.904E-02	La-140	6.904E-02
Mn-54	7.480E+02	Mn-54	4.246E+00	Mn-54	7.523E+02
		Mn-56	5.560E-02	Mn-56	5.560E-02
		Mo-99	1.682E-04	Mo-99	1.682E-04
		Na-22	3.029E-03	Na-22	3.029E-03
		Na-24	1.158E-01	Na-24	1.158E-01
Nb-94	1.113E-04	Nb-94	2.938E-07	Nb-94	1.116E-04
Nb-95	1.091E+01	Nb-95	1.660E+00	Nb-95	1.257E+01
Ni-63	8.259E+02	Ni-63	4.930E+02	Ni-63	1.319E+03
Np-237	3.404E-10	Np-237	7.275E-05	Np-237	7.275E-05
		Np-239	4.258E-08	Np-239	4.258E-08
		P-32	3.640E-04	P-32	3.640E-04
		Pa-231	2.010E-04	Pa-231	2.010E-04
		Pb-210	1.320E-06	Pb-210	1.320E-06
		Pb-212	1.704E-04	Pb-212	1.704E-04
Pm-147	6.701E-03	Pm-147	2.555E-04	Pm-147	6.956E-03

Table 4-6. (continued).

Soil vault row unidentified activity distribution		Pit unidentified activity distribution		Soil vault row and pit unidentified activity distribution	
Nuclide	Ci	Nuclide	Ci	Nuclide	Ci
		Pr-144	1.027E+01	Pr-144	1.027E+01
		Pu-236	1.364E-07	Pu-236	1.364E-07
Pu-238	1.172E-06	Pu-238	7.974E-04	Pu-238	7.986E-04
Pu-239	5.540E-05	Pu-239	1.130E-02	Pu-239	1.136E-02
		Pu-239	5.961E-07	Pu-239	5.961E-07
Pu-240	4.881E-06	Pu-240	1.431E-03	Pu-240	1.435E-03
Pu-241	3.634E-05	Pu-241	3.714E-03	Pu-241	3.750E-03
Pu-242	6.869E-11	Pu-242	1.438E-05	Pu-242	1.438E-05
		Ra-225	6.386E-08	Ra-225	6.386E-08
		Ra-226	5.142E-02	Ra-226	5.142E-02
		Ra-228	4.267E-05	Ra-228	4.267E-05
		Rb-86	1.277E-06	Rb-86	1.277E-06
		Re-188	3.960E-04	Re-188	3.960E-04
		Rh-106	5.144E+00	Rh-106	5.144E+00
		Rn-222	4.262E-05	Rn-222	4.262E-05
Ru-103	6.684E-30	Ru-103	1.065E-02	Ru-103	1.065E-02
Ru-106	8.150E-04	Ru-106	5.312E+00	Ru-106	5.313E+00
		S-35	5.543E-06	S-35	5.543E-06
Sb-124	5.047E-04	Sb-124	2.931E-04	Sb-124	7.977E-04
Sb-125	7.937E+00	Sb-125	2.456E+00	Sb-125	1.039E+01
Sc-46	1.400E-01	Sc-46	4.458E-03	Sc-46	1.445E-01
		Se-75	1.935E-03	Se-75	1.935E-03
Sn-113	6.795E-02	Sn-113	1.405E-04	Sn-113	6.809E-02
Sr-85	8.184E-04	Sr-85	4.136E-06	Sr-85	8.225E-04
		Sr-89	1.267E+00	Sr-89	1.267E+00
Sr-90	3.990E-01	Sr-90	6.232E+00	Sr-90	6.631E+00
		Sr-91	1.873E-04	Sr-91	1.873E-04
		Sr-92	6.812E-05	Sr-92	6.812E-05
Ta-182	5.560E+01	Ta-182	5.746E-03	Ta-182	5.561E+01
Tc-99	2.033E-05	Tc-99	1.267E-05	Tc-99	3.300E-05
		Te-129	6.957E-04	Te-129	6.957E-04
		Te-132	1.277E-05	Te-132	1.277E-05
		Th-228	4.411E-01	Th-228	4.411E-01
		Th-229	9.065E-08	Th-229	9.065E-08
		Th-230	2.550E-06	Th-230	2.550E-06
		Th-232	4.092E-04	Th-232	4.092E-04
		Th-234	2.018E-07	Th-234	2.018E-07
		U-232	9.445E-02	U-232	9.445E-02
		U-233	1.268E-04	U-233	1.268E-04
U-234	6.325E-08	U-234	6.253E-04	U-234	6.254E-04
U-235	1.069E-06	U-235	2.366E-03	U-235	2.367E-03
U-236	3.073E-09	U-236	8.554E-06	U-236	8.557E-06
U-238	3.448E-04	U-238	9.186E-02	U-238	9.220E-02
		V-48	1.065E-03	V-48	1.065E-03
		Y-88	1.277E-04	Y-88	1.277E-04
Y-90	1.192E-04	Y-90	5.249E+00	Y-90	5.249E+00
Y-91m	2.614E-24	Y-91m	2.802E-02	Y-91m	2.802E-02
		Y-93	4.713E-03	Y-93	4.713E-03
Zn-65	2.818E+00	Zn-65	1.101E+00	Zn-65	3.919E+00
Zr-95	5.960E+00	Zr-95	2.801E+00	Zr-95	8.760E+00
W-185	1.533E+01			W-185	1.533E+01
W-187	2.566E+00			W-187	2.566E+00
Sn-117m	3.344E-01			Sn-117m	3.344E-01
Sn-119m	2.456E+01			Sn-119m	2.456E+01
Sn-121m	3.364E-05			Sn-121m	3.364E-05
Te-125m	1.169E-01			Te-125m	1.169E-01
Ni-59	3.757E+00			Ni-59	3.757E+00
Gd-153	3.645E-03			Gd-153	3.645E-03
TOTAL	5.446E+03	TOTAL	1.420E+03	TOTAL	6.865E+03

Within the intruder scenarios, the soil vaults consistently yielded higher doses than the pits. Using nominal parameter values, the soil vaults yielded doses (190 mrem) that were 38% of the 500 mrem dose standard for the acute scenarios, and the pits yielded doses (11 mrem) that were 2.2% of the dose standard. For the chronic scenarios, soil vaults yielded doses (66 mrem/yr) that were 66% of the 100 mrem/yr dose standard, and pits yielded doses (35 mrem/yr) that were 35% of the dose standard. The maximum doses for pits were calculated approximately 1,000,000 years after site closure without incorporating leaching of radionuclides from the waste. If leaching were incorporated, the doses from the pits would be reduced substantially. The maximum doses for soil vaults occurred at the end of institutional control, so leaching would have little affect on the doses. Based on these results, the soil vault scenarios were the dominant contributor to dose for the intruders, and the pits were not considered further in the inventory uncertainty analysis.

Intruder doses were recalculated using the soil vault unidentified activity distribution developed in the previous section (see Table 4-6) for the acute drilling scenario and the chronic drilling scenario (see Table 4-7). As shown in Table 4-7, the dose for the acute drilling scenario did not change, the dose for the chronic drilling scenario decreased slightly, and the assignment of unidentified activity is not critical for the intruder analyses in this performance assessment.

4.2.1.3 Groundwater All-Pathways Scenario. Using the alternative inventory for unidentified activity that was developed in Section 4.2.1.1 (see Table 4-6), the groundwater all-pathways dose assessment was performed using nominal hydrologic data. The peak dose at 100 m south of the RWMC facility boundary during the post-institutional control period was 17 mrem/yr using the 50% Cs-137 and 50% Sr-90 unidentified activity assignment. Using the alternative inventory assignment, the peak dose at the RWMC facility boundary (100 m) during the post-institutional control period was also 17 mrem/yr.

Table 4-7. Nominal and alternative intruder doses for soil vaults.

Scenario	Nominal EDE	Alternative EDE
Acute drilling	190 mrem[a]	190 mrem[b]
Chronic drilling	66 mrem/yr[a]	61 mrem/yr[b]

a. Calculated based on conversion of unidentified activity to 50% Cs-137 and 50% Sr-90.
b. Calculated based on conversion of unidentified activity to the soil vault activity distribution on Table 4-6.

The peak dose at the INEL Site boundary 5500 m south of the RWMC during the operational and institutional control periods was 0.57 mrem/yr using the 50% Sr-90 and 50% Cs-137 inventory assignment. Using the alternative inventory assignment, the peak dose at the INEL Site boundary (5500 m) was also 0.57 mrem/yr.

Based on the analyses, the uncertainty in the assignment of unidentified activity is not an important component of the uncertainty in the inventory used in the performance assessment.

No changes were made to

4.2.2 Groundwater Pathway

and

4.2.3 Atmospheric Pathway

4.2.4 Intruder Analyses

This section describes the uncertainty and sensitivity analyses regarding intruder dose assessments for direct contact with waste.

4.2.4.1 Uncertainty. In the context of the intruder dose assessments, structural uncertainty was defined as the uncertainty in the structure of the scenario. Structural uncertainty in the intruder dose assessments was evaluated using a wide range of alternative intruder scenarios. For example, two separate acute scenarios (drilling and construction) were used to evaluate structural uncertainty in the acute exposure scenarios. To evaluate structural uncertainty in the chronic exposure scenarios, two variations of the chronic drilling and basement excavation scenarios were developed using different shielding factors, dietary regimes, and inhalation rates. In addition, site-specific variations of the intruder scenarios were evaluated, such as spreading out drill cuttings on a flat plane instead of using a mud pit.

Intruder dose assessments include parameter uncertainty in radionuclide dose conversion factors and human intrusion and terrestrial transport models.

As with the atmospheric pathway, the uncertainty in the radionuclide dose conversion factors is the subject of considerable research and is beyond the scope of these analyses. However, the intruder analyses for this performance assessment used the most conservative combinations of inhalation and ingestion dose conversion factors as implemented in the GENII dosimetric data base.

Throughout the intruder analyses, soil vaults yielded higher doses than pits. For example, the doses because of direct contact with waste through the chronic drilling scenario for soil vaults ranged from 34 to 66 mrem/yr, while the doses for pits because of direct contact with waste ranged from 0.78 to 1.5 mrem/yr for the chronic drilling scenario, based on a 1000-year maximum time of compliance. In the acute scenarios, the scenario with the largest dose for soil vaults (drilling) resulted in a dose of 190 mrem, while the scenario with the largest dose for pits (drilling) resulted in a dose of 8.3 mrem.

Using the 100 mrem/yr chronic exposure standard as a reference point, the doses through the chronic drilling scenario were below the standard by a factor of 1.5 for soil vaults and 67 for pits for the chronic drilling scenario. Using the 500 mrem acute exposure criterion as a reference point, the acute doses were below the reference point by a factor of 2.6 for soil vaults and a factor of 60 for pits. Based on these results, soil vault performance is more important than pit performance relative to the chronic exposure standard, and the chronic exposure standard is more important than the acute exposure standard. Therefore, the uncertainty analysis was limited to the chronic drilling scenario for soil vaults.

Within the soil vault chronic drilling scenario, the external exposure pathway was the dominant pathway, contributing over 70% of the dose. Cesium-137 was the critical radionuclide, contributing 98% of the dose through the external exposure pathway. Therefore, the uncertainty analysis was further refined to examine only Cs-137 doses through the external exposure pathway. The uncertainty in inventory was not examined because it was previously shown to be unimportant for intruders (see Section 4.2.1.2).

A simple Monte Carlo analysis of the external Cs-137 doses through the chronic drilling scenario was performed to assess uncertainty. Four parameters were varied in the uncertainty analysis:

1. Volume of contaminated soil brought to the surface
2. Mixing volume of contaminated soil on the surface
3. Exposure time
4. Shielding factor.

The volume of contaminated soil brought to the surface was the product of the area of the well[b] and the thickness of the waste. These parameters had nominal values of 0.0324 m^2[c] and 3.05 m, respectively. The nominal value for the volume of contaminated soil brought to the surface was 0.0989 m^3. No statistical data were available for this parameter. Instead, the volume was increased and decreased by 50% and assigned a triangular distribution in the uncertainty analysis (see Table 4-16).

The mixing volume of contaminated soil on the surface was the product of the lot size and the mixing depth. These parameters had nominal values of 2200 m^2 and 0.61 m, respectively. The nominal value for the mixing volume of contaminated soil on the surface was 1342 m^3. No statistical data were available for this parameter. Instead, the mixing volume was increased and decreased by 50% and assigned a triangular distribution in the uncertainty analysis (see Table 4-16).

The nominal value of the exposure time was 8760 h/yr, the maximum value possible. For the uncertainty analysis, the exposure time was assigned a lognormal distribution with a geometric mean of 540 and a geometric standard deviation of 1.72 (Farris 1988) (see Table 4-16). The exposure time was treated independently from the shielding factor.

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b. In the chronic intruder-agriculture scenario for soil vaults, intrusion by basement excavation is precluded by the depth to the waste, and only intrusion by drilling is possible.

c. Based on a well diameter of 8 in.

Table 4-16. Stochastic data used in intruder analyses.

Parameter	Nominal value	Statistical distribution
Volume of contaminated soil brought to the surface	0.0989 m^3	~TRIA(0.0495, 0.0989, 0.148)
Mixing volume of contaminated soil on the surface	1,342 m^3	~TRIA(671, 1342, 2013)
Exposure time	8,760 h/yr	~LN(540, 1.72)
Shielding factor	0.36 and 0.70	~UNIF(0.36, 0.70)

The nominal values for the shielding factor were 0.36 and 0.70. For the uncertainty analysis, these values were used as the minimum and maximum of a uniform distribution (see Table 4-16).

Using the nominal values for parameters, a dose of 50 mrem/yr resulted for Cs-137 doses through external exposures. The uncertainty analysis yielded a geometric mean of 2.3 mrem/yr and a geometric standard deviation of 1.9 using 5000 Monte Carlo replications. Based on these results, a 95% confidence interval of 0.65 to 8.1 mrem/yr was constructed. The nominal dose of 50 mrem/yr was above the upper bound of the 95% confidence interval, which illustrates the conservative nature of the nominal data, and both doses were well below the chronic exposure criterion of 100 mrem/yr.

4.2.4.2 Sensitivity. Because the intrusion model for external exposures to Cs-137 in the chronic drilling scenario had such a simple structure (a linear combination of five parameters with one quotient), a simple sensitivity analysis was done using the results of the Monte Carlo uncertainty analysis. The rank correlation coefficient (ρ) was used to measure sensitivity. The exposure time was found to be the most sensitive parameter ($\rho = 0.82$). The volume of contaminated soil brought to the surface, the mixing volume of contaminated soil on the surface, and the shielding factor all exhibited small but similar sensitivities ($\rho = 0.32$, -0.31, and 0.29 respectively).

4.3 Integration and Interpretation

4.3.1 All-Pathways and Groundwater Protection

4.3.1.1 Interpretation of Results for Operational and Institutional Control Periods. For members of the public, groundwater was demonstrated to be the primary pathway of concern. During the operational and institutional control periods, the member of the public was located at the INEL Site boundary. The all-pathways dose through groundwater for this member of the public was estimated to be 0.57 mrem/yr, less than 3% of the 25 mrem/yr standard. This dose was estimated using a groundwater intake rate of 258 L/yr. If a groundwater intake rate of 730 L/yr (2 L/d) were used in the assessment, a dose of 0.69 mrem/yr was estimated, still less than 3% of the 25 mrem/yr standard. For these analyses, H-3, C-14, I-129, K-40, Tc-99, Sr-90, and Ni-59 were the primary radionuclides of concern.

During the operational and institutional control periods, only beta-gamma emitting radionuclides reached the INEL Site boundary. The drinking water dose was estimated to be 0.19 mrem/yr, less than 5% of the groundwater protection standard of 4 mrem/yr. The peak Sr-90 and H-3 activity concentrations were estimated to be 1.7E-4 and 2300 pCi/L, respectively. These activity concentrations were well below the concentrations that yield 4 mrem/yr total body dose, 8 pCi/L for Sr-90 and 20,000 pCi/L for H-3. When the drinking water doses and the H-3 and Sr-90 activity concentrations were combined in a sum of fractions calculation, the maximum time-dependent sum of fractions was 0.13.

4.3.1.2 Interpretation of Results for Post-Institutional Control Period. During the post-institutional control period, the member of the public was located 100 m from the edge of the waste. Two impact peaks were observed: (1) a near term peak 140 years after closure because of mobile fission and activation products and (2) a long term peak 270,000 years after closure because of long-lived actinides. In the near term, the all-pathways dose through groundwater was estimated to be 17 mrem/yr , 68% of the 25 mrem/yr standard. This dose occurred in the year 2160 and was due primarily to C-14. If a groundwater intake rate of 730 L/yr (2 L/d) were used in the assessment, a dose of 20 mrem/yr was estimated, 80% of the 25 mrem/yr standard. In the long term, the all-pathways dose through groundwater was estimated to be 7.3 mrem/yr, 29% of the 25 mrem/yr standard. This dose occurred 270,000 years after the end of institutional control and was due primarily to U-238 and its progeny. If a groundwater intake rate of 730 L/yr (2 L/d) were used in the assessment, a dose of 18 mrem/yr was estimated, 72% of the 25 mrem/yr standard.

For the near term peak consisting of fission and activation products, the groundwater protection performance objective was 4 mrem/yr because of man-made beta-gamma emitting radionuclides. The drinking water dose was estimated to be 5.6 mrem/yr, which exceeded the 4 mrem/yr standard. This dose occurred in the year 2170 and was due primarily to C-14. The peak Sr-90 and H-3 activity concentrations were estimated to be 6.7E-2 pCi/L and 980 pCi/L, respectively. These activity concentrations were well below the concentrations that yield 4 mrem/yr total body dose, 8 pCi/L for Sr-90 and 20,000 pCi/L for H-3. When the drinking water doses and the H-3 and Sr-90 activity concentrations were combined in a sum of fractions calculation, the maximum time-dependent sum of fractions was 1.4.

For the long-term peak consisting of long-lived actinides, the groundwater protection performance objective was (a) a limit on concentration of 5 pCi/L for Ra-226 and Ra-228 combined, (b) a limit on concentration of 15 pCi/L for gross alpha particle activity, including Ra-226, but excluding radon and uranium, and (c) a limit on concentration of 20 µg/L for uranium. Based on the results in Rood (1997), at the time of peak impact 270,000 years after the end of institutional control, the uranium concentration was 1.9 µg/L, about 9.5% of the 20 µg/L standard. The Ra-226 concentration was 4.9 pCi/L, 98% of the 5 pCi/L standard. The Ra-228 concentration was 0.0016 pCi/L, 0.03% of the 5 pCi/L standard. The gross alpha concentration was 7.7 pCi/L, 51% of the 15 pCi/L standard. These concentrations were primarily due to U-238, U-234, and their progeny.

Several observations are crucial to the interpretation of these results. The first is that the groundwater protection performance objective is the limiting performance objective, not the all-pathways performance objective. The second is that the impacts at the INEL Site boundary are a small fraction of the all-pathways and groundwater protection performance objectives. This is a reasonable result based on the long distance to the boundary, 5500 m. This means that total inventory limits at the RWMC would not be particularly meaningful if based on the impacts at the INEL Site boundary. The third important observation has to do with the relationship between the radionuclide concentration, the receptor location, and the time period of the assessment. The groundwater concentrations reported in Rood (1994, 1997) showed that the radionuclide concentrations were always higher at the 100 m location for the post-institutional control period when compared to the radionuclide concentrations at the INEL Site boundary during the operational and institutional control periods. In addition, the radionuclide concentrations at the 100 m location during the post-institutional control period were higher than any other point between the 100 m location and the INEL Site boundary. This means that there were no high dose pockets between the 100 m location and the INEL Site boundary and, therefore, the receptor location did not leap frog the point of maximum radionuclide concentration in the groundwater.

4.3.1.2.1 Near Term Impacts—For the 100-m location in the near term, C-14 results in an appreciable fraction (68%) of the all-pathways standard and exceeds the groundwater protection performance objective. Several options are available to mitigate this situation. The first, and perhaps most obvious, is to place a total inventory limit on C-14. In the RWMC performance assessment, about 70 Ci of C-14 was assumed to be disposed from 1984 through 2020. About 3.8 Ci of C-14 is already disposed as trash and about 6.2 Ci is already disposed in activated metal. The performance assessment postulated disposal of an additional 19 Ci of C-14 as trash and an additional 41 Ci in activated metal, for a total of 23 Ci as trash and 47 Ci in activated metal. Based on the analyses in Rood (1997), a total of 21 Ci of C-14 could be disposed as trash or a total of 260 Ci could be disposed as activated metal to meet the limiting groundwater protection performance objective. This means that additional C-14 disposed as trash would have to be reduced by 2 Ci (from 19 to 17 Ci) to meet the groundwater protection performance objective. Additional C-14 in activated metal does not appear to pose a problem, and it could be increased from 41 to 250 Ci. The sum of fractions rule would be used for combinations of trash and activated metal. Section 4.3.4 summarizes the total inventory limits for C-14 and other radionuclides derived through the RWMC performance assessment.

The limits for additional C-14 in trash and activated metal would place the RWMC right at the performance objective. For this reason, lower limits will be set in the RWMC waste acceptance criteria (WAC) to provide a more ample margin of safety and to account for radionuclides whose peaks may overlap with C-14, such as I-129 and K-40. As mentioned previously, the sum of fractions would be used for combinations of trash and activated metal, based on the 4 mrem/yr groundwater protection performance objective.

In addition to placing inventory limits on C-14, several other actions could be taken. For example, the peak groundwater doses occur in the year 2170, 50 years after the end of institutional control. Institutional control could be extended for an additional 100 years to the year 2220; this would result in an estimated dose of 1.8 mrem/yr, 45% of the 4 mrem/yr groundwater protection performance objective. The areal extent of institutional control could also be extended. Based on the analyses in Rood (1997), compliance with the 4 mrem/yr groundwater protection performance objective would be achieved if the 100 m buffer zone were extended to 600 m. This is a much smaller area to control and would represent a smaller commitment of resources when compared to controlling all the way to the INEL Site boundary, 5500 m from the RWMC.

Ongoing research at the INEL is also investigating the sorptive properties of carbon released from typical waste forms in RWMC surface soils. Preliminary results indicate that carbon has an effective sorption coefficient greater than zero, possibly about 4 to 7 mL/g. While these results are not final, they do suggest that carbon may undergo some sorptive reactions in RWMC soils. The maximum dose from C-14 would be reduced by about an order of magnitude using a sorption coefficient of about 5 mL/g; C-14 doses would be reduced by about a factor of 20 using a sorption coefficient of 7 mL/g. If C-14 doses are reduced by an order of magnitude, then the drinking water doses would be about 2.3 mrem/yr, 58% of the 4 mrem/yr groundwater protection performance objective. Verification and documentation of carbon's sorptive properties have a high priority for future performance assessment maintenance activities at the INEL. New total inventory limits will be developed when these results are final and will take into account any shift in the time at which the peak occurs and possible overlap with peaks from other radionuclides, such as I-129 and K-40.

Studies are also underway to determine site-specific distribution coefficients for nickel, strontium, niobium, technetium, iodine, cesium, uranium, americium, and plutonium. These studies, which were initiated in FY 1996, will be conducted using RWMC-derived soil and water as much as possible. Another key element of these studies will be to determine the chemical form for radionuclides in the RWMC environment.

Total inventory limits have also been developed for other important radionuclides, such as I-129, K-40, Ni-59, Tc-99, Sr-90, and H-3 (see Rood 1997). For radionuclides whose drinking water dose exceeded 0.4 mrem/yr (i.e., one-tenth of the groundwater protection performance objective), these total inventory limits will be incorporated into the RWMC WAC. This would apply to I-129, K-40, and Ni-59. Section 4.3.4 summarizes the total inventory limits for these radionuclides.

As part of performance assessment maintenance, the INEL will continue to upgrade the hydrologic model used in the performance assessment. Preliminary results are presented in Rood (1997) based on a hydrologic model that includes dispersion in the unsaturated zone and three-dimensional dispersion in the aquifer. These results show that the groundwater protection performance objective will be met using existing inventories but at doses very close to the 4 mrem/yr performance objective. Therefore, it is likely that total inventory limits will remain in place to provide an ample margin of safety.

To improve waste disposal practices, a prototype high integrity container (HIC) made from ferralium-255 duplex steel has been procured and tested. These HICs are based on the Vectra Technologies line of HICs used to dispose of commercial Class B and Class C low-level waste. The HICs will be recommended for disposing of certain high impact waste streams, such as reactor core structurals, tritium bearing waste streams, and C-14 contaminated trash. Most high integrity containers have about a 300 to 500 year lifetime. While this would not reduce appreciably the total amount of C-14 released, it would however "broaden" the peak of the C-14 release from trash and reduce the peak groundwater concentrations and doses.

4.3.1.2.2 Long-Term Impacts—At the 100-m location in the long term, U-238 and U-234 result in Ra-226 concentrations that are an appreciable fraction (98%) of the 5 pCi/L groundwater protection performance objective. Uranium-238 contributes about 88% of the Ra-226; U-234 contributes only about 9.3% of the Ra-226. These impacts occur at 270,000 years, well beyond the 1000 year maximum time of compliance for DOE performance assessments. These impacts also occur outside of the 10,000 year time of compliance that was traditionally used in other performance assessments. Therefore, total inventory limits will be not established for the long-lived radionuclides U-238, U-235, U-234, Pu-239, Th-232, Th-230, Ra-226, and Np-237.

4.3.1.3 Ongoing and Future Research Activities. As discussed in Section 4.2.2, there is substantial uncertainty in the data used in the groundwater flow and transport calculations; consequently, a simple conceptual model was used. Based on a simple perturbation analysis, groundwater concentrations derived from nominal estimates, as opposed to least favorable or most favorable estimates, were used. The range of groundwater concentrations and doses was moderate, which indicates the need for continued hydrological research at the RWMC. Key areas that need to be examined and incorporated in the radiological performance assessment include unsaturated flow and transport, especially those parameters related to the unsaturated zone groundwater travel time; seasonal variation in water infiltration; flooding within the local basin; and geochemical interactions between waste, soil, basalt, and radionuclides. These data will also be used to refine the conceptual model for groundwater flow and transport at the RWMC to provide more realistic estimates and refine the uncertainty in the estimates.

The Engineered Barriers Test Facility, designed to test the long-term hydrological performance of selected closure covers and engineered barriers, has been constructed north of RWMC. The completion of the Engineered Barriers Test Facility is the initial step toward preparing a comprehensive closure/post closure plan for the current LLW disposal area. The data collected will be used to validate and improve assumptions used in RWMC performance assessment and to design a final closure cover for the current LLW disposal area.

The facility has 10 test plots and will test two closure covers, which were selected after extensive study: (1) a thick soil cover and (2) a bio-capillary barrier cover. The thick soil cover incorporates use of the native Spreading Area B soil currently used for backfill at the RWMC. This cover design is the baseline cover assumed in the performance assessment and will provide performance data for the most economical cover (provided it performs satisfactorily) that can be used at INEL. The bio-capillary barrier cover is based on EPA and U.S. Nuclear Regulatory Commission guidance on closure covers and consists of layers of cobbles, gravel, and geotextile membranes placed strategically between the layers of soil to maximize evapotranspiration by capillary effect and reduce potential for intrusion by plants and animals. The actual testing and data collection is expected to begin in July 1996 and will continue through September 2002. The covers will be tested under normal precipitation conditions as well as more severe (wetter) conditions than are normally expected at the RWMC.

As part of the DOE Order 5820.2A implementation program, waste generators are being assisted by the Treatment/Disposal Performance Improvement Program to improve waste characterization practices, as well as to identify and characterize Specific Performance Assessment Restricted waste. Based on these characterization efforts, the activity of hard-to-measure radionuclides shipped to the RWMC in the past is being examined and revisions of the data for past disposals are being coordinated. The waste inventory data that will be used in the Composite Analysis are also being examined. The information available from these studies will be incorporated in the performance assessment during next update.

Based on the findings of the waste characterization efforts, it has been recommended that disposal of the following waste streams be restricted on a case-by-case basis:

- All neutron activated metals such as reactor core structurals, baffles, etc.

- All ion exchange media used for purifying primary coolant or for purifying in-core test loop coolants.

In addition, special performance assessment evaluations have been performed for waste streams such as irradiated beryllium blocks, nonfuel bearing spent nuclear fuel assembly hardware, and Waste Experimental Reduction Facility incinerator ash from treatment of combustible trash. These special performance assessment evaluations have resulted in changes in disposal practices or restrictions on disposal for these waste streams.

As discussed previously, studies are also underway to determine site-specific distribution coefficients for carbon, nickel, strontium, niobium, technetium, iodine, cesium, uranium, americium, and plutonium. These studies, which were initiated in FY 1996, will be conducted using RWMC-derived soil and water as much as possible. Another key element of these studies will be to determine the chemical form for radionuclides in the RWMC environment.

A large quantity of radioactivity buried at the RWMC is in the form of irradiated reactor core structurals or nonfuel bearing components. In addition, U-238 is often disposed as depleted uranium metal. The current performance assessment uses generic corrosion rates as reported in Oztunali and Roles (1986). A current literature search for corrosion rates of metals in soil environments suggests that the corrosion rates used by the U.S. Nuclear Regulatory Commission in Oztunali and Roles are very conservative. A Long-Term Corrosion Test Program has been proposed to measure corrosion of certain metals buried at the RWMC to predict the near-field release rates of radionuclides.

A preconceptual study for the active waste monitoring system for the LLW disposal area at the RWMC was completed in September 1994. The monitoring system was designed to provide information on contaminant migration from waste emplaced in the LLW pits and soil vaults. This information is vital for predicting further contaminant migration through the unsaturated zone. The monitoring system is also designed to provide early detection of contaminant migration that is originating strictly from the waste emplaced in the LLW disposal area and to distinguish this material from material originating at the adjacent CERCLA-managed area. The monitoring system will also provide the opportunity for corrective action to either mitigate, reduce, or eliminate contaminant migration.

The predicted releases of H-3 and C-14 from waste forms like irradiated beryllium blocks are a significant contributor to doses estimated via the groundwater pathway. Because of the large quantity of H-3 and C-14 in beryllium blocks and the mobility of H-3 and C-14 after release, a monitoring program was initiated for H-3 in 1994 and for C-14 in first part of 1996. The tritium concentration was measured in the soil pore gas, surface soil, and in ambient air above the area where the beryllium block were disposed. The results of the monitoring indicate that the release rate of tritium from the beryllium blocks is higher than can be accounted for by diffusion alone and is most likely because of block corrosion. The performance assessment model estimate for the H-3 release caused by corrosion is about 300 Ci/yr. The results of sampling for FY 1995 are not inconsistent with this estimate. Results also indicate that migration of HT and HTO in the subsurface environment is expected to vary significantly with seasonal changes in soil and weather conditions.

The measurements for C-14 in soil pore gas were initiated in FY 1996. The objective of this sampling is to determine the concentration of C-14 in CO_2 present in the soil near disposed beryllium blocks. The first batch of samples was collected and is being sent to the laboratory for analysis.

4.3.1.4 Integration of Other Analyses. The failure of the Mackay Dam was examined for flooding potential. A detailed flood-routing analysis of a hypothetical failure of Mackay Dam resulting from hydrologic and seismic failures showed the RWMC would not be affected by this severe flooding (Koslow and Van Haaften 1986). The RWMC is disconnected from the Big Lost River by a lava ridge that is a hydraulic barrier. This study concluded that the diversion dam would give way before significant flow occurred to the spreading areas. As a result, there is little danger that flooding from the Big Lost River will affect the RWMC.

In both the near term and the long term, compliance with performance objectives was evaluated, using scenarios consistent with those used in risk assessments done at the INEL as part of the INEL FFA/CO, an agreement between DOE-ID, the EPA, and the Idaho Department of Health and Welfare. A residential scenario at the INEL Site boundary was used during the operational and institutional control periods; during the post-institutional control period, a residential scenario 100 m from the waste was used. This is consistent with FFA/CO risk assessments, which do not apply MCLs as ARARs to groundwater near the RWMC (i.e., onsite) until after the end of institutional control. This is also consistent with the INEL *Comprehensive Facility and Land Use Plan*, which projects a 100-year period of institutional control with no change in the INEL Site boundary. In addition, existing land use patterns near the INEL Site boundary to the south of the RWMC indicate that the area near the RWMC would most likely be used for grazing after the end of institutional control, not for farming.

As discussed in Section 1.3.3, a comprehensive RI/FS is planned for the waste disposed in the RWMC from 1952 through 1993. Forecast waste from 1994 through 2003 will be assessed as a sensitivity case. The Record of Decision is scheduled to be published in January 1999. The cumulative risk assessments in this RI/FS will assess the impact of upgradient sources of groundwater contamination, such as from the Test Reactor Area (WAG-2) and the Idaho Chemical Processing Plant (WAG-3). These analyses will be very similar to the Composite Analysis required by the *Implementation Plan for Defense Nuclear Facilities Safety Board Recommendation 94-2 (Revision 1)*; however, the Composite Analysis for the RWMC is scheduled to be completed by January 1998, 1 year before the Record of Decision. Because the RI/FS analyses and the Composite Analysis are similar, the RI/FS and Composite Analysis will use common data, such as for inventory, and similar modeling approaches.

4.3.1.5 Existing Radionuclide Concentrations. Existing levels of radionuclides in groundwater at the RWMC are discussed in Section 5.1.4.3. Tritium (a man-made beta-gamma emitting radionuclide) has been detected in Wells 87 and 90 and the RWMC Production Well (see Figure 2-18 for well locations); no other radionuclides were detected in the wells. The average concentrations of H-3 in Wells 87 and 90 and in the RWMC Production Well were 1.0, 1.4, and 1.5 pCi/mL, respectively (i.e., 1000, 1400, and 1500 pCi/L). The MCL for H-3 is 20,000 pCi/L; the H-3 concentrations observed near the RWMC are less than 10% of the MCL. The H-3 is attributed to past disposal of wastewater at the Test Reactor Area and the Idaho Chemical Processing Plant. It is also possible that there is a small source of H-3 at the RWMC. The H-3 levels have been declining and are expected to decline in the future because percolation ponds and injection wells, the source of the wastewater, have been closed or by-passed. By the year 2170 (the time of peak near term impact estimated in the RWMC performance assessment), the H-3 from these sources is expected to be undetectable at the RWMC and does not affect compliance with performance objectives.

Gross alpha, Ra-226, Ra-228, and uranium background concentrations in the Snake River Plain Aquifer were summarized in Knobel et al. (1992). The background gross alpha concentration ranged from 0 to 2 pCi/L, the background Ra-226 concentration ranged from 0 to 0.3 pCi/L, and the background uranium concentration ranged from 0 to 3 μg/L. These concentrations are compared to the concentrations estimated in the RWMC performance assessment in Table 4-18. It can be seen that adding background concentrations to the concentrations estimated in the RWMC performance assessment does not affect compliance with performance objectives.

4.3.1.6 Integration of Groundwater and Atmospheric Doses. The 25 mrem/yr all-pathways performance objective applies to both the groundwater and atmospheric doses. During the operational and institutional control periods, the dose through the atmospheric pathway was 0.0026 mrem/yr and the dose through the groundwater pathway was 0.57 mrem/yr. Based on the prevailing wind patterns and the direction of groundwater flow, it is unlikely that the atmospheric and groundwater receptors would be collocated. However, in the unlikely event that the

Table 4-18. Comparison of background and RWMC performance assessment-estimated gross alpha, Ra-226, Ra-228, and uranium concentrations.

Performance objective	Background	RWMC performance assessment estimate
5 pCi/L Ra-226	0– 0.1 pCi/L	4.9 Ci/L
5 pCi/L Ra-228	0– 0.3 pCi/L	0.0016 pCi/L
15 pCi/L gross alpha	0– 2 pCi/L	7.7 pCi/L
20 μg/L uranium	0–3 μg/L	1.9 μg/L

atmospheric and groundwater receptors were collocated, the total dose would be 0.573 mrem/yr, 2.3% of the 25 mrem/yr standard. During the post-institutional control period, the dose through the atmospheric pathway was 1.3 mrem/yr and the dose through the groundwater pathway was 17 mrem/yr. In the unlikely event that the atmospheric and groundwater receptors were collocated, the total dose would be 18.3 mrem/yr, 73% of the 25 mrem/yr standard.

4.3.1.7 Summary. Table 4-19 compares the results of the performance assessment to the performance objectives. As previously discussed, two distinct areas of impact were observed: (1) near term impacts due primarily to C-14 and (2) long-term impacts due primarily to U-238. The near term drinking water dose from C-14 exceeded the groundwater protection performance objective, and the long term Ra-226 concentration from U-238 was very close to the groundwater protection performance objective. Table 4-20 summarizes the ongoing and planned activities at the INEL that would mitigate (i.e., reduce) these impacts. In addition, Table 4-20 summarizes possible additional measures that would reduce these impacts.

Taken collectively, the activities and measures discussed previously and summarized in Table 4-20, especially total inventory limits for critical radionuclides, provide reasonable assurance that the RWMC will comply with the performance objectives contained in DOE Order 5820.2A.

Table 4-19. Comparison of results with performance objectives for all-pathways and groundwater protection.

Performance objective	Regulatory reference	Operational and institutional control periods[a]	Post-institutional control period[b]
4 mrem/yr man-made beta-gamma EDE	Groundwater protection[c]	0.19 mrem/yr	5.6 mrem/yr (near term)[d]
20,000 pCi/L H-3 concentration	Groundwater protection	2,300 pCi/L	980 pCi/L (near term)
8 pCi/L Sr-90 concentration	Groundwater protection	1.7E-4 pCi/L	6.7E-2 pCi/L (near term)
5 pCi/L Ra-226 and Ra-228 concentration	Groundwater protection	--[e]	4.9 pCi/L (long term)[d]
15 pCi/L gross alpha concentration	Groundwater protection	--[e]	7.7 pCi/L (long term)
20 μg/L uranium concentration	Groundwater protection	--[e]	1.9 μg/L (long term)
25 mrem/yr	All-pathways[f]	0.57 mrem/yr	17 mrem/yr (near term) 7.3 mrem/yr (long term)

a. During the operational and institutional control periods, from 1984 to 2120, the receptor is at the INEL Site boundary.
b. During the post-institutional control period, from 2120 to the time of peak impact, the receptor is 100 m from the RWMC.
c. Derived from current and proposed MCLs, see Section 1.3.4.7.
d. The peak near term impacts occur in 2160-2170. The peak long term impacts occur 270,000 years after the end of institutional control.
e. During the operational and institutional control periods, the long-lived actinides do not reach the INEL Site boundary.
f. From DOE Order 5820.2A.

Table 4-20. Areas of impact and mitigation activities.

Area of impact	Ongoing activities	Planned activities	Possible additional measures
Near term impacts (Primarily due to C-14)	Total inventory limit. Site-specific distribution coefficient. Improved cover (Engineered Barriers Test Facility). Improved inventory. Special performance assessment evaluations. Monitoring.	Upgrade hydrologic model and data. Site-specific corrosion rates (Long-Term Corrosion Test Program).	Extend time of institutional control. Extend area of institutional control. Use high integrity container for trash.
Long term impacts (Primarily due to U-238)	Site-specific distribution coefficient. Improved cover (Engineered Barriers Test Facility). Improved inventory. Special performance assessment evaluations. Monitoring.	Upgrade hydrologic model and data. Site-specific corrosion rates (Long-Term Corrosion Test Program).	

4.3.2 Atmospheric Pathway

Table 4-21 compares the results of the performance assessment to the performance objectives for the atmospheric pathway. The atmospheric pathway proved to be a relatively minor contributor to dose at the RWMC using conservative assumptions. Therefore, total inventory limits derived through the atmospheric scenario would be bounded by the total inventory limits derived through the groundwater protection scenario. Although biointrusion by plant roots and harvest ants could possibly occur, the assessment assumed that every plant's roots and every harvester ant burrow enter the waste. In addition, site-specific rooting depths were found to just barely contact the waste. Based on site-specific studies of burrow depths, intrusion by burrowing small mammals was found not to be a problem. In addition, the material brought to the surface by plants and harvester ants was assumed to be instantaneously available for atmospheric transport. Given these considerations and the highly unlikely event that a receptor moves to within 100 m of the RWMC SDA, the RWMC should meet the dose objectives in DOE Order 5820.2A.

Table 4-21. Comparison of results with performance objectives for atmospheric pathway.

Time period	EDE (mrem/yr)	Standard (mrem/yr)
Operational and institutional control		
INEL baseline[a]	0.0015	
Contaminated soil areas at the RWMC	5.7E-6	
Gaseous H-3 and C-14	0.0011	
Total	0.0026	10
Post-institutional control		
INEL baseline[a]	0.0015	
Pits	0.026–0.039	
Soil vaults	0.079–0.13	
Gaseous H-3 and C-14	1.1	
Total	1.2–1.3	10
Radon Flux		
Pits	0.057 pCi/m^2-s	
Soil vaults	0.0015 pCi/m^2-s	
Total	0.059 pCi/m^2-s	20 pCi/m^2-s

a. The INEL baseline consists of monitored and unmonitored emission points at the INEL and existing diffuse sources at other areas of the INEL.

4.3.3 Inadvertent Intruders

Table 4-22 compares the results of the performance assessment to the performance objectives for inadvertent intruders. The results of the inadvertent intruder analyses provide reasonable assurance that the performance objectives in DOE Order 5820.2A will be met for both the chronic and acute scenarios. A wide range of intruder scenarios were evaluated, with site-specific attributes incorporated into the scenarios. The most critical of these was the use of a 22-in. irrigation well, rather than the 4-in. well used in 10 CFR 61. Also, two sets of analyses were performed: one with conservative parameter values and the other with more realistic parameter values. Intruder calculations were performed at various points in time, providing further evidence that the dose objectives will be met, even when the maximum time of compliance is extended past 1000 years.

Leaching was not incorporated into the intruder dose assessments involving direct contact with waste. This will have little impact on the doses from soil vaults because peak soil vault doses occur in 2120 and little leaching can occur over this relatively short time period. However, for pits this is an extremely conservative assumption because the peak doses for pits occurred 1,000,000 years after site closure.

Radon doses to intruders were also well below the dose objectives in DOE Order 5820.2A even when added to the results of the chronic intruder scenarios. These results were obtained using realistic data collected from instrumented basement structures, as opposed to conservative default values.

Soil vaults yielded the maximum intruder doses. This was because of the presence of large quantities of Cs-137. The maximum intruder doses occurred in 2120, at the end of institutional control. If an intruder barrier that lasts until 2220 were to be incorporated into the design of an engineered barrier at the RWMC, the doses would be reduced substantially. Because most intruder barriers are designed to last between 300 and 1000 years, this goal appears to be feasible and provides additional assurance that the requirements of DOE Order 5820.2A would be met.

The results of the inadvertent intruder analyses in the RWMC performance assessment were used to derive waste concentration limits for pits and soil vaults (Maheras 1997b). These waste concentration limits are presented in Section 4.3.4 and are based on a maximum time of compliance of 1000 years.

Table 4-22. Comparison of results with performance objectives for intruders.

Case	1000 year time of compliance EDE	Year	Unlimited time of compliance EDE	Year	Standard
Pits					
Peak chronic scenario[a]	1.5 mrem/yr[c]	2120	35 mrem/yr[d]	1,000,000 years after closure	
Peak chronic scenario[b]	0.78 mrem/yr[c]	2120	19 mrem/yr[d]	1,000,000 years after closure	
Biointrusion	1.4 mrem/yr	2120	1.4 mrem/yr	2120	
Radon	21 mrem/yr	3020	35 mrem/yr	4320	
Total	23-24 mrem/yr		55-71 mrem/yr		100 mrem/yr
Peak acute scenario	8.3 mrem[e]	2120	11 mrem[f]	1,000,000 years after closure	500 mrem
Soil vaults					
Peak chronic scenario[a]	66 mrem/yr[c]	2120	66 mrem/yr[c]	2120	
Peak chronic scenario[b]	34 mrem/yr[c]	2120	34 mrem/yr[c]	2120	
Biointrusion	5.2 mrem/yr	2120	5.2 mrem/yr	2120	
Radon	0.087 mrem/yr	3020	13 mrem/yr	53,000 years after closure	
Total	39-71 mrem/yr		52-84 mrem/yr		100 mrem/yr
Peak acute scenario	190 mrem[e]	2120	190 mrem[e]	2120	500 mrem

a. 8030 m^3/yr inhalation rate, Rupp diet, and 0.70 shielding factor.
b. 5840 m^3/yr inhalation rate, Yang and Nelson diet, and 0.36 shielding factor.
c. Chronic drilling scenario.
d. Chronic basement excavation scenario.
e. Acute drilling scenario.
f. Acute construction scenario.

4.3.4 Summary of Performance Assessment-Derived Limits

4.3.4.1 Total Inventory Limits. Table 4-23 presents the total inventory limits for the RWMC and the inventory assessed in the RWMC performance assessment. The total inventory limits for important radionuclides identified in the RWMC performance assessment were determined based on the groundwater protection performance objectives (Rood 1997). The groundwater protection performance objectives are summarized in Section 4.3.1.

The radionuclides for which total inventory limits were determined included the fission and activation products H-3, C-14, I-129, K-40, Tc-99, Sr-90, and Ni-59. Total inventory limits were not determined for U-238, U-235, U-234, Pu-239, Th-232, Th-230, Ra-226, and Np-237 because the impacts from these radionuclides occur at 270,000 years, well in excess of the 1000 year maximum time of compliance for DOE performance assessments.

The total inventory limits were based on the impacts at a downgradient well 100 m from the waste during the post-institutional control time period. As discussed in Section 4.3.1, total inventory limits derived at other locations and other time periods are either not as stringent as the total inventory limits at the 100 m location or are not consistent with INEL land use plans.

Table 4-23. Total inventory limits for the RWMC.

Radionuclide	Maximum total inventory limit (Ci)	Inventory assessed in RWMC performance assessment (Ci)	Basis
H-3	6.1E+6	3.0E+5	20,000 pCi/L
C-14 as trash	2.2E+1	2.3E+1	4 mrem/yr
C-14 as activated metal	1.8E+2	4.7E+1	4 mrem/yr
I-129	1.7E-1	7.6E-2	4 mrem/yr
K-40	3.9	1.8	4 mrem/yr
Tc-99	6.9E+1	2.2	4 mrem/yr
Sr-90	6.2E+5	5.2E+3	8 pCi/L
Ni-59	1.4E+5	1.8E+4	4 mrem/yr

4.3.4.2 Waste Concentration Limits. Tables 4-24 and 4-25 present the waste concentration limits for pits and soil vaults based on the results of the inadvertent intruder analyses in the RWMC performance assessment (Maheras 1997b). These waste concentration limits were based on a maximum time of compliance of 1000 years. In almost all cases, the lowest waste concentration limits were obtained through the acute intruder drilling scenario. This was due primarily to contaminated dust being inhaled by the driller. It should be noted that inhalation of contaminated dust was not considered by the U.S. Nuclear Regulatory Commission in developing the acute drilling scenario used to calculate the waste concentration limits in 10 CFR 61; wet drilling using a mud pit was assumed. However, local, site-specific information indicates that air drilling, as opposed to wet drilling, is far more likely in southeast Idaho.

Tables 4-26 and 4-27 also present the dominant scenario, time, pathway, and radionuclide for the soil vault and pit waste concentration limits. For the uranium isotopes, the acute scenario at 1000 years after closure determines the waste concentration limits. Inhalation is the dominant pathway. In almost all cases, the first member of the decay series is the dominant radionuclide. However, in the U-235 series, Ac-227 contributes a significant fraction of the dose.

For the plutonium isotopes, americium, and curium, the acute scenario at 100 years after closure determines the waste concentration limits. As with the uranium isotopes, inhalation is the dominant pathway and the first member of the decay series is the dominant radionuclide. The exceptions are the Pu-241 series, where Am-241 is the dominant radionuclide, and the Cm-242 series, where Pu-238 is the dominant radionuclide.

For H-3, Be-10, C-14, Ni-59, and Ni-63, the acute scenario at 100 years after closure determines the waste concentration limits. The dominant pathway for most of these radionuclides is inhalation, although for Ni-59, the dominant pathway is external.

For Co-60, Sr-90, Tc-99, Nb-94, I-129, and Cs-137, the chronic scenario at 100 years after closure determines the waste concentration limits. The dominant pathway for Co-60, Nb-94, and Cs-137 is external and the dominant pathway for Sr-90, Tc-99, and I-129 is ingestion.

The waste concentration limits for soil vaults and pits are very similar because drilling is the only means of intrusion based on a maximum time of compliance of 1000 years. For fission and activation products, the site-specific waste concentration limits determined in this analysis were generally higher than the waste concentration limits listed by the U.S. Nuclear Regulatory Commission in 10 CFR 61; as a matter of policy, the 10 CFR 61 limits would be used. Two important exceptions were noted: Sr-90 and Cs-137. Because these radionuclides have relatively short half-lives, 28.6 and 30.17 years for Sr-90 and Cs-137, respectively, disposing of waste using an intruder barrier that prevents intrusion for 300 to 500 years would increase the waste concentration limits to concentrations in reasonable agreement with the 10 CFR 61 limits. This option is evaluated in Maheras (1997b).

For the long-lived radionuclides Ni-63, Tc-99, and I-129, the waste concentration limits determined in this analysis were significantly greater than the waste concentration limits in 10 CFR 61. This was due to two major reasons. First, in 10 CFR 61, intruder doses were based on basement excavation. The volume of waste brought to the surface during the intruder agriculture scenario could range from about 35 to 100 m^3, depending on the site and disposal technology. However, in this analysis, intrusion by basement excavation is precluded by disposal depth, so the volume of excavated waste ranges from 0.0989 to 0.1978 m^3 and the waste concentration limits could be 180 to 1000 times greater than the limits in 10 CFR 61.

The performance objectives in DOE Order 5820.2A also differ from those used to develop the limits in 10 CFR 61. In DOE Order 5820.2A, the chronic intruder performance objective is 100 mrem/yr, while in 10 CFR 61, the performance objective is 500 mrem/yr. Therefore, the limits determined in this analysis could be 5 times less than the limits in 10 CFR 61. Based on both basement excavation and different performance objectives, the limits determined in this analysis could be up to 200 times greater than the limits in 10 CFR 61. Maheras (1997b) also examines the impacts of basement excavation on the waste concentration limits by increasing the maximum time of compliance to 10,000 years.

For actinides, the site-specific waste concentration limits are often significantly less than the 10 CFR 61 limits because air drilling and inhalation of contaminated dust was incorporated into the acute intruder drilling scenario. This appears to be a situation where using site-specific data has resulted in limits more stringent than the generic limits in 10 CFR 61. However, the acute intruder drilling scenario does not account for dilution by uncontaminated soil during drilling. Maheras (1997b) examines the impacts on the waste concentration limits of incorporating this process into the scenario.

Biointrusion was also evaluated as a means to expose inadvertent intruders (Maheras 1995). Based on the analyses presented in Maheras (1995) and Maheras (1993), biointrusion yields smaller surface soil concentrations than scenarios involving direct contact with the waste (e.g., through drilling). Therefore, the limits that would be calculated through the biointrusion scenario are bounded by the limits determined in this analysis.

Table 4-24. Waste concentration limits for soil vaults based on 1000 year maximum time of compliance

Radionuclide	Limit (Ci/m^3)	Limiting scenario	Dominant pathway	Limiting time	10 CFR 61 limit (Ci/m^3)
U-238	4.15E-2	Acute	Inhalation	1000 years	--
U-235	1.77E-2	Acute	Inhalation	1000 years	--
U-234	3.77E-2	Acute	Inhalation	1000 years	--
U-233	1.56E-2	Acute	Inhalation	1000 years	--
Pu-238	2.90E-2 (1.93E+1 nCi/g)	Acute	Inhalation	100 years	0.15 (100 nCi/g)
Pu-239	1.17E-2 (7.80 nCi/g)	Acute	Inhalation	100 years	0.15 (100 nCi/g)
Pu-240	1.20E-2 (8.00 nCi/g)	Acute	Inhalation	100 years	0.15 (100 nCi/g)
Pu-241	3.98E-1 (2.65E+2 nCi/g)	Acute	Inhalation	100 years	5.25 (3500 nCi/g)
Pu-242	1.25E-2 (8.33 nCi/g)	Acute	Inhalation	100 years	0.15 (100 nCi/g)
Am-241	1.36E-2 (9.07 nCi/g)	Acute	Inhalation	100 years	0.15 (100 nCi/g)
Cm-242	5.66 (3.77E+3 nCi/g)	Acute	Inhalation	100 years	30 (20,000 nCi/g)
H-3	1.61E+7	Acute	Inhalation	100 years	40 (Class A waste)
Be-10	1.47E+1	Acute	Inhalation	100 years	--
C-14	2.53E+3	Acute	Inhalation	100 years	8 80 (activated metal)
Ni-59	3.60E+2	Acute	External	100 years	220
Ni-63	3.33E+3	Acute	Inhalation	100 years	700 7000 (activated metal)
Co-60	1.66E+5	Chronic	External	100 years	700 (Class A waste)
Sr-90	2.48E+1	Chronic	Ingestion	100 years	7000
Tc-99	2.38E+1	Chronic	Ingestion	100 years	3
Nb-94	5.33E-1	Chronic	External	100 years	0.2
I-129	7.90	Chronic	Ingestion	100 years	0.08
Cs-137	1.69E+1	Chronic	External	100 years	4600

Table 4-25. Waste concentration limits for pits based on 1000 year maximum time of compliance

Radionuclide	Limit (Ci/m^3)	Limiting scenario	Dominant pathway	Limiting time	10 CFR 61 limit (Ci/m^3)
U-238	4.14E-2	Acute	Inhalation	1000 years	--
U-235	1.77E-2	Acute	Inhalation	1000 years	--
U-234	3.77E-2	Acute	Inhalation	1000 years	--
U-233	1.56E-2	Acute	Inhalation	1000 years	--
Pu-238	2.90E-2 (1.93E+1 nCi/g)	Acute	Inhalation	100 years	0.15 (100 nCi/g)
Pu-239	1.17E-2 (7.80 nCi/g)	Acute	Inhalation	100 years	0.15 (100 nCi/g)
Pu-240	1.20E-2 (8.00 nCi/g)	Acute	Inhalation	100 years	0.15 (100 nCi/g)
Pu-241	3.98E-1 (2.65E+2 nCi/g)	Acute	Inhalation	100 years	5.25 (3500 nCi/g)
Pu-242	1.25E-2 (8.33 nCi/g)	Acute	Inhalation	100 years	0.15 (100 nCi/g)
Am-241	1.36E-2 (9.07 nCi/g)	Acute	Inhalation	100 years	0.15 (100 nCi/g)
Cm-242	5.66 (3.77E+3 nCi/g)	Acute	Inhalation	100 years	30 (20,000 nCi/g)
H-3	1.61E+7	Acute	Inhalation	100 years	40 (Class A waste)
Be-10	1.47E+1	Acute	Inhalation	100 years	--
C-14	2.53E+3	Acute	Inhalation	100 years	8 80 (activated metal)
Ni-59	1.89E+2	Acute	External	100 years	220
Ni-63	3.33E+3	Acute	Inhalation	100 years	700 7000 (activated metal)
Co-60	8.30E+4	Chronic	External	100 years	700 (Class A waste)
Sr-90	1.24E+1	Chronic	Ingestion	100 years	7000
Tc-99	1.19E+1	Chronic	Ingestion	100 years	3
Nb-94	2.67E-1	Chronic	External	100 years	0.2
I-129	3.95	Chronic	Ingestion	100 years	0.08
Cs-137	8.43	Chronic	External	100 years	4600

Table 4-26. Dominant scenarios, times, radionuclides, and pathways for soil vault waste concentration limits

Radionuclide	Limiting scenario	Limiting time	Dominant radionuclide	Percent	Dominant pathway	Percent
U-238	Acute	1000 years	U-238	99	Inhalation	100
U-235	Acute	1000 years	Ac-227 U-235	47 43	Inhalation Inhalation	100 99
U-234	Acute	1000 years	U-234	98	Inhalation	100
U-233	Acute	1000 years	Th-229 U-233	60 40	Inhalation Inhalation	100 100
Pu-238	Acute	100 years	Pu-238	99	Inhalation	100
Pu-239	Acute	100 years	Pu-239	100	Inhalation	100
Pu-240	Acute	100 years	Pu-240	100	Inhalation	100
Pu-241	Acute	100 years	Am-241	99	Inhalation	99
Pu-242	Acute	100 years	Pu-242	100	Inhalation	100
Am-241	Acute	100 years	Am-241	100	Inhalation	99
Cm-242	Acute	100 years	Pu-238	100	Inhalation	100
H-3	Acute	100 years	H-3	100	Inhalation	100
Be-10	Acute	100 years	Be-10	100	Inhalation	100
C-14	Acute	100 years	C-14	100	Inhalation	100
Ni-59	Acute	100 years	Ni-59	100	External	91
Ni-63	Acute	100 years	Ni-63	100	Inhalation	100
Co-60	Chronic	100 years	Co-60	100	External	99
Sr-90	Chronic	100 years	Sr-90	96	Ingestion	100
Tc-99	Chronic	100 years	Tc-99	100	Ingestion	100
Nb-94	Chronic	100 years	Nb-94	100	External	99
I-129	Chronic	100 years	I-129	100	Ingestion	99
Cs-137	Chronic	100 years	Ba-137m	98	External	100

Table 4-27. Dominant scenarios, times, radionuclides, and pathways for pit waste concentration limits

Radionuclide	Limiting scenario	Limiting time	Dominant radionuclide	Percent	Dominant pathway	Percent
U-238	Acute	1000 years	U-238	99	Inhalation	100
U-235	Acute	1000 years	Ac-227 U-235	47 43	Inhalation Inhalation	100 99
U-234	Acute	1000 years	U-234	99	Inhalation	100
U-233	Acute	1000 years	Th-229 U-233	59 40	Inhalation Inhalation	99 100
Pu-238	Acute	100 years	Pu-238	99	Inhalation	100
Pu-239	Acute	100 years	Pu-239	100	Inhalation	100
Pu-240	Acute	100 years	Pu-240	100	Inhalation	100
Pu-241	Acute	100 years	Am-241	99	Inhalation	100
Pu-242	Acute	100 years	Pu-242	100	Inhalation	100
Am-241	Acute	100 years	Am-241	100	Inhalation	100
Cm-242	Acute	100 years	Pu-238	100	Inhalation	100
H-3	Acute	100 years	H-3	100	Inhalation	100
Be-10	Acute	100 years	Be-10	100	Inhalation	100
C-14	Acute	100 years	C-14	100	Inhalation	100
Ni-59	Acute	100 years	Ni-59	100	External	95
Ni-63	Acute	100 years	Ni-63	100	Inhalation	100
Co-60	Chronic	100 years	Co-60	100	External	100
Sr-90	Chronic	100 years	Sr-90	96	Ingestion	100
Tc-99	Chronic	100 years	Tc-99	100	Ingestion	100
Nb-94	Chronic	100 years	Nb-94	100	External	100
I-129	Chronic	100 years	I-129	100	Ingestion	99
Cs-137	Chronic	100 years	Ba-137m	97	External	100

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Appendix G

RWMC Performance Assessment ALARA Analysis

Appendix G

RWMC Performance Assessment ALARA Analysis

DOE Order 5820.2A states that "reasonable effort should be made to maintain releases of radioactivity in effluents to the general environment as low as reasonably achievable" (ALARA). This requirement applies to members of the public and does not apply to inadvertent intruders.[a] This ALARA analysis presents the doses estimated in the RWMC performance assessment and evaluates options that could reduce these doses.

In the RWMC performance assessment, the all-pathways dose has two components: (1) dose through the groundwater pathway and (2) the dose through the atmospheric pathway. The dose through the groundwater pathway was estimated to be 17 mrem/yr, 68% of the DOE Order 5820.2A 25 mrem/yr standard and 17% of the DOE Order 5400.5 100 mrem/yr limit. In contrast, the dose through the atmospheric pathway was estimated to be 1.3 mrem/yr, 13% of the 40 CFR 61 Subpart H 10 mrem/yr standard and 1.3% of the DOE Order 5400.5 100 mrem/yr limit. The estimated radon flux, 0.059 pCi/m^2-s, was 0.30% of the 20 pCi/m^2-s standard from 40 CFR 61 Subpart Q. Based on these results, the groundwater pathway was the most important all-pathways scenario for members of the public.

The 17 mrem/yr dose through the groundwater pathway was for a member of the public located 100 m from the RWMC during the post-institutional control period, in the year 2160. The majority of the dose is due to C-14. The dose is based on a single family farm/home garden scenario, so the affected population would also be small, probably involving no more than 10 people based on an average family size that ranges from 2.78 to 4.28 in the counties that surround the INEL. Based on an affected population of 10 people, the collective dose integrated over 300 years was estimated to be 17 person-rem. Over the same period of time, the collective dose from background radiation on the Eastern Snake River Plain would be about 1000 person-rem.

In the RWMC performance assessment, several options were evaluated for reducing these doses. In the first option, the impacts of extending the period of institutional control were evaluated. If institutional control were extended for an additional 100 years to the year 2220, doses would be reduced to 7.6 person-rem. Based on a monetary equivalence of $1000 to $10,000 per person-rem, this option would be cost effective from an ALARA standpoint if it cost $9,400 to $94,000, over 200 to 300 years. Clearly, this option cannot be justified solely on the basis of reducing doses to levels that are ALARA.

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a. Letter from R. F. Pelletier to Distribution, September 5, 1996, "Draft Recommendations on Prospective Assessments for Long-Term Management of Low-Level Radioactive Waste."

In the second option, the impacts of expanding the areal extent of institutional control were evaluated. If the 100-m buffer zone were expanded to 600 m, doses would be reduced to about 12 person-rem. This is a much smaller area to control and would represent a smaller commitment of resources when compared to controlling all the way to the INEL Site boundary, 5500 m from the RWMC. Based on a monetary equivalence of $1000 to $10,000 per person-rem, this option would be cost effective from an ALARA standpoint if it cost $12,000 to $120,000, over about 300 years. Clearly, this option also cannot be justified solely on the basis of reducing doses to levels that are ALARA.

In the third option, the costs of various covers were examined. The thick soil cover analyzed in the RWMC performance assessment was estimated to cost $4.1 M. A bio-capillary barrier cover was estimated to cost $2.7 M and a RCRA-specification cover was estimated to cost $2.5 M. If each cover met the DOE Order 5820.2A performance objectives, then based on a monetary equivalence of $1000 to $10,000 per person-rem, the thick soil cover would not be cost-effective from an ALARA standpoint unless it saved 160 to 1600 person-rem. The bio-capillary barrier cover would not be cost-effective from an ALARA standpoint unless it saved 20 to 200 person-rem. Given the already small collective doses already estimated in this ALARA analysis, it is unlikely that the thick soil cover can be justified, even partially, on the basis of reducing doses to levels that are ALARA, but a bio-capillary barrier cover may be able to be justified, at least partially, on the basis of reducing doses to levels that are ALARA. It should be noted that the ALARA analysis performed as part of the Composite Analysis will evaluate the cover design used for the RWMC on an integrated basis, for both pre- and post-1988 waste.

In a fourth option, the use of high integrity containers was evaluated. Cost estimates for high integrity containers are about $20,000 per container. Based on a monetary equivalence of $1000 to $10,000 per person-rem, a single high integrity container would be cost effective from an ALARA standpoint if it resulted in a dose reduction of 2 to 20 person-rem. Given the already small collective doses already estimated in this ALARA analysis, it is unlikely that the widespread use of high integrity containers would be cost effective from an ALARA standpoint. However, high integrity containers may be the only option for disposal of certain high impact waste streams, such as reactor core structurals and tritium bearing waste streams. The impacts of using the high integrity containers for these waste streams will be determined based on the specific waste stream and generator.

Conclusions

The current waste disposal practices at the RWMC have resulted in extremely small estimates of collective doses to members of the public. A range of options was evaluated for reducing these doses. These options included: (1) extending the period of institutional control, (2) extending the areal extent of institutional control, (3) use of various covers, and (4) use of high integrity containers. Based on a monetary equivalence of $1000 to $10,000 per person-rem, most options will probably not be cost effective from an ALARA standpoint. This conclusion is not sensitive to the assumed population size; if the population size were increased to 100 people, the conclusions would generally be the same, although some options that were marginal would now become more attractive (e.g., the use of a bio-capillary barrier cover). Widespread use of high integrity containers would remain unattractive, except for certain high impact waste streams.