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ENVIRONMENTAL EVALUATION OF ALTERNATIVES FOR LONG-TERM MANAGEMENT OF DEFENSE HIGH-LEVEL RADIOACTIVE WASTES AT THE IDAHO CHEMICAL PROCESSING PLANT

SEPTEMBER 1982

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FOREWORD

The U. S. Department of Energy (DOE) is responsible for developing and implementing methods for the safe and environmentally acceptable disposal of high-level radioactive wastes. In accordance with this responsibility, the DOE is considering the selection of a strategy for the long-term management of high-level waste stored at the Idaho Chemical Processing Plant (ICPP) at the Idaho National Engineering Laboratory (INEL). These wastes have been generated at the INEL from defense and test programs since about 1953. Initially, the waste was stored as a liquid and allowed to decay. Since 1963, liquid wastes have been converted to calcine, which is a solid, more compact, and less mobile waste form. The current mode of defense waste confinement assumes continued maintenance of facilities and active surveillance to assure that the waste poses no significant threat to public health and safety.

DOE is considering the selection of a strategy for the long-term management of the defense high-level wastes at the ICPP. To assist in this decision, this report describes the environmental impacts of alternative strategies. These alternative strategies include leaving the calcine in its present form at the INEL, or retrieving and modifying the calcine to a more durable waste form and disposing of it either at the INEL or in an offsite federal repository.

Since completing the environmental evaluations presented in this report, repository performance standards have been proposed (10 CFR 60, 40 CFR 191). Current proposed performance standards would ensure against some of the scenarios used in this study to evaluate the effects of offsite disposal in a geologic repository. Consequently, the estimated effects of repository failure presented in this report may overestimate the effects of deep geologic disposal compared to near-surface disposal.

This report addresses only the alternatives for a program to manage the high-level waste generated at the ICPP. Management programs for other types of INEL waste and wastes generated at other sites are beyond the scope of this document.

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SUMMARY

Statement of Purpose and Need

At the Idaho Chemical Processing Plant (ICPP), over 6 million gallons of liquid high-level wastes have been produced from the processing of nuclear fuels used in United States defense programs. In the late 1940's, the decision was made to manage these wastes by storing the liquid waste as an acidic solution in stainless steel tanks within underground reinforced concrete vaults.

In the late 1950's, a decision was made to convert the liquid waste to a solid form. In 1963, the Waste Calcining Facility began operating as a demonstration plant for solidification of liquid waste into a product called calcine. Since that time, the Waste Calcining Facility has converted 4 million gallons of liquid waste into 73,000 cubic feet of calcine. As of October 1980, approximately 2.5 million gallons of high-level liquid waste were stored at the ICPP awaiting calcination. A new calcining facility is scheduled to begin processing liquid waste in 1982. The calcine is stored in stainless steel bins within reinforced concrete vaults which have an expected life of at least 500 years. Paralleling this waste solidification program is an ongoing program to develop the technology necessary to retrieve the calcine from storage and modify it into a more durable, less dispersible waste form.

A strategy is needed for the long-term management of the ICPP defense high-level wastes. The strategy must be consistent with the principal objective of the national waste management program: to isolate radioactive waste from the biosphere in an environmentally acceptable manner. DOE is considering the selection of such a strategy. The objective of this report is to provide environmental evaluation of several alternative long-term management strategies.

Alternatives

Five long-term management alternatives are evaluated in this document. Included are the effects of waste disposal at the Idaho National Engineering

Laboratory (INEL) and disposal at an offsite federal geologic repository. Consideration is given to leaving the waste calcine in place, delaying calcine retrieval and processing, and separating the long-lived actinides from the generally shorter-lived fission products. Several waste forms have been used for illustrative purposes to establish the range of environmental effects that would result from implementing a final waste management strategy. The environmental effects of disposal at the INEL are based on site-specific investigations. The effects at a federal geologic repository are based on a generic site as described in the final environmental impact statement on the long-term management of commercially generated radioactive waste.

The alternatives selected for evaluation are

Alternative 1. Leave-in-Place (No-Action Alternative);

Alternative 2. Retrieve, Modify the Calcine, and Dispose at the INEL;

Alternative 3. Retrieve, Modify the Calcine, and Dispose Offsite;

Alternative 4. Retrieve, Separate the Actinides, Dispose of the Actinides Offsite, and Dispose of the Actinide-Depleted Calcine at the INEL; and

Alternative 5. Delay Retrieval, Modify the Calcine, and Dispose Offsite.

Affected Environment

The ICPP is located at the INEL on the eastern Snake River Plain in southeastern Idaho. The semiarid region is underlain by a succession of basaltic lava flows. No seismic activity has been identified in the immediate vicinity of the INEL; however, volcanic activity is recurrent throughout the region. There is no surface water at the ICPP. All surface water entering the INEL either evaporates or recharges the Snake River Plain Aquifer which flows through fractured and porous basalt about 450 feet beneath the ICPP.

The type of soil, rainfall, and extended drought periods severely limit the growth of vegetation at the INEL. Wildlife on or near the INEL is characteristic of open western rangeland. Land use at the INEL is limited to the controlled grazing of cattle and sheep.

Air quality at the INEL meets the national secondary air quality standards. Particulate levels are exceeded occasionally in the region primarily because of agricultural activities. The water of the Snake River Plain Aquifer is of high quality and is used for irrigation and drinking purposes. The area is generally devoid of cultural artifacts.

The population within approximately 50 miles of the ICPP was about 130,000 in 1970 and includes portions of the Fort Hall Indian Reservation. Tourism and agriculture are major sectors of the local economy.

Environmental Consequences

The environmental consequences of implementing the alternatives evaluated in this report are discussed in terms of short- and long-term effects. Short-term effects occur during the period of institutional control, which is assumed to continue for 100 years. Short-term effects result from facility construction, operations, waste shipment, and decontamination and decommissioning of the processing facilities. Long-term effects occur in the disposal phase after the period of institutional control is assumed to cease. Radiological effects are calculated for the time period extending one million years into the future.

The effects are further divided into categories of effects which are certain to occur and effects of abnormal events which are not expected to occur. Each category is divided into radiological and nonradiological effects.

The method used to determine environmental effects was to develop a series of scenarios for each phase of alternative implementation. The scenarios are based on conservative assumptions and include routine operations, hypothetical accidents, and abnormal or unpredictable natural phenomena.

Nonradiological Effects

No significant short-term nonradiological effects were identified for any of the alternatives. Long-term effects would be primarily the nonradiological effects of toxic chemicals disposed at the INEL. The waste contains cadmium and mercury which are toxic when ingested. Under extreme conditions, not expected to exist at the ICPP, federal and state drinking water standards for cadmium and mercury could be exceeded for about 5 miles downgradient of the discharge point until chemical reactions and dispersion in the aquifer reduce the concentrations to harmless levels. Effects of cadmium and mercury are associated with Alternatives 1 and 2 (pellets). Effects of cadmium are associated with Alternative 4 since mercury is removed during actinide separation. The probability of occurrence is one in a million years.

During the construction phase of Alternatives 2, 3, 4, and 5, the most significant commitment of resources would be stainless steel required for fabrication of equipment from specialty alloys, and diesel fuel. The maximum consumption of diesel fuel would occur in Alternative 4, which requires 1.1 million gallons. This amount is about 65 percent of the diesel fuel used at the INEL in 1978.

Nonradiological effects of facility operation would be minimal. Airborne emissions would be well within applicable standards at all site boundaries. Wastewater discharges would be within drinking water standards. Minimal socioeconomic effects would result from any of the alternatives since construction and operating work force requirements would be within current INEL employment fluctuations.

Modifying the waste form by vitrification or pelletization would be moderately energy intensive. The maximum energy demand is estimated to be 1.60 megawatts (Alternative 4), which is 37 percent of the 1980 electrical demand at the ICPP. This is equivalent to the electrical demand of 250 houses. The maximum diesel fuel required for waste shipment [2.7 million gallons, Alternatives 3 (glass) and 5] would heat 5400 houses in Idaho Falls, Idaho for one year.

Continued use of the subsurface area for waste confinement would not preempt foreseeable alternative uses of the land. No minerals, oil, or natural gas deposits have been identified at the INEL. Incremental impacts of ICPP waste disposal at an offsite geologic repository would be minimal because of the small disposal area required for ICPP wastes compared to the area required for disposal of commercial wastes.

Radiological Effects

The short-term radiological effects are generally very low for any alternative. For routine operations, waste shipment, decontamination and decommissioning, and disposal, they are well within the fluctuation of background radiation. The maximum dose commitment for an individual from routine operations is calculated to be 3×10^{-6} rem [Alternatives 2 and 3 (glass)]. The maximum dose commitment for an individual in the short-term period results from an aircraft impact at the INEL in 1990 (5.20 rem). Associated health effects (cancer deaths) are estimated to be in the range of 5.54 to 17.0. The probability that such an event would occur is very low (2.0×10^{-7} event/year).

Waste management workers, including train crews, would be exposed to radiation, but exposure from routine operations would be within the allowable occupational limit of 5 rem per year.

The effects of decontamination and decommissioning of retrieval and processing facilities required to implement Alternatives 2, 3, 4, and 5 would be minor compared to effects of current ICPP operations. Additional nonradioactive solid waste and low-level radioactive waste would be disposed at the INEL.

In the long-term period, radiological effects of certain-to-occur events would not be significant. Alternative 1 would cause the highest radiation dose to the maximum individual due to living at the contaminated site. The number of health effects (cancer deaths) would depend on the size of the exposed population. For this study, a population of 5 was assumed to be exposed which gives a health effect in the range of 0.020 to 0.061 in 2,500.

Another event which could occur in the future, after the waste disposal bins have disintegrated, would cause a higher range of health effects (cancer deaths) in the individuals exposed due to the larger population (10) assumed to be exposed. Intrusion into the waste by a prospector or an archaeologist in 2500 is estimated to cause maximum health effects in the range of 0.033 to 0.10 (Alternative 1). Living over the waste in 2500 is assumed to affect 5 individuals and is estimated to cause maximum health effects in the range of 4.12×10^{-5} to 1.26×10^{-4} (Alternative 1). The most probable number of health effects from these events is zero.

The effects of abnormal events postulated to occur in the long-term period would be greatest for alternatives that involve onsite disposal. A severe geologic disruption of the waste is estimated to result in 146 to 449 health effects (cancer deaths) in a population of 206,000 people (Alternatives 1 and 2) if the event occurred in 2100. Land use at the INEL would be restricted until the extent of contamination was determined and, if necessary, decontamination was complete. Should the event occur several hundred years in the future, radiological effects would be reduced about ten times; if the event were to occur several thousand years in the future, radiological effects would be reduced about 100 times. However, the occurrence of such an event during the long term is speculative.

Mitigative Measures

Application of mitigative measures would ensure compliance with state and federal regulations and standards. Environmental monitoring is a continuing activity at the INEL. The monitoring program includes air quality monitoring, collection of water and soil samples, detection of moisture in subsurface soils, and monitoring of animal populations at the INEL. This program would indicate the effectiveness of pollution-control measures used in alternative implementation and indicate whether improved measures would be required.

During construction, procedures to control wind-generated dust and to reduce disturbance of vegetative cover would be used to minimize air quality effects. Wastewater generated during construction would be treated before

discharge to the environment. Nonradiological construction hazards would be minimized by adherence to occupational safety regulations.

The environmental effects of calcine retrieval and waste form modification would be minimized by employing state-of-the-art pollution control technology. State-of-the-art technology would be used to ensure maximum energy efficiency. All solid waste would be disposed at the INEL in landfills that conform to applicable regulations. The use of radiation shielding during shipment of the waste would reduce the radiation dose rates to levels below those specified by transportation regulations. All activities would be conducted to ensure that radiation doses remain as low as practicable.

Comparisons of the Alternatives and Conclusions

The waste management alternatives are compared in several different ways. The short-term and long-term effects of implementing the alternatives are divided into effects that are certain to occur, effects that are not certain to occur, and factors that are difficult to quantify. A preliminary cost estimate is included and the environmental trade-offs are discussed for each alternative.

There are relatively few differences in short-term effects between alternatives. Waste form modification would significantly reduce the effects of a waste shipment accident. Alternatives that involve offsite disposal (Alternatives 3 and 5) are the most expensive to implement. Actinide separation would require the most facilities and expose the largest number of waste management workers to radiation, but implementation costs would be about half the cost of the other alternatives which involve offsite waste disposal. Radiological effects of routine operations and waste shipment for all alternatives are minor in comparison with background radiation and applicable regulations.

Long-term nonradiological effects that result from abnormal events have the most significant consequences. Onsite waste disposal [Alternatives 1, 2 (pellets), and 4] could cause contamination of the Snake River Plain Aquifer

by cadmium and mercury within about 5 miles downgradient of the ICPP in an area about 5 miles wide until chemical reactions and dispersion in the aquifer reduce the concentrations to harmless levels. The aquifer is a significant source of drinking and irrigation water.

The most significant potential radiological effects would result from a severe geologic disruption of the waste. Land use at the INEL would be restricted until the extent of contamination was determined and, if necessary, decontamination was complete. However, the probability of such an occurrence in the long-term period is speculative.

In comparing alternatives, the basic trade-off is onsite versus offsite disposal. Onsite disposal involves certain long-term risks. These risks are groundwater contamination, an aircraft impact, and a severe geologic disruption which have low probabilities of occurrence. Offsite disposal is associated with short-term effects such as worker doses, energy use, and high implementation cost. The question implicit in evaluation of these trade-offs and selection of an alternative is, what human effects, resource use, and economic cost should be expended now as a premium to insure against future risks?

Appendixes

The projected environmental effects presented in this report are based on a series of assumptions and calculations. The assumptions and the methods used to calculate the effects are explained in greater detail in the accompanying appendixes. The appendixes also refer the reader to other supporting technical documents.

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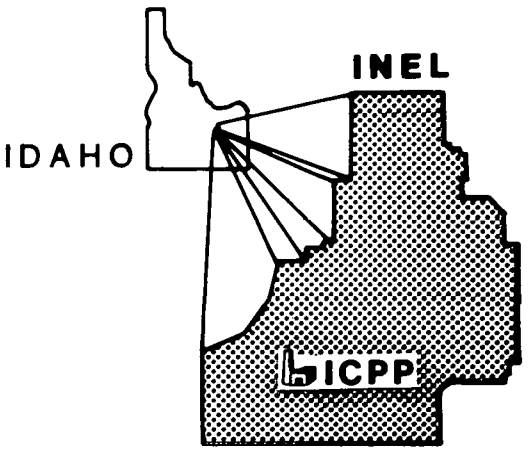
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1.0 STATEMENT OF PURPOSE AND NEED

1.1 Introduction



The Idaho National Engineering Laboratory (INEL) is a government-owned, contractor-operated laboratory where experimental nuclear reactors are built, operated, and tested. It is administered by the Department of Energy (DOE). The semi-arid 894-square-mile tract of land comprising the INEL is located west of Idaho Falls, Idaho, along the northern edge of the eastern Snake River Plain. No permanent residents live on the site. The eastern Snake River Plain Aquifer lies 450 feet below the ICPP. (A general map is shown in Figure 3-1.)

The ICPP is located in the south central part of the INEL. The purpose of this facility is to recover usable uranium in spent nuclear fuels generated by national defense programs. The recovery process begins by dissolving the spent fuel in acid. The liquid remaining after uranium removal is characterized by relatively high levels of heat and penetrating radiation. After being allowed to cool through radioactive decay in underground stainless steel tanks, the liquid waste is converted to a solid through a process called calcination. During the calcination process, as the liquid is evaporated, the dissolved material solidifies to form calcine, a dry material with a sand-like texture. The calcine, which amounts to 12-15 percent of the original liquid volume, contains nearly all of the inert and radioactive material that was present in the liquid waste. It is stored in large stainless steel bins located in underground reinforced concrete vaults. As of October 1980, 4 million gallons of the high-level liquid waste had been converted to about 73,000 cubic feet of calcine. Approximately 2.5 million gallons of liquid waste remain in storage awaiting calcination.

The calcining process used at the ICPP has proved to be a safe, effective means of managing the radioactive waste. The stainless steel bins and underground concrete vaults are expected to retain their integrity for at least 500 years. The adequacy of the present management strategy was confirmed in the final environmental impact statement on waste management operations at the INEL (ERDA, 1977d).

However, the waste contains certain actinide elements and other radionuclides that will remain radioactive for an extended period of time. If future generations are to be protected from this potential hazard, it will be necessary to ensure that the waste is effectively isolated from the biosphere until it has decayed to harmless levels.

Since the 1950's, the DOE and its predecessor agencies have considered a variety of means for HLW disposal. An extensive program to develop immobile waste forms for HLW is being conducted.

1.2 Scope of This Document

This report describes the environmental impacts of several alternative strategies for the long-term management of defense high-level wastes at the INEL. Two of the alternatives involve onsite disposal; three involve offsite disposal. For offsite disposal, nine disposal options are further considered.

In cases where specific equipment or facility characteristics are not known, generic information on a range of effects has been used for illustrative purposes. For example, the effects of HLW disposal at a federal geologic repository are based on a generic site in the final environmental impact statement on management of commercially generated radioactive waste (GEIS). Scenarios used in the GEIS to evaluate the effects of accidents during repository operation and after its closure are used in this study to evaluate the consequences of emplacing ICPP waste in a geologic repository. The same event probabilities and size of the population assumed to be affected by the events are also used. Several waste forms have been used for illustrative purposes to establish the range of environmental effects that would result from the alternatives.

Since completing the environmental evaluations presented in this report, repository performance standards have been proposed (10 CFR 60, 40 CFR 191). Current proposed performance standards would ensure against some of the scenarios used in the GEIS and in this study to evaluate the consequences of repository failure.

Defense HLW is also generated at the fuel reprocessing plants on the Hanford Reservation near Richland, Washington, and at the Savannah River Plant near Aiken, South Carolina. It is not believed desirable to ship raw waste from one site to another for processing. Moreover, the waste at the different sites has different properties. The Hanford, West Valley (Nuclear Fuel Services), and Savannah River high-level wastes are the most similar because they are all alkaline wastes. However, they were generated from different fuels and by different separation processes. The ICPP wastes and commercial wastes are intrinsically different acid wastes. These differences in waste properties require development of specific processes for each type of waste. For these reasons, separate analyses are being prepared for the defense HLW at each of the three defense sites. This document does not include consideration of the HLW at other defense sites, and decisions on ICPP wastes will not foreclose options available at other sites.

Low-level and transuranic wastes produced at the INEL are not discussed in this document because they are in different initial forms from the high-level waste and are likely to be disposed in different final forms. Therefore, separate programs must be developed to handle each type of waste. Alternatives for long-term management of the transuranic wastes at the INEL are discussed in separate documents.

1.3 Need

A strategy is needed for the long-term management of the ICPP defense high-level wastes. The strategy must be consistent with the principal objective of the national waste management program: to isolate the radioactive waste from the biosphere in a manner that is safe and environmentally acceptable. DOE is considering the selection of such a strategy.

The objective of this report is to provide environmental evaluation of several alternative long-term management strategies.

1.4 Background

1.4.1 Department of Energy Defense High-Level Waste Management Program

The DOE is undertaking activities which will lead to the technology necessary to isolate high-level wastes in the United States. These activities are

- selecting a realistic alternative(s) for disposing of defense HLW;
- developing candidate waste disposal forms and processes in order to provide data on which to base design of full-scale facilities; and
- constructing and operating the facilities necessary to immobilize and dispose of the wastes.

All of these activities will overlap as the plan is implemented. The selection of a strategy for the long-term management of ICPP HLW is one component of this federal program.

1.4.2 Related Program Documentation

The DOE and its predecessor agencies have published several documents regarding HLW disposal. These documents have helped to facilitate the decisionmaking process in a stepwise manner. Comments received at each stage in the process have been considered in the preparation of subsequent studies.

The first volumes to be published in the high-level waste management decisions process were the final environmental impact statement on waste management operations at the INEL (ERDA, 1977d) and the defense waste document (DWD) prepared in 1977. Evaluations attempted to narrow the number of possible disposal options and to determine cost parameters. A DWD was prepared for high-level waste at each of the DOE sites at Savannah River, South Carolina (ERDA, 1977c), Hanford, Washington (ERDA, 1977a), and the ICPP (ERDA, 1977b). These statements enumerated and analyzed many of the alternatives available

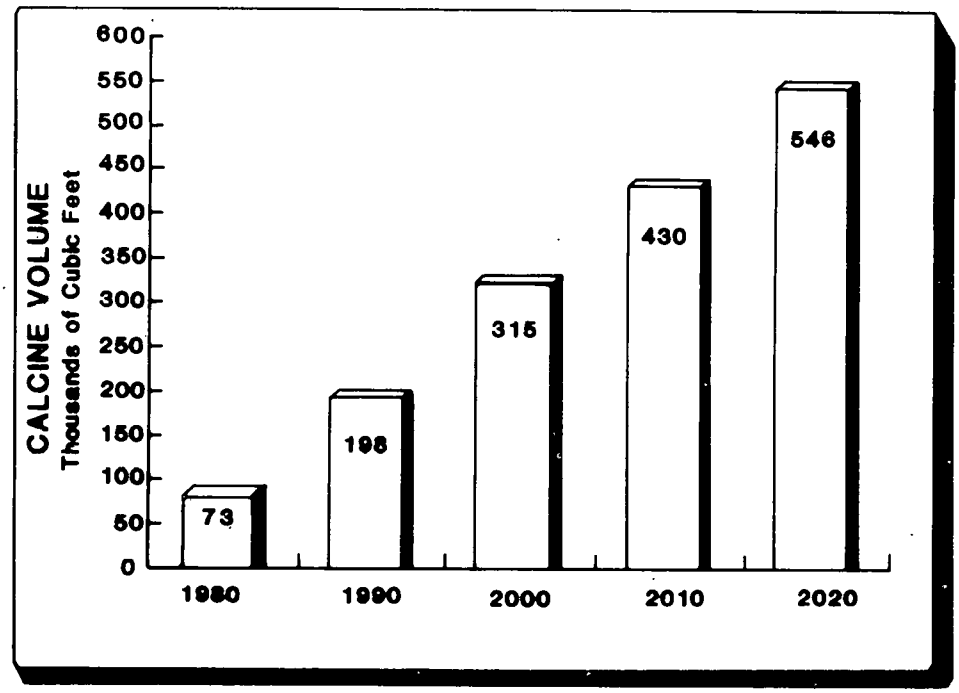
for waste management with respect to required technologies, public risks, and preliminary costs. The DWDs also provided a technical basis for further study of the alternatives for long-term HLW management. Each DWD was distributed to the public and to governmental agencies for comments. Comments received on the ICPP DWD are addressed in subsequent sections of this report and are summarized in Appendix C.

1.4.3 Description of ICPP High-Level Waste

1.4.3.1 Physical Description

As stated previously, HLW at the ICPP results primarily from the chemical processes that separate uranium from other materials after nuclear fuel is dissolved. Additional liquid waste is generated by routine activities such as the chemical analysis of process streams and the decontamination of processing equipment. The liquid waste is stored in large stainless steel tanks inside concrete vaults until it can be converted to a solid. During calcination, liquid waste is sprayed into a heated vessel containing hot, calcined waste particles which are agitated by an upward-flowing hot air stream. The water in the liquid evaporates, leaving solids, including the radioactive material, coated on the particles in the vessel. The solid material (calcine), is continuously withdrawn from the calciner vessel and stored in large stainless steel bins inside vented concrete vaults. Air circulated around the bins removes the decay heat. This air is monitored for radioactive contamination.

For this report, it is assumed that by the year 2020, fuel reprocessing will have been discontinued, and all liquid waste, both the present inventory and the waste produced up to that date, will have been converted to calcine. As of October, 1980, 4 million gallons of liquid waste had been converted to about 73,000 cubic feet of calcine. It is estimated that by the year 2020, the volume of calcine will be about 7.5 times the present volume, as shown in the bar graph on the following page.



Based on corrosion studies of samples of the bin material, the stainless steel bins are expected to retain their integrity for as long as several thousand years. For the calculations contained in this report, a bin life of 500 years has been assumed. The bins and vaults provide temporary storage that has kept the oldest calcine dry and isolated for 17 years. It is expected that they will continue to do so for as long as the calcine remains in the bins. An illustration of the bin-vault complex is shown in Figure 1-1.

Calcine resembles a mixture of talcum powder and sand-like spherical particles, as shown in the picture on Page 1-8.

Examination of the stored calcine in the bins shows that it has not caked during several years of storage; thus it appears that removal from the bins would still be possible after an extended storage time. Preliminary tests indicate that such removal may be possible using a vacuum-type transport system.

The calcine particles have been found to be quite porous and these, in combination with the fine powder, present a very large surface area. This allows for extensive dissolution from the calcine of some of the radioactive

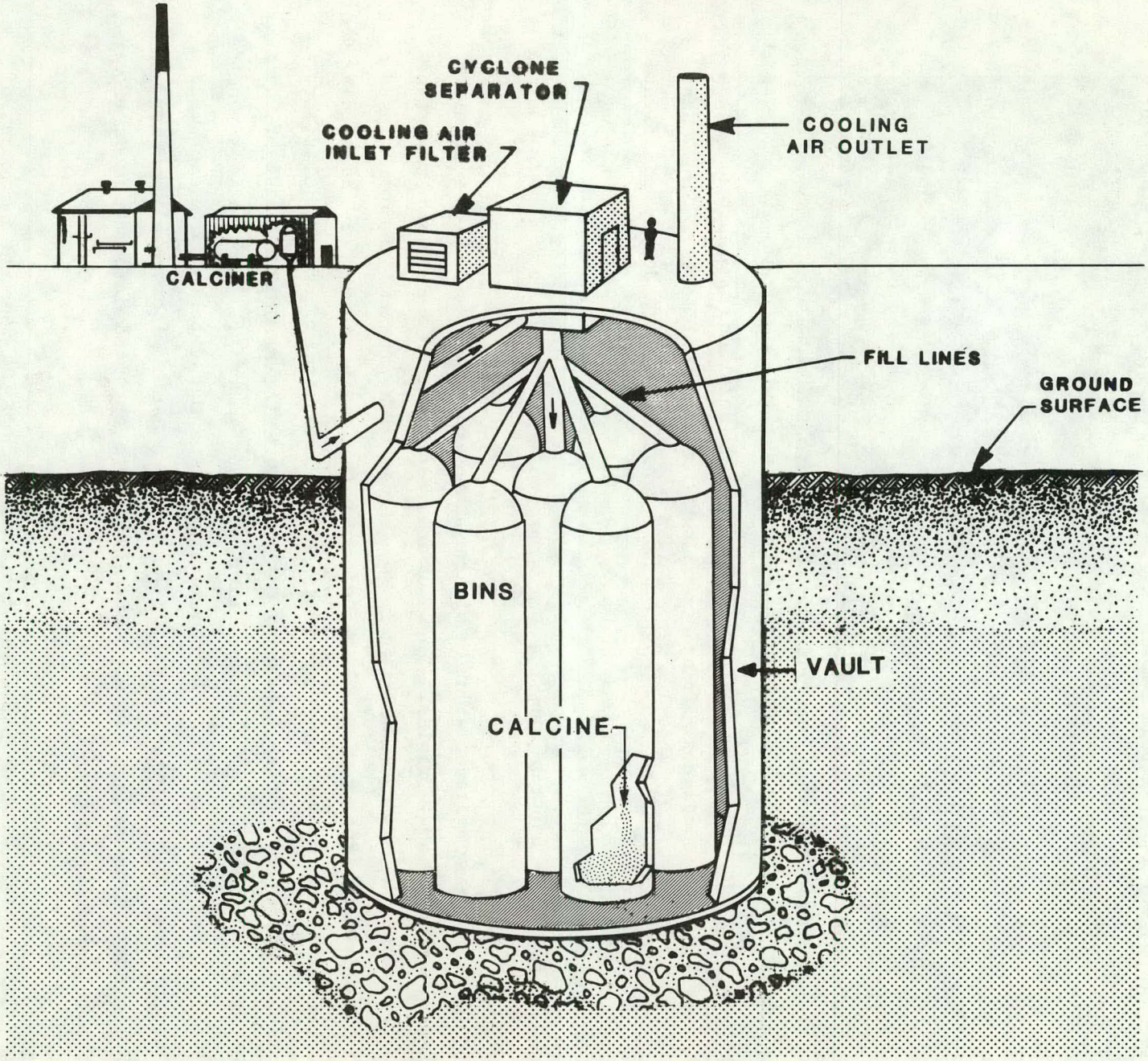
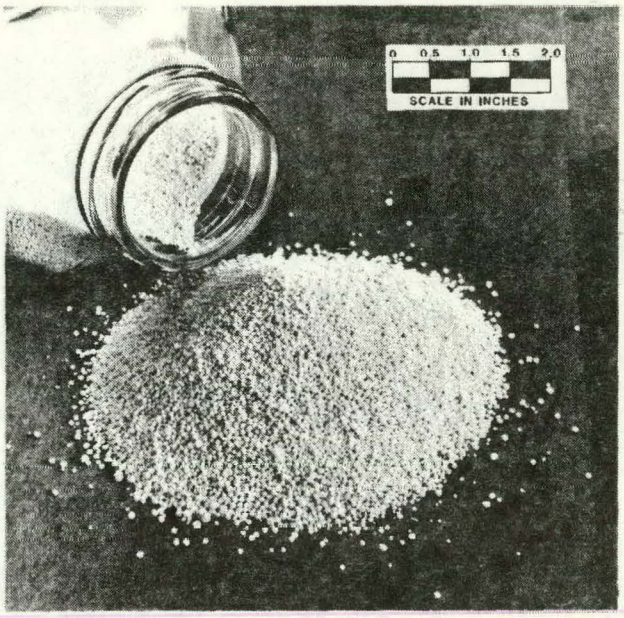


Figure 1-1. Bin-Vault Complex



and nonradioactive components in the presence of water. The fine powder is also easily dispersed by wind or traffic if exposed to the environment.

Another important characteristic of the calcine is the production of heat. The fission products and other radioactive material present in the calcine mixture undergo a process called radioactive decay (see Subsection 1.4.3.3). Heat generated during the decay process results in elevated temperatures in the stored calcine. The heat generation rate drops as the short-lived radionuclides decay to nonradioactive elements. The heat generation rate decreases by a factor of approximately 100 during the first 50 years of storage.

1.4.3.2 Chemical Description

Calcine is composed primarily of nonradioactive aluminum oxide, zirconium oxide, and calcium fluoride. These nonradioactive materials come from the fuel element jackets (cladding), metals alloyed with uranium, chemicals used to dissolve the fuel, chemicals added to permit safe storage of the highly corrosive liquid wastes, and chemicals added to control fluoride volatility during calcination. These compounds make up about 90 percent by weight of the calcine, depending on the composition of the cladding. The oxides and fluorides are relatively stable chemicals and are not expected to react with the bin material (stainless steel), the vault material (concrete), or soil, should contact be made. See Appendix A for more detailed information on the chemical composition of calcines.

Calcine from certain processes contains mercury (0.3 percent by weight of total calcine by 2020), and future calcine will contain cadmium (up to 9 percent by weight of total calcine by 2020). As long as the calcine remains in the storage bins, cadmium and mercury do not pose a threat to the

environment. In the conservative groundwater migration scenario evaluated for this report, cadmium and mercury concentrations in hypothetical wells are shown to exceed the levels allowed by drinking water standards. A discussion of the groundwater migration scenario is provided in Appendix A, and Section 4 of this report contains additional details on the toxicity of cadmium and mercury.

At present, the calcine has no known commercial value. The low nitrate content (1-3 percent) makes it unsuitable for other purposes such as fertilizer. Thus it does not appear that calcine would have any intrinsic value to individuals in future generations.

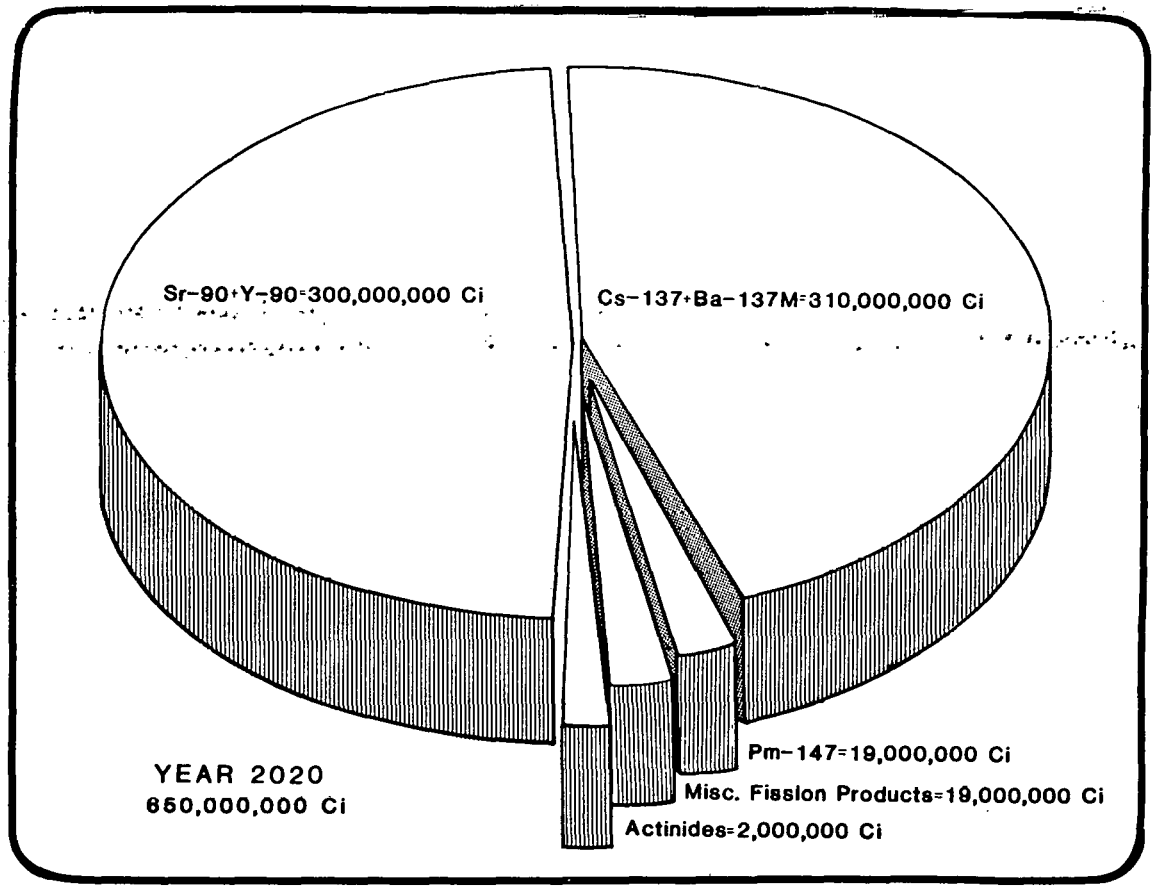
1.4.3.3 Radiological Description

An important property of the calcine for the purpose of environmental impact evaluations is its radiological composition. Key points about the radiological composition are given here; more detail is found in Appendix A.

By the year 2020, the total activity of the waste will be about 6.5×10^8 curies (Ci). Although a variety of radionuclides is present, the major radionuclides are cesium (Cs) and strontium (Sr) as shown in the pie diagram on the following page.

Cesium and strontium are major emitters of gamma and beta radiation. In addition, the actinides, plutonium-239 and plutonium-238, are major emitters of alpha radiation.

Because alpha radiation cannot penetrate the skin, it is not harmful to people if the exposure is external. However, the situation is different if the radioactive material is inhaled or ingested. Once in the body, the material may be concentrated and retained in a specific organ resulting in prolonged radiation exposure. Inhalation is generally the most important pathway for exposure to radiation from actinides because the alpha particles they emit directly irradiate the lung tissues. Subsequently, a portion of the inhaled material is carried by the blood stream and the lymphatic system to other organs, such as the bone and liver.



Beta and gamma radiation are of concern because they are more penetrating than alpha radiation. They can penetrate the body of a person who approaches the radiation source. Consequently, beta and gamma radiation contribute significantly to the whole-body dose. Beta- and gamma-emitters can also be harmful if ingested. They can concentrate in parts of the body where they continue to irradiate body tissues. Organs that are at risk from alpha radiation can also be affected by beta and gamma radiation.

The problems with processing and handling HLW, and the potential environmental effects of radionuclide releases, will change with time because radiation given off by the waste during radioactive decay changes with time.

During the first several hundred years, the waste emits primarily beta and gamma radiation. The beta-gamma radiation from strontium and cesium overshadows the alpha and beta-gamma radiation from the actinides present. The high radiation levels necessitate the use of heavy shielding during waste processing and transportation.

After several hundred years, strontium and cesium will have decayed significantly, leaving predominantly alpha radiation from the actinides. While there is some beta-gamma radiation from actinides and from other residual short-lived radionuclides, the impact is much less than the effects of beta-gamma radiation emitted during the first several hundred years. The shielding required for worker protection and during transportation is reduced. However, the waste must still be contained to prevent the radionuclides from escaping to the environment.

During the time cesium and strontium are undergoing radioactive decay, other radionuclides not initially present in the waste in significant quantities will increase to more significant levels. This results from decay processes in which a radionuclide decays to form another radionuclide not initially present in the waste. An example is the decay of plutonium-238, which, after several decay steps, forms radon-222, a radioactive gas. The effects of radon emissions are evaluated in Appendix A and described in Subsection 4.5.2.2 for the time period 2100 to 1,000,000.

REFERENCES FOR SECTION 1

DOE (U.S. Department of Energy), "Final Environmental Impact Statement, Management of Commercially Generated Radioactive Waste," DOE/EIS-0046-F, October 1980.

ERDA (U.S. Energy Research and Development Administration), "Alternatives for the Long-Term Management of Defense High-Level Radioactive Waste, Hanford Reservation, Richland, Washington," ERDA 77-44, 1977a.

ERDA (U.S. Energy Research and Development Administration), "Alternatives for the Long-Term Management of Defense High-Level Radioactive Waste, Idaho Chemical Processing Plant, Idaho Falls, Idaho," ERDA 77-43, 1977b.

ERDA (U.S. Energy Research and Development Administration), "Alternatives for the Long-Term Management of Defense High-Level Radioactive Waste, Savannah River Plant, Aiken, South Carolina," ERDA 77-42, 1977c.

ERDA (U.S. Energy Research and Development Administration), "Final Environmental Impact Statement, Waste Management Operations, Idaho National Engineering Laboratory," ERDA-1536, September 1977d.

2.0 ALTERNATIVES

2.1 Introduction

This section describes the alternatives for long-term waste management of high-level waste at the INEL evaluated in this report. The shipping mode, transportation effects, and effects at the repository are discussed in Subsection 2.1. Subsection 2.3 provides a description of each alternative, the status of the required technology, a flow diagram of the operational steps required to implement each alternative, a conceptual design of the facilities required to implement each alternative, and a graphic illustration of each treatment process. More detailed descriptions appear in supporting documents (ERDA, 1977a; DOE, 1980b). The measures to mitigate adverse environmental effects of the alternatives are summarized in Subsection 2.4.

Selected environmental effects projected for each alternative are compared in summary tables at the end of Section 2. These tables are based on the environmental data presented in Section 3 and on the description of environmental effects and the consequence analysis presented in Section 4.

The long-term waste management alternatives include disposal of modified calcine onsite at the Idaho National Engineering Laboratory (INEL) and disposal offsite at a federal geologic repository. Other alternatives include the delayed implementation of calcine retrieval and processing, and the separation of the long-lived actinides from the generally shorter-lived fission products in the waste. It is assumed that calcine is the initial waste form for each alternative. However, for Alternative 4, which is based on actinide separation, the initial waste forms are calcine and the high-level liquid waste which had not been converted to calcine at the beginning of processing.

In evaluating the waste management alternatives, it is assumed that implementation would begin in 1990 and would be complete by 2020, except in Alternative 5, which extends to the year 2500. The purpose of Alternative 5 is to evaluate the effects of radionuclide decay. Consequently, 100-, 300-,

and 500-year delay periods have been selected for evaluation. In Alternative 5, the period of operation is assumed to be the same as that in the other alternatives, and the calcine is assumed to be modified by converting it to glass.

The content of this report and supporting appendixes are organized in the following manner. Supporting information and strategy alternatives eliminated from further study are discussed in Section 2 in addition to the data that summarize the environmental consequences discussion in Section 4. Mitigative measures for construction, operational, and disposal activities are also discussed in Section 2. A description of the affected environment is provided in Section 3. An analysis of the environmental consequences of implementing each alternative is given in Section 4. The consequences are discussed in terms of their short- and long-term effects, effects that result from events that are certain to occur, and effects that result from abnormal events that are unlikely to occur. A summary of the effects by alternative is provided.

Described in Appendix A is the methodology used to calculate the radiological dose commitments and health effects discussed in Sections 2 and 4. The methodology used to calculate the nonradiological contaminant concentrations in air and water is also presented in Appendix A. Waste releases are postulated to occur in a series of scenarios. An example of each type of calculation performed in this report is included in the description of each scenario.

Appendix B consists of a series of tables. These tables contain the results of the radiological dose calculations for each of the scenarios and the alternatives to which the scenario applies. Data in Sections 2 and 4 are taken from the tables in Appendix B.

Appendix C presents the substantive comments received on the Idaho Defense Waste Document considered in the preparation of this report.

Discussed in Appendix D are the waste form parameters used to evaluate the environmental impacts of the various strategy alternatives.

In this report, the flow of information is presented as follows. A summary and comparison of the health effects for the scenarios which cause the most significant effects are presented in Section 2. Whole-body equivalent doses and health effects for routine operations and abnormal events are presented in Section 4. Appendix A describes the calculational methodology and presents a sample calculation for the dose commitments and health effects resulting from each scenario. Appendix B presents complete dose commitment data. Individual organ doses that contribute to the whole-body dose equivalents are given in Appendix B.

2.2 Selection of Alternatives

2.2.1 Strategy Alternatives

The waste management alternatives evaluated in this report include offsite disposal and onsite disposal at the INEL. These alternatives are:

- Alternative 1. Leave-in-Place (No-Action Alternative);
- Alternative 2. Retrieve, Modify the Calcine, and Dispose at the INEL;
- Alternative 3. Retrieve, Modify the Calcine, and Dispose Offsite;
- Alternative 4. Retrieve, Separate the Actinides, Dispose of the Actinides Offsite, and Dispose of the Actinide-Depleted Calcine at the INEL; and
- Alternative 5. Delay Retrieval, Modify the Calcine, and Dispose Offsite.

A composite of the alternatives is illustrated in Figure 2-1.

Various offsite disposal technologies were evaluated in the final environmental impact statement on the management of commercially generated radioactive waste (GEIS) (DOE, 1980). Although defense waste was not explicitly treated in the GEIS, and environmental studies resulting from disposal of that waste were not included, a conclusion was reached that systems that can adequately dispose of commerical radioactive wastes can reasonably be expected to adequately dispose of defense wastes, since the processed wastes from the

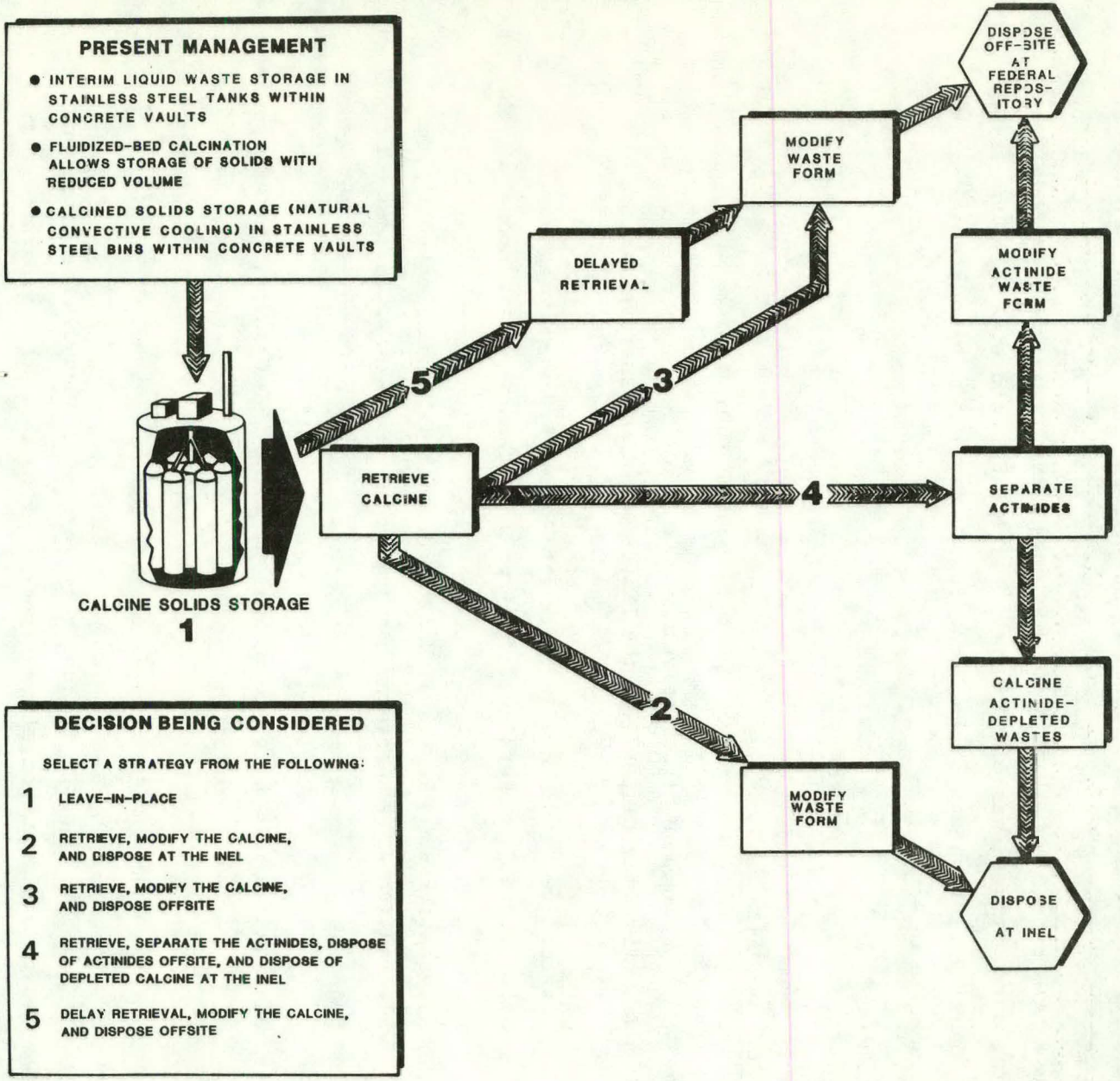


Figure 2-1. Composite of Alternatives

national defense program produce less heat and lower radiation intensities than do wastes from the same quantity of similarly processed commercial fuel. A comparison of ICPP waste with commercial waste supports this conclusion.

The defense waste processed at the ICPP differs from the commercial waste discussed in the GEIS in that it produces less heat and consequently has a lower disposal temperature and lower radiation intensities than a similar quantity of commercial waste.

The entire fuel element is dissolved during reprocessing at the ICPP, leading to a more dilute waste than results from commercial fuel where only the fuel pellets are dissolved during reprocessing. Because there are fewer fission products per unit volume in ICPP waste, the decay heat is much less than in commerical waste.

2.2.2 Disposal Options

The alternatives selected for evaluation in this report include the disposal of ICPP defense waste in a deep mined geologic repository. This and other disposal options covered in the GEIS are discussed in this section.

2.2.2.1 Deep Mined Geologic Disposal

It was estimated in the GEIS that about 180,000 canisters (900,000 cubic feet of high-level waste) will be generated by the commercial program through the year 2040. Each canister will have a heat generation rate of about 3.2 kilowatts, totaling 576,000 kilowatts. It is assumed that the high-level waste reprocessed at the ICPP will total about 20,000 canisters (as glass), totaling about 800,000 cubic feet by 2040. However, each canister will have a heat generation rate of about 0.35 kilowatt, totaling only about 7,000 kilowatts. Based on a heat loading criterion, the defense waste could be disposed in approximately one-tenth the area required for the same volume of commercial waste. If the delay alternative is selected, an even smaller repository area is required. This area could be larger, however, if a repository criterion other than heat loading is selected.

Thus, repository loading criteria generally would be less stringent (in terms of quantities of waste per unit area) for ICPP wastes than for commercial waste. Also, since the ICPP waste contains a lower concentration of fission products, the environmental consequences will be less from dispersion of the ICPP waste than from dispersion of an equal amount of commercial waste. Because of the difference in the amount of uranium consumed before processing and the dilution from dissolving the entire fuel element, the ICPP waste contains only about one-tenth the activity that is present in the same volume of commercial waste. Because of this, accidents involving the same quantity of wastes will have less severe consequences for the defense waste. An analysis of the commercial waste, as given in the GEIS, therefore applies to the ICPP defense waste since the waste is well within the boundaries of the commercial waste in all pertinent parameters.

2.2.2.2 Very Deep Hole Waste Disposal Concept

A very deep hole concept has been suggested that involves the placement of nuclear waste in holes as much as 6 miles deep in geologic formations. Desirable site characteristics for this type of repository include crystalline and sedimentary rocks located in areas of tectonic and seismic stability.

Both spent fuel and high-level waste canisters could be disposed in very deep holes. However, it is not economically feasible to dispose of high-volume wastes [e.g., transuranic (TRU) waste] in this manner. There is some question as to whether holes of the required size and depth could be drilled.

The principal advantage of the very deep hole concept is that certain (but not all) wastes can be placed farther from the biosphere in a location where it is believed that circulating groundwater is unlikely to communicate with the biosphere. Development of this technology would take 12 to 25 years.

2.2.2.3 Rock-Melt Waste Disposal Concept

The rock-melt concept for radioactive waste disposal calls for the direct placement of liquids or slurries of high-level wastes, or of dissolved spent

fuel (with the possible addition of small quantities of other wastes), into underground cavities. After the liquid has evaporated, the heat from radioactive decay would melt the surrounding rock. It is postulated that the melted rock would form a complex waste form by reaction with the high-level waste. During a period of about 1000 years, the waste-rock mixture would resolidify, trapping the radioactive material in what is believed would be a relatively insoluble matrix deep underground. Since solidification takes about 1000 years, the waste is most mobile during the time the fission products present the greatest hazard.

Wastes from reprocessing activities, such as hulls, end fittings, and TRU wastes remaining after dissolution, are not believed to be suitable for rock-melt disposal; therefore, some other disposal method would have to be used in conjunction with the rock-melt disposal concept.

2.2.2.4 Island-Based Geologic Disposal Concept

Island-based disposal involves the emplacement of wastes in deep, stable geologic formations in much the same way as in the conventionally mined geologic disposal concept. In addition, this disposal method relies on a unique hydrologic system associated with island geology. Island-based disposal would accommodate all forms of waste as would a conventionally mined geologic repository; however, additional port facilities and additional transportation steps would be required. Remoteness of the probable candidate islands has been cited as an advantage in terms of isolation.

2.2.2.5 Subseabed Disposal Concept

It has been suggested that wastes could be isolated from the biosphere by emplacement thousands of yards below the ocean's surface in sediments which have been deposited on the ocean floor over a period of millions of years. Laboratory experiments have shown that these sediments have high sorptive capacity for many radionuclides that might leach from breached waste packages. The water column is not considered a barrier; however, it would inhibit human intrusion and could contribute to dilution by dispersal of radionuclides that might escape the sediments.

Subseabed disposal is an attractive alternative disposal technique, at least for high-level waste and spent fuel, because it appears technically feasible that the waste can be placed in areas of relatively high stability. If at some point all of the barriers were to fail, the ocean's great dilution capacity and slow current movement should retard the return of radionuclides in biologically significant concentrations to the human environment. It is estimated that the research needed prior to implementation of subseabed disposal would not be as costly or time consuming as research for some of the other alternatives. However, in comparison to mined repositories on the continent, the subseabed concept, like island-based geologic disposal, has the disadvantages of requiring special port facilities and additional transportation steps.

While subseabed disposal is believed to be technologically feasible, implementation would require favorable resolution of international and domestic legal problems. Studies have not yet fully determined whether subseabed disposal can provide isolation of wastes equal to that of deep geologic repositories. It is estimated that development of this technology will take 12 to 15 years.

2.2.2.6 Ice Sheet Disposal Concept

Disposal in continental ice sheets has been suggested as a means of isolating high-level radioactive waste. Past studies have specifically addressed the emplacement of waste in either Antarctica or Greenland. The alleged advantages of ice sheet disposal, which are disposal in a cold, remote area and in a medium that should isolate the wastes from man for many thousands of years, cannot be proven on the basis of current knowledge.

Proposals for ice sheet disposal of high-level waste and/or spent fuel suggest three emplacement concepts. (Present concepts for waste disposal in ice sheets call for TRU reprocessing waste to be placed in mined geologic waste repositories.) (1) Passive, slow-descent concept: waste is emplaced in a shallow hole and the waste canister melts its own way to the bottom of the ice sheet. (2) Anchored emplacement concept: similar to passive slow-descent but an anchored cable limits the descent depth, allows retrieval of the

canister, and prevents movement to the bottom of the sheet. (3) Surface storage concept: storage facility is supported above the ice sheet surface and eventually melts into the sheet.

Regardless of which emplacement concept is selected, ice sheet disposal would offer the advantages of remoteness, low temperatures, and isolation provided by the ice for thousands of years. However, transportation and operational costs would be high, ice dynamics are uncertain, and adverse global climatic effects as a result of melting portions of the ice are a remote possibility. The Antarctic Treaty now precludes waste disposal in the Antarctic ice sheet. The availability of the Greenland ice sheet for waste disposal would depend upon acceptance by the governments of Denmark and Greenland.

A great deal of research appears to be needed before the potential of ice sheet disposal is determined. Even though the apparent bowl-shaped ice cap of Greenland would allow wastes to melt to the bottom of the bowl where they might remain permanently, the consequences of release of radioactive decay heat to the ice are uncertain. Because ice sheets are located in areas where weather and environmental conditions are extreme, it can be anticipated that transportation of the wastes to the site, waste emplacement, and site characterization would be difficult.

2.2.2.7 Well-Injection Disposal Concepts

Two methods of well-injection have been suggested: deep-well liquid injection and shale/grout injection.

Deep-well liquid injection involves pumping acidic liquid waste to depths of 3300 to 16,000 feet in porous or fractured strata that are isolated from the biosphere by relatively impermeable overlying strata. The waste is expected to remain in liquid form and may therefore progressively disperse and diffuse through the host rock. Unless limits of movement are well defined, this mobility within the porous host formation would cause concern about eventual release to the biosphere.

In the shale/grout injection method, the shale is fractured by high-pressure injection and then the waste, mixed with cement and clays, is injected into fractured shale formations at depths of 1000 to 1600 feet. There it is allowed to solidify in a set of thin, solid disks. Shale has very low permeability and predictably good sorption properties. The formations selected for injection would be those in which it can be shown that fractures would be created parallel to the bedding planes and in which the wastes would be expected to remain within the host shale bed. This requirement is expected to limit the injection depths to the range stated above.

This alternative is applicable only to reprocessing wastes or to spent fuel that has been processed to liquid or slurry form. Therefore, not all wastes generated could be disposed by the shale/grout injection method, and a suitable additional technique would be required.

2.2.2.8 Transmutation Concept

In the transmutation concept, spent fuel would be reprocessed to recover uranium and plutonium (or in cases where uranium and plutonium are not to be recycled, processed to obtain a liquid high-level waste stream). The remaining high-level waste stream would be separated into two streams: an actinide waste stream and a fission product stream. The fission product stream would be concentrated, solidified, and disposed at a mined geologic repository. The waste actinide stream would be combined with uranium or uranium and plutonium, fabricated into fuel rods, and reinserted into a reactor. In the reactor, about 5 to 7 percent of the recycled waste actinides would be transmuted to stable or short-lived isotopes. These isotopes would be removed during the next recycle step for disposal in the repository. Numerous recycles would result in nearly complete transmutation of the waste actinides; however, additional waste streams would be generated with every recycle. Transmutation provides no reduction in the quantities of long-lived radionuclides (such as technetium-99 and iodine-129) in the fission product stream that is shipped offsite for geologic disposal. This concept is a variation of the actinide separation process (Alternative 4) discussed in this document.

2.2.2.9 Space Disposal Concept

Space disposal has been suggested as a unique option for permanently removing nuclear high-level wastes from the earth's environment. In the reference concept, high-level waste is formed into a ceramic-metal matrix and packaged in special flight containers for insertion into a solar orbit where it would be expected to remain for at least one million years. The National Aeronautics and Space Administration has studied several space disposal options since the early 1970's. The concept involves the use of a special space shuttle that would carry the waste package to an orbit where a transfer vehicle would separate from the shuttle and place the waste package, along with another propulsion stage, into an earth-escape trajectory. The transfer vehicle would return to the shuttle, and the remaining rocket stage would insert the waste into a solar orbit.

Space disposal is of interest because once the waste is placed in orbit, its potential for environmental impacts and human health effects is judged to be nonexistent. However, the degree of risk of launch pad accidents and orbit failures has not been determined.

The space disposal option appears feasible for selected long-lived waste fractions of radionuclides, such as iodine-129, or even for the total amount of reprocessed high-level waste that will be produced. Space disposal of unreprocessed fuel rods and other high-volume wastes does not appear to be either economically feasible or practical because of the large number of flights that would be required.

2.2.2.10 Conclusions

The principal objective of the disposal of radioactive waste is to provide reasonable assurance that these wastes, in biologically significant concentrations, will be permanently isolated from the human environment. In evaluating the various technologies available for permanent offsite disposal of the high-level wastes at ICPP, this document relies heavily on the analysis and conclusions reached in the final environmental impact statement for the long-term management of commercially generated radioactive waste (GEIS) (DOE,

1980). This reliance is based on the determination that the characteristics of the defense waste at ICPP are comparable to those commercial high-level wastes analyzed in the GEIS. The defense wastes at the ICPP produce less heat and lower radiation intensities than a similar quantity of commercial waste. The repository space requirements of defense wastes at the ICPP are substantially less than those considered in the GEIS, and, therefore, should not materially affect repository requirements.

All waste disposal technologies were evaluated in detail in the GEIS. Factors which were considered regarding each disposal method included: (1) radiological effects during the operational period, (2) nonradiological effects, (3) compliance with existing national and international law, (4) independence for future development of the nuclear industry, and (5) potential for corrective or mitigating actions.

A mined geologic repository is the preferred disposal option based on the distinct advantages in minimizing radiological effects during the operation period; the advanced status of development; and the ability (ease) of corrective or mitigative actions (e.g., retrievability) if waste isolation from the human environment is threatened. With respect to the other evaluation factors, the only category in which an alternative technology might offer an advantage would be the radiological effects during the postoperational period for which space disposal has an advantage. However, this is considered a long-term advantage and would be more than offset by near-term disadvantages.

From consideration of technical feasibility, only two of the alternative waste disposal methods appear to warrant further study: subseabed and very deep hole. For subseabed, the DOE has decided to continue studies of the environmental, technical, legal, and institutional feasibility of isolating wastes within the sedimentary geologic formations of the deep seabed. This concept is considered a longer-term supplementary disposal method to mined repositories. The DOE also feels that very deep hole disposal warrants some additional study as a possible backup for high-level waste disposal. Further development of the very deep hole concept will emphasize the capability to take corrective or mitigating actions.

The other disposal methods (island, transmutation, rock melt, ice sheet, and well injection) were found to have no clear advantages over mined geologic disposal and to provide no additional complementary function. In some cases, these other technologies appeared clearly less desirable. For instance, in the rock melt disposal concept, the waste is expected to be liquid for the first 1000 years, and, thus, is most mobile during the period of greatest fission product hazard.

In summary, there appear to be no environmental issues that would reasonably preclude pursuit of a program strategy favoring disposal of high-level defense wastes in deep geologic repositories. Thus, if a decision were reached to retrieve the high-level waste at the ICPP and dispose of it off-site, the use of deep mined geologic repositories is the preferred alternative.

2.2.3 Other Parameters Considered in Evaluation of Strategy Alternatives

To analyze the environmental impacts of strategy alternatives, it is necessary to assume certain waste forms and processes so that calculations can be performed which show the range of environmental effects that can be expected from the alternative strategies. The three waste forms used in this report for this purpose are stabilized calcine, pellets, and glass. The existing waste form, calcine, is also used to evaluate the "no-action" alternative (Alternative 1). These waste forms are used in this report only to provide representative parameters for purposes of analyzing alternative strategies. Appendix D compares the characteristics of a variety of waste forms and presents the data basic to the selection of calcine, pellets, and glass in this report. It is expected that the environmental impacts from whatever waste form is finally selected for ICPP wastes will not exceed those described in this report.

In order to perform a comparative evaluation of the alternatives described in this report, it was necessary to postulate a mode of waste shipment (railroad) and the use of specific shipping containers. Development

of the various components of the transportation element is an ongoing process and will be based on the results of ongoing testing programs and the deliberations of other governmental agencies such as the U.S. Department of Transportation and the U.S. Nuclear Regulatory Commission. Furthermore, before any waste is shipped, detailed analysis of transportation hazards will be completed. However, the environmental impacts of the final waste shipment system are expected to be no greater than those described in this report.

For the purpose of this report, a 1500-mile, (maximum probable distance) one-way route by rail to a federal repository is assumed. Conceptual rail cask design provides for the transport of three stainless steel waste canisters in a single cask. A conceptual canister is 15 feet long with a diameter adequate (assumed to be 2 feet) to keep the radiation level within the limit permitted by federal regulations (49 CFR 173.393). It has been estimated that a 3-canister cask loaded with vitrified calcine would weigh about 92 tons.

In estimating the maximum and minimum radiological effects of routine shipping operations, waste was assumed to be shipped to the repository along a maximum population route. The route follows major rail lines, passing through urban, suburban, and rural areas. Distances through urban, suburban, and rural areas were estimated to be 37, 53, and 1,410 miles, respectively.

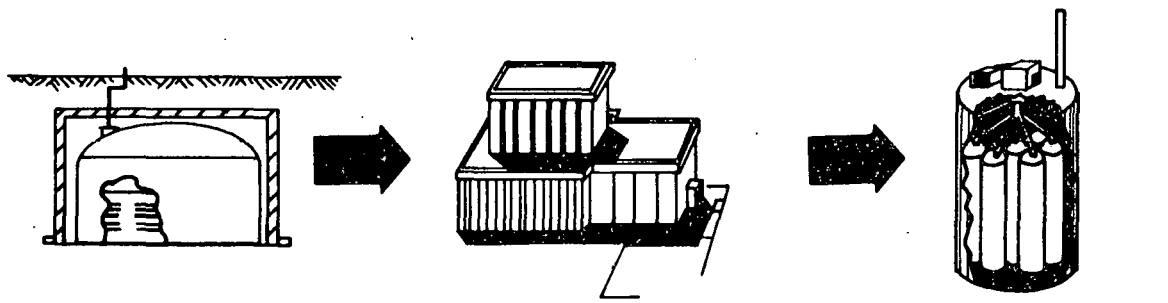
Evaluations of various geologic media, a search for suitable respository locations, conceptual design activities, and safety analyses are underway in a national program (see Subsection 1.4). For the comparative evaluations in this report, a mined repository in a deep geologic formation was assumed. Again, the environmental impacts at the respository which is finally utilized are expected to be no greater than those analyzed in this report.

2.3 Description of Alternatives

The description of the retrieval and calcination facilities for the alternatives described in this section are based on preconceptual and conceptual designs (Parsons, 1976 and 1977).

2.3.1 Leave-in-Place - Alternative 1

The processing steps required to implement Alternative 1 are shown in the following illustration.



In Alternative 1, waste processing as it exists today at the INEL is continued. The defense high-level liquid waste is removed from storage tanks at the ICPP and calcined in the waste calcination facility. The calcine is then stored in stainless steel bins in a reinforced concrete vault at the ICPP as shown in Figure 2-2. Construction of additional bins will be required until all high-level liquid waste has been solidified. The effects of calcination have been evaluated in another environmental document (AEC, 1974). Since Alternative 1 involves the continuation of present operations, this alternative constitutes the "no-action" alternative.

2.3.1.1 Facility Description

The storage facilities consist of vertical stainless steel bins that are housed in reinforced concrete vaults anchored on bedrock. There are currently four calcine storage facilities at the ICPP. Three of these have been filled.

The first bin set consists of four bins (12 feet in diameter), each with three concentric tanks. The spaces between the bins are for convective air cooling. The second and third bin sets consist of seven cylindrical bins approximately 12 feet in diameter and 43 to 60 feet tall. The fourth facility has three cylindrical bins but is essentially the same as the second and third

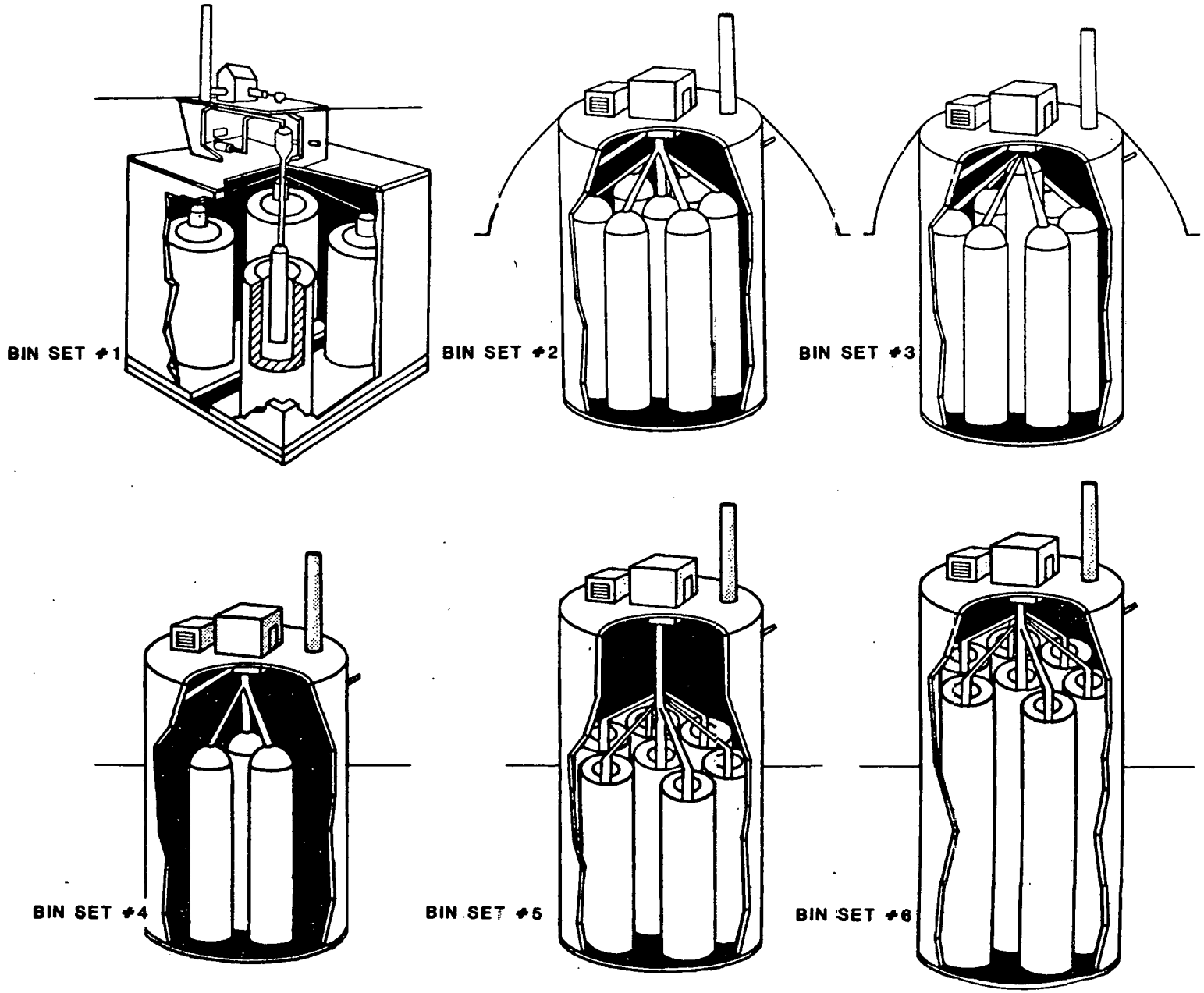


Figure 2-2. Calcine Storage Facilities at the ICPP

bin sets. The fourth facility will be available for use when the new waste calcining facility begins operation. The fifth and sixth bin sets will have annular bins. The concrete vaults for the fifth and sixth bin sets will be cylindrical, without earth berms, similar to the fourth bin set. The first storage facility is not equipped with an access port to retrieve the calcine. The other facilities have retrieval ports and all are equipped to allow detection of contamination in the vault exhaust stack or accumulation of water on the vault floor (see Figure 2-2).

Convective air circulation in the vaults is provided by air inlet ducts extending to the bottom of the vaults and by short exhaust stacks from the top of the vaults. The design provides for the installation of fans to increase air circulation, dampers to control or stop air circulation, and mountings that could be used for the installation of high efficiency particulate air (HEPA) filters in the vault stacks, should the need arise. A radiation monitor is installed on each vault stack downstream of the location provided for HEPA filters. Thermocouples are located in the bins, on the bin walls, and in the vaults for temperature monitoring. A small sump in the floor of each vault is equipped with a liquid-level monitor and a steam jet for removing any liquid collected.

The filled bins are connected to the ICPP stack through the waste calcining facility cell vent system and atmospheric protection system (APS). The cell vent system discharges through a line to the APS. The APS has two components: a deep-bed graded fiberglass prefilter and a HEPA filter. Emissions are carefully analyzed for radionuclide content.

The total capacity in the first three bin sets is about 77,000 cubic feet. A new facility of about 35,000-cubic-foot capacity will be required every 2 or 3 years based on the projected schedule of waste calcining operations (see Subsection 1.4). Bin sets having a capacity of 240,000 cubic feet will be needed when processing is assumed to begin in 1990. Twelve additional bin sets will be installed as needed through 2020 when calcine production is assumed to terminate. These future facilities will have an annular design similar to the fifth and sixth bin sets (see Figure 2-2).

An artist's rendition of the completed disposal complex required for Alternative 1 is shown in Figure 2-3. The complex is built to meet applicable federal requirements (ERDAM, 1977). This means that an earthquake registering X on the modified Mercalli scale (7.75 on the Richter scale) and centered 15 miles from the disposal site is not expected to cause damage to the calcine bins that results in calcine release. The facilities are also designed to resist 175-mile-per-hour winds. The estimated maximum tornado damage would be the loss of the exhaust stack and the instrument station on top of a vault. No major damage to the bins resulting in calcine release is expected.

Even though it is assumed that surveillance would be discontinued after 100 years, the disposal complex would provide waste containment for at least 500 years. No new technology would be developed for the "leave-in-place" alternative. Any improvements in the technology of environmental monitoring would be adopted as developed.

For decommissioning and disposal, the space within the vault surrounding the bins will be filled with a concrete-like substance as illustrated in Figure 2-4. The volume of this filler is about four times that of the bin volume. Encapsulation would provide additional protection against intrusion, damage to vaults from seismic activity, and surface water entry into the vault.

2.3.1.2 Future Decisions

No future decisions on waste management strategy would be required for the no-action alternative.

2.3.2 Retrieve, Modify the Calcine, and Dispose at the INEL - Alternative 2

The processing steps required to implement Alternative 2 are shown in the illustration on page 2-21.

The illustration shows that in Alternative 2, calcine from the calcine storage bin sets at the ICPP would be retrieved from the stainless steel bins

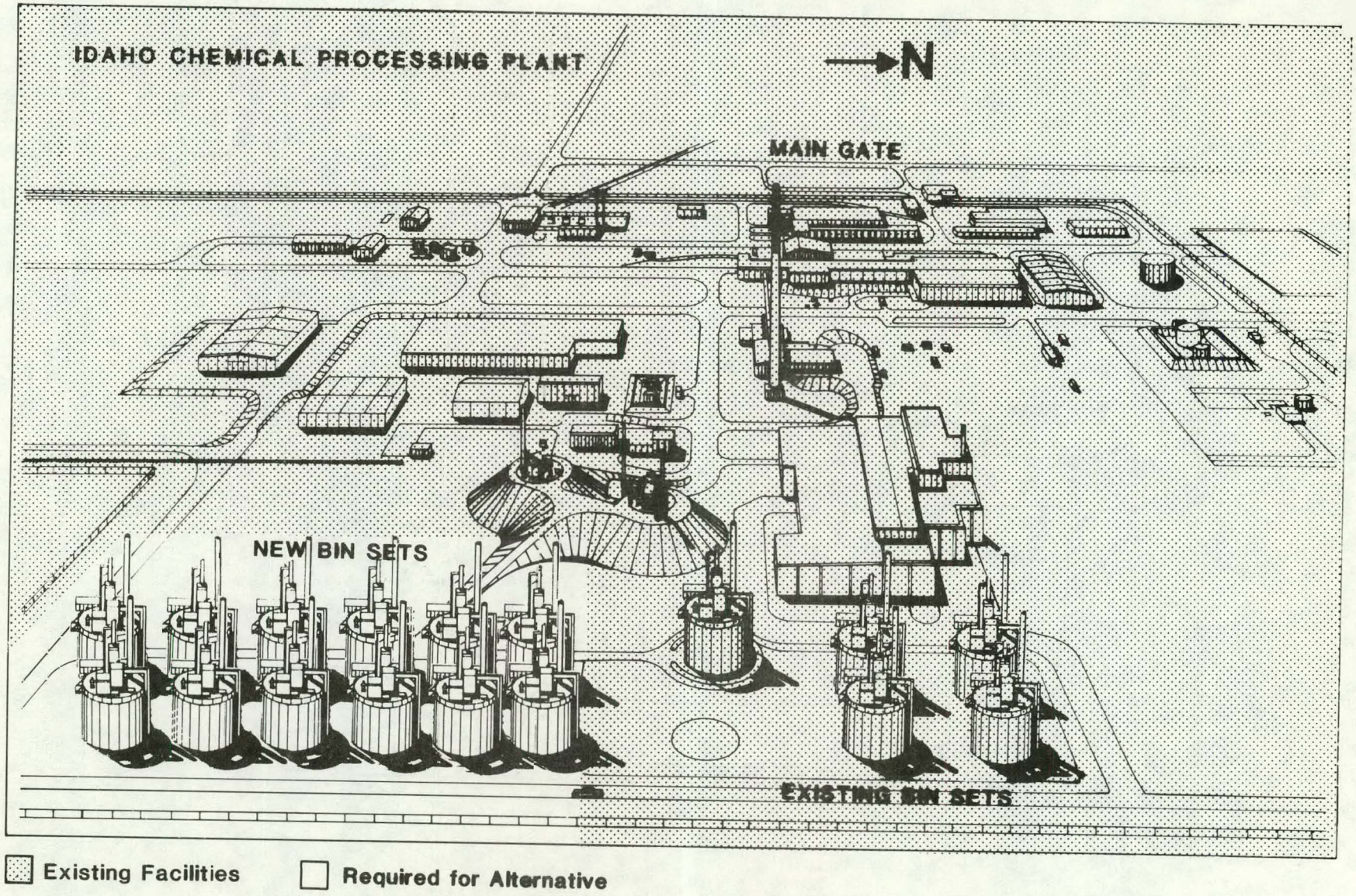


Figure 2-3. Facilities for Alternative 1 (Leave-In-Place)

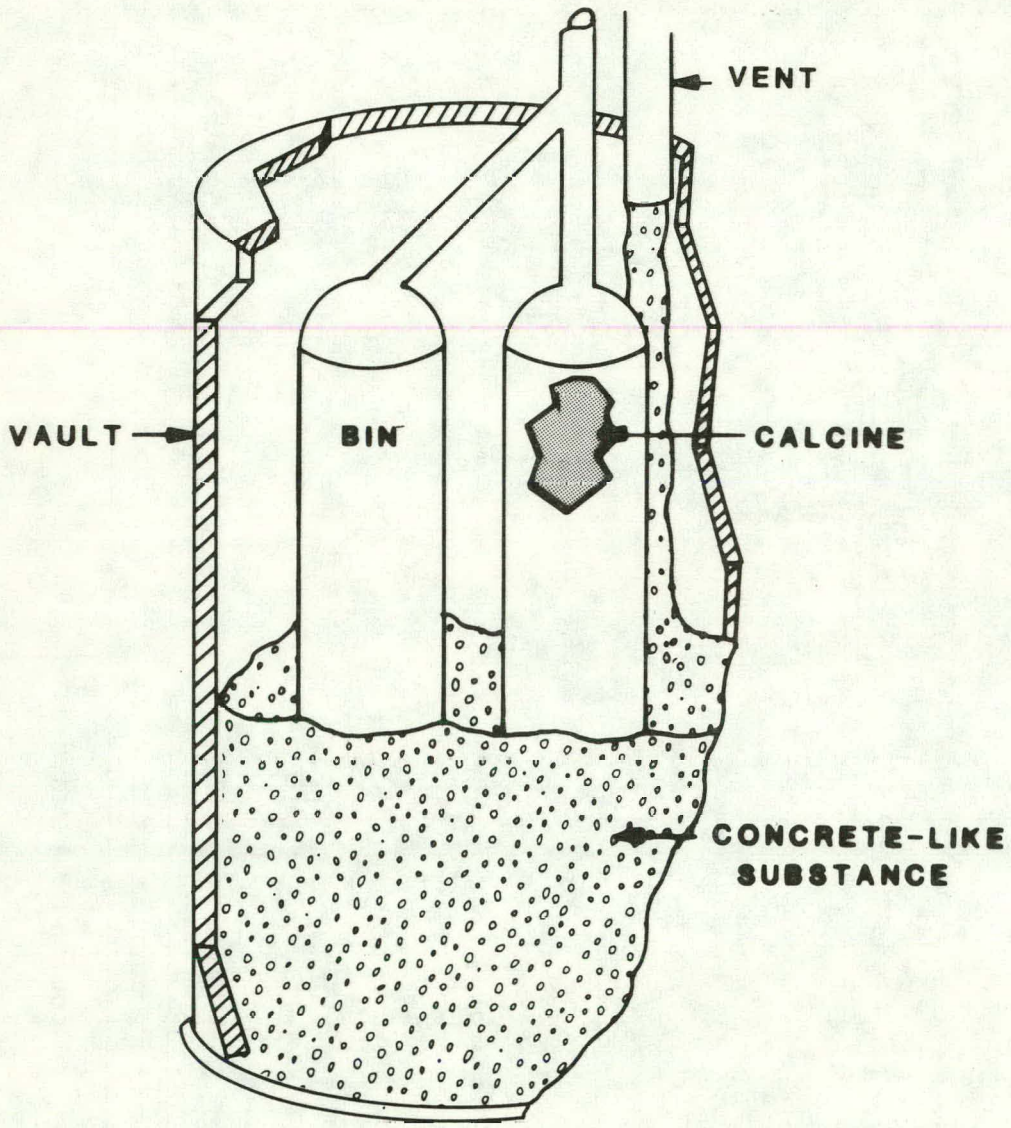
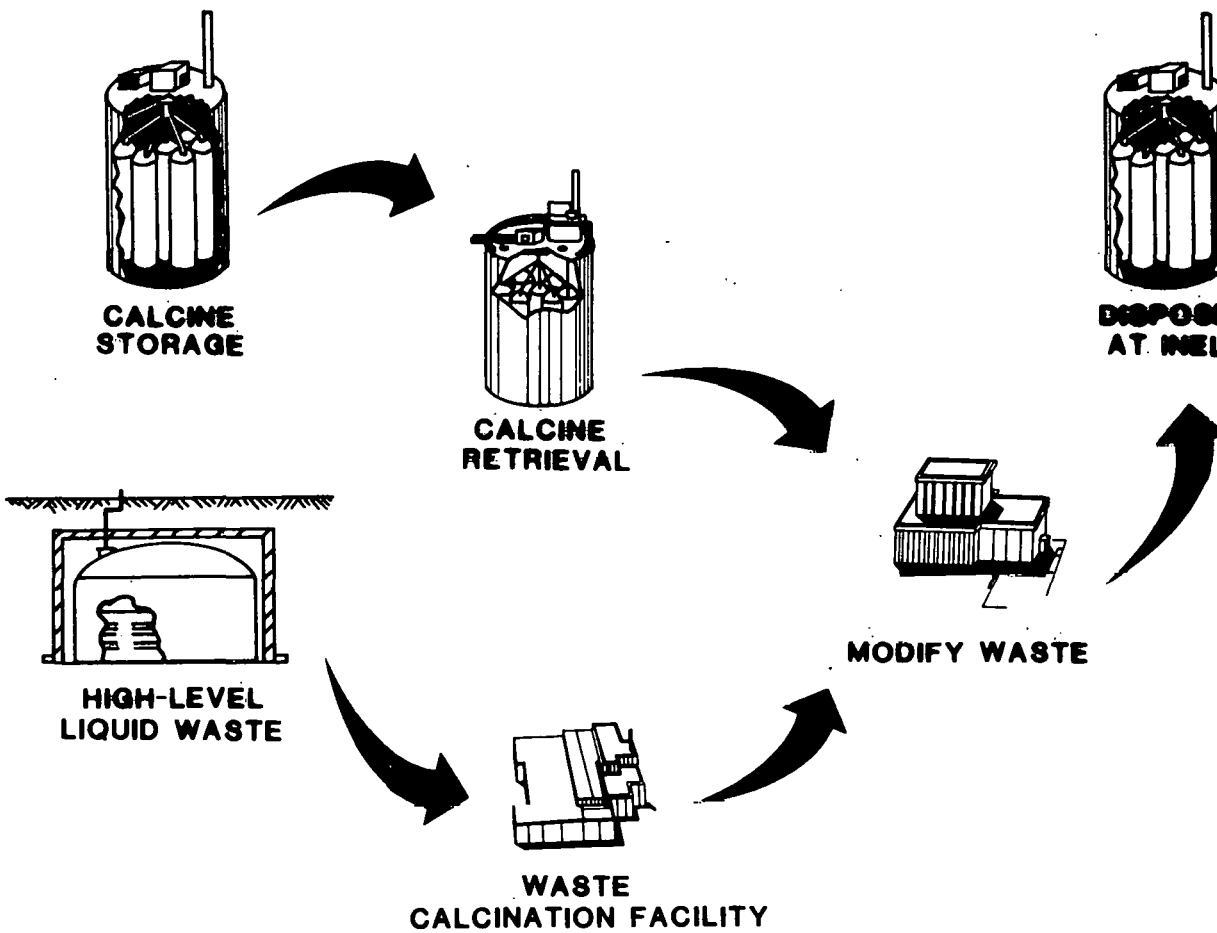


Figure 2-4. Encapsulation for Decommissioning at the ICPP

and the waste form modified for disposal onsite. Concurrently, high-level liquid waste from tanks at the ICPP would be calcined, and the calcine would be modified and disposed at the INEL.

In Alternative 2, onsite disposal of the waste is evaluated. The waste forms considered are pelletized calcine and vitrified calcine. Both are more stable and less dispersible than the calcine. The impacts resulting from these two forms, and from the unmodified calcine in Alternative 1, represent the range of impacts that could result from any waste form.



2.3.2.1 Calcine Retrieval

In order to modify the calcine and provide a more stable waste form, the calcine produced before 1990 must be removed from the storage bins. This is accomplished by vacuuming the particles from the bins. The calcine retrieval facility, illustrated in Figure 2-5, consists of a movable shielded room that can be placed over the calcine storage facility to be emptied. Remotely controlled manipulators and mechanical devices would be used to lower and direct a pneumatic suction nozzle into a bin. Shielded underground ducts would direct the calcine to a receiving hopper in the waste modification facility. Retrieval air would be cooled, filtered, and recycled during retrieval operations to reduce the amount of offgas requiring treatment before monitoring and release to the atmosphere.

2.3.2.2 Calcine Pelletization

In the pelletization process shown in Figure 2-6, the calcine is mixed with solid binders, such as metakaolin, silicates, borates, or hydrated lime. The mixture is fed onto a rotating disc pelletizer where it is wetted by a spray of acidic liquid binder, such as phosphoric or nitric acid. The materials combine to form pellets about 1/8- to 1/4-inch in diameter. The pellets are heat treated to produce ceramic pellets which are abrasion resistant, leach resistant, substantially free of fine particles, free flowing, and stable up to about 1475° F (Lamb, 1979). The cooled pellets are returned pneumatically to the calcine storage bins for disposal. Pelletization would require about 50 percent more disposal volume than the original calcine.

2.3.2.3 Calcine Vitrification

Calcine is converted to a glass in a process called vitrification. The vitrified product is produced by melting calcine with ground glass (glass frit) in an electric furnace at 2000 to 2200°F. The glass could be produced in various forms. For this report, it is assumed that the vitrified product would be poured into a metal cylinder, approximately 2 feet in diameter and

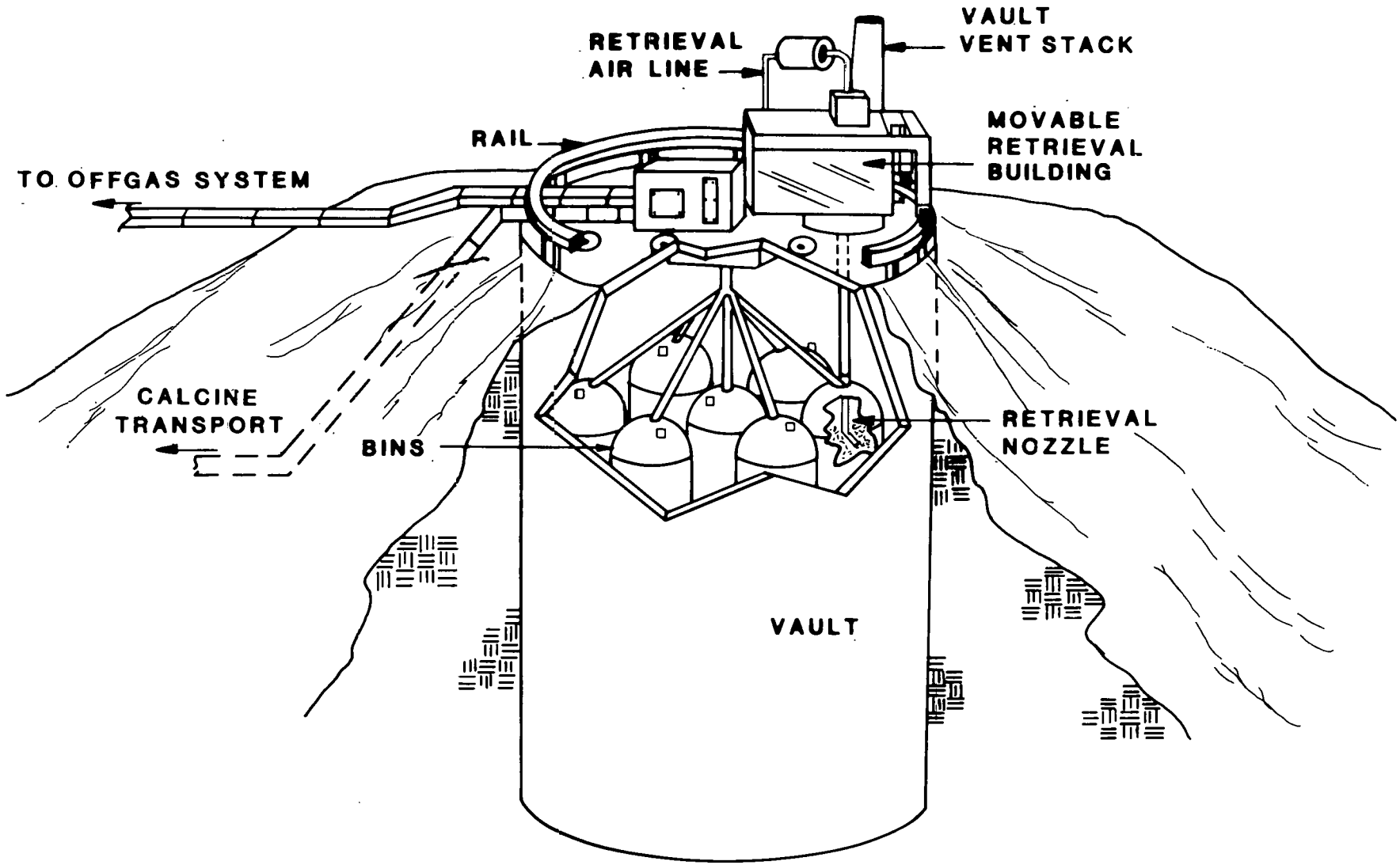


Figure 2-5. Calcine Retrieval

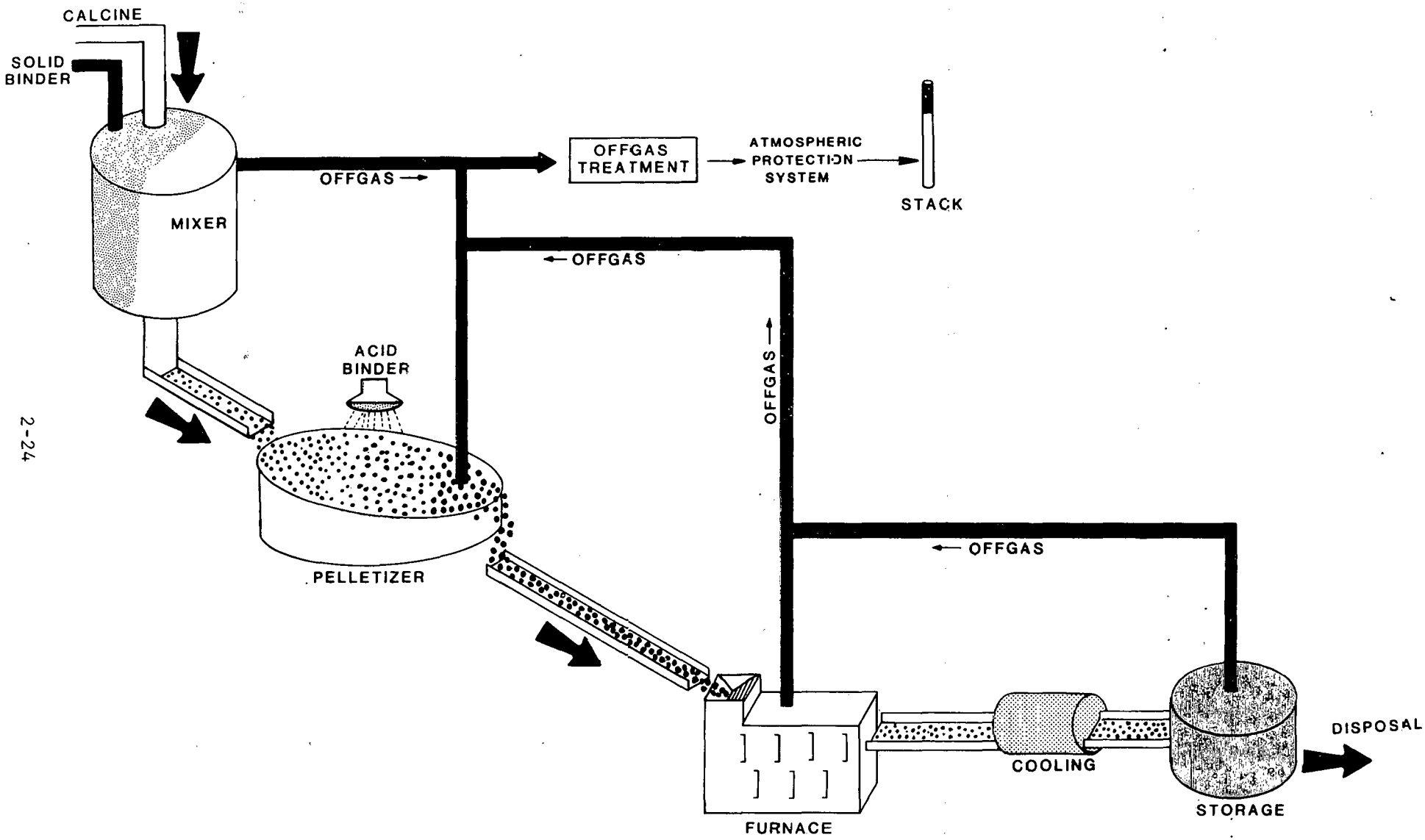


Figure 2-6. Pelletization Process

15 feet long for a total volume of 40 cubic feet (Figure 2-7). The glass is similar to certain natural rocks such as obsidian. It is highly leach resistant and, on impact, resists shattering into respirable-sized particles (Cole, 1980). The volume of the vitrified product is approximately 50 percent greater than the volume of the original calcine.

The filled canisters would be allowed to cool slowly to reduce the chance of the glass cracking because of thermal shock. A cap would be welded over the canister opening, the canister would be surveyed for contamination and, if necessary, decontaminated. The canisters would then be tested for leaks. Canisters that do not pass inspection would either be repaired or overpacked with another canister, or the glass would be removed and recast. Canisters that pass inspection would be placed in an air-cooled room. When sufficiently cool, the canisters would be loaded into shielded shipping casks and transported to an underground facility near the ICPP for disposal. The disposal facility would consist of steel-lined cylinders fitted with concrete plugs at the top and bottom (ERDA, 1977b).

2.3.2.4 Facility Description

The calcine retrieval facility is described in Subsection 2.3.2.1.

The proposed location for the waste modification facility for all waste forms would be approximately 250 feet southeast of the new waste calcination facility at the ICPP. This location would be in accordance with site selection criteria (10 CFR 100). Figures 2-8a and 2-8b illustrate facilities required to implement Alternative 2 at the ICPP: Figure 2-8a illustrates the disposal of pelletized calcine; Figure 2-8b illustrates the disposal of glass.

Pelletization Facility

The calcine pelletization building would be approximately rectangular in form with maximum outside dimensions of 84 feet wide by 248 feet long. The

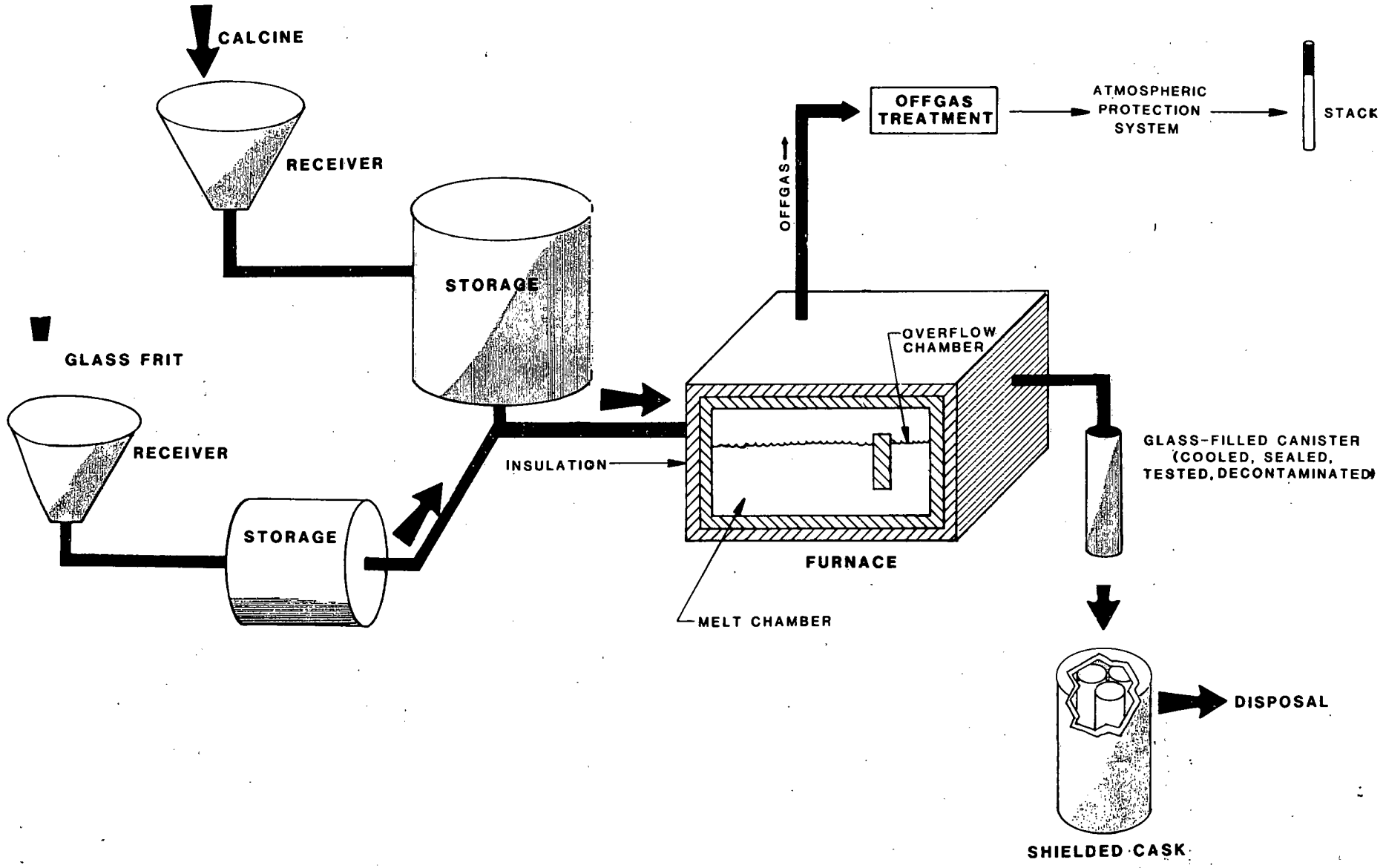


Figure 2-7. Vitrification Process

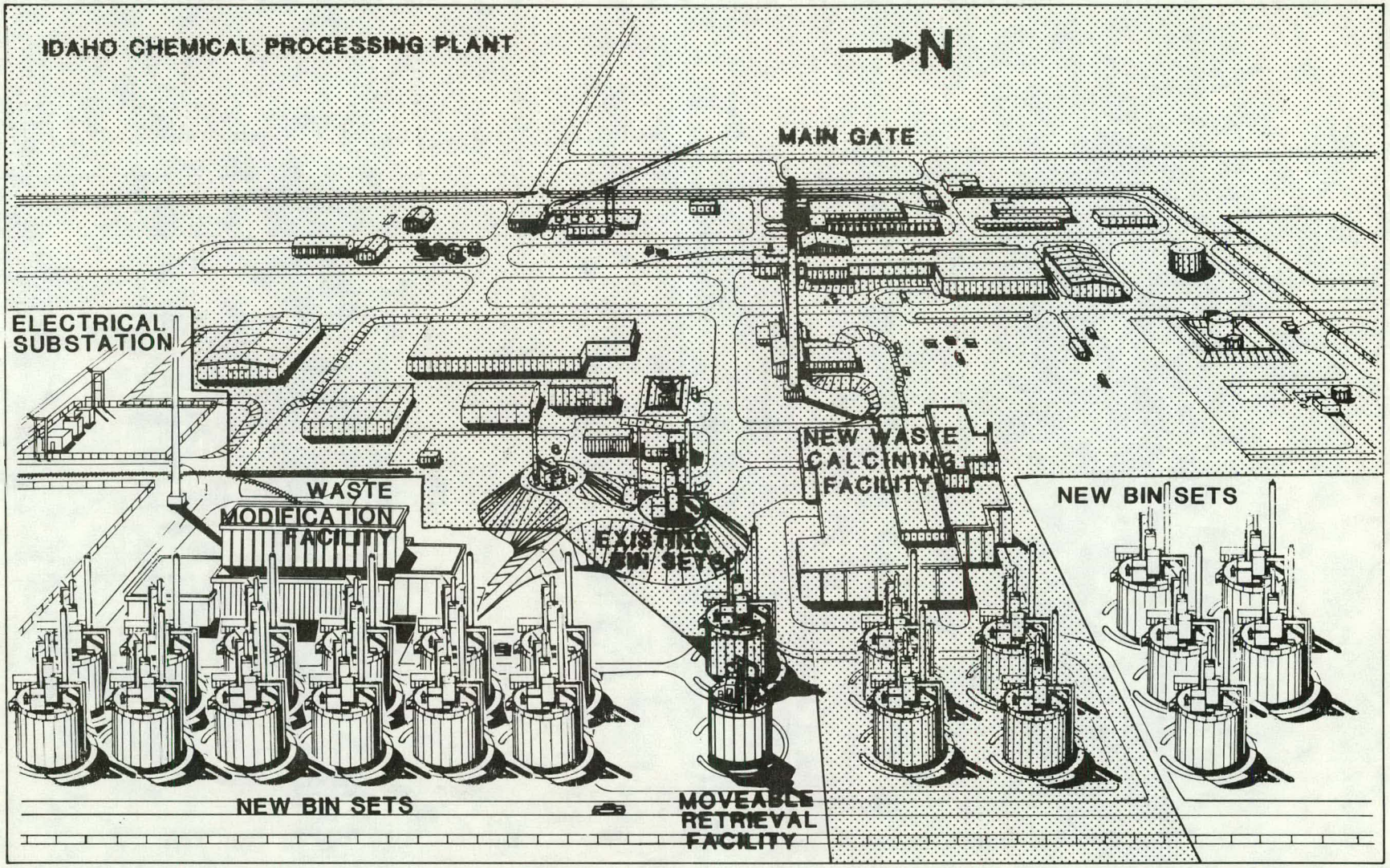


Figure 2-8a. Facilities for Alternative 2 (Retrieve, Modify the Calcine (Pellets), Dispose at the INEL)

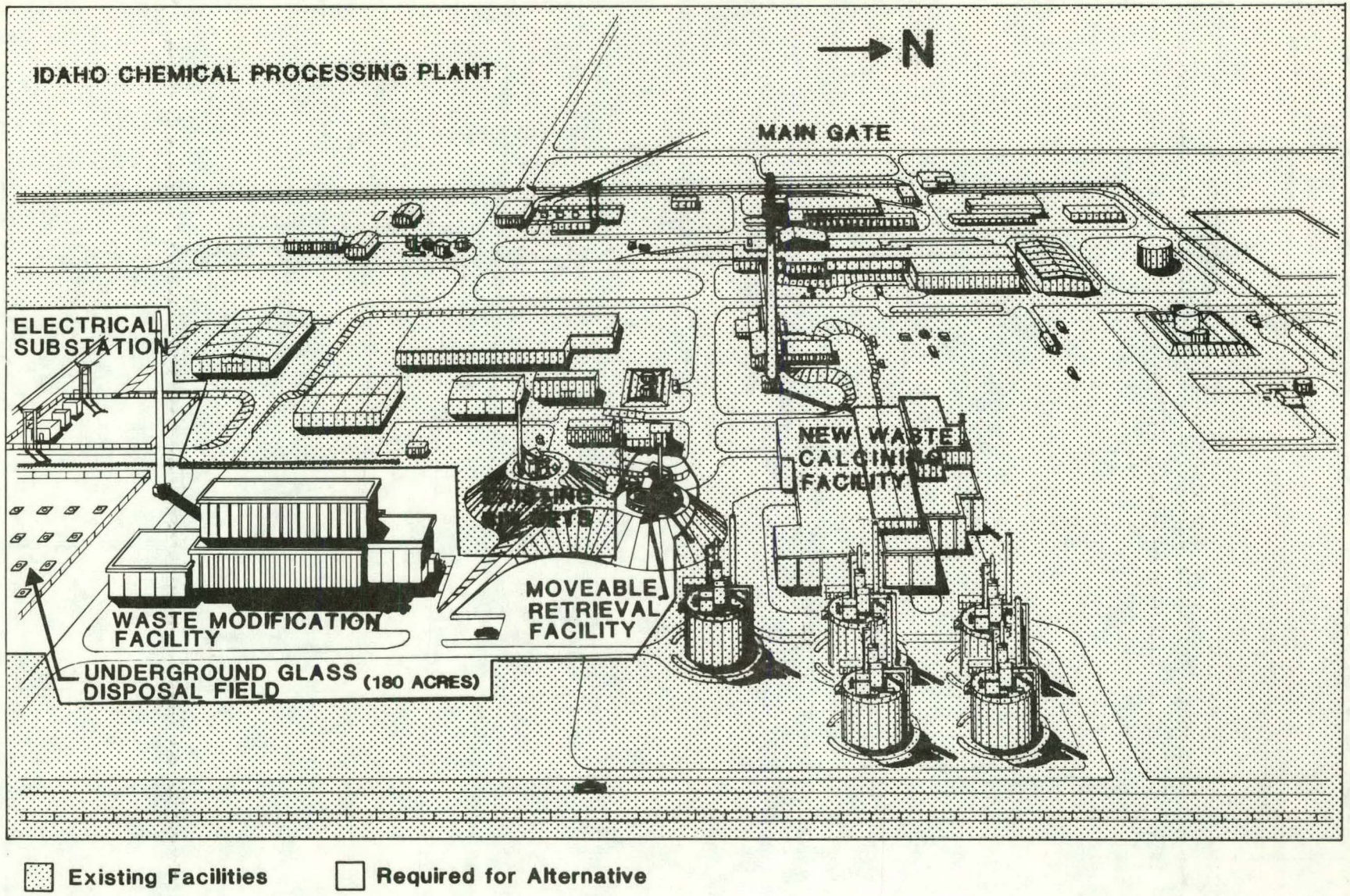


Figure 2-8b. Facilities for Alternative 2 (Retrieve, Modify the Calcine (Glass), Dispose at the INEL)

building would be a two- and three-story, reinforced concrete-mat-foundation structure designed to withstand any credible natural phenomenon, including earthquakes and tornadoes (ERDAM, 1977). The concrete roof slab would be supported by hollow precast box girders which clear-span the process cells, the loft, and operating corridors.

The cell system would be located in the core of the facility surrounded by operating corridors on three sides with the fourth side adjoining the offgas treatment system. All ventilation air flow would be from an area of lower potential contamination to an area of higher potential contamination.

The pelletization building would also include a control room, offices, an air conditioning system, Halon fire extinguishing system, electrical substations, raw material storage, a process maintenance area, loft crane, and decontamination facilities. The cells would be lined with stainless steel, and both process cells and the decontamination cell would have hot sumps and drains.

Vitrification Facility

The calcine vitrification building would be approximately rectangular in form with maximum outside dimensions of 78 feet wide by 210 feet long. This building would be a two- and three-story, reinforced concrete-mat-foundation structure designed to withstand any credible natural phenomenon, including earthquakes and tornadoes (ERDAM, 1977). The concrete roof slab would be supported by hollow precast box girders which clear-span the process cells, the loft, and operating corridors.

The cell system would be located in the core of the facility, surrounded by operating corridors on three sides, with the fourth side adjoining the offgas treatment system. All ventilation air flow would be from an area of lower potential contamination to an area of higher potential contamination.

The vitrification building would also include a control room, offices, an air conditioning system, electrical substation, Halon fire extinguisher

system, raw material storage, a process maintenance area, loft crane, decontamination facilities, and canister receiving-shipping bay. The bay would be capable of accommodating either rail cars or trucks. The cells would be lined with stainless steel. Both process cells and decontamination cells would be equipped with hot sumps and drains.

A subsurface storage area, capable of handling approximately one week's production of vitrified calcine, would be provided consisting of large-diameter piping. The base of the pipe would contain a grate of energy-absorbing honeycomb structure that could support the weight of one canister. The honeycomb structure would permit the passage of cooling air over the containers. The top portion of the pipes would be mounted in the concrete floor of the storage area and fitted with a shielding plug. A plenum beneath the storage area floor would conduct cooling air to the base of the support pipe.

Pollution Control System

All processing facilities would be equipped with an appropriate offgas treatment system and atmospheric protection system (APS). In the offgas treatment system, particulate matter and volatile gases are removed from the process air stream. A typical system contains a series of coolers, scrubbers, separators, mist eliminators, and HEPA filters. The system would be designed to remove contaminants from each specific offgas stream.

The APS is a series of two filters: a deep-bed graded fiberglass prefilter, and a HEPA filter designed to remove 99.97 percent of 0.3-micrometer particles in the gas that leaves the facility stack. The APS serves as a back-up protection system.

2.3.2.5 Status of Technology

A prototype calcine retrieval system is under construction near the ICPP. Samples of calcine have been retrieved from ICPP storage bins (Westra, 1979). These samples have not sintered or caked after storage for 12 years (Staples, 1979). This indicates that retrieval by a vacuum system would be possible even after an extended storage time.

The pelletization process has been demonstrated on a pilot plant scale (Priebe, 1980). Further development of the retrieval and pelletization processes would be required before implementing Alternative 2.

The vitrification process has been verified on a laboratory scale using simulated ICPP calcine (Gombert, 1980). Further testing will be conducted on a pilot plant scale.

2.3.2.6 Decontamination and Decommissioning

For Alternative 2, the calcine bin sets, calcine retrieval and pneumatic transport system, and the waste form modification facility would require decontamination and decommissioning (D&D).

All waste processing facilities would include features that facilitate D&D at the completion of processing activities. Included would be such features as the use of easily decontaminated surfaces, equipment designed for dismantling into easily handled components, and a processing building design that would promote simple and inexpensive D&D.

The D&D would be expected to last about 2 years for each of the bin sets and would be completed by the year 2100. The interior surfaces of the buildings that became contaminated during operations would be cleaned, but equipment that could not be decontaminated would be disposed either at the INEL or shipped to an offsite federal geologic repository.

The technology for D&D is, in general, well established. Current research and development in the field will improve remote control cutting techniques and the volume reduction and handling techniques required for contaminated materials.

2.3.2.7 Disposal at the INEL

Space is available near the ICPP for near-surface disposal of modified calcine. Disposal of pelletized calcine at the INEL would require an additional 4 acres to accommodate the 22 new bin sets that would be required to contain the increased volume of pellets.

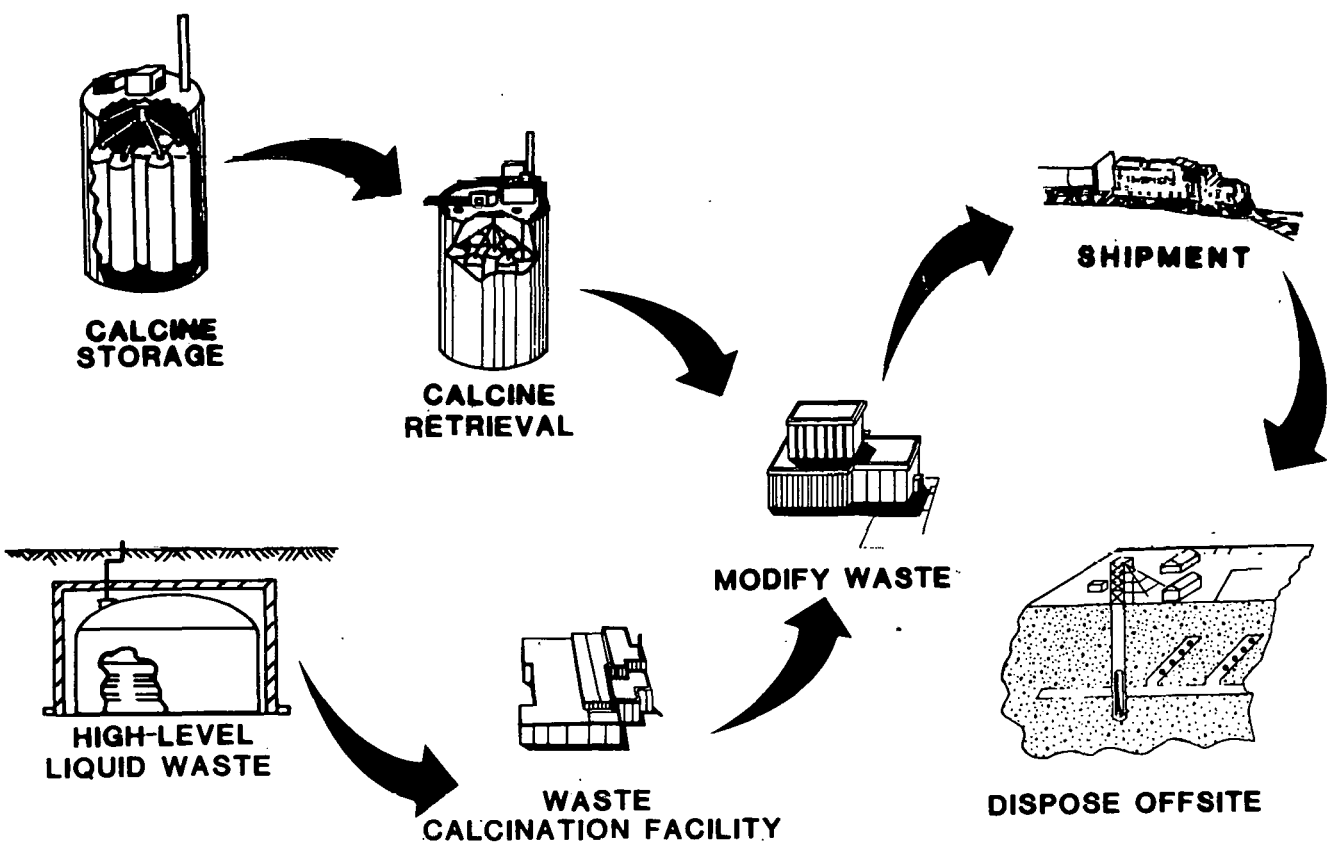
Existing calcine storage bins would not accommodate the vitrified calcine. A 180-acre area, approximately twice the size of the existing ICPP site, would be required for the disposal of the estimated 20,000 glass-filled canisters.

2.3.2.8 Future Decisions

If disposal at the INEL (Alternative 2) is selected as the waste management strategy for ICPP-generated calcine, other decisions will be required in the future. These decisions will include the choice of waste form, the process required to produce the waste form, and the disposal location and method if a glass-like waste form is selected. Each of these decisions will be based on future environmental reviews.

2.3.3 Retrieve, Modify the Calcine, and Dispose Offsite - Alternative 3

The processing steps required to implement Alternative 3 are shown in the illustration below.



The illustration shows that in Alternative 3, calcine from the calcine storage bin sets at the ICPP would be retrieved from the bins and the waste form modified for disposal offsite. Concurrently, high-level liquid waste from tanks at the ICPP would be calcined, and the calcine would be modified and shipped offsite for disposal.

Disposing of the calcine offsite in a federal geologic repository is evaluated in this alternative. The waste forms considered are stabilized calcine and vitrified calcine. Stabilized calcine has a relatively higher leach rate and is more dispersible than vitrified calcine. Therefore, these forms incorporate the range of environmental effects expected to result from any waste form that might finally be selected for disposal in a federal repository.

2.3.3.1 Calcine Retrieval

The calcine retrieval process would be the same as described in Subsection 2.3.2.1.

2.3.3.2 Calcine Stabilization

Calcine stabilization is a process in which the calcine is heated to a temperature high enough to drive off residual nitrates and water that remain after calcination. Without stabilization, the ICPP calcine would contain sufficient concentrations of nitrates and water to cause concern should a fire occur after a shipping accident. In the event of fire, the waste could be exposed to very high temperatures, thereby releasing the residual nitrates and causing internal pressure which could breach the canisters. Another concern is that excess water and nitrates could cause an increase in the internal canister pressure during the long-term period of disposal. Stabilization would lessen the probability of canister breaching after disposal. However, stabilization would not alter the leachability and dispersibility of calcine.

Calcine would be stabilized after it is retrieved from the storage facilities and transported pneumatically to the stabilization facility. The residual nitrates would be decomposed and residual water driven from the

calcine at elevated temperatures. The water vapor and oxides of nitrogen would be treated by the offgas treatment system. The stabilization process would be monitored continuously by measuring nitrogen oxides in the offgases. A process diagram is shown in Figure 2-9.

The filled canisters would be welded shut, decontaminated, and inspected for leaks. Canisters that did not pass inspection would either be repaired or provided with an overpack canister. Canisters that pass inspection would be placed in shielded shipping casks for transport to an offsite federal geologic repository.

2.3.3.3 Calcine Vitrification

The calcine vitrification process is described in Subsection 2.3.2.3.

2.3.3.4 Facility Description

The calcine retrieval facility is described in Subsection 2.3.2.1; the vitrification facility is described in Subsection 2.3.2.4.

Stabilization Facility

The facilities required to implement Alternative 3 at the ICPP are illustrated in Figure 2-10. Facility location would be in accordance with site selection criteria (10 CFR 100). The proposed location of the calcine stabilization building would be approximately 250 feet southeast of the new waste calcining facility and would be approximately rectangular in shape with maximum outside dimensions of 80 feet wide by 200 feet long. This building would be a two- and three-story, reinforced concrete-mat-foundation structure designed to withstand any credible natural phenomenon, including earthquakes and tornadoes (ERDAM, 1977). The concrete roof slab would be supported by hollow precast box girders which clear-span the process cells, the loft, and operating corridors.

The cell system would be located in the core of the facility, surrounded by operating corridors on three sides, with the fourth side adjoining the

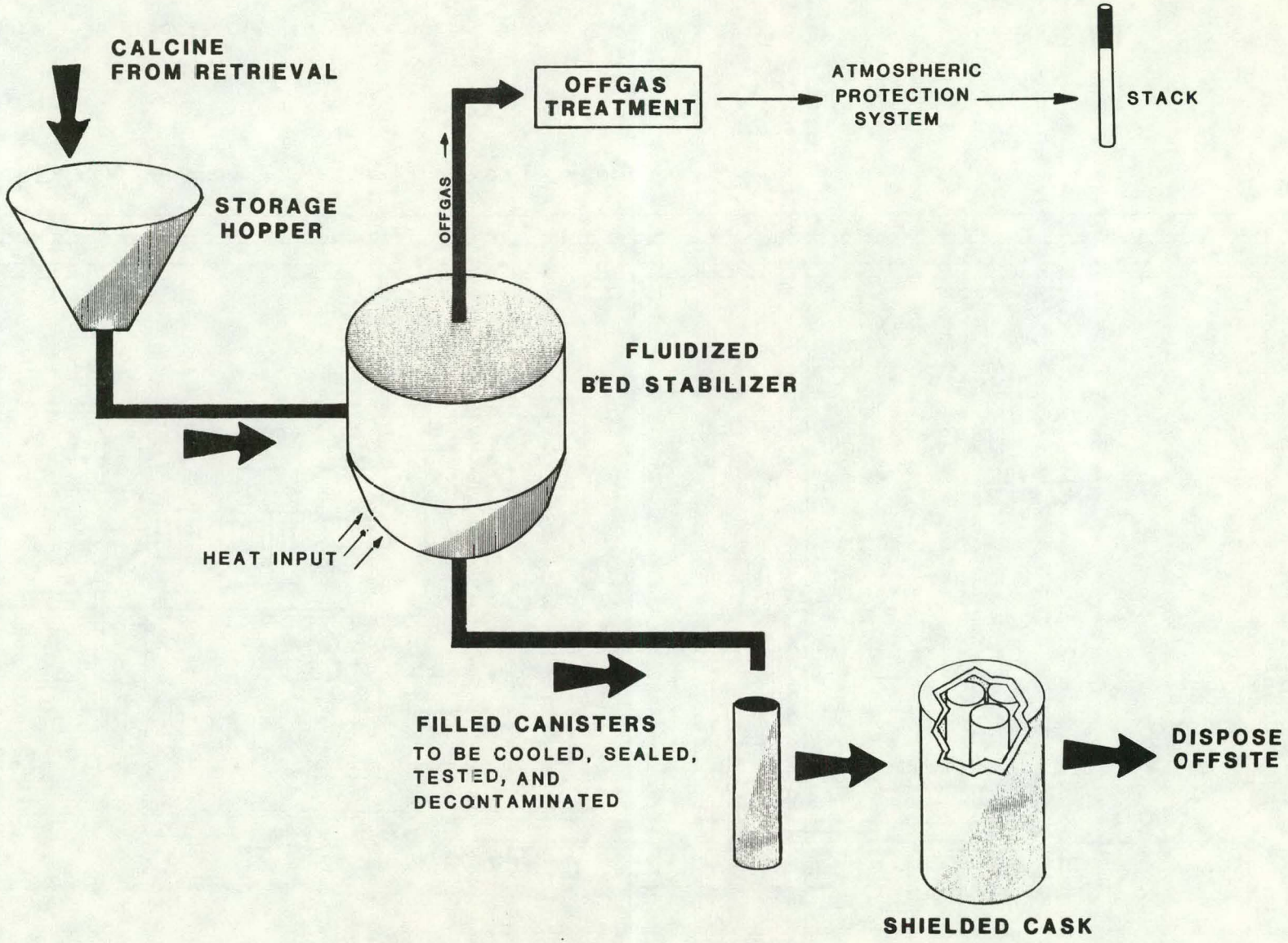


Figure 2-9. Calcine Stabilization

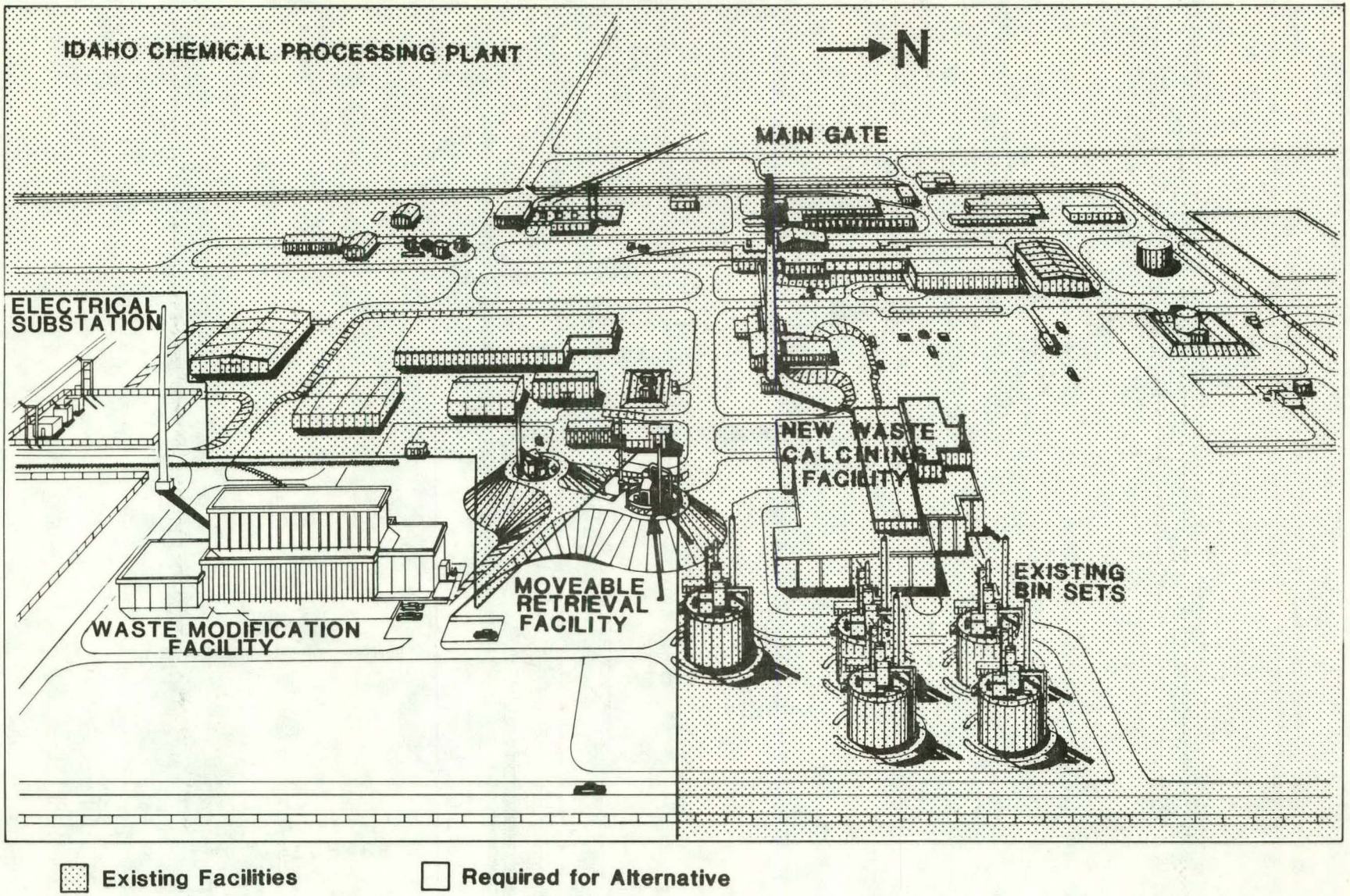


Figure 2-10. Facilities for Alternative 3 (Retrieve, Modify the Calcine and Dispose Offsite)

offgas treatment system. All ventilation air flow would be from an area of lower potential contamination to an area of higher potential contamination.

The stabilization building would also include a control room, offices, an air conditioning system, electrical substation, Halon fire extinguisher system, a process maintenance area, loft crane, decontamination facilities, and canister receiving-shipping bay. The bay would be capable of accommodating either rail cars or trucks. The cells would be lined with stainless steel. Both process cells and decontamination cells would be equipped with hot sumps and drains. Storage facilities similar to those described in Subsection 2.3.2.4 would be provided.

All offgas and ventilation air from the retrieval and waste modification facilities would pass through a treatment system as discussed in Subsection 2.3.2.4.

2.3.3.5 Status of Technology

The status of the technology for calcine retrieval and vitrification is discussed in Subsection 2.3.2.5.

Stabilization of calcine by heating in a fluidized bed has been performed on a pilot plant scale (Pomiak, 1980). Further development is required to verify the process and to determine optimum conditions and processing equipment.

2.3.3.6 Decontamination and Decommissioning

For Alternative 3, decontamination and decommissioning would be required for the calcine retrieval and transport systems, the waste form modification facility, and the empty calcine storage bins. Typical D&D operations are discussed in Subsection 2.3.2.6.

2.3.3.7 Disposal at a Federal Geologic Repository

Suitable sites for a federal geologic repository are being investigated. A typical repository, and the effects associated with its construction and

operation, are described in detail in environmental impact statements. Geologic media available for location of a federal repository include salt, granite, tuff, and basalt. The conceptual repository is constructed in a room and pillar arrangement using conventional mining techniques. Access to the subsurface area is by shafts which are used during waste emplacement and mining operations. Waste is received at the surface facilities and transferred to subsurface rooms for emplacement. The waste canisters are placed in holes in the floor of the emplacement room. Thermal criteria control canister spacing and limit heat output of individual waste canisters. During the initial period of operation (assumed to be about 50 years), the canisters are considered to be retrievable.

During the initial period, the integrity of the repository is evaluated. After repository performance has been adequately verified, the waste would no longer be emplaced in a readily retrievable manner. All rooms would be filled with waste, backfilled, and the remaining underground areas would be decommissioned. Repository decommissioning is completed by decontaminating, and perhaps dismantling the surface facilities, and monitoring the repository location (Section 5.3, DOE, 1980b).

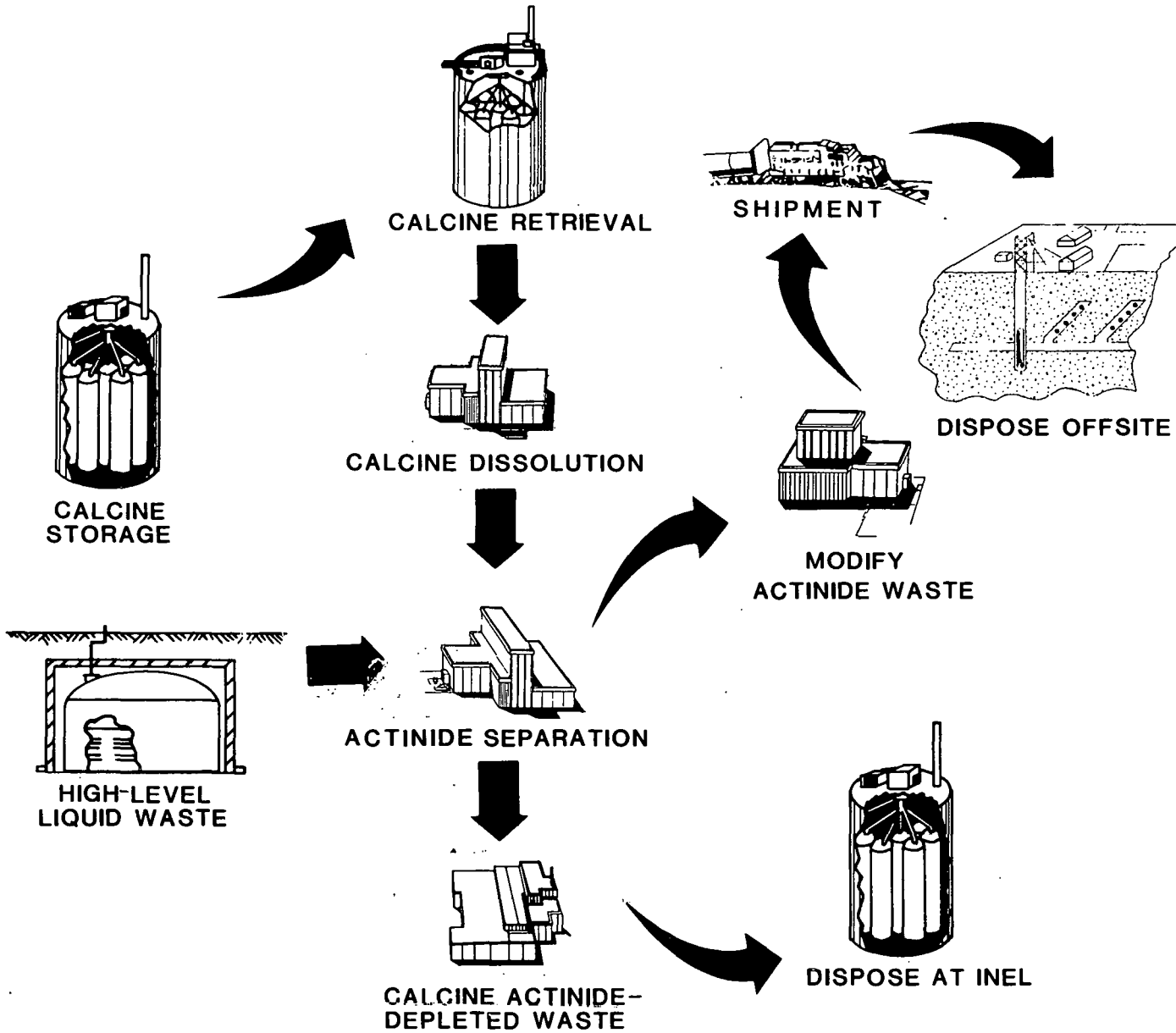
The space required for disposal of either stabilized or vitrified calcine would be approximately 175 acres. This area is less than 10 percent of the area estimated for a conceptual geologic repository (2000 acres).

2.3.3.8 Future Decisions

If disposal at an offsite federal repository (Alternative 3) is selected as the waste management strategy for ICPP-generated calcine, other decisions will be required in the future. These decisions will include the choice of waste form, the process required to produce the waste form, the mode and route for waste shipment, and the design and location of a repository. Each of these decisions will be based on future environmental reviews.

2.3.4 Retrieve, Separate the Actinides, Dispose of Actinides Offsite, and Dispose of Depleted Calcine at the INEL - Alternative 4

The processing steps required to implement Alternative 4 are shown in the following illustration.



The illustration shows that in Alternative 4, the calcine would be retrieved from the storage bins at the ICPP, dissolved, combined with high-level liquid waste from tanks, and the actinide fraction separated. The actinide-depleted solution containing most of the fission products would be recalcined and returned to the bins at the ICPP for disposal. The actinide fraction would be mixed with undissolved calcine from the dissolution step, then dried; the waste form would be modified (assumed to be glass), and shipped offsite for disposal.

2.3.4.1 Actinide Separation

In order to separate the actinides from the waste, the calcine would be retrieved from the bins using the process described in Subsection 2.3.2.1. After transport to the actinide dissolution facility, the calcine would be dissolved in nitric acid. For evaluation purposes, it has been assumed that 2 percent of the calcine would remain undissolved and would be combined with the actinide fraction for vitrification and offsite disposal. The undissolved calcine would consist mainly of nonradioactive compounds.

A flow diagram of the calcine dissolution process is shown in Figure 2-11. Liquid waste produced after 1990 would not be calcined prior to the actinide removal step. Instead, it would be combined with the dissolved calcine, and the actinides would be removed from solution by the organic solvent extraction process shown in Figure 2-12. The organic chemical, dihexyl-N, N-diethylcarbamylmethylenephosphonate (DHD), would be used.

The separated actinide fraction would be solidified and combined with any undissolved calcine that remained after calcine dissolution. The solidified actinide waste would be combined with glass frit, vitrified in small-batch-size equipment and shipped to an offsite geologic repository for disposal. The remaining actinide-depleted solution would be calcined and returned to the storage bins for disposal at the ICPP. Cadmium and mercury present in the waste prior to actinide separation would remain at the ICPP. Cadmium would be disposed with the waste calcine. Mercury would be treated separately.

2.3.4.2 Facility Description

The calcine retrieval facility is described in Subsection 2.3.2.1.

Calcine dissolution, actinide separation, and calcination of the actinide-depleted waste fraction would be accomplished in separate facilities. Facility location would be in accordance with site selection criteria (10 CFR 100). An artist's description of the ICPP and facilities required to implement Alternative 4 is shown in Figure 2-13.

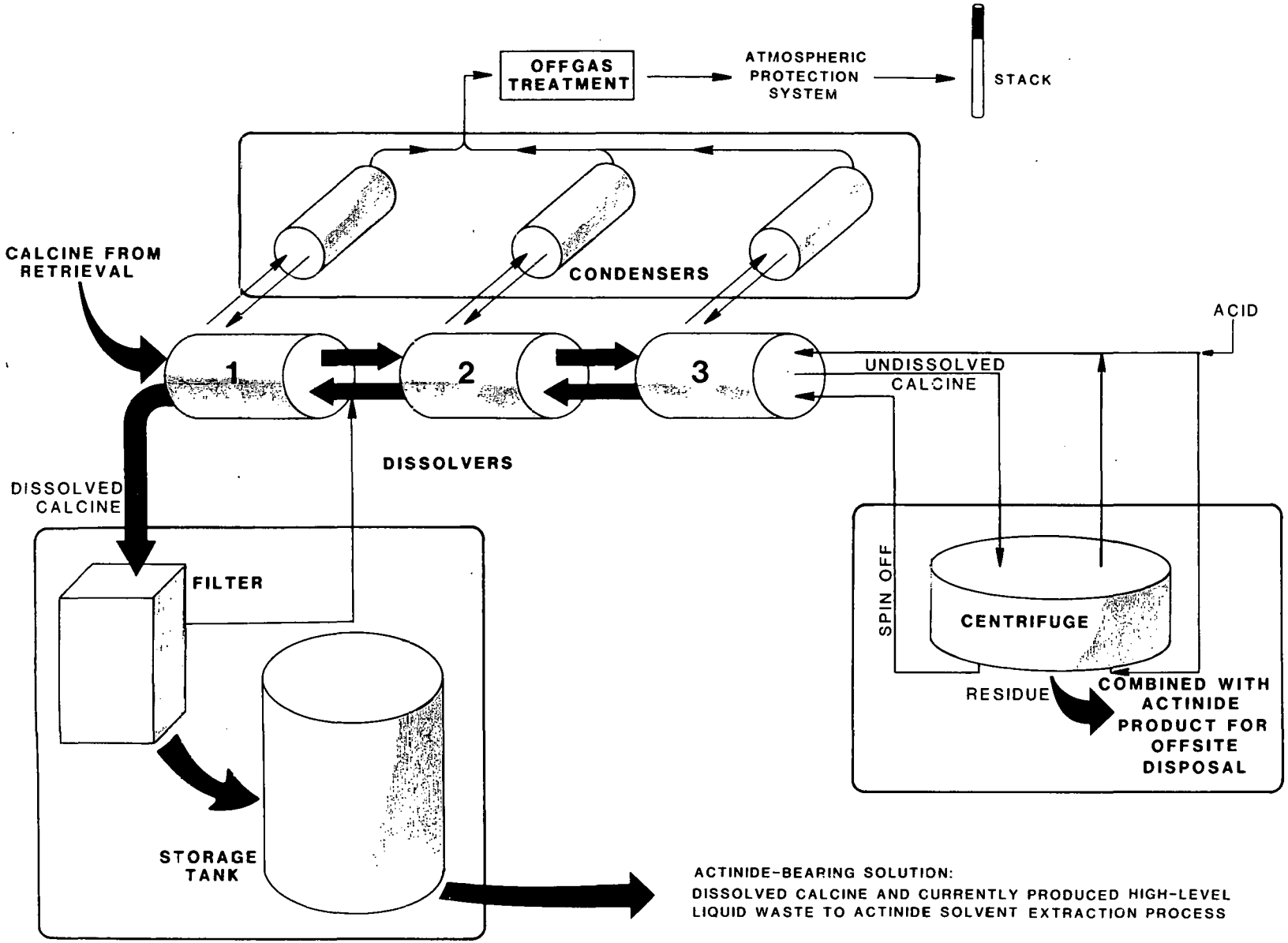


Figure 2-11. Calcine Dissolution Process

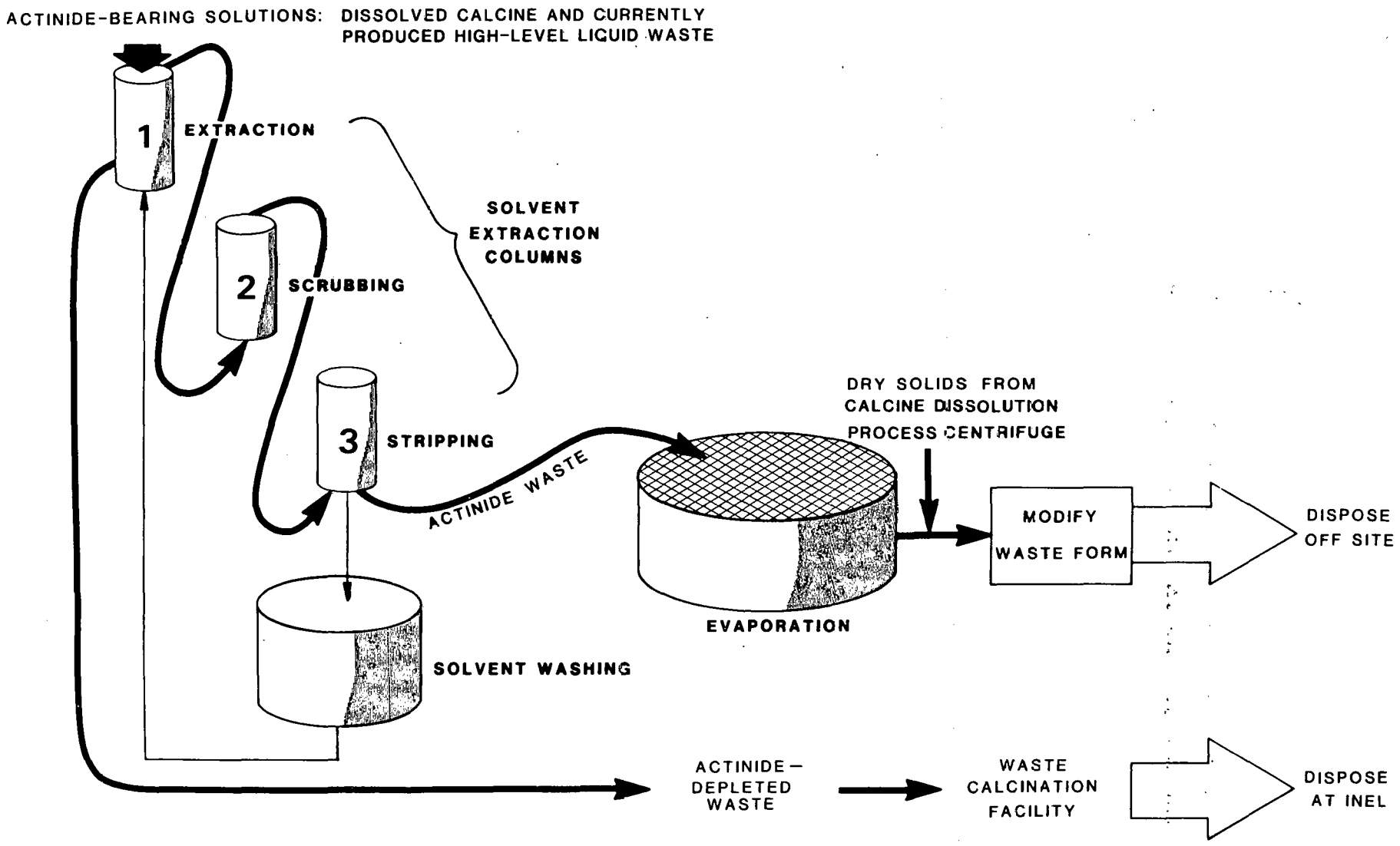


Figure 2-12. Actinide Solvent Extraction Process

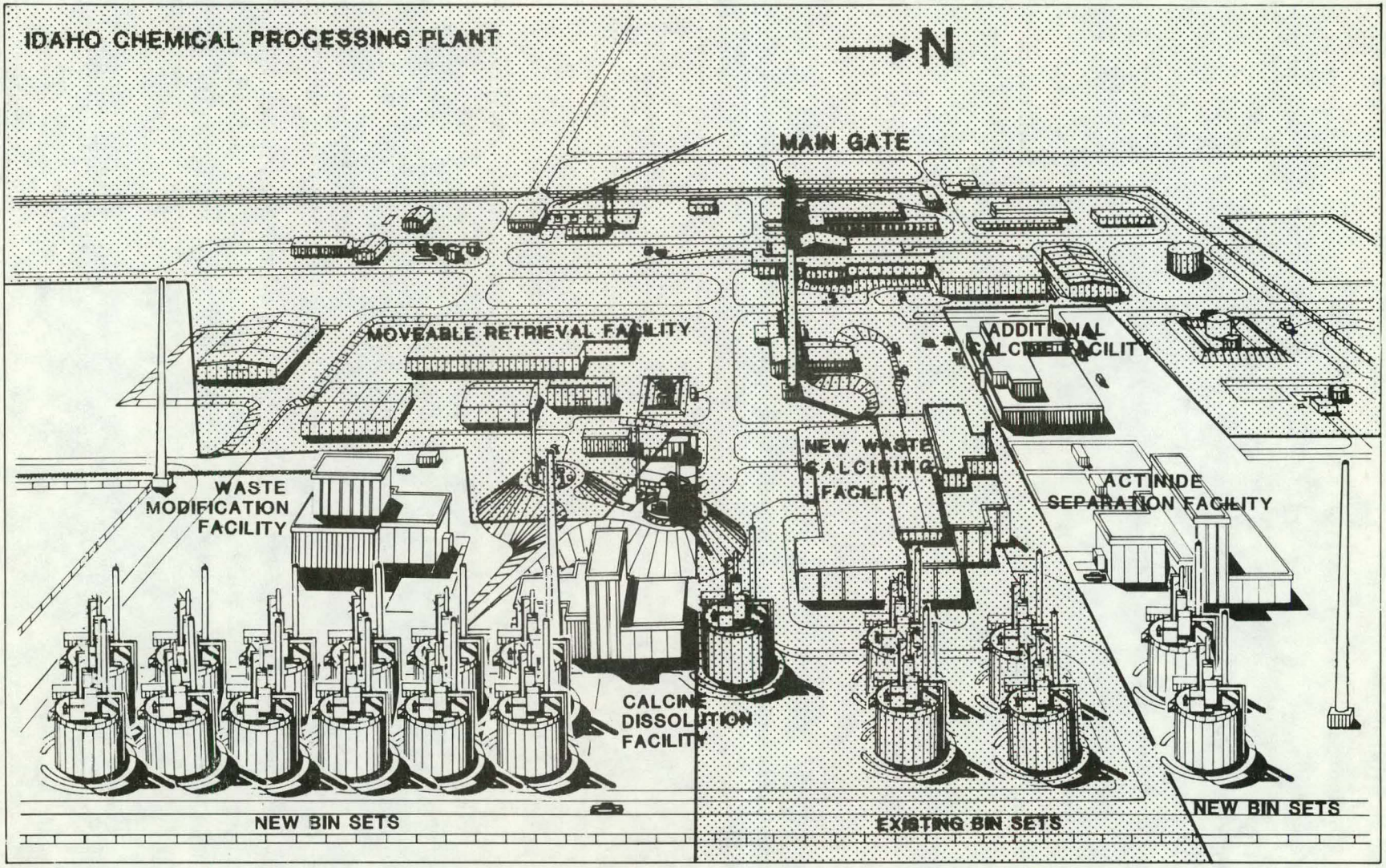


Figure 2-13. Facilities for Alternative 4 (Retrieve, Separate the Actinides, Dispose of Actinides Offsite, and Dispose of Depleted Calcine at the INEL)

The proposed location for the calcine dissolution building would be approximately 70 feet east of the third calcine storage vault. The building would be 74 feet wide and 112 feet long at its extreme outside dimensions. The building would be a two- and three-story, reinforced concrete-mat-foundation structure designed to withstand any credible natural phenomenon, including earthquakes and tornadoes (ERDAM, 1977). The concrete roof slab over the cells would be supported by hollow precast box girders.

The cell system has an operating corridor on one side and the offgas treatment system on the opposite side. The two ends are part of the outside wall. All ventilation air flow would be from an area of lower potential contamination to an area of higher potential contamination.

The calcine dissolution building would also include a control room, offices, an air conditioning system, electrical switchgear, Halon fire extinguishing system, a process maintenance area, loft crane, decontamination facilities, and canister receiving-shipping bay. Transport of waste between the calcine dissolution and actinide separation buildings would be by enclosed pipeline. The cells would be lined with stainless steel. Both the process cells and the decontamination cell would be equipped with hot sumps and drains.

The actinide separation building would be located approximately 125 feet north of the northeast corner of the new waste calcining facility. The building containing the hot cells, where the actinide separation process would be located, would be 84 feet wide and 100 feet long. The building would include administrative offices, a control room, locker room, and health physics facilities. The area above the cells would extend approximately four stories upward and the rest of the building would be a two-story structure. The building would be a reinforced concrete-mat-foundation structure designed to withstand any credible natural phenomenon, including earthquakes and tornadoes (ERDAM, 1977). The concrete roof slab over the cells would be supported by hollow precast box girders.

The cell system would have an operating corridor on one long side and the offgas treatment system on the opposite side. The two short ends of the

building would be part of the outside wall. All ventilation air flow would be from an area of lower potential contamination to an area of higher potential contamination.

The actinide separation building would also include an air conditioning system, electrical switchgear, Halon fire extinguishing system, a process maintenance area, loft crane, and decontamination facilities. The cells would be lined with stainless steel. Both the process cells and the decontamination cell would be equipped with hot sumps and drains.

A separate calcination facility would be required to process the actinide-depleted waste. This calcination facility, located approximately 100 feet northwest of the new waste calcining facility, would be similar to the present waste calcining facility building and would be constructed to accommodate the increased waste volume requiring calcination.

All offgas and ventilation air from the retrieval and processing facilities would pass through a treatment system as discussed in Subsection 2.3.2.4.

2.3.4.3 Status of Technology

Actinide separation has been achieved in laboratory and pilot scale tests (Maxey, 1980). Preliminary calcine dissolution laboratory tests indicate that about 98 percent of the solid zirconium calcine and 99 percent of the plutonium present can be dissolved in nitric acid. Large-scale experiments are needed to verify and improve upon the preliminary results. The use of the organic solvent DHD has been verified on a laboratory scale (Maxey, 1980).

The status of vitrification technology is discussed in Subsection 2.3.2.5.

2.3.4.4 Decontamination and Decommissioning

For Alternative 4, D&D would be required for the calcine retrieval and transport system, the calcine dissolution facility, the actinide separation

facility, a supplemental actinide-depleted waste calcining facility, and a waste form modification facility. Typical D&D operations are described in Subsection 2.3.2.6.

2.3.4.5 Disposal

Both onsite and offsite disposal would be required to implement Alternative 4. The vitrified actinides would be approximately 2 percent of the original volume of calcine and less than 1 percent of the volume of calcine produced from uncalcined defense high-level liquid waste. The reduced volume of actinides would be shipped to a federal geologic repository for disposal. Less than 1 acre of space would be required in the repository. The remaining actinide-depleted waste, approximately 110 percent of the original calcine volume, would be disposed at the ICPP. In addition to the 8 original calcine storage bin sets, 14 new bin sets would be required.

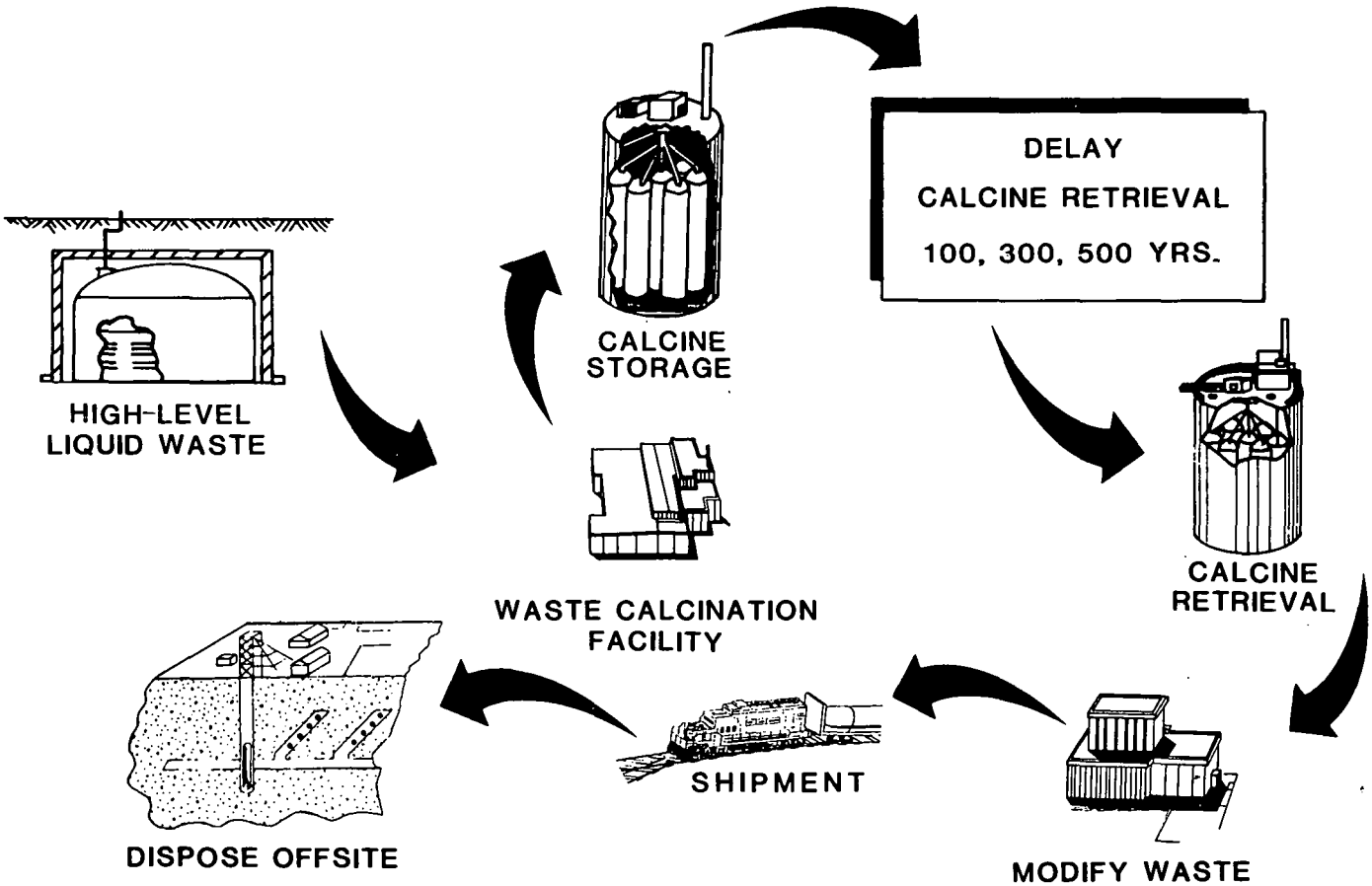
2.3.4.6 Future Decisions

If actinide separation (Alternative 4) is selected as the waste management strategy for ICPP-generated calcine, other decisions will be required in the future. These decisions will include the choice of waste form for the actinide fraction, the process required to produce the waste form, and the mode and route for waste shipment. In addition, decisions on the design and location of an offsite federal geologic repository will be required. These decisions will be based on future environmental reviews.

2.3.5 Delay Retrieval, Modify the Calcine, and Dispose Offsite - Alternative 5

The processing steps required to implement Alternative 5 are shown in the illustration on next page.

The illustration shows that in Alternative 5, processing of high-level liquid waste in the waste calcination facility and the storage of the calcine product in stainless steel bins would be completed at the ICPP as in Alternative 1. After a delay period of 100, 300, or 500 years, the calcine would be retrieved, the waste modified, and shipped offsite for disposal.



The processing required to implement Alternative 5 is the same as that for Alternative 3 (Subsection 2.3.3). The waste form is assumed to be glass. Calcine retrieval from the storage bins would be delayed for either 100, 300, or 500 years. The purpose of the delay is to permit decay of the short-lived radionuclides and thereby simplify waste treatment and handling procedures. In Alternative 5, retrieval is assumed to begin either in the year 2090, 2290, or 2490. Institutional control is assumed during the interim storage period in order to effectively evaluate the consequences of delayed retrieval. Should institutional control cease during the delay period, Alternative 5 would be equivalent to Alternative 1. For Alternative 1, the lifetime of the bins has been conservatively estimated to be 500 years which is consistent with the maximum 500-year delay period assumed for the purposes of this evaluation.

This alternative has several advantages. Time would be allowed for development of new and perhaps better technology. The reduced future radiation

levels could allow the construction of less expensive processing facilities and reduce the requirements for remote handling techniques. Less shielding of the shipping canisters would be required, thereby reducing shipping costs. Because of the decrease in heat generated during the decay process, far less space would be required for the disposal of the canisters and repository costs could be reduced. However, the waste storage area at the ICPP would be as large as the area required for Alternative 1. Delaying waste retrieval would allow the same chance for intrusion into the waste as for Alternative 1 should institutional control cease.

Although periods of 100 to 500 years were evaluated as limiting cases for the delay alternative, significantly shorter delay periods may have advantages. Delay for 10 to 20 years, for example, would allow improvement in status of waste form development and could allow waste forms to be selected which would minimize potential waste form/rock interactions in the geologic repository.

2.3.5.1 Calcine Retrieval

The calcine retrieval process would be the same as described in Subsection 2.3.2.1.

2.3.5.2 Calcine Vitrification

The calcine vitrification process is described in Subsection 2.3.2.3.

2.3.5.3 Facility Description

The calcine retrieval facility is described in Subsection 2.3.2.1; the vitrification facility is described in Subsection 2.3.2.4. An artist's description of the facilities required to implement Alternative 5 is shown in Figure 2-14.

2.3.5.4 Status of Technology

The status of the technology for calcine retrieval and vitrification is discussed in Subsection 2.3.2.5.

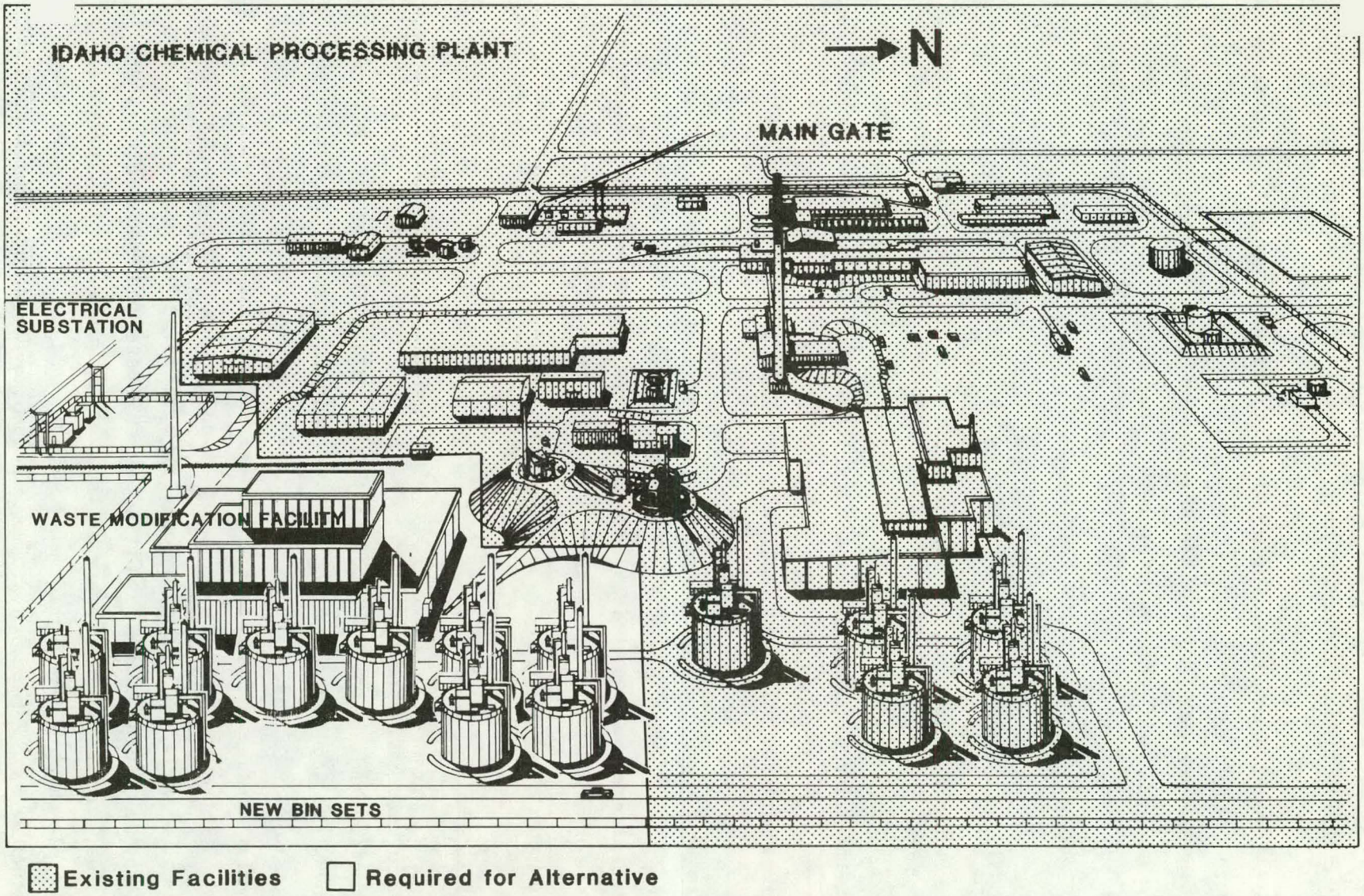


Figure 2-14. Facilities for Alternative 5 (Delay Retrieval, Modify the Calcine, and Dispose Offsite)

2.3.5.5 Decontamination and Decommissioning

For Alternative 5, decommissioning of the storage vaults would be accomplished prior to delayed retrieval by encapsulating the bins within each vault as described in Subsection 2.3.1.1. Decontamination and decommissioning of the calcine retrieval and transport systems, the waste form modification facility, and the empty calcine storage bins would be required. Typical D&D operations are discussed in Subsection 2.3.2.6

2.3.5.6 Disposal

Disposal would be in a federal geologic repository as discussed in Subsection 2.3.3.7. The area required for disposal within the repository is dependent primarily on the heat generated by the waste. Consequently, less than 20 acres would be required after a delay of 100 years; less than 1 acre would be required after delays of 300 and 500 years.

2.3.5.7 Future Decisions

Future decisions required if delayed retrieval (Alternative 5) is selected as the waste management strategy for ICPP-generated calcine are discussed in Subsection 2.3.3.8.

2.4 Mitigative Measures

Appropriate mitigative measures for each alternative would be taken during construction and operation. Corrective or mitigating action is frequently taken to reduce environmental effects and maintain as low radiation levels as possible. Mitigative measures taken during construction would generally involve special procedures such as erosion control techniques. Most measures taken during the operations and D&D phases would involve special design provisions such as pollution control systems. The application of mitigative measures would ensure compliance with state and federal regulations, standards, and licensing requirements. Environmental monitoring would be conducted to evaluate the performance of the mitigative measures used during construction and operation. Monitoring procedures are discussed in Subsection 3.5.

2.4.1 Construction Phase

During construction, air quality effects would be minimized by using dust suppressants in appropriate areas, limiting the disturbance of vegetative cover to those areas necessary for the construction of facilities, and using erosion control and restorative procedures to minimize wind-generated dust. Wastewater would be treated before discharge. Potential surface erosion from runoff water would be minimized by restoring the disturbed area through approved erosion-control techniques. All sites (not committed for facilities) disturbed by construction activities would be restored to their natural state where possible.

Routine hazards to construction workers would be minimized by adherence to the regulations of the Occupational Safety and Health Administration and other construction safety regulations.

The INEL operating procedures prescribe measures for ensuring the protection of antiquities and historic sites as required by federal and state regulations. The regulations require, at a minimum, site reconnaissance before construction to determine the presence of antiquities. During construction, a qualified archaeologist would be on call to evaluate any unforeseen finds.

2.4.2 Operations Phase

Maintenance and surveillance would be continued during the operations phase of the leave-in-place alternative. Monitoring would indicate whether additional mitigative measures for waste confinement are needed.

Many mitigative measures would be used in implementing the waste-processing alternatives. Adverse environmental effects would be minimized by adherence to all applicable federal and state regulations. Air pollution and releases of radionuclides would be controlled by using state-of-the-art technology in the offgas treatment and ventilation systems. Environmental monitoring would be conducted to detect any radiological and nonradiological effects of operations and D&D activities. Facilities and equipment would be

designed to facilitate D&D activities. Restoration and rehabilitation, during and after D&D activities, would help mitigate potentially adverse effects. To minimize fossil fuel consumption, alternative energy sources would be used where feasible. State-of-the-art technology would ensure maximum energy efficiency.

All nonradioactive solid waste would be disposed at the INEL site in sanitary landfills operated in compliance with all applicable federal and state regulations. Low-level solid waste would be sent to the Radioactive Waste Management Complex for disposal.

During shipment, special design provisions would reduce the radiation levels from the beta- and gamma-emitting waste below the limits specified in shipping regulations.

2.4.3 Disposal Phase

Impacts of disposal at the INEL would be mitigated by careful facility design and monitoring procedures. Waste stored or disposed at the INEL would be in near-surface facilities. Institutional control is assumed to cease in the year 2100. Prior to this time, as a preventive measure, the space between the bins and vaults would be filled with a concrete-like substance. The mitigative measures employed to reduce the environmental effects at the offsite federal repository are discussed in the Environmental Impact Statement for Commercially Generated Radioactive Waste (Section 6.2, DOE, 1980b).

The probability of waste containment failure at a geologic repository would be minimized by careful design, thorough assessment of repository performance, and provision of redundant systems. A form of corrective action is the proposed requirement that waste containers be retrievable for 50 years following termination of waste emplacement operations. Following repository closure, remote instrumentation could be installed to detect unexpectedly high radionuclide concentrations. Should system failure occur, mitigating actions could include restricting public access to contaminated aquifers and evacuation of affected areas.

2.5 Comparison of Alternatives

2.5.1 Approach

The purpose of this subsection is to compare the effects of each alternative. Throughout this subsection an effort is made to measure any effects resulting from the proposed alternatives against certain recognized standards and measures, such as federal and state pollutant standards, existing background levels of contaminants, and commonly recognized health effects.

Many of the radiological calculations in this document are based on assumptions and scenarios that only approximate what might happen in a specific situation. For instance, the fraction of a spill that becomes airborne, the actual stability of the atmosphere at the time of release, the wind direction, and the time a person remains within a region where a radionuclide release has occurred are all approximated. To compensate for the lack of precise data, health effect calculations are based on conservative upper-limit models to ensure that a predicted consequence will not be understated.

Environmental trade-offs are discussed in several approaches to comparing alternatives. One approach is to compare the effects that are certain to occur. No matter which alternative is selected, certain effects, such as construction impacts and resource commitments, will definitely occur. The magnitude of these effects may differ very little from alternative to alternative, or differences between alternatives may be significant.

In addition, regardless of which alternative is chosen, incidents which could potentially occur are inherent in each alternative. These events have varying probabilities of occurrence and include a severe geologic disturbance (with an extremely low probability of occurrence) and an aircraft impact at the INEL. These uncertain effects are compared by analysis of their occurrence probabilities so that uncertain effects can be compared quantitatively to effects of events that are certain to occur.

A second way to evaluate the wide range of effects of each alternative is to examine the impacts on this generation compared to the impacts on future generations. For example, the risk to workers of retrieving and modifying the calcine in the near future, while the calcine is still very radioactive, is weighed against the smaller risk to workers and the population of delaying retrieval until the calcine has had up to 500 years to decay.

A third way to consider the effects of each alternative is to examine the trade-offs of effects as they relate to individuals, populations, and workers. For example, the leave-in-place alternative (Alternative 1) would affect workers least because it requires the least handling of the waste. However, the leave-in-place alternative presents a greater risk to the public than some other alternatives because of the potential contamination of the Snake River Plain Aquifer or potential dispersal of the waste by a severe geologic disruption.

Tables 2-1 through 2-9 compare the environmental and other effects of the candidate waste management alternatives. The effects have been compiled from those discussed in Section 4. Footnotes to the tables provide clarifying information for the selected entries. Information is presented so that direct comparisons can be made among the alternatives in relative terms.

From among the many projected consequences identified in Section 4, only those judged most pertinent to the decisionmaking process are discussed in the comparative study in this subsection. Many of the effects that were evaluated in Section 4 are not included in the tables in this section because the effects are the same for each alternative or the differences among the alternatives are very small. In some cases, an effect, such as hydrocarbon emissions during construction, is not included because it is not significant. (All emissions during construction would be below the detection limits of the instruments used to determine their concentrations.) However, minor effects have been included in the comparative study if they are the most significant in the categories of environmental impacts that were evaluated.

Some effects of implementing the alternatives can be estimated and compared quantitatively. Examples are radiological emissions, the number of

worker injuries from industrial accidents, and costs. Some of the quantifiable effects are certain to occur, either in the short term (up to 100 years) or in the long term (beyond 100 years). Other effects are not certain to occur. Where feasible, occurrence probabilities are cited. The short-term effects from events certain to occur are discussed for each phase of the project (construction, routine operations, D&D, and disposal) so that alternatives may be compared in relative terms for each phase.

Some effects cannot be quantified but are nonetheless important. An example is the reversibility of a waste management action. For each alternative, a qualitative assessment of the difficult-to-quantify factors is given in order to provide a clear rationale for the selection of the environmentally preferred alternative.

No alternative is without some negative effects. The certain effects in the short and long terms are compared with the risks of the uncertain effects which may be caused by events that have different probabilities of occurrence.

2.5.2 Short-Term Effects

Short-term effects are defined as the effects that would occur during the period of institutional control. Institutional control is assumed to continue until 2100, which is consistent with the Environmental Protection Agency's proposed radioactive waste management criteria (EPA, 1978). In order to evaluate the effects of radionuclide decay in Alternative 5, institutional control is assumed to continue for 100, 300, or 500 years.

2.5.2.1 Short-Term Effects of Events Certain to Occur

Certain short-term environmental and other effects will occur when various alternatives are implemented. These obvious effects include energy consumption by construction equipment and waste modification operations. They also include routine exposure of workers to radiation during waste handling procedures. Other short-term impacts, such as the dispersal of radioactive contaminants as a result of an aircraft impact at the INEL, may never occur.

Short-term effects of events that are certain to occur are identified in this subsection to differentiate them from other effects which may never occur. The effects considered in this subsection have occurrence probabilities that indicate they can be expected to occur during the 30-year operating period or during the 100-year short-term period.

Worker injuries and fatalities and hypothetical accidents postulated to occur in the short term are presented in Tables 2-1, 2-2, and 2-3. Even though these effects would not occur routinely and perhaps not at all, they were selected for analysis because they are the worst effects that could be postulated to occur.

2.5.2.1.1 Short-Term Effects of Events Certain to Occur During the Construction Phase

The effects created during the construction phase do not differ significantly from alternative to alternative. Effects are similar to the nonradiological effects created during the other phases of alternative implementation. Airborne emissions and wastewater discharges are not significant when compared with applicable standards.

Compared effects are shown in Table 2-1. The effects reported are the most significant of the effects evaluated. Effects of other air contaminants and effects on water and land use are discussed in Section 4.

Alternative 1 would create the fewest short-term effects because it requires the least additional construction activity. Alternative 4 would require the greatest number of processing facilities, the largest construction work force, and the longest period for construction. Thus, the most diesel fuel consumption and the largest socioeconomic impact on surrounding communities during the construction phase would occur in Alternative 4. However, the maximum number of construction workers (about 600) is within the routine fluctuation of the INEL construction work force. Consequently, the socioeconomic impacts of the maximum construction work force have already been accommodated by local community infrastructures. The maximum diesel fuel use

TABLE 2-1

SUMMARY OF SHORT-TERM EFFECTS CERTAIN TO OCCUR CONSTRUCTION PHASE[a]

Alternative	Particulate Concentration ($\mu g/m^3$) Above Background[b]	Additional Manpower (Man-Yr)	Diesel Fuel Use (10^3 Gal)	Worker Injuries/ Fatalities
1. Leave-in-Place	0.04	800	375	17/0.2
2. Retrieve, Modify Calcine, Dispose at the INEL				
Pelletize Calcine	0.07	2,000	275	51/0.5
Convert Calcine to Glass	0.07	1,000	575	23/0.2
3. Retrieve, Modify Calcine, Dispose Offsite				
Stabilize Calcine	0.04	1,300	875	55/1
Convert Calcine to Glass	0.04	1,300	940	55/1
4. Retrieve, Separate Actinides, Dispose of Actinides Offsite, Dispose of Depleted Calcine at the INEL	0.20	2,755	1,115	78.2/0.8
5. Delay Retrieval, Modify Calcine, Dispose Offsite				
100 Years	0.04	1,110	445	15/0.2
300 Years	0.04	1,005	395	11.2/0.1
500 Years	0.04	1,005	395	11.2/0.1

a. Includes effects at the repository.

b. The national ambient air quality standard is 60 $\mu g/m^3$ (40 CFR 50) which is often exceeded by blowing dust and agricultural activities in the area.

would be about 65 percent of the diesel fuel used at the INEL in 1978. The maximum fuel use during construction would heat 2,230 homes in Idaho Falls during one winter. Impacts on air quality would be undetectable. The INEL is located in a Class II area that is in compliance with all applicable ambient air quality standards. In conclusion, there are no significant short-term environmental effects from the construction phase.

2.5.2.1.2 Short-Term Effects of Events Certain to Occur During the Routine Operations Phase

Depending on the waste management alternative selected, routine operations could include waste calcination, storage, retrieval, modification, actinide separation, and disposal at the INEL or at an offsite geologic repository. These operations require transport of calcine, modified calcine, and products of the actinide separation process from one facility to another and shipment from the INEL to an offsite repository.

In the course of these operations, releases of radiological and nonradiological pollutants would routinely occur to the atmosphere, soil, and water in stack emissions, waste water, and solid waste. Heat discharges would also occur. Releases from routine operations both at the ICPP and during waste shipment would comply with all applicable state and federal standards. Maximum worker doses from radiological exposure would be controlled under a strict radiation control program and would be within occupational exposure limits. Releases that could result from accidents at the ICPP, such as a calcine spill or decontamination solution spill or a canister drop at the federal repository, would not cause exposure limits to be exceeded.

Short-term effects of routine operations and waste shipment are summarized in Table 2-2. Effects included in the table were selected for comparison in this section because they are the most representative of the potential environmental effects.

Effects of current calcining operations are not included in Table 2-2 because each alternative is assumed to begin with calcined waste, and the effects would be the same for each alternative. The following brief summary

TABLE 2-2

SUMMARY OF SHORT-TERM EFFECTS
CERTAIN TO OCCUR IN THE OPERATIONS PHASE

Alternative	Energy Demand (mW)	Additional Labor Force (Man-Years)[a]	NO_2 Conc. Above Background[b] ($\mu g/m^3$)	Operations and Waste Shipment Cost[c] ($\$10^6$)	Operations Worker Injuries/ Fatalities	Waste Shipment Worker Injuries/ Fatalities	Radiation Dose to Workers (Man-Rem)[a]	Population Health Effects (Deaths) From Operations[d]	From Background Radiation	From All Causes of Cancer
1. Leave-in-Place	0	0	0	NA	0.4/0.001	NA	0	NA	3-7	33,400
2. Retrieve, Modify Calcine, Dispose at the INEL										
Pelletize Calcine	1.45	800	1.0	1.5	20/0.07	NA	800	1.79×10^{-6} to 5.49×10^{-6}	3-7	33,400
Convert Calcine to Glass	1.15	1,250	0.44	50.5	31/0.1	NA	1,250	1.79×10^{-6} to 5.49×10^{-6}	3-7	33,400
3. Retrieve, Modify Calcine, Dispose Offsite										
Stabilize Calcine	0.57	5,050	0.40	299	24/0.9	4/0.3	1,220	1.78×10^{-2} to 5.46×10^{-2}	4-12	54,400
Convert Calcine to Glass	1.15	5,200	0.44	709	28/0.1	5/0.4	1,370	2.72×10^{-2} to 8.34×10^{-2}	4-12	54,400
4. Retrieve, Separate Actinides, Dispose of Actinides Offsite, Dispose of Depleted Calcine at the INEL	1.60	4,410	2.3	127	44/0.2	0.2/0.01	1,727	9.37×10^{-4} to 2.87×10^{-3}	4-12	54,400
5. Delay Retrieval, Modify Calcine, Dispose Offsite										
100 Years	1.15	4,340	0.44	709	37/0.14	5/0.4	885	3.67×10^{-2} to 1.03×10^{-1}	9-26	127,000
300 Years	1.15	4,210	0.44	709	37/0.14	5/0.4	531	3.67×10^{-2} to 1.13×10^{-1}	11-32	151,000
500 Years	1.15	4,210	0.44	709	37/0.14	5/0.4	177	3.67×10^{-2} to 1.13×10^{-1}	11-32	151,000

a. Includes additional labor force for operations at ICPP, waste shipment, and operations at the repository.

b. The national ambient air quality standard for nitrogen oxides is 100 $\mu g/m^3$ (40 CFR 50).

c. Costs (1980 dollars) are reported for materials, canisters, and freight charges.

d. Population affected includes those people residing within 50-mile radius of the ICPP and along the waste shipment route; workers are not included. Based on 50-year dose commitment from 1 year of exposure in 1990 for Alternatives 1, 2, 3, and 4; for Alternative 5, in the years 2090, 2290, 2490.

is provided for the reader's information and is based on past operating experience. Current ICPP operations result in emissions of nitrogen oxides and carbon monoxide. However, calculated increases in ambient air concentrations are below instrument detection limits. The calculated average annual increase in nitrogen oxides concentration is 0.80 micrograms per cubic meter and the calculated average hourly increase in carbon monoxide concentration is 0.42 micrograms per cubic meter. Water use at the ICPP is 1000 gallons per minute. The maximum energy demand at the ICPP has been 4.3 megawatts, which is equivalent to the electrical demand of 675 households.

About 500 employees are exposed to radiation as a result of all ICPP activities which results in an annual whole-body equivalent dose that ranges from 375 to 650 man-rem. Each worker receives an average annual dose of 1 rem. The population (165,000) within 50 miles of the ICPP receives an annual whole-body equivalent dose of about 0.005 man-rem from ICPP activities. This is an extremely low dose compared to the annual dose received from background radiation of 24,750 man-rem. It is estimated that a population dose of 0.005 man-rem per year would cause 3.8×10^{-7} to 1.2×10^{-6} health effects in the exposed population.

As seen in Table 2-2, short-term operational effects for Alternative 1 are zero because they are included in the effects of current ICPP activities discussed above. Beside the comparatively small differences in radiological exposures to workers in alternatives involving calcine processing, the main difference in effects among alternatives during the operations phase is created by shipment of the waste offsite to a federal repository.

Alternatives 3 and 5, which involve waste shipment, would cause the highest population exposures to radiation. In Alternative 5, the increased population along the shipment route would cause the population dose commitments to be higher than in Alternative 3, even though the waste has had a longer period to decay.

Alternative 4 would cause the most energy use, socioeconomic, and nonradiological effects during operations because actinide separation requires the most processing facilities, the largest permanent operating work force,

and the longest period of time to accomplish. However, the nonradiological effects are not significant when compared to applicable standards or background pollutant levels. Both onsite and offsite disposal are required.

Alternative 4 would require fewer waste shipments because the actinide fraction is only a small percentage of the total waste. Fewer shipments would result in lower population exposures than in Alternatives 3 and 5. Actinide separation would require less disposal space in the repository with the exception of retrieval delayed 300 to 500 years.

Alternative 5 would postpone the effects of Alternative 3 for 100, 300, or 500 years. Doses to workers would be diminished because radioactivity would have decreased during the decay process. Delaying retrieval 300 or 500 years would allow radioactive decay to significantly reduce space requirements in a repository.

For all alternatives, routine radiological and nonradiological airborne emissions, waste water effluents, solid waste, and heat discharges would be insignificant compared to state and federal standards.

2.5.2.1.3 Short-Term Effects of Events Certain to Occur During the Decontamination and Decommissioning Phase

All waste processing facilities would require decontamination and decommissioning (D&D). The technology is generally available to adequately accomplish D&D. The facilities would be designed to facilitate D&D and effects would be minor. Quantifiable effects would be about 1 percent of the effects from routine operations and thus are not significant. Encapsulation of the bins (Alternative 1) is assumed to have no environmental impact. Actinide separation (Alternative 4) would require the greatest amount of D&D due to the greater number of facilities, and thus would create the greatest radiological exposure to workers and the population; however, the magnitude of even this exposure is not significant. A summary of short-term effects certain to occur during D&D is given in Table 2-3.

TABLE 2-3

SUMMARY OF SHORT-TERM EFFECTS CERTAIN TO OCCUR DURING DECONTAMINATION AND DECOMMISSIONING PHASE[a]

Alternative	Worker Dose (Man-Rem)	Workers Exposed (Number)	Population Health Effects (Deaths) From D&D[b]	Population Health Effects (Deaths) From Background Radiation	Population Health Effects (Deaths) From All Causes of Cancer	D&D Phase Worker Injuries/ Fatalities
1. Leave-in-Place	0	0	0	4-11	50,900	0.5/0.006
2. Retrieve, Modify Calcine, Dispose at the INEL						
Pelletize Calcine	25	13	9.63×10^{-9} to 2.95×10^{-8}	4-11	50,900	0.8/0.009
Convert Calcine to Glass	50	25	9.63×10^{-9} to 2.95×10^{-8}	4-11	50,900	2/0.02
3. Retrieve, Modify Calcine, Dispose Offsite						
Stabilize Calcine	50	25	2.29×10^{-11} to 7.02×10^{-11}	4-11	50,900	2/0.02
Convert Calcine to Glass	50	25	9.63×10^{-9} to 2.95×10^{-8}	4-11	50,900	2/0.02
4. Retrieve, Separate Actinides, Dispose of Actinides Offsite, Dispose of Depleted Calcine at the INEL	75	38	2.76×10^{-11} to 8.47×10^{-11}	4-11	50,900	3/0.03
5. Delay Retrieval, Modify Calcine, Dispose Offsite						
100 Years	30	30	3.18×10^{-12} to 9.75×10^{-12}	8-23	109,200	2/0.02
300 Years	18	30	1.68×10^{-13} to 5.15×10^{-13}	8-23	109,200	2/0.02
500 Years	6	30	8.33×10^{-14} to 2.55×10^{-13}	8-23	109,200	2/0.02

a. Decontamination and decommissioning are assumed to require 2 years.

b. Population affected is within 50-mile radius of the ICPP; workers are not included. Based on 50-year dose commitment from 1 year of exposure in 2020.

2.5.2.1.4 Short-Term Effects of Events Certain to Occur During the Disposal Phase

The activities required to construct waste disposal facilities and to place the waste in those facilities are covered in Subsections 2.5.2.1.1 through 2.5.2.1.3. For the short term, there are no events which are certain to occur after the waste is placed in the disposal facility. Abnormal events which may occur are discussed below.

2.5.2.2 Short-Term Effects of Abnormal Events

Unlike events that are certain to occur, abnormal events have only the potential to occur. Thus, in the evaluation of the alternatives and the selection of a preferred alternative, it must be taken into account that abnormal events have a very low probability of occurrence.

Accidents postulated to occur from routine operations would cause effects that would be indistinguishable from the effects of background radiation (Table 2-4). Events analyzed include an extraction solvent fire, an accident during waste shipment, and a canister drop during disposal operations at the federal repository.

The most significant effect would result from an aircraft impact at the INEL disposal site. The probability of this occurrence is once in 5 million years. The aircraft impact at the INEL would result in about 10 times the health effects caused by background radiation, but the health effects would be so small that they would be indistinguishable from the health effects from all causes estimated to occur in the population surrounding the INEL.

Effects from an accident during waste shipment would be the most significant operational accident. The probability of this occurrence is very low (7×10^{-8} event per year). Individuals at the accident scene and the population in the area would receive a dose commitment of about 10 rem (Alternatives 3 and 4). A waste shipment accident that resulted in release of radionuclides would have the highest probability of occurrence in

TABLE 2-4

SUMMARY OF SHORT-TERM ABNORMAL EFFECTS (ACCIDENTS)[a]

Alternative	Operations: Population Health Effects[c] (Deaths)	Waste Shipment: Population Health Effects[d] (Deaths)	Disposal Phase: Population Health Effects[e] (Deaths)	Population Health Effects (Deaths): From Background Radiation[f]	Population Health Effects (Deaths): From All Causes of Cancer
1. Leave-in-Place	5.54 to 1.7×10^{1}	NA	5.54 to 17	2 to 4	18,000
2. Retrieve, Modify Calcine, Dispose at the INEL					
Pelletize Calcine	5.54 to 1.7×10^{-1}	NA	5.54 to 17	2 to 4	18,000
Convert Calcine to Glass	5.54 to 1.7×10^{-1}	NA	5.54 to 17	2 to 4	18,000
3. Retrieve, Modify Calcine, Dispose Offsite					
Stabilize Calcine	5.54 to 1.7×10^{-1}	3.67×10^{-1} to 1.12	5.54 to 17	2to 4	18,000
Convert Calcine to Glass	5.54 to 1.7×10^{-1}	4.76×10^{-3} to 1.46×10^{-2}	5.54 to 17	2 to 4	18,000
4. Retrieve, Separate Actinides, Dispose of Actinides Offsite, Dispose of Depleted Calcine at the INEL	5.54 to 1.7×10^{-1}	3.75×10^{-1} to 1.15	5.54 to 17	2 to 4	18,000
5. Delay Retrieval, Modify Calcine, Dispose Offsite					
100 Years	6.22 to 1.9×10^{-1}	1.54×10^{-3} to 4.73×10^{-3}	6.22 to 19.1	3 to 8	38,600
300 Years	2.06 to 6.32×10^{-1}	4.27×10^{-4} to 1.31×10^{-3}	2.06 to 6.32	3 to 8	38,600
500 Years	3.04 to 9.90×10^{-1}	2.05×10^{-4} to 6.29×10^{-4}	0.99 to 3.04	3 to 8	38,600

a. Based on 50-year dose commitment from 1 year of exposure and the event with the highest probability of occurrence.

b. Includes effects at the repository.

c. Effects listed are for aircraft impact scenario (Table 4-20) in year 1990 (Alternatives 1, 2, and 3) and in 2090, 2290, and 2440 (Alternative 5) (Table 4-20) which has a probability of 2×10^{-1}. For Alternative 4, the effects are from an extraction solvent fire in 2020 (Table 4-17) which has a probability of 1×10^{2}.

d. Effects listed are for waste shipment accident in 1990-2000 (Table 4-18) which has a probabililty of 7×10^{-8} for Alternative 4.

e. Effects listed are for aircraft impact scenario in year 1990 (Table 4-20) which has a probability of 2×10^{-7}.

f. Health effects (cancer deaths) from background radiation and all causes of cancer are based on the population in the 50-mile radius of the INEL: 107,000 in 1990, and 230,000 in 2100, 2300, and 2500.

Alternative 3 because of the greater number of waste shipments. The mobility of the waste form would affect the amount of radioactive material that would become airborne. Thus, the calculated doses from vitrified calcine are about one one-hundredth of the doses from stabilized calcine.

2.5.3 Long-Term Effects

Long-term effects are defined as effects that would occur after the 100-year period of institutional control. In Alternative 5, the long-term period is defined as beginning after the 500-year period during which disposal has been delayed.

2.5.3.1 Long-Term Effects of Events Certain to Occur

In this subsection, the most significant radiological and nonradiological long-term effects of events certain to occur are evaluated and compared in summary form by examination of the scenario which gives the maximum effects. The effects considered in this subsection have occurrence probabilities that indicate they can be expected to occur in less than 1 million years.

The long-term effects of events certain to occur apply only to waste disposal at the INEL. Disposal at the offsite federal geologic repository (Alternatives 3, 4, and 5) would create no inevitable long-term effects because this repository will provide isolation of the waste in deep geologic formations for which there is only the potential, not certainty, for entry into the biosphere. In Section 4, the parameters are discussed in detail for living over the waste, intrusion into the waste, and living at the site contaminated by previous intruders. These scenarios are compared in this subsection and summarized in Table 2-5. This analysis is provided because, although the probability that these events will occur is difficult to predict, they could occur at some time during the long-term period.

The effects of radon gas on members of future generations who might move onto the INEL after institutional control has ceased are evaluated in the living-over-the-waste scenario. The effects of radon are caused by inhalation of radon trapped in buildings. Since radon exposure would be limited to

TABLE 2-5

SUMMARY OF LONG-TERM EFFECTS CERTAIN TO OCCUR[a]

Alternative and Scenario	Probability of Occurrence (Event/Year)	Population Exposed[b]	Maximum Individual Dose (Rem)	Population Dose (Man-Rem)[b]	Population Health Effects (Deaths) From Radiation[b]	From Cadmium[b]	From Mercury[b]	From Background Radiation[c]	From All Causes of Cancer
1. Leave-in-Place									
Intrusion into Waste	1×10^{-2}	10	43.8	4.38×10^{2}	3.28×10^{-2} to 1.01×10^{-1}	NA[d]	NA	0.0001-0.0004	2
Living at Contaminated Site	1×10^{-2}	5	5.31×10^{1}	2.65×10^{2}	1.99×10^{-2} to 6.11×10^{-2}	NA	NA	0.00006-0.0002	1
Living Over Waste	1.0×10^{-2}	5	1.10×10^{-1}	5.50×10^{-1}	4.12×10^{-5} to 1.26×10^{-4}	NA	NA	0.00006-0.0002	1
2. Retrieve, Modify Calcine, Dispose at the INEL									
Pelletize Calcine									
Intrusion into Waste	1×10^{-2}	10	1.05×10^{1}	1.05×10^{2}	7.87×10^{-3} to 2.41×10^{-2}	NA	NA	0.0001-0.0004	2
Living at Contaminated Site	1×10^{-2}	5	8.08	4.04×10^{1}	3.03×10^{-3} to 9.29×10^{-3}	NA	NA	0.00006-0.0002	1
Living Over Waste	1.0×10^{-2}	5	9.20×10^{-2}	4.60×10^{-1}	3.45×10^{-5} to 1.06×10^{-4}	NA	NA	0.00006-0.0002	1
Convert Calcine to Glass									
Intrusion into Waste	1×10^{-2}	10	6.80×10^{-1}	6.80	5.10×10^{-4} to 1.56×10^{-3}	NA	NA	0.0001-0.0004	2
Living at Contaminated Site	1×10^{-2}	5	7.75	3.88×10^{1}	2.91×10^{-3} to 8.91×10^{-3}	NA	NA	0.00006-0.0002	1
Living Over Waste	1.0×10^{-2}	5	1.50×10^{-2}	7.50×10^{-2}	5.62×10^{-6} to 1.72×10^{-5}	NA	NA	0.00006-0.0002	1
3. Retrieve, Modify Calcine, Dispose Offsite									
Intrusion into Waste	NA	NA	NA	NA	NA	NA	NA	NA	NA
Living at Contaminated Site	NA	NA	NA	NA	NA	NA	NA	NA	NA
4. Retrieve, Separate Actinides, Dispose of Actinides Offsite, Dispose of Depleted Calcine at the INEL									
Intrusion into Waste	1×10^{-2}	10	8.51	8.51×10^{1}	6.38×10^{-3} to 1.96×10^{-2}	NA	NA	0.0001-0.0004	2
Living at Contaminated Site	1×10^{-2}	5	2.70×10^{1}	1.35×10^{2}	1.01×10^{-2} to 3.10×10^{-2}	NA	NA	0.00006-0.0002	1
Living Over Waste	1.0×10^{-2}	5	2.20×10^{-3}	1.10×10^{-2}	8.25×10^{-7} to 2.53×10^{-6}	NA	NA	0.00006-0.0002	1
5. Delay Retrieval, Modify Calcine, Dispose Offsite									
Intrusion into Waste	NA	NA	NA	NA	NA	NA	NA	NA	NA
Living at Contaminated Site	NA	NA	NA	NA	NA	NA	NA	NA	NA
Living Over Waste	NA	NA	NA	NA	NA	NA	NA	NA	NA

a. Events apply to onsite disposal only. Airborne concentrations of cadmium and mercury are not a health hazard. Pollution from cadmium and mercury applies only to the groundwater migration scenario.

b. Effects result from each occurrence of the event. Event could occur several times in the long term.

c. From 1 year of exposure to background radiation.

d. NA, not applicable.

people who might build houses on lots directly over the bins, only a few individuals (5) could be affected.

2.5.3.2 Long-Term Effects of Abnormal Events

Effects of abnormal events at the INEL and at an offsite federal geologic repository are given in Table 2-6.

It is difficult to predict with great accuracy what significant changes will occur to the earth over the period of time discussed in this report. Geologic studies show that major changes occur to the surface of the earth as ice ages come and go, glaciers form new lakes, erosion occurs, and volcanoes and earthquakes change surface features. Certain formations below the surface, however, are known to have remained relatively unchanged throughout very long periods of time.

Because of the uncertainties associated with geologic changes on the surface of the earth, it is impossible to determine all the effects on the waste that could occur if it is left in near-surface disposal. Unforeseen changes in geologic conditions could cause earthquakes and volcanic activity which would destroy waste containment and disperse the calcine. Rather than attempt to evaluate these many potential scenarios, one major abnormal event is analyzed to determine the maximum potential effects of any abnormal event. To estimate the effects of a severe geologic disruption at the INEL, the event is assumed to have the same probability of occurrence as a volcano exploding up through the waste. The occurrence probability of a volanco erupting through the waste is 1×10^{-8} per year. Since the purpose of evaluating a severe geologic disruption is to determine the worst effects of waste dispersion, the event is assumed to occur at the beginning of the long-term period when the waste would have had only a short time to decay. This provides a conservative (high) estimate. The health effects of waste dispersion for the year 2100 are given in Table 2-6.

The effects of a rising water table or other events which could result in contamination of the aquifer are considered in the waste-migration-into-groundwater scenario.

TABLE 2-6

SUMMARY OF LONG-TERM ABNORMAL EFFECTS[a,b,c]

Alternative and Scenario	Probability Of Occurrence (Event/Year)	Population Exposed[c]	Maximum Individual Dose (Rem)	Population Dose (Man-Rem)	Population Health Effects (Deaths)				
					From Radiation	From Cadmium	From Mercury	From Background Radiation	From All Causes of Cancer
1. Leave-in-Place									
Groundwater Migration	1×10^{-6}	5	6.30×10^{-1}	3.15	2.36×10^{-4} to 7.24×10^{-4}	5	5	0.00006-0.0002	1
Severe Geologic Disruption	1.0×10^{-8}	206,000	1.58×10^{1}	1.95×10^{6}	1.46×10^{2} to 4.49×10^{2}	NA	NA	3-8	34,600
2. Retrieve, Modify Calcine, Dispose at the INEL									
Pelletize Calcine									
Groundwater Migration	1×10^{-6}	5	6.3×10^{-3}	3.15×10^{-2}	2.36×10^{-6} to 7.24×10^{-6}	5	5	0.00006-0.0002	1
Severe Geologic Disruption	1.0×10^{-8}	206,000	1.58×10^{1}	1.95×10^{6}	1.46×10^{2} to 4.49×10^{2}	NA	NA	3-8	34,600
Convert Calcine to Glass									
Groundwater Migration	1×10^{-6}	5	1.39×10^{-6}	6.95×10^{-6}	5.21×10^{-10} to 1.60×10^{-9}	0	0	0.00006-0.0002	1
Severe Geologic Disruption	1.0×10^{-8}	206,000	1.58×10^{1}	1.95×10^{6}	1.46×10^{2} to 4.49×10^{2}	NA	NA	3-8	34,600
3. Retrieve, Modify Calcine, Dispose Offsite									
Stabilize Calcine									
Solution Mining	1.0×10^{-6}	40,000,000	1.71×10^{-2}	6.84×10^{5}	5.13×10^{1} to 1.57×10^{2}	0	0	390-1,200	6,720,000
Fault and Flooding	2.0×10^{-13}	2,000,000	1.78	3.56×10^{4}	2.67 to 8.19	0	0	20-60	336,000
Exploratory Drilling	5.0×10^{-7}	25	2.36	5.90×10^{1}	4.42×10^{-3} to 1.36×10^{-2}	NA	NA	0.0002-0.0008	5
Groundwater Migration	NA	NA	NA	NA	NA	NA	NA	NA	NA
Convert Calcine to Glass									
Solution Mining	1.0×10^{-6}	40,000,000	1.71×10^{-2}	6.84×10^{5}	5.13×10^{1} to 1.57×10^{2}	0	0	390-1,200	6,720,000
Fault and Flooding	2.0×10^{-13}	2,000,000	1.78×10^{-4}	3.56	2.67×10^{-4} to 8.19×10^{-4}	0	0	20-60	336,000
Exploratory Drilling	5.0×10^{-7}	25	1.55	3.87×10^{1}	2.91×10^{-3} to 8.91×10^{-3}	NA	NA	0.0002-0.0008	5
4. Retrieve, Separate Actinides, Dispose of Actinides Offsite, Dispose of Depleted Calcine at the INEL									
Dispose of Actinides Offsite									
Solution Mining	1.0×10^{-6}	40,000,000	1.71×10^{-2}	6.84×10^{5}	5.13×10^{1} to 1.57×10^{2}	0	NA	390-1,200	6,720,000
Fault and Flooding	2.0×10^{-13}	2,000,000	1.78×10^{-6}	3.56×10^{-2}	2.67×10^{-6} to 8.19×10^{-6}	0	NA	20-60	336,000
Exploratory Drilling	5.0×10^{-7}	25	2.71×10^{2}	6.78×10^{3}	5.08×10^{-1} to 1.56	NA	NA	0.0002-0.0008	
Dispose of Depleted Calcine at the INEL									
Groundwater Migration	1×10^{-6}	5	6.20×10^{-1}	3.12	2.34×10^{-4} to 7.18×10^{-4}	5	5	0.00006-0.0002	1
Severe Geologic Disruption	1.0×10^{-8}	206,000	1.11×10^{1}	1.37×10^{6}	1.03×10^{2} to 3.16×10^{2}	NA	NA	3-8	34,600

TABLE 2-6

SUMMARY OF LONG-TERM ABNORMAL EFFECTS[a,b,c]
(concluded)

Alternative and Scenario	Probability Of Occurrence (Event/Year)	Population Exposed	Maximum Individual Dose (Rem)	Population Dose (Man-Rem)	Population Health Effects (Deaths) From Radiation		From Cadmium	From Mercury	From Background Radiation	From All Causes of Cancer
5. Delay Retrieval, Modify Calcine, Dispose Offsite[d]										
100 years										
Solution Mining	1.0×10^{-6}	40,000,000	1.45×10^{-2}	5.80×10^{5}	4.35×10^{1}	to 1.33×10^{2}	0	0	390-1,200	6,720,000
Fault and Flooding	2.0×10^{-13}	2,000,000	1.78×10^{-4}	3.56	2.67×10^{-4}	to 8.19×10^{-4}	0	0	20-60	336,000
Exploratory Drilling	5.0×10^{-7}	25	1.13	2.82×10^{1}	2.12×10^{-3}	to 6.50×10^{-3}	NA	NA	0.0002-0.0008	5
300 years										
Solution Mining	1.0×10^{-6}	40,000,000	1.06×10^{-2}	4.24×10^{5}	3.18×10^{1}	to 9.75×10^{1}	0	0	390-1,200	450-1,380
Fault and Flooding	2.0×10^{-13}	2,000,000	1.78×10^{-4}	3.56	2.67×10^{-4}	to 8.19×10^{-4}	0	0	20-60	336,000
Exploratory Drilling	5.0×10^{-7}	25	9.65×10^{-1}	2.41×10^{1}	1.81×10^{-3}	to 5.55×10^{-3}	NA	NA	0.0002-0.0008	5
500 years										
Solution Mining	1.0×10^{-6}	40,000,000	7.8×10^{-3}	3.1×10^{5}	2.4×10^{1}	to 7.2×10^{1}	0	0	390-1,200	450-1,380
Fault and Flooding	2.0×10^{-13}	2,000,000	1.8×10^{-4}	3.56	2.7×10^{-4}	to 8.2×10^{-4}	0	0	20-60	336,000
Exploratory Drilling	5.0×10^{-7}	25	8.80×10^{-1}	2.20×10^{1}	1.65×10^{-3}	to 5.06×10^{-3}	NA	NA	0.0002-0.0008	5
Groundwater Migration	NA	NA	NA	NA	NA		NA	NA	NA	NA

a. NA, not applicable. Cadmium and mercury are disposed at the INEL in Alternatives 1 and 2. Mercury is disposed at the INEL in Alternative 4. Airborne concentrations of cadmium and mercury are not a health hazard. Cadmium is disposed at the INEL in Alternative 4.

b. Effects are based on 1 year of exposure for the years specified: Waste migration into groundwater, 2500; Severe geologic disruption, 2100; Solution mining, 2500 (Alternatives 3 and 4), 2600, 2800, 3000 (Alternative 5); Fault and Flooding, 2600 (Alternatives 3 and 4), 2700, 2900, 3100 (Alternative 5); Exploratory drilling 2500 (Alternatives 3 and 4), 2600, 2800, 3000 (Alternative 5).

c. Population doses are taken from the GEIS on commercially generated radioactive waste (DOE, 1980).

d. If the severe geologic disruption were to occur during the period of delay, the effects of Alternative 5 would be no worse than the effects of Alternative 1.

The most serious long-term effect would be groundwater contamination by cadmium and mercury as the result of waste migration into groundwater after disintegration of the waste bins. Federal and state drinking water standards could be exceeded in Alternatives 1 and 4 for a distance of about 5 miles downgradient of the discharge to the aquifer. Adverse health effects would result from ingestion of contaminated drinking water and food grown with contaminated irrigation water until chemical reactions within the aquifer system reduced the concentration of toxic chemicals to harmless levels. The radiological effects of waste migration into groundwater would be much less severe than the nonradiological effects and would decrease with time as the radionuclides decay. None of these events would create health effects in the general population that would be distinguishable from the effects of background radiation.

Abnormal events associated with deep geologic disposal in a federal repository that were analyzed include solution mining, exploratory drilling, and fault and flooding (Alternatives 3, 4, and 5). The solution mining scenario would only affect a repository located in salt beds. It is estimated that the greatest number of people (40,000,000) to be affected by INEL waste would be those who consume table salt produced by solution mining at the repository where the INEL waste is buried. However, even though the health effects (51-157) estimated for solution mining are apparently significant, individuals would receive a dose that is only 11 percent of the background radiation dose.

The selection of events to be evaluated was made on the basis of the severity of the resulting effects rather than on the probability of the event's occurrence. These effects, given in Table 2-6, are considered to be the worst effects imaginable over the long term for all of the abnormal events studied.

2.5.4 Unquantifiable Factors

Difficult-to-quantify factors for both the short-term and long-term periods are evaluated and compared in Table 2-7. Process reversibility (th capability to convert a waste form to an alternate form) and the degree of

TABLE 2-7

SUMMARY OF UNQUANTIFIABLE FACTORS

Alternative	Process Reversibility		Degree of Institutional Control Required to Ensure Isolation	
	Short Term	Long Term	Short Term	Long Term
1. Leave-in-Place	Good	Good	High	High
2. Retrieve, Modify Calcine, Dispose at the INEL				
Pelletized Calcine	Good	Good	High	High
Convert Calcine to Glass	Poor	Poor	High	Low
3. Retrieve, Modify Calcine, Dispose Offsite				
Stabilized Calcine	Good	Good	Low	Low
Convert Calcine to Glass	Poor	Poor	Low	Low
4. Retrieve, Separate Actinides, Dispose of Actinides Offsite, Dispose of Depleted Calcine at the INEL				
Depleted Calcine	Good	Good	High	High
Vitrified Actinides	Poor	Poor	Low	Low
5. Delay Retrieval, Modify Calcine, Dispose Offsite				
100 Years	Good	Poor	High	Low
300 Years	Good	Poor	High	Low
500 Years	Good	Poor	High	Low

institutional control required to ensure isolation of the waste are considered. Process reversibility is rated from poor to good; the degree of institutional control required to ensure isolation is rated from low to high for the short-term and long-term periods. Failure of institutional control in Alternatives 1, 2, and 4, which involve onsite disposal, could result in contamination of the Snake River Plain Aquifer by toxic chemicals should waste containment fail. This event would cause the most concern in Alternatives 1 and 4 where the calcine would be disposed in an unmodified, more easily dispersed form. Should institutional control cease during the delay period in Alternative 5, effects would be similar to the leave-in-place alternative.

As shown in Table 2-7, the most stable forms of calcine are the most difficult waste forms to alter should the waste become valuable or future technological discoveries make it desirable to change a waste disposal decision. In comparing Alternatives 2, 3, and 4, which involve calcine modification, with Alternative 1 and Alternative 5 during the delay period, the degree of waste form reversibility is a significant factor to be considered.

The degree of institutional control required to ensure waste isolation becomes significant in the long term. A 100-year period of institutional control has been assumed. Longer periods of institutional control in Alternatives 1, 2, 4, and 5 would decrease the potential for adverse environmental effects.

Under any alternative, the degree of process reversibility and the degree of institutional control required over the long term are conflicting factors that require a trade-off. The alternatives which are the easiest to reverse are also the ones which require the longest continuous institutional control.

2.5.5 Program Costs

A comparative summary of program costs is given in Table 2-8. These are preliminary costs based on preliminary conceptual designs. The data are included to indicate the relative cost differences among alternatives and to provide insight into the capital investment required to implement Alternatives 2, 3, 4, and 5. Costs for Alternative 5 have not been escalated

TABLE 2-8

COSTS OF IMPLEMENTING THE WASTE MANAGEMENT ALTERNATIVES (MILLIONS OF 1980 DOLLARS)[a]

Alternative	Construction (Capital)				Operations					D&D		Disposal	Total Cost[b]
	Casks	Retrieval	Processing	Storage	Manpower	Materials	Canisters	Energy	Waste Shipment	Manpower	Materials	Repository[c]	
1. Leave-in-Place	NA	NA	NA	109	NA	NA	NA	NA	NA	1	7	[d]	120
2. Retrieve, Modify Calcine, Dispose at the INEL													
Pelletize Calcine	NA	7	20	197	40	1.5	NA	1.4	NA	1	15	[d]	285
Convert Calcine to Glass	14	7	39	107	63	255	244	1.4	1.5	2	2	[d]	735
3. Retrieve, Modify Calcine, Dispose Offsite													
Stabilize Calcine	56	7	39	NA	48	NA	162	1.4	137	2	2	190	645
Convert Calcine to Glass	85	7	39	NA	55	255	244	1.4	210	2	2	190	1090
4. Retrieve, Separate Actinides, Dispose of Actinides Offsite, Dispose of Depleted Calcine at the INEL	3	7	195	130	85	120	3	4.1	4	3	10	1	560
5. Delay Retrieval, Modify Calcine, Dispose Offsite	85	7	39	109	70	255	244	1.4	210	2	19	19	1060

a. NA, not applicable.

b. Total costs have been rounded.

c. Costs of disposal at the INEL are included in construction and operating costs.

d. No maintenance and surveillence costs are explicitly included as they would be covered by a general sitewide program.

because costs for retrieval, modification, shipment, and disposal several hundred years in the future are impossible to predict. Alternatives which involve waste shipment and disposal at an offsite geologic repository (Alternatives 3 and 5) are the most expensive to implement. Implementation of Alternative 5 would be the most costly because, although appreciable savings would be realized by deferring modification and shipment until after the waste had cooled, Alternative 5 involves the most steps: construction of additional bins for storage; extension of institutional controls (monitoring) for as much as 500 years (400 years more than for any other alternative); and, finally, waste form modification, shipment, and disposal at an offsite repository.

2.5.6 Environmental Trade-Offs

The selection of a preferred alternative will require difficult trade-offs among conflicting effects. These trade-offs necessitate decisions on whether society should pay now to avoid future effects. For example, it may be asked whether it is preferable to increase worker exposure during actinide separation (Alternative 4) in order to save waste shipment and disposal costs. Table 2-9 summarizes the most significant environmental effects of the various alternatives. Only the 500-year delay case is shown for Alternative 5 since it is most representative of the advantages gained from delay. Highlighted in Table 2-9 are the differences between effects which are certain to occur and uncertain effects which may be caused by abnormal events, since the principal issue is to identify what effects should be incurred now in order to avoid potential adverse effects in the future.

As can be seen, there is no alternative that does not create some adverse effects in the short term or pose some risks in the long term. Following are additional points that can be noted from examination of Table 2-9.

- The most significant nonradiological effect is the five deaths from cadmium and mercury poisoning if the waste is disposed onsite (Alternative 1). The event has a low probability (one event every million years) and this estimate is quite conservative (high). It

TABLE 2-9

SUMMARY OF SIGNIFICANT ENVIRONMENTAL EFFECTS[a,b]

EFFECTS FROM CERTAIN-TO-OCCUR EVENTS	EFFECTS FROM ABNORMAL EVENTS
ALTERNATIVE 1 - Leave-in-Place (Base Case)	
• Cost $120 million • No energy demand • 17.9 industrial worker injuries • 0.207 industrial worker fatality • 0.101 cancer death from intrusion into the waste; occurrence probability is 1 event in 100 years • 0.000126 cancer death from living over waste; occurrence probability is 1 event in 100 years	• 0.000724 cancer death from groundwater contaminated by radionuclides; occurrence probability is 1 event in 1 million years • 5 deaths from groundwater contaminated by cadmium and mercury; occurrence probability is 1 event in 1 million years • 17 cancer deaths from aircraft impact; occurrence probability is 1 event in 5 million years • 449 cancer deaths from severe geologic event; occurrence probability is 1 event in 1 million years
ALTERNATIVE 2 - Pellets	
• Cost $285 million • 1.45-megawatt energy demand • 71.8 industrial worker injuries • 0.579 industrial worker fatality • 800 man-rem routine worker dose • 0.00000549 cancer death from routine radiological releases; occurrence probability is 1 event per year • 0.30 cancer death from operational accident; occurence probability is 1 event in 10 years • 0.0241 cancer death from intrusion into the waste; occurrence probability is 1 event in 100 years • 0.000106 cancer death from living over waste; occurrence probability is 1 event in 100 years	• 0.00000724 cancer death from groundwater contained by radionuclides; occurrence probability is 1 event in 1 million years • 5 deaths from groundwater contaminated by cadmium and mercury; occurrence probability is 1 event in 1 million years • 17 cancer deaths from aircraft impact; occurrence probability is 1 event in 5 million years • 449 cancer deaths from a severe geologic disruption; occurrence probability is 1 event in 1 million years
ALTERNATIVE 2 - Glass	
• Cost $735 million • 1.15-megawatt energy demand • 56 industrial worker injuries • 0.3 industrial worker fatality • 1250 man-rem routine worker dose	• 0.0000000016 cancer death from groundwater contaminated by radionuclides; occurrence probability is 1 event in 1 million years

TABLE 2-9

SUMMARY OF SIGNIFICANT ENVIRONMENTAL EFFECTS[a,b]
(continued)

EFFECTS FROM CERTAIN-TO-OCCUR EVENTS	EFFECTS FROM ABNORMAL EVENTS
ALTERNATIVE 2 - Glass (continued)	
• 0.00000549 cancer death from routine radiological releases; occurrence probability is 1 event per year • 0.39 cancer death from operational accident; occurrence probability is 1 in 10 years • 0.00156 cancer death from intrusion into the waste; occurrence probability is 1 event in 100 years • 0.0000172 cancer death from living over waste; occurrence probability is 1 event in 100 years	• 0 death from groundwater contaminated by cadmium and mercury; occurrence probability is 1 event in 1 million years • 17 cancer deaths from aircraft impact; occurrence probability is 1 event in 5 million years • 449 cancer deaths from severe geologic disruption; occurrence probability is 1 event in 1 million years
ALTERNATIVE 3 - Stabilized Calcine	
• Cost $645 million • 0.57-megawatt energy demand • 85 industrial worker injuries • 1.14 industrial worker fatalities • 1220 man-rem routine worker dose • 0.0000000120 cancer death from routine radiological releases; occurrence probability is 1 event per year • 0.055 cancer death from exposure during waste shipment; occurrence probability is 1 event per year • 0.30 cancer death from operational accident; occurrence probability is 1 event in 10 years	• 1.12 cancer deaths from waste shipment accident; occurrence probability is 1 event in 33.3 thousand years • 157 cancer deaths from solution mining; occurrence probability is 1 event in 1 million years • 17 cancer deaths from aircraft accident; occurrence probability is 1 event in 5 million years
ALTERNATIVE 3 - Glass	
• Cost $1090 million • 1.15-megawatt energy demand • 90 industrial worker injuries • 1370 man-rem routine worker dose • 0.00000549 cancer death from routine radiological releases; occurrence probability is 1 event per year	• 0.0146 cancer death from waste shipment accident; occurrence probability is 1 event in 33.3 thousand years • 157 cancer deaths from solution mining; occurrence probability is 1 event in 1 million years • 17 cancer deaths from aircraft impact; occurrence probability is 1 event in 5 million years

TABLE 2-9

SUMMARY OF SIGNIFICANT ENVIRONMENTAL EFFECTS[a,b]
(continued)

EFFECTS FROM CERTAIN-TO-OCCUR EVENTS	EFFECTS FROM ABNORMAL EVENTS
ALTERNATIVE 3 - Glass (continued)	
• 0.083 cancer death from exposure during waste shipment; occurrence probability is 1 event per year • 0.30 cancer death from operational accident; occurrence probability is 1 event in 10 years	
ALTERNATIVE 4 - Actinide Separation	
• Cost $560 million • 1.60-megawatt energy demand • 125.4 industrial worker injuries • 1.04 industrial worker fatalities • 1727 man-rem routine worker dose • 0.0000000135 cancer death from routine radiological releases; occurrence probability is 1 event per year • 0.00287 cancer death from exposure during waste shipment; occurrence probability is 1 event per year • 0.30 cancer death from operational accident; occurrence probability is 1 event in 10 years • 0.00000253 cancer death from living over waste; occurrence probability is 1 event in 100 years • 0.0196 cancer death from intrusion into the waste; occurrence probability is 1 event in 100 years	• 0.000718 cancer death from groundwater contaminated by radionuclides; occurrence probability is 1 event in 1 million years • 5 deaths from groundwater comtaminated by cadmium and mercury; occurrence probability is 1 event in 1 million years • 17 cancer deaths from aircraft impact; occurrence probability is 1 event in 5 million years • 1.15 cancer deaths from waste shipment accident; occurrence probability is 1 event in 14 million years • 316 cancer deaths from severe geologic disruption; occurrence probability is 1 event in 100 million years
ALTERNATIVE 5 - 500-Year Delay	
• Cost $1060 million • 1.15-megawatt energy demand • 55.2 industrial worker injuries • 0.66 industrial worker fatality • 177 man-rem routine worker dose • 0.0000000000255 cancer death from routine radiological releases; occurrence probability is 1 event per year	• 0.000629 cancer death from waste shipment accident; occurrence probability is 1 event in 33.3 thousand years • 72 cancer deaths from solution mining; occurrence probability is 1 event in 1 million years • 17 cancer deaths from aircraft impact; occurrence probability is 1 event in 5 million years

TABLE 2-9

SUMMARY OF SIGNIFICANT ENVIRONMENTAL EFFECTS[a,b]
(concluded)

EFFECTS FROM CERTAIN-TO-OCCUR EVENTS	EFFECTS FROM ABNORMAL EVENTS
ALTERNATIVE 5 - 500-Year Delay (cont.)	
• 0.113 cancer death from exposure during waste shipment; occurrence probability is 1 event per year • 0.00255 cancer death from operational accident; occurrence probability is 1 event in 10 years	

a. For perspective, radiological effects can be compared with cancer deaths expected to result from background radiation and deaths from all causes of cancer. Health effects at the INEL are estimated for the projected population residing in the 50-mile area surrounding the ICPP in 2020 (303,000 people). Health effects at the federal repository are based on the population estimated in the environmental impact statement for commercially generated radioactive waste (2,000,000 people) (DOE, 1980b).

Estimated cancer deaths in the surrounding population from one year of background radiation are

at the INEL, 3.4 to 10.5 and
at the repository, 19.5 to 59.8.

Estimated cancer deaths in the surrounding population from all causes are

at the INEL, 50,900 and
at the repository, 336,000.

b. Numbers reported in this table are not rounded off so that they can be traced from chapter to chapter throughout the document. Rounding off (e.g., 17.9 to 18) would be more indicative of the degree of accuracy.

assumes that future generations are not aware of the cadmium and mercury in the water supply and/or are unable to prevent waste migration away from the bins.

- Alternative 4 uses about twice as much energy as the other processes because of the extra processing steps of actinide separation and recalcination. The maximum energy demand is equivalent to the annual electrical demand by 250 homes in Idaho Falls.

- Actinide removal (Alternative 4) does not eliminate nonradiological effects at the INEL because cadmium is not removed during the actinide separation process and would, therefore, be disposed at the INEL in the actinide-depleted waste.

- The effects which are certain to occur from routine releases, intrusion into the waste, and living over the waste or on land contaminated by the waste (Alternatives 1, 2, and 4) are not significant. They are unlikely to result in health effects which can be specifically related to exposure to waste radionuclides.

- The risk to workers for all alternatives is larger than the risk to the population.

- Worker doses range from no additional dose in the case of Alternative 1, to 1,728 man-rem for Alternative 4, but in no alternative will doses come close to exceeding any occupational exposure guidelines. Worker doses are not considered to be a significant detrimental effect for any alternative.

- After decay has occurred during the 500-year delay period in Alternative 5, worker doses would be reduced by about a factor of 10 compared to Alternative 3; however, institutional controls would be required throughout the delay period.

- The potential worker injuries and fatalities from construction and operation of facilities for the various alternatives are comparable to or less than those usually experienced in similar industries.

- The aircraft accident causes the same effects for all alternatives since it is assumed to happen while the calcine is still at the INEL. The 17 cancer deaths that might be related to such an event are certainly of concern, but the overall risk to the public is not considered significant in view of the low probability that the event will happen (1 event every 10 million years).

- The largest potential environmental impact for Alternatives 1, 2, and 4 would be from severe geologic disruption of the waste. Should such an event occur, it is possible that the effects of the event itself would be much greater than the deaths that would result from radioactive contamination. Most of the dose would come from the long-lived transuranic elements, so decay would not reduce the effects very rapidly.

- An offsite geologic repository (Alternatives 3, 4, and 5) does not offer protection against all risks. In fact, a solution mining accident at the repository (in salt) would have greater potential impact than the aircraft impact accident at the INEL.

- The basic trade-off is onsite versus offsite disposal. Onsite disposal has long-term risks. These risks are groundwater contamination, an aircraft impact, and a severe geologic disruption all of which have low probabilities of occurrence. Offsite disposal is associated with short-term effects such as worker doses, energy use, and high implementation cost. The question implicit in evaluation of these trade-offs and selection of an alternative is, what human effects, resource use, and economic cost should be expended now as a premium to insure against future risks?

REFERENCES FOR SECTION 2

AEC (U.S. Atomic Energy Commission), "Environmental Statement -- New Waste Calcining Facility National Reactor Testing Station, Idaho," WASH-1531, June 1974.

49 CFR 173.393 (Code of Federal Regulations, Transportation), "General Packaging and Shipment Requirements," 1979.

40 CFR 50 (Code of Federal Regulations, Protection of Environment), "National Secondary Ambient Air Quality Standards," 1979.

10 CFR 100 (Code of Federal Regulations, Energy), "Reactor Site Criteria," 1979.

Cole, H. S. et al., "Properties of Vitrified ICPP Zirconia Calcine," ENICO-1038, July 1980.

DOE (U.S. Department of Energy), "Final Environmental Impact Statement, Management of Commercially Generated Radioactive Waste," DOE/EIS-0046F, October 1980.

EPA (U.S. Environmental Protection Agency), "Criteria for Radioactive Wastes: Recommendations for Federal Radiation Guidance," Federal Register, Part IX, November 15, 1978.

ERDA (U.S. Energy Research and Development Administration), "Alternatives for the Long-Term Management of Defense High-Level Radioactive Waste, Idaho Chemical Processing Plant, Idaho Falls, Idaho," ERDA 77-43, 1977a.

ERDA (U.S. Energy Research and Development Administration), "Final Environmental Impact Statement, Waste Management Operations Idaho National Engineering Laboratory," ERDA-1536, September 1977b.

ERDAM (U.S. Energy Research and Development Administration), "Facilities General Design Criteria," ERDA Appendix 6301, March 1977.

Gombert, D. and M. Y. Pong, "Operation of a Laboratory-Scale Glass Melter to Vitrify ICPP Zirconia Calcine," ENICO-1058, October 1980.

Lamb, K. M., and H. S. Cole, "Development of a Pelleted Waste Form for High-Level ICPP Zirconia Wastes," ICP-1185, April 1979.

Maxey, H. R. et al., "Removal of Actinides from ICPP Fuel Reprocessing Wastes -- Engineering Studies Terminal Report," ENICO-1057, September 1980.

Pomiak, G. S., et al., "Stabilizing Simulated ICPP Waste Calcine in a 10 cm Fluidized Bed," ENICO-1063, November 1980.

Priebe, S. J. and J. H. Valentine, "Description of a Pilot Plant to Produce a Pelleted Form from Simulated ICPP High-Level Calcined Waste," ENICO-1032, March 1980.

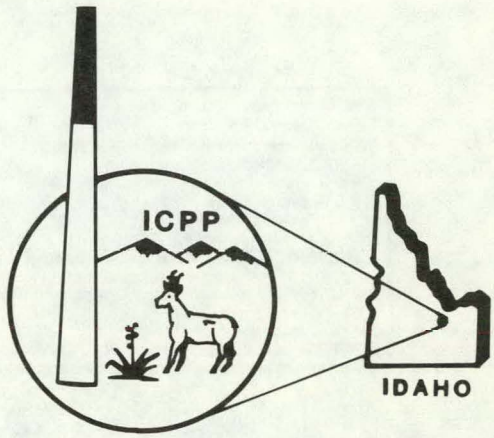
Staples, B. A. et al., "Properties of Radioactive Calcine Retrieval from the Second Calcined Solids Facility at ICPP," ICP-1189, March 1979.

The Ralph M. Parsons Company, "Preconceptual Design Documentation Defense Waste Document Study," ERDA, February 1977.

The Ralph M. Parsons Company, "Conceptual Design Documentation Calcined Solids Retrievability Facility," ERDA, September 1976.

Westra, A. G. et al., "Sampling of Stored High-Level Radioactive Calcined Waste at ICPP," ICP-1186, May 1979.

3.0 AFFECTED ENVIRONMENT



This section describes the environmental setting of the Idaho National Engineering Laboratory (INEL) and of the Idaho Chemical Processing Plant (ICPP) in particular. More detailed information is available in the environmental evaluations of the INEL waste management operations (ERDA, 1977). The INEL is located on the northwest margin of the eastern Snake River Plain, a semiarid area overlain by recent basaltic lava flows. The INEL covers 894 square miles in sparsely populated southeastern Idaho. The ICPP, located in the south central portion of the site, lies in Butte County (see location map, Figure 3-1).

3.1 Physical Environment

The objective of this subsection is to summarize the various geological, hydrological, and meteorological factors essential for conducting an accurate environmental assessment for disposing of high-level radioactive waste at the ICPP.

3.1.1 Geology

The Snake River Plain is a crescent-shaped valley of 19,260 square miles. It is approximately 200 miles in length, varies in width from 50 to 100 miles, and is bordered on the north and northwest by the Lost River, Lemhi, and Beaverhead mountain ranges. The valley consists of basaltic flows and interbedded sedimentary strata overlain by successive wind- and water-deposited sediments. (Kuntz, 1978 and 1980; Nace, et al., 1972 and 1975).

The 12,000-foot peaks of the adjacent mountains are in sharp contrast to the plain which rises gently from an elevation of 2300 feet in the west to 6000 feet in the east. At the ICPP, the elevation is approximately 4,920 feet.

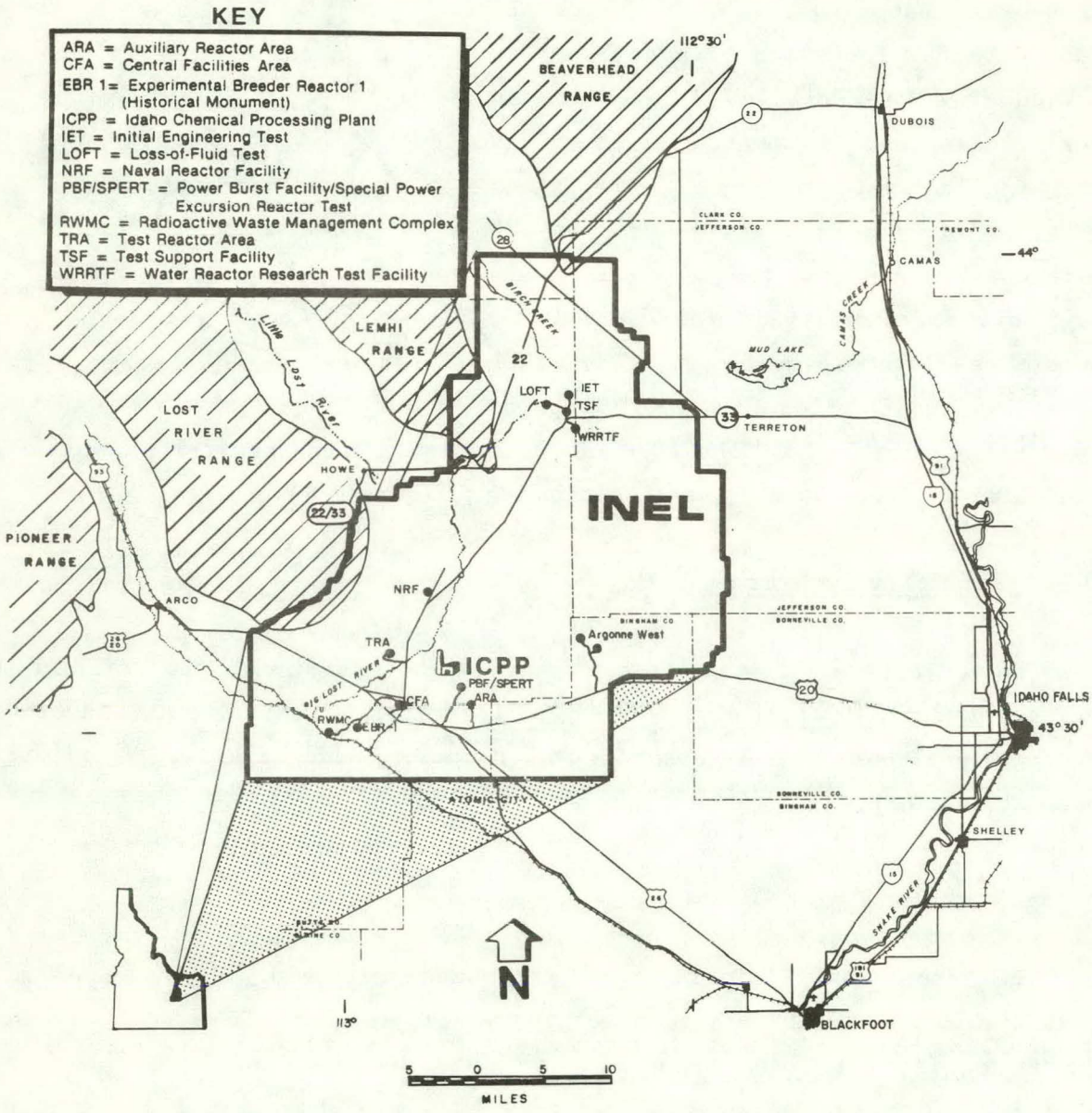


Figure 3-1. Location Map of the INEL

The Snake River Plain is the product of extensive geologic activity. The bordering mountain ranges consist of Paleozoic and Mesozoic rocks (63 to 600 million years old), folded and intruded and later uplifted along the major faults during Basin and Range tectonism. A generalized geologic map of the eastern Snake River Plain is shown in Figure 3-2. The rift zones (see discussion in Subsection 3.1.2) in the Snake River Plain appear to be extensions of the range-front faults in the adjoining mountains. This suggests that the Basin and Range structures may continue beneath the plain. Tectonic development in the plain, however, is expressed in the form of volcanic rift zones.

3.1.2 Volcanic Activity

Except for small areas along the mountain fronts and three buttes (rhyolite domes), the entire INEL area is underlain by a succession of basaltic lava flows ranging in age from 13 million years to the present. The basalt was formed chiefly from pahoehoe-type lavas. The flows have been extruded from rifts and from volcanoes whose locations are rift-controlled. The flows formed layers of hard rock whose thickness varies from 10 to 100 feet. The flows are fractured and fissured, and have variable vertical permeability. The physical characteristics and horizontal distribution of the flows also vary. Unconsolidated material, cinders, and breccia are interbedded with the basalt. The beds are nearly horizontal, and no significant structural deformation is evident.

Volcanic occurrences on the Snake River Plain have tended to localize on rift zones. Rift zones and volcanic structures near and at the INEL are shown in Figure 3-3. The ICPP could be affected by volcanic activity in the Arco Rift Zone and to a lesser extent by activity in the Howe-East Butte Rift Zone.

The Arco Rift Zone extends 30 miles southeastward from the north margin of the Snake River Plain at Arco to the longitudinal axis of the plain near Atomic City. Located along the Arco Rift Zone are extensional fractures, a graben structure, rifts, and numerous basalt volcanoes. The youngest basalt flows in the Arco Rift Zone are approximately 10,500 to 12,000 years old.

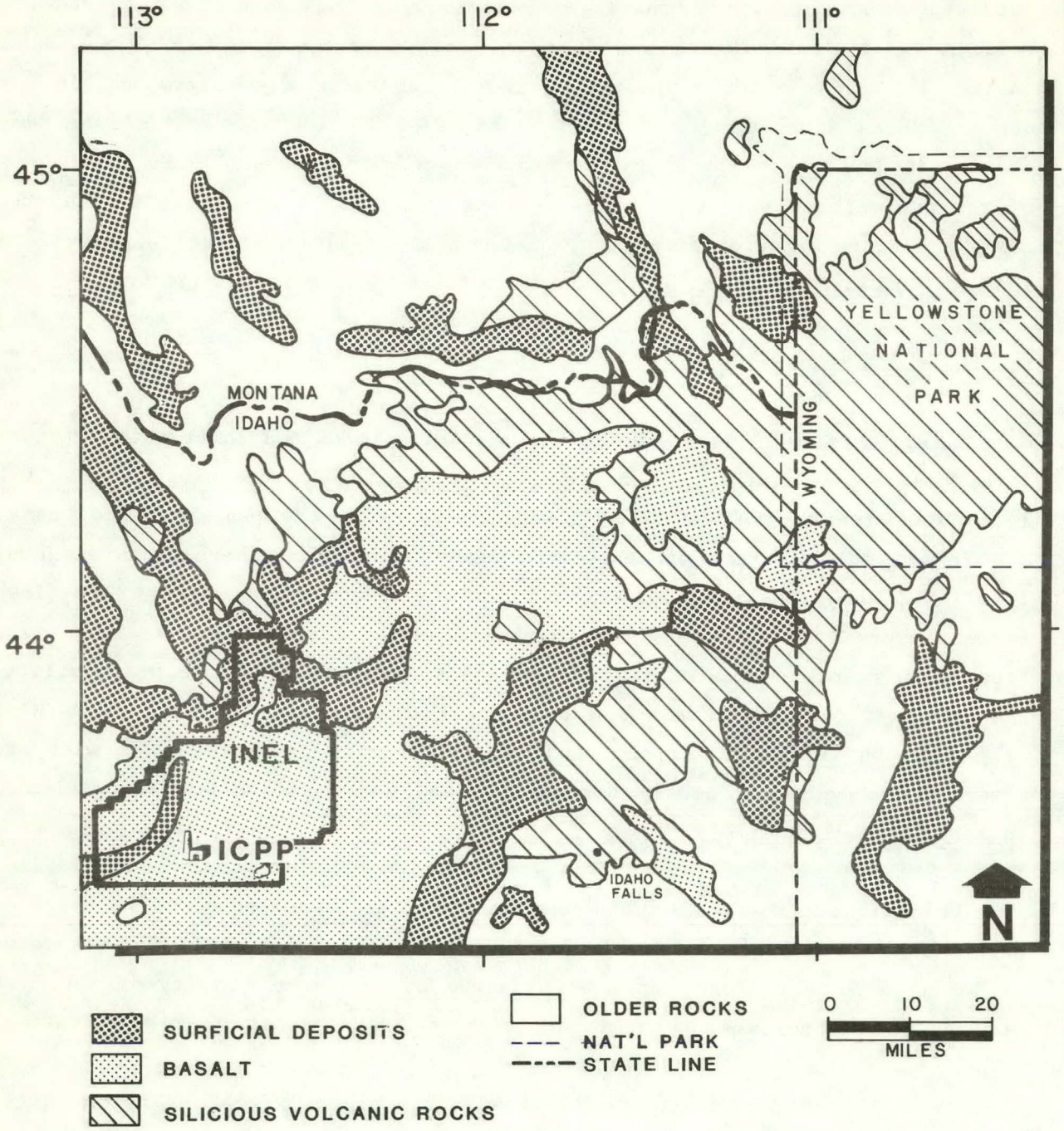


Figure 3-2. Generalized Geologic Map of the Eastern Snake River Plain

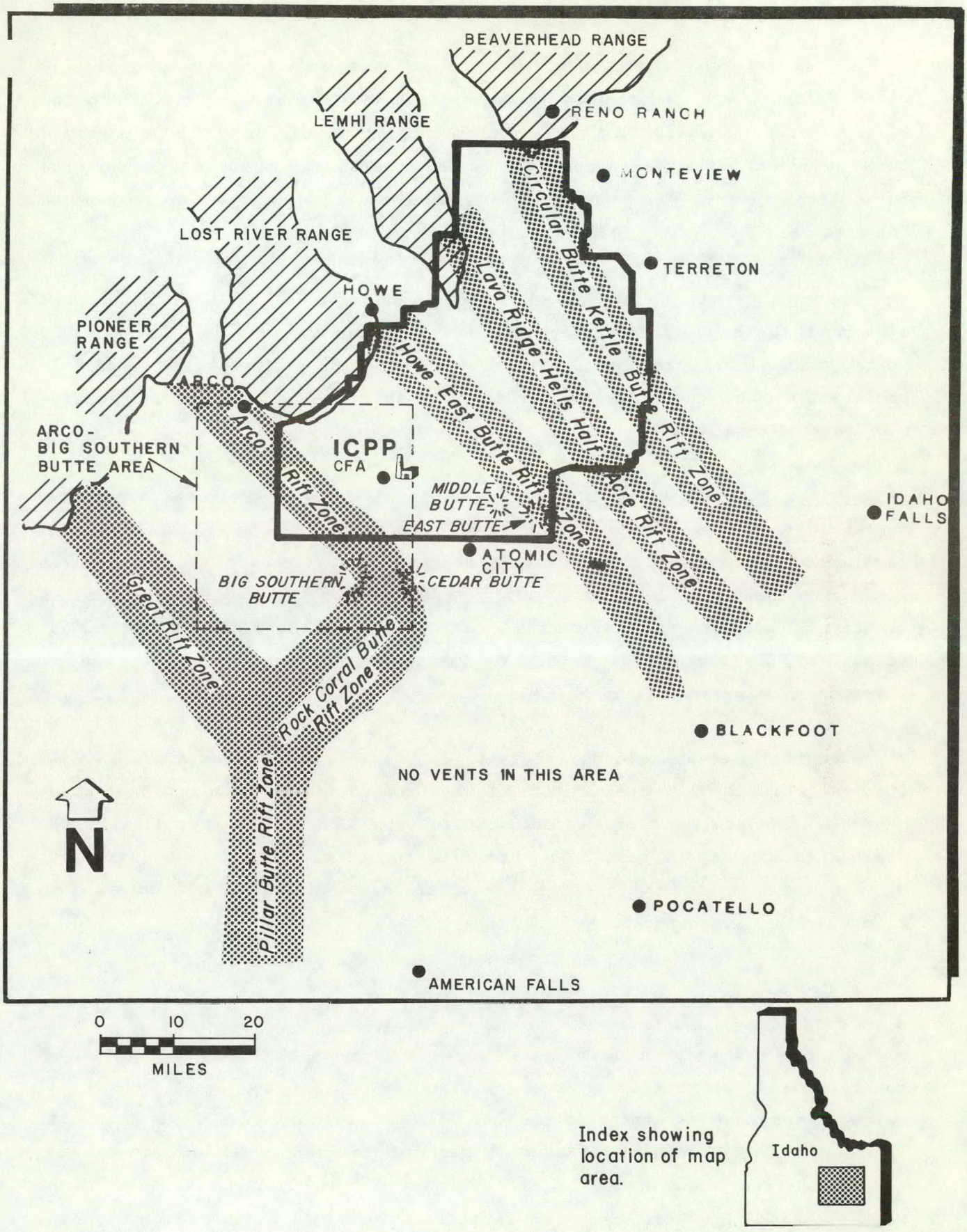


Figure 3-3. Rift Zones and Volcanic Structures near the INEL

It is inferred that these basalt rocks are underlain by geologically older volcanic and sedimentary rocks, perhaps ranging in age from 25 to 600 million years. Rhyolitic volcanic rocks, ranging in age from approximately 4 to 10 million years, are exposed along the north and south margins of the Snake River Plain. These rocks are presumed to underlie the basalt beneath the site.

A recent study of the Arco Rift Zone (Kuntz, 1978) has led to the conclusion that the region has been volcanically active for the last 400,000 years, that it has been the location of much of the geologically recent volcanic activity in the Snake River Plain, and that it is likely to be the site of future volcanic action.

Future volcanic occurrences are postulated to be of the same types that currently characterize the plain: shield volcanoes, fissure eruptions, and lava cones. A small but significant number of eruptions in the Snake River Plain have been of the hydromagmatic type. These were moderately violent eruptions that occurred when the molten lava encountered groundwater at relatively shallow depths. Volcanic material ejected from this type of volcano was dispersed as far as 3 miles from its source.

The most recent volcanic activity in the region occurred about 1500 to 2000 years ago at the present site of the Craters of the Moon National Monument, approximately 30 miles southwest of the ICPP. This area lies in the Great Rift Zone (see Figure 3-3). The mean recurrence interval for all types of volcanic activity in the Arco-Big Southern Butte area (see area outlined in Figure 3-3) is suggested to be 3000 years (Kuntz, 1978).

3.1.3 Hydrology

Surface water at the INEL consists of three streams that drain through mountain valleys: Big Lost River, Little Lost River, and Birch Creek. All three streams are intermittent on the INEL. These three drainages terminate in four playas in the north-central part of the INEL. No surface streams leave the site. Activities at the ICPP would have little effect on these water bodies. However, the ICPP is within the flood plain of the Big Lost River (Figure 3-4).

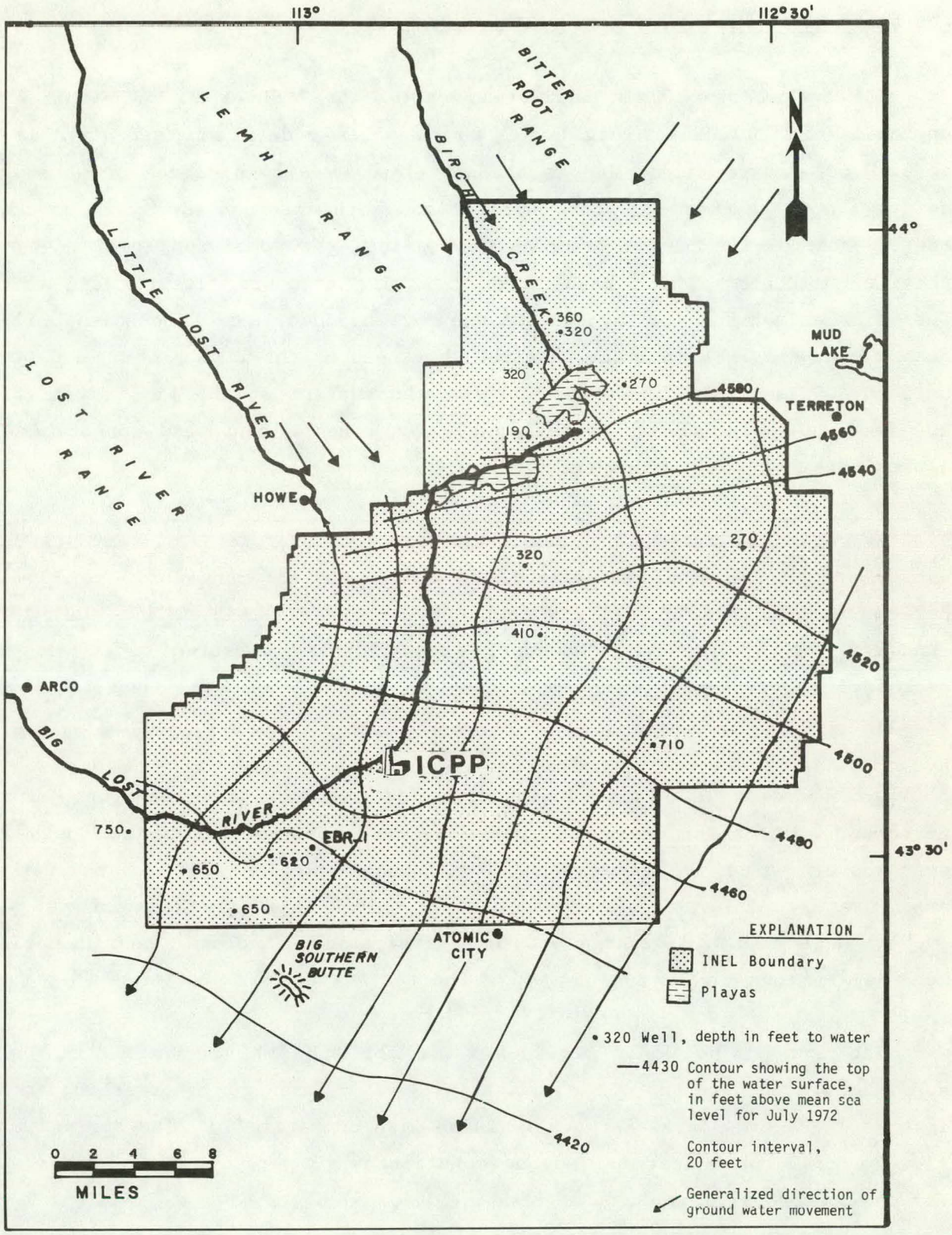


Figure 3-4. Groundwater Table Levels and Flow Path at INEL

The Snake River Plain Aquifer

The Snake River Plain Aquifer underlies the INEL area. The aquifer is approximately 200 miles long by 30 to 60 miles wide, comprises an area of about 9,600 square miles, and is characterized by a high degree of heterogeneity. It is composed of thin basalt flows with interbedded layers of sediments. Most of the permeable zones occur along the upper and lower edges of the basaltic flows which have large irregular fracture fissures and voids. The thickness of the aquifer has not been established, but three holes drilled recently at the INEL indicate that the thickness of the more permeable part is between 1000 and 2500 feet. The depth to the aquifer at the INEL varies from 200 feet in the northeast corner to 900 feet in the southwest corner and is approximately 450 feet below the ICPP.

Average flow rates vary due to the aquifer heterogeneity. Studies conducted at the INEL indicate natural flow rates in the range of 5 to 20 feet per day with an average near 10 feet per day (Barraclough and Jenson, 1976; Mundorff, et al., 1964). However, these locally measured rates are not necessarily representative of all flow rates throughout the aquifer (ERDA, 1977).

Groundwater flow is predominantly to the southwest, recharging in the north and northeastern margin of the basin and discharging to the south and southwestern areas (Figure 3-4). The annual discharge of the aquifer is approximately 6.5 million acre-feet (2.12×10^{12} gallons) (Norvitch, et al., 1969). Most of the discharge occurs as irrigation withdrawals and as springs near Hagerman and in the region west of Pocatello.

The aquifer not only provides water for the INEL operations but also supplies agriculture and other industries. Water from springs emerging in the Twin Falls-Hagerman area is used to raise fish commercially. The spring water flow of 1600 cubic feet per second constitutes 76 percent of the water used for the commercial production of fish in Idaho.

The visitor center at the Experimental Breeder Reactor I (EBR-I), 6 miles south of the ICPP, is supplied with drinking water from the aquifer. Monitoring of this well for tritium indicates that the well is relatively unaffected by current ICPP operations (ERDA, 1977). Other withdrawals from the aquifer downgradient from the ICPP occur at two wells which serve the Central Facilities Area, 4 miles south of the ICPP. Atomic City, 11 miles south, depends on the aquifer for both domestic and irrigation water supplies. The effects of aquifer contamination which could result from the release of calcine waste are analyzed for three hypothetical wells in Appendix A and discussed in Section 4 of this report.

At various locations beneath the INEL site, there are zones of perched water above the aquifer (see Figure 3-5). Recharge effects from the Big Lost River are very pronounced in the Snake River Plain Aquifer and in the perched water beneath the river. Perched water has also been found beneath the ICPP. It occurs in the shallow alluvium and in the basalt at a depth between 340 and 420 feet (Robertson, et al., 1974). The U.S. Geological Survey (USGS) routinely monitors the perched water for the presence of radionuclides and chemical pollutants.

3.1.4 Seismology

The INEL is located in Seismic Zone 2, as defined by the Uniform Building Code, October 1981, an area where destructive earthquakes may occur. No earthquake considered destructive [modified Mercalli scale intensity IX or higher (approximate magnitude 6.8 on the Richter scale)] has been recorded in the Snake River Plain. Between 1884 and 1976, 67 earthquakes with an intensity equivalent to a modified Mercalli scale intensity of V (approximately 3.8 on the Richter scale), or greater, have occurred in the eastern portion of the Snake River Plain. Of these, 29 had epicenters in Idaho, with many of the epicenters lying in or near the mountains surrounding the eastern Snake River Plain. Earthquakes at the INEL have reached a modified Mercalli intensity of V or VI, (approximate magnitude 3.8 or 4.5 on the Richter scale). The most recent large earthquake, accompanied by surface faulting about 100 miles

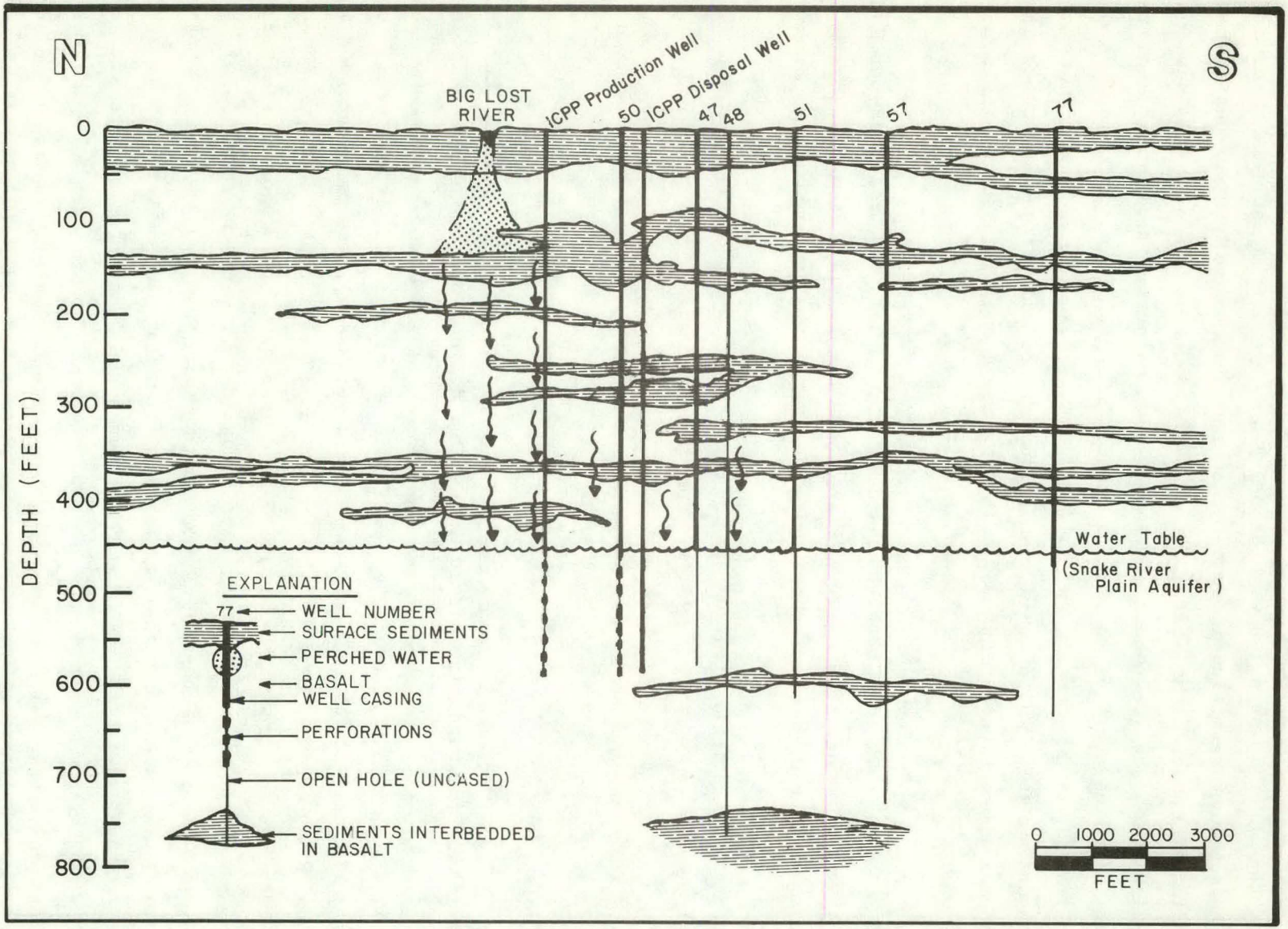


Figure 3-5. Geologic Cross Section Through the ICPP Area Showing Generalized Stratigraphy, Perched Water, Wells, and Regional Water Table (Modified from Robertson, et al., 1974)

northeast of the INEL, occurred in August 1959. It did not cause any damage at the INEL.

The USGS conducted a microseism study in 1968-1969 to determine whether the Arco or Howe faults located a few miles from the INEL boundary, or possibly other faults in the region, are sources of microseisms. No seismic activity was detected in the vicinity of the INEL. The absence of microseisms, however, does not preclude the possibility that the earth's crust in this region contains stored elastic strains. Such strains might be released by slippage along a dormant fault to produce an earthquake.

Five seismographs record vertical motion at Howe Peak (northwest of the INEL), at Taylor Mountain (southeast of Idaho Falls), at Hamer, Idaho (northwest of the INEL), at Cedar Butte (west of Atomic City), and at Juniper Gulch (north of Monteview). This instrument network is capable of detecting microseisms from the strain accumulating along faults in the mountains. It will also detect any microseisms that would precede volcanic activity in the Snake River Plain. To date, microseisms have been detected in the adjacent mountains and in distant locations, but no seismic activity has been identified as originating beneath the INEL.

3.1.5 Topography and Soils

The topographic surface of the INEL ranges in elevation from 4,692 to 7,448 feet above sea level. The soils present at the INEL vary in texture and mineral composition (McBride, et al., 1978). This is a consequence of the types of rocks from which the soils were derived. The soil at the ICPP consists of clay soil and sandy gravel with lenses of silty sand to a depth of approximately 40 feet. The sandy loam and loess generally found at the INEL are deposits derived largely from windblown sands. These soils have different ion exchange properties and sorption characteristics. The clay soil tends to have a higher sorption rate than the sand and gravels because of its larger surface area and different chemical composition. Figure 3-6 indicates the irrigation potential of the INEL.

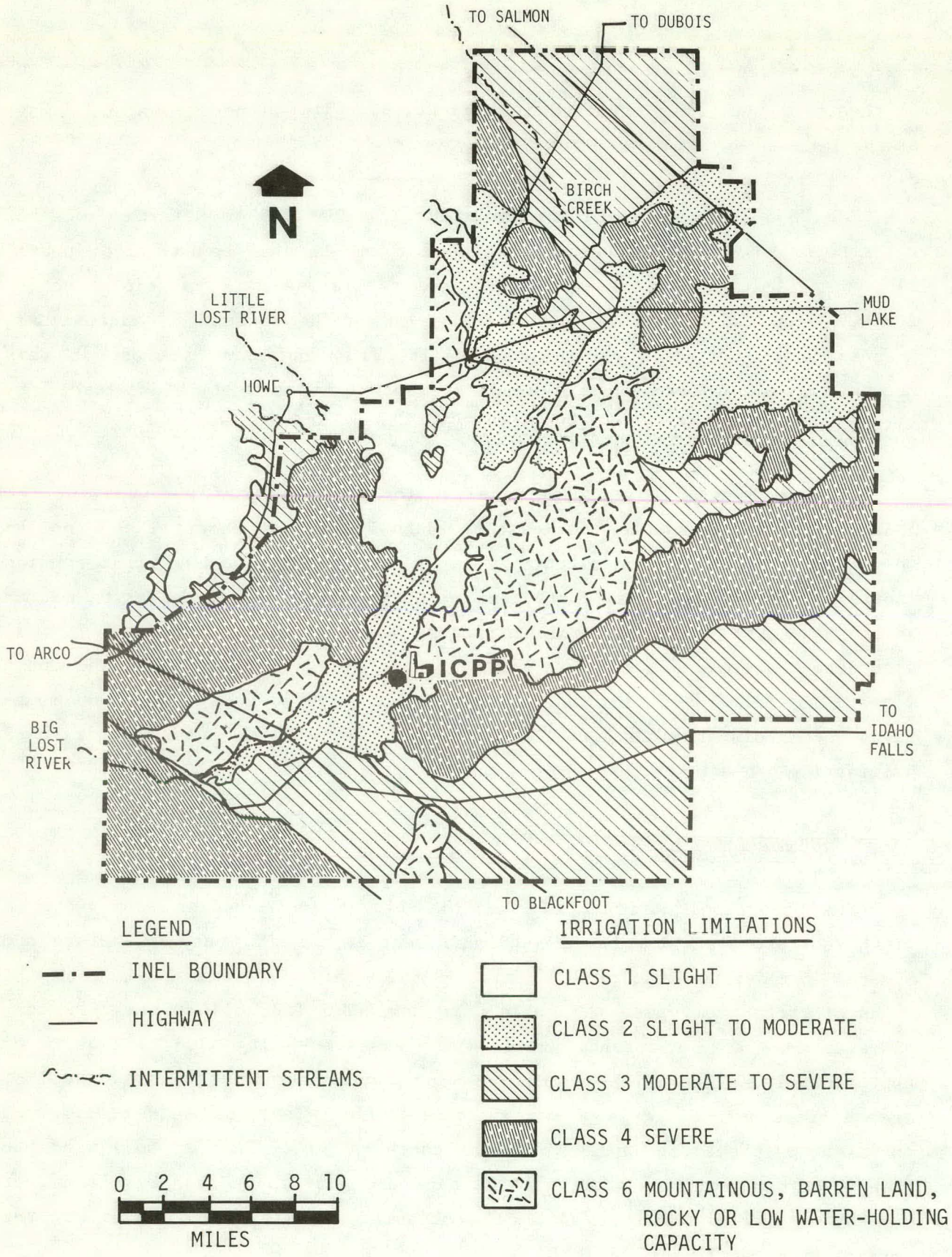


Figure 3-6. Irrigation Limitations at the INEL

Although the soils at the INEL are classified as having acceptable erosion rates for agricultural uses, other factors, such as limited moisture retention and annual precipitation, severely restrict the potential use of the land area for crop production (USDA, 1975; ERDA, 1977) as described in Subsection 3.3.

3.1.6 Meteorology*

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

3.1.6.1 Climate

The climate of the Snake River Plain is characteristic of a semiarid steppe area. The topographic features that affect local weather patterns are the northeast-southwest orientation of the plain and the mountain ranges. Air masses entering the Snake River Plain must first cross mountain barriers where much of the moisture precipitates. Therefore, rainfall at the INEL site is light.

During the 22-year period of record, temperature extremes at the INEL have varied from a low of -43°F in January to a high of 103°F in July. During winter, the average maximum temperature is approximately 31°F, and the average minimum is approximately 6°F. Summer data indicate an average maximum temperature of 83°F and an average minimum of about 46°F.

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* This subsection is based on data collected from 1954 to 1966 (Yanskey, et al., 1966). Data collected since 1966 are being prepared for publication. These data are generally consistent with previous data. Most of the data reported in this section were gathered at the INEL's Central Facilities Area, approximately 4 miles south of the ICPP.

Weather conditions at the INEL include temperature inversions. Winds and clouds associated with stormy weather may prevent normal nighttime inversions. Daytime inversions may occur during the season of lowest sun angle (winter) and extend into spring if a snow cover is present.

The INEL site is in a belt of westerly winds that are channeled by the terrain into a prevailing southwest-to-northeast direction. During the summer months, a very sharp diurnal reversal in wind direction occurs. Winds blowing from the southwest (upslope) predominate during daylight hours, and northeasterly winds prevail at night. A reversal normally occurs a few hours after sunrise and again shortly after sunset.

The average hourly wind speed reaches a minimum of about 5 miles per hour in December and a maximum of 9 miles per hour in April and May. The greatest hourly average speed was 51 miles per hour from the west-southwest (measured at a 20-foot level at the Central Facilities Area). The highest instantaneous speed recorded at this level was 78 miles per hour, with the wind from the west-southwest. Calm conditions prevail 10 percent of the time. Strong wind gusts can occur in the immediate vicinity of thunderstorms. These gusts are usually quite localized and of short duration.

One mechanism for the transport of radionuclides at the ICPP in the event of a major accident is the wind; it could carry radionuclides to population centers and agricultural areas around the INEL. Simultaneous measurements of wind velocity and direction are made at numerous locations on the Snake River Plain. These data were used to determine the atmospheric dispersion characteristics of the INEL which are discussed in Appendix A.

The average annual precipitation at the site is 8.5 inches. The maximum precipitation occurs during May and June and the minimum in July. During the 22-year period of record, there have been 11 occasions when 1.0 inch or more of rain fell in a 24-hour period. The greatest rainfall in a 24-hour period was 1.73 inches in June 1954. Only once has more than 0.5 inch of rain fallen in 1 hour; that occurred on June 10, 1969, when 1.19 inches fell.

Snowfall at the site ranges from a low of about 12 inches per year to a high of about 40 inches per year, with an annual average of 26 inches. Normal winter snowfall occurs from November through April, although occasional snow storms occur in May, June, September, and October.

The potential annual evaporation from saturated ground surface at the INEL site is approximately 36 inches. Eighty percent of this evaporation occurs between May and October. During the warmest month (July), the potential daily evaporation rate is approximately 0.25 inches/day. During the coldest months (December through February), evaporation is low and may be insignificant. Actual evaporation rates are much lower than potential rates because the ground surface is rarely saturated. Evapotranspiration by the sparse native vegetation of the Snake River Plain is estimated at between 6 to 9 inches per year. Periods when the greatest quantity of precipitation water is available for infiltration (late winter to spring) coincide with periods of relatively low evapotranspiration rates (Mundorff, et al., 1964).

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

3.1.6.2 Severe Weather Conditions

An average of two or three thunderstorms occurs during each of the months from June through August. The surface effects from thunderstorms over the Snake River Plain are usually much less severe than those experienced east of the Rocky Mountains or even in the mountains surrounding the plain. Although small hailstones frequently accompany the thunderstorms, damage from hail has not occurred at the INEL.

Since 1949, no confirmed tornadoes have occurred within the boundaries of the site. Ten confirmed and three unconfirmed funnel clouds (vortex clouds that do not reach the ground) have been observed at the site since 1954. Two small unconfirmed tornadoes which caused no damage have touched down just outside the boundary.

3.2 Ecology

Extensive surveys of the flora and fauna indigenous to the INEL have been conducted since before the site was established. The ecology of the site, which has been designated as a National Environmental Research Park, is being investigated. Studies of the movement, accumulation, and effects of radionuclides on wildlife are continuing (Markham, 1976 and 1978). These studies are discussed in Subsection 3.5.3.3.

3.2.1 Flora

The diversity of the ecosystems in the INEL area is due partly to the moderate elevation gradient of the Snake River Plain. Numerous vegetative complexes or community types are found. A generalized map depicting the distribution of the vegetation types found at the INEL is shown in Figure 3-7. The major types are sagebrush (Artemisia tridentata), lanceleaf rabbitbrush (Crysothamnus viscidiflorus), perennial herbs, and a variety of grasses (ERDA, 1977).

A plant species inventory containing 389 species representing 56 botanical families and 213 genera has been documented (Jeppson and Holte, 1978). The most diversified botanical family represented is the sunflower family. The Big Lost River, Little Lost River, and Birch Creek account for the presence of some riparian vegetation. No plants on the federal list of endangered or threatened species have been observed on the site.

3.2.2 Fauna

Small mammals found on the site include weasels, chipmunks, ground squirrels, several species of mice, kangaroo rats, and rabbits. Large mammals include coyotes, bobcats, mule deer, and antelope. Pronghorn antelope inhabit the INEL area throughout the year; however, many of the antelope are migratory. The antelope occasionally fawn on the site in the spring as they move northward into the Birch Creek and Little Lost River valleys.

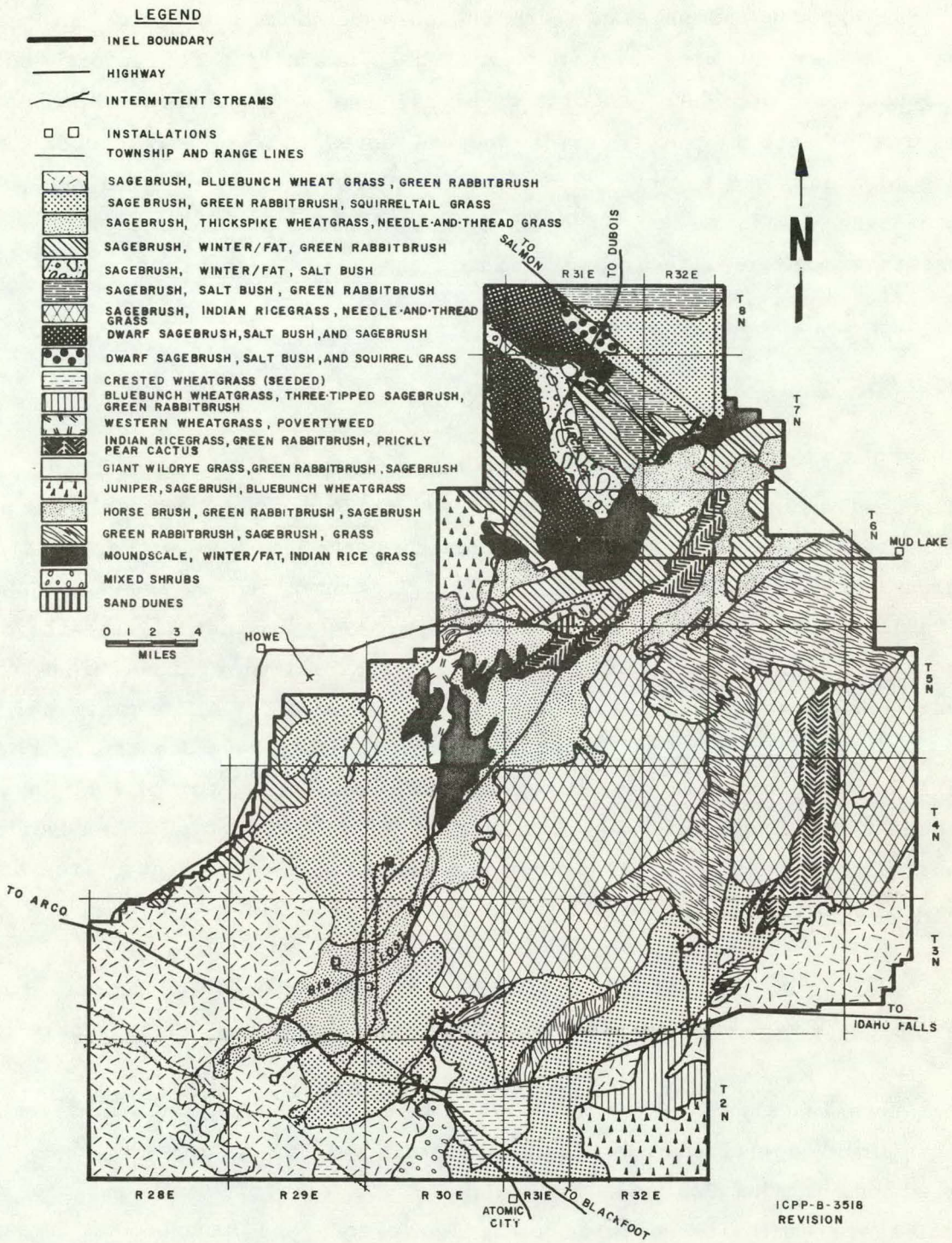


Figure 3-7. INEL Vegetation Map (Modified from McBride, 1978)

Sage grouse and pheasants are the only resident game birds in the INEL area. However, hunting is not permitted. In addition to raptors and other indigenous and introduced species of birds, some migrant species pass through the area. These migratory birds include doves, larks, hawks, ducks, geese, and golden and bald eagles. The only endangered species of bird occasionally frequenting the site are the peregrine falcon and bald eagle. Reptiles represented on the site include lizards and a few species of snakes (Sehman and Linder, 1978).

3.3 Land Use

The INEL site is committed for energy research and development, and is designated a National Environmental Research Park. Approximately 95 percent of the 894 square miles in the research park has been withdrawn from the public domain. The remainder of the land is controlled by the DOE. A series of Public Land Orders (PLOs), dating back to 1946, has established the present uses of the site. Lands originally under the control of the Bureau of Land Management were withdrawn from the public domain under three principal Public Land Orders: PLOs 318, 545, and 637, dated May 13, 1946, January 7, 1949, and April 7, 1950, respectively. Six other PLOs pertaining to the INEL lands have been issued. These orders primarily concern the transfer of managerial responsibilities and do not affect the basic purpose and intent of the original PLOs. The ICPP lies in the area withdrawn under PLO 318.

Existing facilities on INEL lands are widely spaced for increased safety. They occupy a very small percentage of the 894 square miles of available land.

Approximately 330,000 acres of the INEL are open to controlled grazing by cattle or sheep. The areas allocated for grazing at the site are mutually agreed on by the DOE and the Department of the Interior, and the grazing permits are administered through the Bureau of Land Management. Grazing is prohibited within 2 miles of any nuclear facility and no dairy cows are allowed. The ICPP is not included in the grazing zone; but it is within 4 miles of the zone.

TABLE 3-1

PRINCIPAL POPULATION CENTERS AROUND THE ICPP

City	Distance from the ICPP (miles)	Direction from the ICPP	1970 Population
Arco	19	West	1,200
Blackfoot	37	Southeast	8,700
Idaho Falls	42	East	37,100
Pocatello	52	Southeast	39,000

The INEL contributes to the economic stability of the study area. The estimated 1979 payroll for 9,740 employees is $200 million. In June 1978, the INEL employed approximately 9,400 people, about 80 percent of whom were working at the site; the remaining 20 percent were employed in support activities in Idaho Falls. The employment population of the INEL is approximately 4,300 during the day shift. About 950 persons are employed on the three other rotating shifts. There are 600 employees at the ICPP during the day shift (not including construction workers), and about 120 employees are assigned the other rotating shifts.

Most of the INEL employees come from Idaho Falls, Pocatello, and Blackfoot in Bonneville, Bannock, and Bingham Counties, respectively (see Figure 3-1). A recent INEL employee survey showed that the average employee household size was 3.1 persons, of which approximately 1.2 were children.

Social, medical, and recreational services are adequate for the present population. Some community schools are operating at capacity because of recent growth in the area, and several bond issues have been passed to increase capacities and facilities. Excess housing is currently available in Idaho Falls.

Idaho Falls and Pocatello are the major medical centers for southeastern Idaho. Bannock, Bingham, Bonneville, Butte, Lemhi, and Teton Counties have hospitals. Each county has a health and welfare department that provides some basic health services.

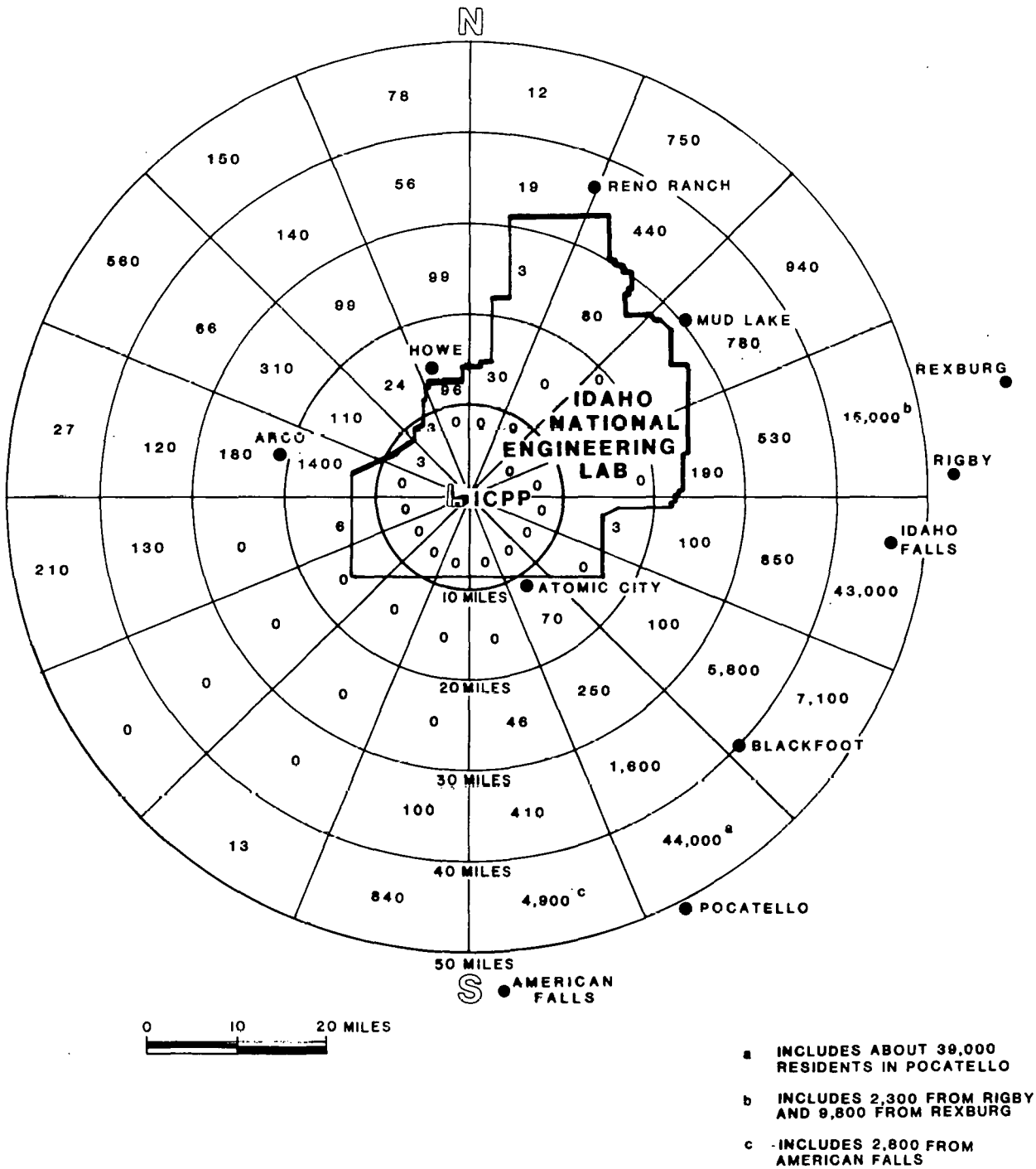


Figure 3-8. Distribution of the 1970 Population Around the INEL Centered at the ICPP

Economic and employment statistics for counties either totally or partially within the study area are presented in Table 3-2. Bonneville and Bannock Counties are the largest population centers in southeastern Idaho and consequently have the largest labor forces. They also have the highest per capita income and the second and third lowest unemployment rates, respectively. Bingham County has the third largest population and the fourth lowest unemployment rate, but the lowest per capita income. Major industries in the region include agriculture, food processing, tourism, and phosphate mining.

Native Americans of the Shoshone-Bannock Tribe reside at the Fort Hall Indian Reservation which lies partially within the study area. Employment statistics for Native Americans residing in the study area are shown in Table 3-3. Bingham County has the largest Native American population in southeastern Idaho (6 percent of the residents and 4 percent of the labor force). Unemployment is generally very high. In Minidoka County, the unemployment rate for Native Americans is four times higher than the rate for the general population. In 1979 there were 63 Native Americans employed at the INEL.

3.5 Environmental Quality and Monitoring Programs

A monitoring program to measure radioactive and nonradioactive materials resulting from routine and accidental releases from the INEL has been operational for many years. This program is carried out by the DOE's Radiological and Environmental Sciences Laboratory, the USGS, and the National Oceanic and Atmospheric Administration. It includes the determination of integrated radiation exposure, air and water quality, and the radionuclide content of foodstuffs and soils. The routine offsite monitoring program is listed in Table 3-4.

The cumulative radiation exposure from background sources at the INEL has been monitored at boundary and distant community locations. The average annual exposures for both locations were found to be the same, 0.15 rem. The calculated dose rate an individual receives from background sources is 0.15 rem per year (NCRP, 1975) and is the background dose used in this report for comparative purposes. Additional details and results of the current monitoring programs are available in annual reports (DOE, 1980).

TABLE 3-2

ECONOMIC AND EMPLOYMENT STATISTICS
FOR COUNTIES IN THE VICINITY OF THE INEL

County	Total Population[a]	Population Within 50-Mile Radius of ICPP[b]	Per Capita Income[b]	Labor Force[a]	Number Employed[a]	Number Unemployed	Unemployment Rate (Percent)[a]
Bannock	63,622	44,000[c]	$ 6,497	31,708	30,198	1,510	4.8
Bingham	36,643	20,079	4,487	16,641	15,685	956	5.7
Blaine	9,140	210	6,253	4,942	4,512	430	8.7
Bonneville	62,790	59,270	6,503	26,382	25,222	1,160	4.4
Butte	3,300	2,840	5,392	1,852	1,776	76	4.1
Clark	813	31	5,090	333	302	31	9.3
Custer	3,300	253	4,623	1,472	1,370	102	6.9
Fremont	10,671	0	4,312	4,548	4,246	302	6.6
Jefferson	14,071	3,216	4,500	5,870	5,515	355	6.0
Lemhi	7,325	0	4,886	2,798	2,560	238	8.5
Madison	17,685	0	4,232	8,470	8,126	344	4.1
Minidoka	19,440	0	4,599	8,372	7,785	587	7.0
Power	6,525	940	4,917	3,079	2,878	201	6.5
TOTALS	225,325	130,839	$66,291	116,467	110,175	6,292	Average 6.3

a. Idaho Department of Employment, Affirmative Action Statistics 1979, May 1979a.

b. Idaho Department of Employment, Idaho Economic Indicators, Vol. XIV, No. 4, April 1979b.

c. Includes residents of City of Pocatello, just outside 50-mile radius.

TABLE 3-3

EMPLOYMENT STATISTICS FOR NATIVE AMERICANS RESIDING IN THE INEL AREA[a]

County	Population	Labor Force	Employed	Number Unemployed	Unemployment Rate (Percent)
Bannock	878	285	222	63	22.1
Bingham	2,107	686	532	154	22.4
Blaine	13	132[b]	120	12	9.1
Bonneville	245	79	69	10	12.6
Butte	14	ND[c]	ND	ND	ND
Clark	8	5[b]	5	0	0
Custer	16	4	3	1	25.0
Fremont	82	30	27	3	10.0
Jefferson	198	48	40	8	16.7
Lemhi	51	4	3	1	25.0
Madison	55	26	21	5	19.2
Minidoka	105	38	27	11	28.9
Power	279	58	37	21	36.2

a. Idaho Department of Employment, Affirmative Action Statistics, (1979a).

b. Includes all minority groups.

c. No data.

3.5.1 Air Quality

Levels of airborne radiological and nonradiological particulates are monitored offsite by a network of 10 continuous air samplers at locations shown in Figure 3-9 (DOE, 1980). The INEL is in Air Quality Control Region 061 in an area that has been designated as Class II by the State of Idaho. National ambient air quality standards must be maintained in Class II areas. Although standards for total suspended particulates and SO_2 are

TABLE 3-4

OFFSITE MONITORING PROGRAM SUMMARY FOR THE INEL

Medium Sampled	Type of Analysis	Frequency of Analysis	Approximate Detection Limit
Air	Gross beta	Weekly	8×10^{-15} µCi/ml
	HTO[a]	3 to 7 weeks	1×10^{-11} µCi/ml
	Specific gamma	Quarterly	1 to 10×10^{-15} µCi/ml
	Pu, Am	Quarterly	6×10^{-18} µCi/ml
	Sr-90	Quarterly	1×10^{-15} µCi/ml
Water	Gross alpha	Semiannually	3×10^{-9} µCi/ml
	Gross beta	Semiannually	5×10^{-9} µCi/ml
	HTO	Semiannually	4×10^{-7} µCi/ml
Milk	I-131	Monthly[b]	1×10^{-9} µCi/ml
	Sr-90	Annually	2×10^{-9} µCi/ml
	H-3	Annually	4×10^{-7} µCi/ml
Wheat	Specific gamma	Annually	4×10^{-9} µCi/g
	Sr-90	Annually	4×10^{-9} µCi/g
Lettuce	Specific gamma	Annually	1×10^{-8} µCi/g
	Sr-90	Annually	8×10^{-8} µCi/g
Soil	Specific gamma	Biennially	4×10^{-8} µCi/g
	Pu, Am	Biennially	4×10^{-9} µCi/g
	Sr-90	Biennially	9×10^{-8} µCi/g
Direct radiation exposure	Thermoluminescent dosimeter	Semiannually	5 mR

a. Tritiated water.

b. One dairy is sampled weekly.

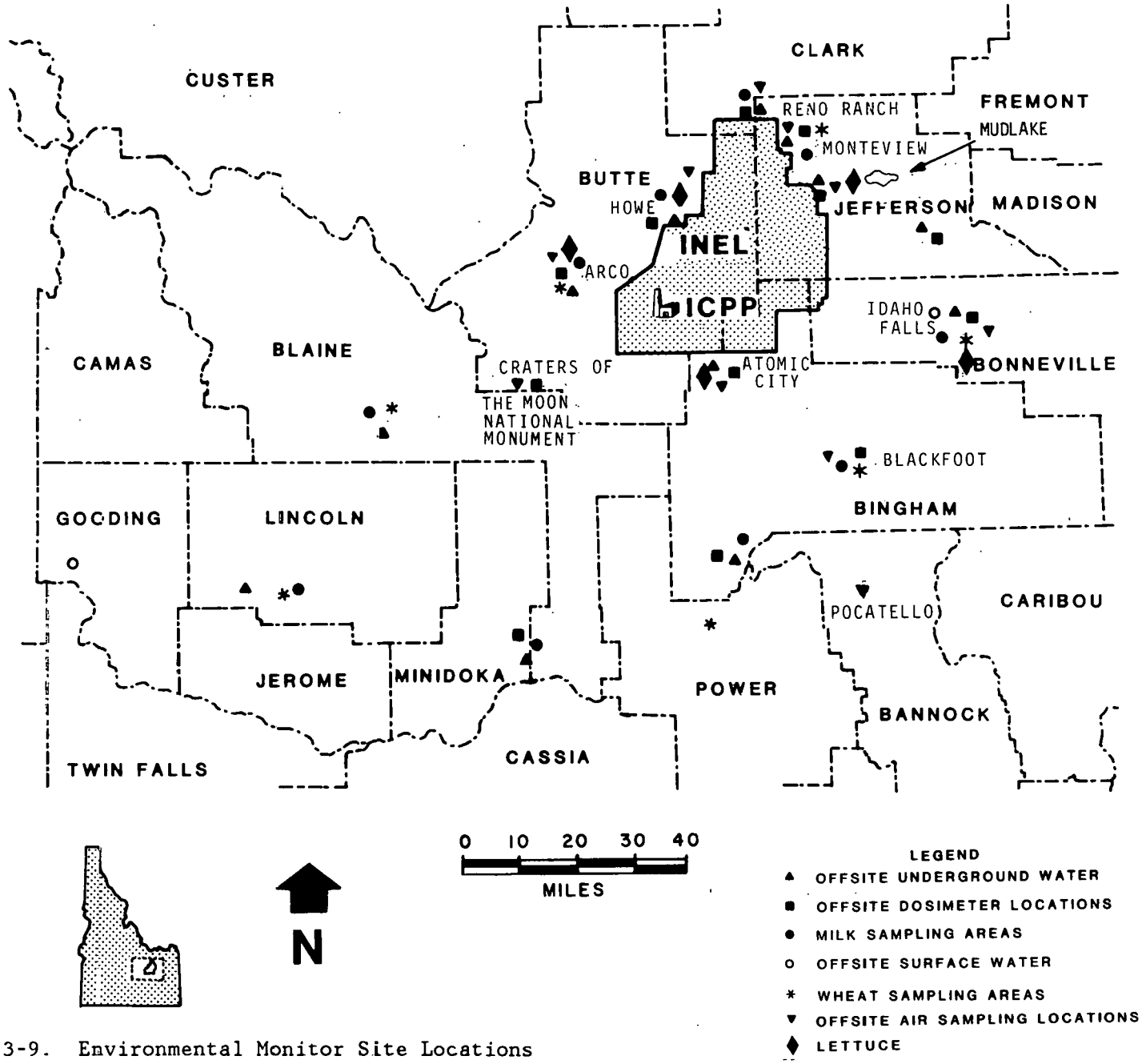


Figure 3-9. Environmental Monitor Site Locations

occasionally exceeded elsewhere in the region (Pocatello and Soda Springs), the INEL area is within all applicable standards.

Because the identity and quantity of radionuclides released from the INEL facilities are known from an extensive effluent monitoring program, an accurate determination of the impact of the INEL operations on the environment can be made. Five-year (1974-1978) average concentrations of radionuclides, as well as the applicable state and federal standards, are presented in Table 3-5. Airborne beta activity measured at onsite locations is rarely statistically different from that of distant locations, both having worldwide fallout and naturally occurring radioactivity. Radionuclide concentrations were well below the concentration guides established for the protection of public health and safety (ERDAM, 1977).

Nonradiological air pollutants, which are currently measured or calculated, are sulfur dioxide (SO_2), nitrogen oxides (NO_x), and total suspended particulates (TSP). In 1972, SO_2 and NO_2 were monitored for a period of nine weeks at five onsite locations. None of the samples had a concentration of SO_2 greater than the detection limit of 7.5 $\mu g/m^3$. The highest NO_2 concentration measured was 4.3 $\mu g/m^3$. Because of low ambient concentrations, subsequent concentrations have been calculated from emissions data reported by the INEL Industrial Waste Management Information System (DOE, 1979). Calculated annual average ground-level concentrations of SO_2 and NO_x at the southern INEL boundary (near Atomic City) are shown in Table 3-6. The calculations utilize the MESODIF model (Start and Wendell, 1974). The ICPP is a major source of SO_2 and the primary source of NO_x emissions at the INEL. At the INEL boundary, calculated concentrations of SO_2 and NO_x are well below the national primary ambient air quality standards (40 CFR 50) shown in Table 3-6.

The air samplers at locations shown in Figure 3-9 are used primarily to detect radioactive particulates. The filters are also weighed quarterly to estimate total suspended particulates. Results are shown in Table 3-6. The average particulate concentrations at groups of stations occasionally exceed the national secondary ambient air quality standard of 60 micrograms per cubic meter (40 CFR 50). Major sources of particulates are believed to be dust from the dry desert floor; offsite farming activities; and in some locations,

TABLE 3-5

RADIOACTIVITY CONCENTRATIONS IN AIR AT OR NEAR THE INEL[a]
(Annual Concentration in Microcuries per Milliliter)

Nuclide	INEL[b]		Southern Boundary[c]		Offsite[d]		Federal Guideline[e]
	5-Yr Avg.	High Conc.	5-Yr Avg.	High Conc.	5-Yr Avg.	High Conc.	
Gross beta ($\times 10^{-15}$)	297	586	250	470	249	530	100,000
Gross alpha ($\times 10^{-18}$)	184	216	160[f]	187	283	334	20,000
Pu-238 ($\times 10^{-18}$)	22	31	NSS[g]	NSS	NSS	NSS	70,000
Pu-239-240 ($\times 10^{-18}$)	43	67	32	100[f]	40	80	60,000
Am-241 ($\times 10^{-18}$)	10	10	7	7	12	12	200,000
Cs-137 ($\times 10^{-15}$)	7.4	20	2.2	4	3.5	6	500,000
Co-60 ($\times 10^{-15}$)	NSS	NSS	NSS	NSS	NSS	NSS	300,000
Sb-125 ($\times 10^{-15}$)	5.8	16.5	1.8	3	0.9	2.6	900,000
Sr-90 ($\times 10^{-15}$)	3.1	4.7	ND[h]	ND	1.9	4.0	30,000
Ce-144 ($\times 10^{-15}$)	33.3	61.6	27.3	56	31.9	63	200,000
Zr-95 ($\times 10^{-15}$)	12.0	42.5	14.0	25	17.4	34	1,000,000
Ru-106 ($\times 10^{-15}$)	17.1	33.8	14.6	32	17.2	33	200,000

a. Data are for 1974-1978 except for Am-241 which is for 1975 only.

b. Measured at the Experimental Field Station, approximately 3 miles north of the ICPP.

c. Measured at Atomic City, approximately 12 miles southeast of the ICPP, unless otherwise indicated.

d. Measured at Idaho Falls, Pocatello, and Blackfoot; values averaged.

e. ERDA Manual Chapter 0524, "Standards for Radiation Protection," Appendix A, (uncontrolled area). 10 CFR 20, Appendix B and State of Idaho standards are the same as ERDA Manual Chapter 0524.

f. Measured at Arco.

g. NSS = not statistically significant at the 95 percent confidence interval.

h. ND = no data.

TABLE 3-6

NONRADIOLOGICAL AIR CONTAMINANT CONCENTRATIONS
ON OR NEAR THE INEL SITE

(Concentrations in Micrograms per Cubic Meter)

Calculated Annual Average Ground-Level Concentration			Measured Annual Average Concentration of Total Suspended Particulates (a)		
Year	Sulfur Dioxide	Nitrogen Oxides	Onsite (11 Stations)	Boundary (7 Stations)	Distant (2 Stations)
1974	0.5	0.3	ND[b]	ND	ND
1975[c]	0.8	0.4	30 - 46	60 - 69	ND
1976	0.6	0.3	14 ± 14	50 ± 20	70 ± 40
1977	0.5	0.4	40 ± 10	60 ± 20	60 ± 20
1978	0.4	0.7	30 ± 20	40 ± 30	80 ± 40
Standard	80	100	60		

a. Average ± the uncertainty at the 95 percent confidence level.

b. ND = no data; no measurements of total suspended particulates were made.

c. Atmospheric particulate monitoring for 1975 included onsite and offsite locations.

vehicle exhaust, industrial activity, and combustion of various fuels for heating. Comparisons of average concentrations of particulates at boundary and distant locations demonstrate no significant contribution from INEL activities to offsite concentrations of particulates.

3.5.2 Water Quality

Water samples are collected semiannually from offsite drinking water production wells and from the Snake River as shown in Figure 3-9.

None of the offsite water samples collected from 1974 through 1979 contained radionuclide concentrations above the detection limits of the analyses.

The detection limits for gross alpha, gross beta, and tritium (3×10^{-9}, 5×10^{-9}, and 4×10^{-7} μCi/ml, respectively) are about 10, 20, and 0.01 percent, respectively, of the concentration guides for an uncontrolled offsite area (ERDAM, 1977). These detection limits are also below EPA community drinking water standards (40 CFR 141).

When in use, 19 onsite water production wells are sampled monthly by the DOE. In addition, the USGS has over 100 observation wells on or near the site, many of which are sampled semiannually. Locations of these wells are shown in the final EIS on INEL waste management operations (ERDA, 1977).

Production wells from 1974 through 1979 have shown no gross alpha activity. Only one sample showed gross beta activity greater than detection limits. Analyses of aquifer samples show that, after 28 years of disposal of low-level radioactive waste to the aquifer, tritium, the most mobile of the radionuclides in the aquifer, is not detectable at any point farther than 2 miles inside the site boundary (7.5 miles from the point of disposal). The shape of the tritium plume and computer projections of the future extent of the plume are shown in the final EIS on INEL waste management operations (ERDA, 1977). Recent sampling for tritium demonstrates the actual 1980 concentrations of tritium in the aquifer are substantially less than those predicted by the model for 1980. Tritium in drinking water at the Central Facilities Area results in less than 4 millirem per year total body dose equivalent to facility workers; i.e., less than that allowed for members of the general public using a community drinking water source (40 CFR 141). Strontium-90 and iodine-129 concentrations were above the detection limit only for those samples collected within 2 miles of the ICPP disposal well, or approximately 6 miles inside the nearest site boundary (ERDA, 1977; Barraclough, 1981). The detection limits for strontium-90 and iodine-129 (5×10^{-9} and 2×10^{-9} μCi/ml, respectively) are about 2 and 3 percent, respectively, of the applicable concentration guides (ERDAM, 1977). Cesium and actinides have been shown to be even less mobile in the aquifer than strontium and iodine (DOE, 1980). Plutonium appears to be retained near the point of release (Polzer, et al., 1976).

Nonradiological pollutants in the aquifer are monitored at the same group of wells that are used for radiological monitoring. The distribution of chlorides, chromium (previously used the test reactor area), sodium, and measurement of specific conductance as of 1968 are provided in the final EIS on INEL waste management operations (ERDA, 1977). These waste constituents are from disposal at the test reactor area and the ICPP. Representations of chlorides, sodium, nitrates, and specific conductance in the aquifer for 1977, 1977, 1979, and 1978, respectively, have been prepared by Barraclough (1981). These plumes are less extensive than the tritium plume mentioned earlier. Representative concentrations are shown in Table 3-7. The ICPP production wells are north of the ICPP, well USGS #40 is located at the ICPP fenceline southwest of the disposal well, well USGS #77 is about 1.2 miles south of the ICPP, the Central Facilities Area production wells are about 2.5 miles south of the ICPP, and the Cerro Grande well is located just outside the southern site boundary about 8.7 miles south of the ICPP. Production wells at the ICPP and Central Facilities Area were tested for inorganic and organic chemicals. Results are below the standards for community drinking water systems (40 CFR 141).

3.5.3 Other Monitoring Programs

3.5.3.1 Soil Sampling

Surface soil samples collected from distant and boundary locations during the period 1971 to 1976 were analyzed for alpha- and gamma-emitting radionuclides and strontium-90.

Background concentrations of natural and fallout radionuclides in the surface soil surrounding the INEL are shown in Table 3-8 (DOE, 1978). Data analysis indicates that radionuclides in the soils at the site boundary, which may have resulted from the INEL operations, cannot be distinguished from worldwide fallout activity.

TABLE 3-7

NONRADIOLOGICAL GROUNDWATER QUALITY

	Production Wells		Monitor Wells			Normal Aquifer Concentration	Drinking Water Standard[a]
	ICPP Well in Service	CFA #1	USGS #40	USGS #77	Cerro Grande		
Chloride April 1977	8	54	123	56	11	9 to 10	No standard
Sodium April 1977	5	14	36	21	8	7 to 9	No standard
Nitrate January 1979	1	18	105	13	-	1 to 5	45
Chromium April 1976	BDL[b]	BDL	BDL	BDL	BDL	-	0.05
Specific Conductance (mho/cm) 1976-79 Average Concentration	3.1×10^{-4}	4.5×10^{-4}	8.4×10^{-4}	4.7×10^{-4}	2.7×10^{-4}	2.5×10^{-4} to 3.3×10^{-4}	No standard

a. EPA National Interim Primary Drinking Water Regulations 40 CFR 141 and Idaho Regulations for Public Drinking Water Systems (Idaho Department of Health and Welfare, 1977).

b. BDL means below detection limit of 0.008 mg/l at 95 percent confidence limit.

TABLE 3-8

RADIONUCLIDES IN SURFACE SOILS SURROUNDING THE INEL (1970 TO 1975)[a]

Radionuclide	Location	Geometric Average[b] (pCi/g)	Geometric Average[b] (pCi/$m^2 \times 10^3$)	Number of Samples	Approximate Detection Limit (pCi/g)	Approximate Detection Limit (pCi/$m^2 \times 10^3$)
Fallout						
Cs-137	Boundary	$0.83 \overset{\times}{\div} 1.2$	$50 \overset{\times}{\div} 1.2$	41	0.04	3
	Distant	$1.14 \overset{\times}{\div} 1.3$	$66 \overset{\times}{\div} 1.3$	18	0.04	3
Sr-90	Boundary	$0.50 \overset{\times}{\div} 1.2$	$29 \overset{\times}{\div} 1.2$	36	0.09	10
	Distant	$0.55 \overset{\times}{\div} 1.7$	$40 \overset{\times}{\div} 1.2$	18	0.09	10
Pu-238	Boundary	$0.0025 \overset{\times}{\div} 1.4$	$0.14 \overset{\times}{\div} 1.2$	35	0.002	0.2
	Distant	$0.0030 \overset{\times}{\div} 1.4$	$0.18 \overset{\times}{\div} 1.3$	18	0.002	0.2
Pu-239	Boundary	$0.018 \overset{\times}{\div} 1.2$	$0.98 \overset{\times}{\div} 1.2$	35	0.004	0.3
	Distant	$0.022 \overset{\times}{\div} 1.4$	$1.17 \overset{\times}{\div} 1.4$	18	0.004	0.3
Pu-241	Boundary	$0.0043 \overset{\times}{\div} 1.3$	$0.26 \overset{\times}{\div} 1.3$	22	0.004	0.3
	Distant	$0.0050 \overset{\times}{\div} 1.6$	$0.31 \overset{\times}{\div} 1.4$	14	0.004	0.3
Natural						
U-238[c]	Southeast Idaho	$1.52 \overset{\times}{\div} 1.03$	$95.1 \overset{\times}{\div} 1.05$	116	0.04	3
Total Series[d]	Southeast Idaho	21	1300	53	NA	NA
Th-232[e]	Southeast Idaho	$1.34 \overset{\times}{\div} 1.04$	$84.1 \overset{\times}{\div} 1.05$	114	0.04	3
Total Series[d]	Southeast Idaho	13	840	53	NA	NA
K-40	Southeast Idaho	$19.5 \overset{\times}{\div} 1.03$	$1220 \overset{\times}{\div} 1.04$	125	0.05	4

a. Soil samples collected to a depth of 5 cm.

b. Geometric average $\overset{\times}{\div}$ 2 standard geometric deviations of the mean. If data are $1.52 \overset{\times}{\div} 1.03$, then upper 95 percent confidence level is 1.52×1.03, and lower 95 percent confidence level is $1.52 \div 1.03$.

c. Based on the Pb-214 activity.

d. Secular equilibrium assumed. Does not account for radon diffusion.

e. Based on the Ac-228 activity.

3.5.3.2 Food Sampling

Milk, wheat, and lettuce are sampled routinely. These products are pathways by which airborne radionuclides, possibly from the INEL operations, might reach the public (see Figure 3-9).

Milk samples are collected monthly except for the Idaho Falls sample which is collected weekly. All milk samples are analyzed for iodine-131, and for strontium-90, and once per year for tritium. Results indicate that radionuclides, when detected, are from fallout and not from the INEL operations (DOE, 1980).

3.5.3.3 Biological Sampling

Investigations of radionuclides in flora and fauna on the INEL site have been conducted for many years. More recent studies by the Radiological and Environmental Sciences Laboratory are summarized in progress reports (Markham, et al., 1976, 1978) and reported in the technical literature. These studies include radionuclide uptake by plants, measurement of radionuclide concentrations in animal tissue, determination of dose rates to animals from exposure to radioactivity, and investigation of movements of animals onsite and offsite. Many of the past and continuing studies seek to characterize the environment of the INEL site.

Some investigations of flora and fauna have pertained specifically to radionuclides released by the ICPP. Thyroids of pronghorn antelope have been analyzed for iodine-131 (Markham, et al., 1980a) and rabbit thyroids have been analyzed for iodine-129 (Bowman, et al., 1976). Mourning dove (Markham, et al., 1976), sage grouse (Connelly and Ball, 1978), raptors (Craig, et al., 1979), and antelope (Markham, et al., in press) have been examined for the presence of a wide variety of gamma-emitting radionuclides. Antelope bone has been tested for strontium-90 (Markham, et al., 1980b). Although detectable concentrations of these radionuclides have been found, there is no significant health hazard to the animals since annual doses are substantially less than those allowed for the general human population. Nor is there a health hazard to any human who might consume game animals which have detectable levels of

these radionuclides. Hunting is prohibited on the INEL. The maximum annual dose to a person eating meat from an animal contaminated by present ICPP activities would be 4 millirem, or 3 percent of background radiation (DOE, 1980).

REFERENCES FOR SECTION 3

Barraclough, J. T. and R. G. Jensen, "Hydrology of the National Reactor Testing Station Idaho, 1971-1973," IDO-22055, 1976.

Barraclough, J. T., et al., "Hydrology of the Solid Waste Burial Ground as Related to the Potential Migration of Radionuclides," Idaho National Engineering Laboratory, IDO-22056, August 1976.

Barraclough, J. T., et al., "Hydrologic Conditions at the Idaho National Engineering Laboratory, Idaho, Emphasis 1974-1978," Draft, 1981.

Bowman, G. C., et al., "Iodine-129 in Rabbit Thyroids on the INEL Site," in 1975 Progress Report, Idaho National Engineering Laboratory Site Radioecology-Ecology Programs, O. D. Markham, Ed., IDO-12080, June 1976.

Caldwell, H. H., Ed., Idaho Economic Atlas, Idaho Bureau of Mines and Geology, Moscow, Idaho, 1970.

40 CFR 50, (Code of Federal Regulations), "Protection of Environment," "National Primary and Secondary Ambient Air Quality Standards," U.S. Government Printing Office, Washington, D.C., July 1980.

40 CFR 141, (Code of Federal Regulations), Title 40, "Protection of Environment," Part 141, "National Interim Primary Drinking Water Regulations," U.S. Government Printing Office, Washington, D.C., May 1980.

Connelly, J. W. and I. J. Ball, "The Ecology of Sage Grouse on the Idaho National Engineering Laboratory Site," in Ecological Studies on the Idaho National Engineering Laboratory Site - 1978 Progress Report, O. D. Markham, Ed., IDO-12087, December 1978.

Craig, T. H., et al., "Radionuclide Concentrations in Nestling Raptors near Nuclear Facilities," Wilson Bull. 91:72-77, March 1979.

DOE (U.S. Department of Energy), "1979 Environmental Monitoring Program Report for Idaho National Engineering Laboratory Site," IDO-12082 (79), May 1980.

DOE (U.S. Department of Energy), "Industrial Waste Management Information for 1978 and Record-to-Date," IDO-10057 (78), 1979.

ERDA (U.S. Energy Research and Development Adminstration), "Final Environmental Impact Statement: Waste Management Operations, INEL" ERDA- 1536, U.S. Government Printing Office, Washington, D.C., 1977.

ERDAM (U.S. Energy Research and Development Administration), "Standards for Radiation Protection," ERDA Manual Chapter 0524, 1977.

Idaho Department of Employment, Affirmative Action Statistics 1979, May 1979a.

Idaho Department of Employment, Idaho Economic Indicators, Vol. XIV, No. 4, April 1979b.

Idaho Department of Health and Welfare, "Idaho Regulations for Public Drinking Water Systems," Title I, Chapter 8, 1977.

Jeppson, R. J. and K. E. Holte, "Flora of the Idaho National Engineering Laboratory Site" in Ecological Studies on the Idaho National Engineering Laboratory Site, Progress Report, O. D. Markham, Ed., IDO-12087, December 1978.

Kuntz, M. A., "Geology of the Arco-Big Southern Butte Area, Snake River Plain, and Potential Volcanic Hazards to the Radioactive Waste Management Complex and Other Waste Storage and Reactor Facilities at the Idaho National Engineering Laboratory, Idaho," Open File Report 78-691, U.S. Geological Survey, 1978.

Kuntz, M. A., "An Evaluation of Potential Volcanic Hazards at the Radioactive Waste Management Complex, Idaho National Engineering Labora- tory, Idaho," Open File Report 80-388, U.S. Geological Survey, 1980.

Markham, O. D., Ed., "Ecological Studies on the Idaho National Engineering Laboratory Site," Progress Report, IDO-12087, December, 1978.

Markham, O. D., Ed., "1975 Progress Report, Idaho National Engineering Laboratory, Site Radioecology-Ecology Programs," IDO-12080, June, 1976.

Markham, O. D., et al., "Iodine-131 Concentrations in Air, Milk, and Antelope Thyroids in Southeastern Idaho," Health Physics 38:321-326, March 1980a.

Markham, O. D., et al., "Plutonium in the Lungs of Pronghorn Antelope Near a Nuclear Fuel Reprocessing Plant," Health Physics 37:398-400, September 1979.

Markham, O. D., et al., "Radionuclides in Pronghorn Resulting from Nuclear Fuel Reprocessing and Worldwide Fallout," J. Wildl. Manage., in press.

Markham, O. D., et al., "Strontium-90 Concentrations in Pronghorn Antelope Bones Near a Nuclear Fuel Reprocessing Plant," Health Physics 38:811-816, May 1980b.

McBride, R. et al., "Vegetation Types and Surface Soils of the Idaho National Engineering Laboratory Site," IDO-12084, U.S. Department of Energy, Idaho Operations Office, Idaho Falls, Idaho, 1978.

Mundorff, M. J., et al., "Groundwater for Irrigation in the Snake River Basin in Idaho," U.S. Geological Survey Water Supply Paper 1654, 1964.

Nace, R. L., et al., "Generalized Geologic Framework of the National Reactor Testing Station - A Summary," U.S. Geological Survey Professional Paper 725-B, 1975.

Nace, R. L., et al., "Physical Environment of the National Reactor Testing Station, Idaho - A Summary II," U.S. Geological Survey Professional Paper 725-A, 1972, p. 38.

NCRP (National Council on Radiation Protection and Measurement), "Natural Background Radiation in the United States," NCRP-45, NCRP Publication Office, Washington, D.C., 1975.

Norvitch, R. F., et al., "Artificial Recharge to the Snake River Plain Aquifer; An Evaluation of Potential and Effect," Water Information Bulletin No. 12, issued by Idaho Department of Reclamation, Boise, Idaho, 1969, p. 20.

Polzer, W. L. et al., "Special Analyses for Plutonium and Americium in Water from the Snake River Plain Aquifer," IDO-12081, November, 1976.

Robertson, J. B., et al., "Influence of Liquid Waste Disposal on the Geochemistry of Water at the National Reactor Testing Station, Idaho--1952-1970," U.S. Geological Survey Water Resources Division, Idaho Falls, Idaho, IDO-22053, February 1974.

Sehman, R.W. and A. D. Linder, "Amphibian and Reptilian Fauna of the Idaho National Engineering Laboratory Site," IDO 12086, August, 1978.

Start, G. E. and L. L. Wendell, "Regional Efflüent Dispersion Calculations Considering Spatial and Temporal Meteorological Variations," Technical Memorandum ERL ARL-44, National Oceanic and Atmospheric Administration, 1974.

USDA (U.S. Department of Agriculture), Soil Conservation Service, "Soil Survey of Jefferson County, Idaho," 1975.

Yanskey, G. R., et al., "Climatology of the National Reactor Testing Station," IDO-12048, U.S. Atomic Energy Commission, 1966.

4.0 ENVIRONMENTAL CONSEQUENCES

4.1 Introduction

This section summarizes the environmental effects of implementing the alternatives evaluated in this document. More detailed information about environmental effects is available in supporting documents (ERDA, 1977b; DOE, 1980a) and in Appendixes A and B.

The method used to determine environmental effects of the candidate alternatives was to develop a series of scenarios for the construction phase, operations and waste shipment phase, decontamination and decommissioning phase (D&D), and disposal phase of each alternative. The scenarios are based on conservative assumptions and consider both events that are certain to occur if an alternative is implemented and abnormal events that are not expected to occur. Consequently, the environmental impacts discussed in this section should not be exceeded by the impacts of the alternative finally selected for implementation.

A pictorial diagram is included for each scenario to help the reader visualize what happens. Calculations were performed to estimate environmental effects for the assumed conditions of the scenario. For example, in case of an accident during operations, the cause of the release is depicted; the benefit of the atmospheric protection system is described by showing that the plume of radioactive material would exit through the facility ventilation system; the maximum individual (the individual exposed to the greatest concentration of contaminants) is located at the Idaho National Engineering Laboratory (INEL) boundary in the path of the plume; and the affected population is shown to be located in the plume's path at a greater distance from the INEL.

The scenarios are grouped so that the discussion of effects focuses both on events that are certain to occur and events that are not expected to occur in the short and long term. Certain-to-occur events include construction activities, routine operations, and operational accidents as well as individual intrusion into and living over the waste after institutional

control has ceased. Events that are not expected to occur include events of nature that severely disrupt the waste containment or isolation.

In this section, the assumptions and methodology used to determine environmental effects are stated. The concepts of risk and health effects are described to give perspective to the radionuclide and toxic chemical exposures postulated to occur from the release scenarios. Significant environmental effects are identified and grouped in two ways. They are first discussed by effect (Subsection 4.5) and then summarized by alternative (Subsection 4.6). The environmental effects are discussed in detail. A comparative analysis is provided in Section 2.

4.2 Assumptions and Methodology

4.2.1 Evaluation of Release Scenarios

In order to estimate the environmental effects of implementing the waste management alternatives evaluated in this report, a series of scenarios that describes releases of toxic chemicals and radionuclides was developed. The purpose of the scenarios is twofold: (1) by applying the same scenario to each alternative, a consistent comparison of alternatives is achieved; thus, even though the calculated effects are only as accurate as the assumptions, the differences between the alternatives should be valid; and (2) by basing the scenarios on conservative assumptions, the effects of toxic chemical and radionuclide releases from implementing the alternative finally selected should be less than the effects described in this report.

In order to select a waste management strategy based on a thorough understanding of the environmental consequences, it is necessary to consider several scenarios for waste releases at the ICPP and at an offsite federal repository. Every effort has been made to consider all conceivable types of radionuclide releases and exposure pathways, and then choose representative or bounding cases on which to base the calculations. Release scenarios have been evaluated for all phases of alternative implementation. Nonradiological and radiological effects have been considered for each phase of alternative implementation. The release scenarios evaluated in this report are described

briefly below. More detailed descriptions appear in Subsection 4.5 and Appendix A.

Construction activities would cause only nonradiological effects. Air quality effects would result from vehicle exhaust and fugitive dust.

Some operational releases would cause radiological effects. Dose commitments are calculated for routine operations and accidents postulated to occur during waste processing and decontamination and decommissioning of the processing facilities. Operational and waste shipment phase waste releases are postulated to occur from the following scenarios:

- routine operations,
- routine waste shipment exposure,
- waste shipment accident,
- calcine spill,
- aircraft impact that strikes the bins,
- decontamination solution spill, and
- extraction solvent fire during actinide removal.

Disposal phase waste releases at the INEL are postulated to occur from the following scenarios:

- waste migration into groundwater after bin disintegration,
- intrusion into the bins by an archaeologist or prospector,
- living at the contaminated site while consuming food grown in soil that has been contaminated by prior intrusions,
- living over the bins after containment failure, and
- severe geologic disruption that disperses the waste.

Environmental effects of construction and routine operation of the federal repository are addressed in detail in the EIS for commercially generated radioactive waste (DOE, 1980a). Repository effects will occur regardless of the disposal of INEL waste at the repository. However, the fraction of repository effects due to disposal of INEL waste have been calculated and included in the effects of alternatives that involve offsite disposal.

Several accident scenarios postulated for the federal repository have been modified in order to evaluate the effects of accidents resulting from disposal of INEL waste. Calculations of effects at the repository due to disposal of INEL waste are based on the inventory of INEL waste within the repository. The scenarios evaluated at the geologic repository are

- waste canister dropped down a mine shaft which ruptures the canister and disperses radioactive waste,
- fault and flooding of the repository which leaches and disperses radioactive waste,
- exploratory drilling which penetrates a waste canister and brings the waste to the surface, and
- solution mining for recovery of table salt after waste containers have disintegrated. (This scenerio is applicable only in a repository located in a salt formation.)

The effects of radionuclides released in the scenarios are dependent on how the public is exposed to radiation. Potential exposure pathways for airborne releases are shown in Figure 4-1. The pathways include external exposure to direct radiation and internal exposure resulting from inhalation and ingestion of radionuclides. The ingestion pathway includes the consumption of contaminated foods as well as consumption of contaminated drinking water. There are no operational waterborne releases of radionuclides from implementation of the waste management alternatives.

The exposure pathways are identified for each scenario in Table 4-1. Also summarized in Table 4-1 are the persons affected by exposure to radionuclides from the release scenarios. Some of the pathways result in exposure to only a single or a few individuals. These individuals are considered to be members of the total population and the exposures are included in the population totals. However, occupational exposures are not included in the population totals.

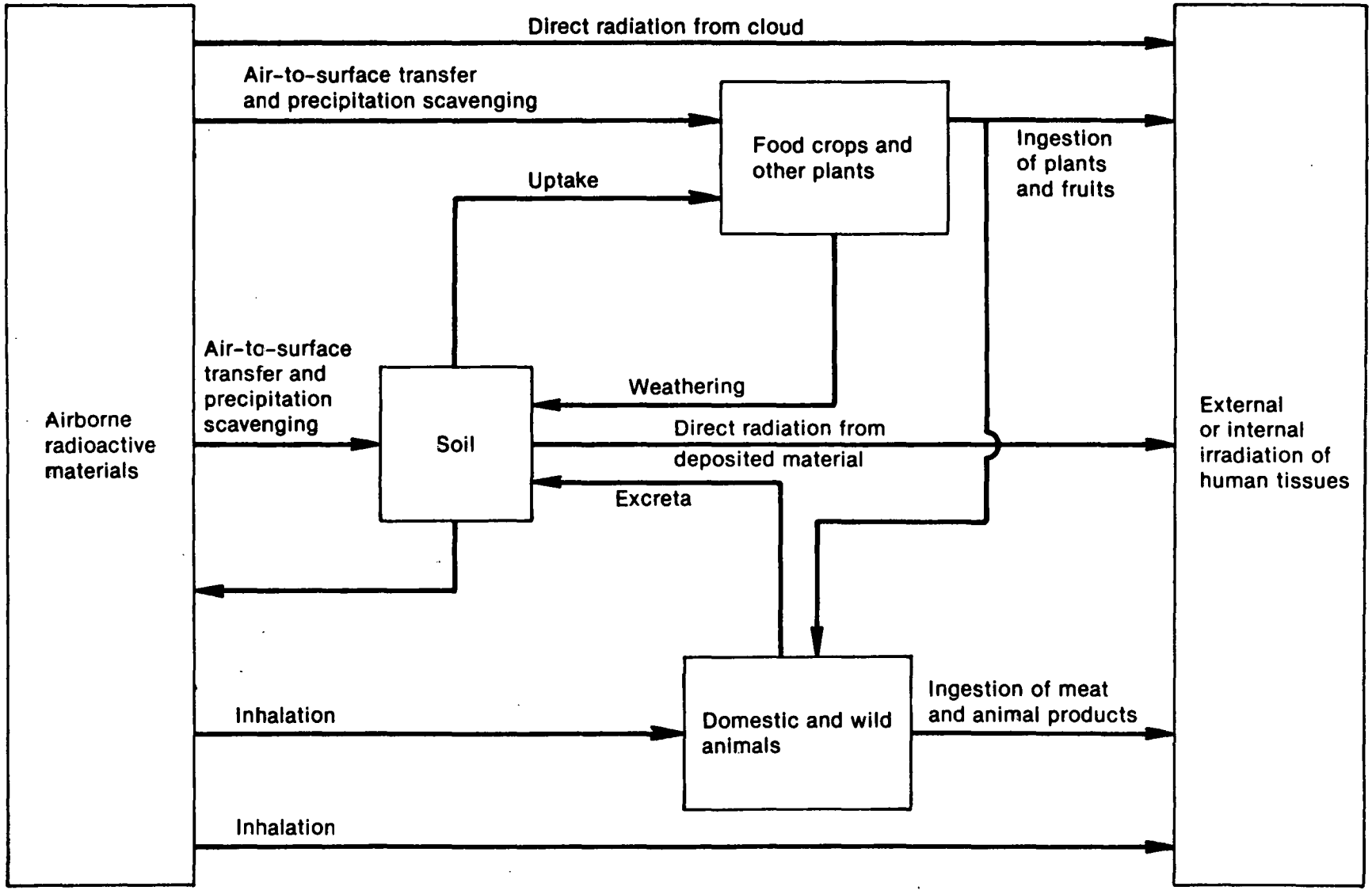


Figure 4-1. Potential Exposure Pathways for Airborne Releases

TABLE 4-1

MODES OF EXPOSURE

Scenario	Exposure Pathway[a]	Affected Party		
		Individual	Population[b]	Worker
At the ICPP				
Routine Releases	Inhalation, ingestion, direct radiation	x	x	c
Routine Waste Shipment	Direct radiation	x	x	x
Occupational Exposure	Direct radiation			x
Calcine Spill	Inhalation, ingestion	x	x	c
Decontamination Solution Spill	Inhalation, ingestion	x	x	
Extraction Solvent Fire	Inhalation, ingestion	x	x	c
Waste Shipment Accident	Inhalation	x	x	x
Living Over the Waste	Inhalation	x	x	
Waste Migration into Groundwater	Ingestion	x	x	
Intrusion into the Waste	Inhalation, direct radiation	x		
Living at Contaminated Site	Inhalation, ingestion, direct radiation	x	x	
Aircraft Impact	Inhalation	x	x	c
Severe Geologic Disruption	Inhalation, ingestion	x	x	c
At the Repository				
Waste Canister Drop	Inhalation, ingestion	x	x	x
Fault and Flooding	Ingestion	x	x	
Solution Mining	Ingestion	x	x	
Exploratory Drilling	Inhalation, ingestion, direct radiation	x		

a. Pathways listed are shown by calculation to be the dominant contributors to the radiation dose.

b. Some of the scenarios do not result in widespread population exposures, but in exposure to only a few individuals. These scenarios at the ICPP are Living Over the Waste, Intrusion into the Waste, and Living at Contaminated Site; at the repository, Exploratory Drilling.

c. Any worker exposure is included in the occupational exposure.

4.2.2 Definition of Radiological Terms

Calculated radiological effects on the public for a hypothetical or routine release of radioactive material are reported in this report using the terms "dose commitment," "maximum individual dose," "population dose," "population risk," and "health effects." Definitions of these terms follow:

- Dose commitment* is the integrated dose that results from an intake of radioactive material when the dose is evaluated from the beginning of intake to a later time.

- Maximum individual dose (rem) is that dose commitment incurred by an individual located in an unrestricted area at the site boundary who receives the maximum possible dose commitment as a result of the release of radioactive material.

- Population dose (man-rem) is that dose commitment incurred by the population in the 50-mile radius study area as a result of the release of radioactive material.

- Whole-body equivalent dose (rem) is the summation of the weighted dose commitments for all organs within the body that result from intake of radioactive material.

- Population risk (man-rem per year) is obtained by multiplying the population dose commitment for a given release by the expected frequency of the release (events per year).

- Health effects are obtained by multiplying the population dose commitment for a given release by appropriate weighting factors

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* The dose commitment cited in this report is a 50-year dose commitment. It is based on 1 year of exposure to radioactive material of an adult population with a 50-year life expectancy. The term "dose" is often substituted for "dose commitment."

recently updated by the National Academy of Sciences Committee on the Radiological Effects of Ionizing Radiation* (NASNRC, 1980).

The maximum individual is assumed to reside at the point of maximum ground-level air concentration of radionuclides at the INEL boundary. This point is located approximately 8 miles south of the ICPP. For routine operational releases, individuals in the population within 50 miles of the ICPP receive an average dose that is calculated to be 4 percent of the maximum individual dose.

Potential radiation doses for each exposure pathway have been calculated for the time period extending 1 million years after 2100. Doses have been calculated for the short-term period of institutional control, which is assumed to cease in 2100. For the delay alternative (Alternative 5), institutional control is assumed through the year 2500. Doses have been calculated for operational releases and for accidents postulated to occur during the operations, waste shipment, and D&D phases of waste management activities. Doses have also been calculated for abnormal events of nature postulated to occur after disposal and after institutional control is assumed to have ceased. The long-term period assumes potential radiation exposure until the waste has decayed to harmless levels. Decay products, such as radium-226, continue to increase until they reach their highest radiation level about 200,000 years after 2100.

The dose commitments are compared with those delivered by background radiation. The annual dose a person receives from background radiation in southeastern Idaho is about 0.15 rem for the whole body (NCRP, 1975). The annual background dose at the federal repository is assumed to be 0.13 rem (DOE, 1980a).

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* "The National Commission on Radiation Protection wishes to caution governmental policy-making agencies of the unreasonableness of interpreting or assuming 'upper limit' estimates of carcinogenic risk at low radiation levels as actual risks, and of basing unduly restrictive policies on such an interpretation or assumption" (NCRP, 1975).

Dose-limiting recommendations have been proposed by the National Council on Radiation Protection and Measurements (NCRP, 1975). These values are the basis of the Nuclear Regulatory Commission (NRC) regulations as published in the Code of Federal Regulations and of the DOE guidelines published in Chapter Manuals (ERDAM, 1977) that must be observed at federal facilities. The 0.5-rem dose limit published in these regulations for an individual member of the public is cited in this report to give perspective to discussions about dose commitments.

4.2.3 Guidelines for the Evaluations

The radionuclide inventory upon which the dose calculations are based is given in Appendix A. Radionuclide concentrations in calcine have been estimated from the expected composition of high-level liquid waste before calcination. No iodine-129 or carbon-14 is present in the calcine. The concentration of fission products and daughters is based on estimates of the radionuclide content of future fuels to be processed at the ICPP. Actinide concentrations are based on the ICPP high-level liquid waste in 1978. Uranium isotope concentrations are based on the ratios of the nuclides in the ICPP waste. Liquid high-level waste is assumed to be cooled 3 years prior to calcination.

Demographic data for the area within 50 miles of the site include populations that are outside the study area but very close to the study area boundary. Thus, the populations of Pocatello, Rexburg, Rigby, and American Falls have been included as though they were located within 50 miles of the ICPP. It is assumed that population growth is linear for 150 years from 1970, reaches a level 5 times the 1970 census of 130,000, and remains constant thereafter at 650,000. The population along the waste shipment route is assumed to double in 150 years. The slower growth rate is assumed because the transportation route passes through primarily rural areas where a more rapid population increase along the railroad lines would not be expected. The population along the waste shipment route is estimated to be 125,000 in 1990, reach 250,000 in 2140, and remain constant thereafter. The population at the federal repository is assumed to remain constant at 2 million people (DOE, 1980a).

Several other assumptions are used to determine environmental consequences. Institutional control over the waste is assumed to continue for 100 years in accordance with proposed EPA criteria (EPA, 1978). Since processing is assumed to begin in 1990 and be complete by 2020, institutional control is assumed to end in the year 2100, except for Alternative 5. In Alternative 5, in order to evaluate the effects of radionuclide decay, institutional control is assumed to continue for 100, 300, or 500 years.

Nonradiological effects are compared with applicable standards and regulations. The State of Idaho standards for ambient air quality (Idaho, 1979) and public drinking water systems (Idaho, 1977) are consistent with the respective Environmental Protection Agency (EPA) standards for air quality (40 CFR 50) and the national primary drinking water regulations (40 CFR 141).

The geologic changes that might occur at the INEL (see Subsection 3.1) throughout long time periods are unknown. Since predictions of major geologic changes would only be speculative, the land in the study area is assumed to remain habitable and arable for the entire period of evaluation. However, to account for a major geologic change or event that could disperse the waste, the effects of a severe geologic disruption are considered. The event is assumed to have the same probability of occurrence as a volcano exploding up through the waste.

Sabotage is not specifically addressed as an event that would cause exposure to radionuclides. Other accidents that would cause similar exposures (aircraft impact and a waste shipment accident) have been evaluated. Because large quantities of radionuclides are concentrated at the ICPP, the ICPP is a potential target for sabotage; however, the remoteness of the site and the small surrounding population diminish its appeal as a target. Even if the calcine were released from the bins by an act of sabotage, most of the waste would be diffused and/or deposited prior to reaching nearby population centers. Operations at the INEL are designed to protect against sabotage: access is controlled, surveillance is maintained, personnel and materials are monitored. The physical size and strength of the calcine bins and shipping casks make sabotage unlikely.

The source terms and calculational methodology used to calculate doses and health effects are given in Appendix A. Included in Appendix A are inventories of radionuclides and toxic chemicals, meteorological data and dispersion factors, demographic data, accident assumptions, mathematical models, a description of the scenarios for which normal and abnormal waste releases are postulated, and a sample calculation for determining dose commitments and concentrations of nonradiological pollutants in air and water. Results of the calculations are given in Appendix B.

4.3 Health Effects

To improve understanding of the radiological dose commitments cited in this report, health effects that might result in the exposed population have been estimated. Health effects are the cancer deaths predicted to occur in a population group that receives a specified dose of radiation. Health effects in humans have been measured directly only at acute doses near 100 rem or higher. At the level of exposure considered in this report, the health effects are almost impossible to separate from similar effects caused by background radiation and other causes. Consequently, health effects of low-level radiation have been predicted only as possibilities rather than as certainties.

There are several other health effects such as genetic and nonfatal malignancies that can result from exposure to radiation. However, calculating these effects is not necessary to perform the comparative evaluations required in this report.

Health effects that result from ingestion of toxic chemicals present in the waste are also discussed. Health effects of cadmium and mercury are the number of deaths that would occur from chronic consumption of drinking water containing cadmium and mercury levels that exceed federal and state standards and the consumption of foods grown from this water.

4.3.1 Exposure to Nonradioactive Chemicals

The methodology used to evaluate the effects of toxic chemical migration is the same as that used for radionuclides. The approach is considered to be conservative because cadmium and mercury would tend to precipitate and remain in the basalts and sediments as the leachate becomes dispersed rather than migrate within the aquifer system. Under the assumed conditions, the estimated concentrations of cadmium and mercury in hypothetical wells exceed federal and state drinking water standards for a distance of 5 miles downgradient of the point of discharge to the aquifer. Beyond about 5 miles, no health effects would be observed, and the aquifer would be available for all drinking water, agricultural, and aquaculture uses. The use of groundwater would be restricted only until dispersion and chemical reactions in the aquifer reduced toxic chemical concentrations to harmless levels. Ongoing studies will provide more definitive information about the potential effects of toxic chemical migration at the INEL.

4.3.2 Exposure to Radiation

The consequences of the small dose commitments resulting from the waste management alternatives considered in this report are measured by the health effects that can be observed in the general population. Health effects are discussed to give perspective to the dose commitments.

Health effects from exposure to radiation can be discussed in terms of short-term effects, occurring within about 1 year of the accident, and long-term effects, occurring several years later (NRC, 1974).

4.3.2.1 Short-Term Effects

The acute whole-body dose which is lethal to about 50 percent of the exposed population within 60 days after exposure is about 500 rem (NRC, 1974). This value is based on the assumption that exposed individuals receive suitable medical treatment. With only minimal medical treatment, the estimated value is about 340 rem.

In the range of 75 to 125 rem, some individuals may experience symptoms of radiation sickness such as nausea and fatigue, but the likelihood of complete recovery is good.

In this report, 50-year dose commitments, rather than acute doses, have been calculated. Since a 50-year dose commitment is not an instantaneous dose, it cannot be compared directly with the acute doses discussed above. For example, in Table 4-19, a maximum individual dose of 10 rem is given for Alternative 4. This alternative involves the shipment of concentrated actinide waste. Because actinide elements would deliver a dose over an extended time period, a 10-rem, 50-year dose commitment would be approximately equivalent to 0.2 rem per year for 50 years.

For those radionuclides present in the INEL waste having approximately 30-year half-lives, the dose would be about 0.3 rem during the first year, dropping to 0.1 rem in the fiftieth year. The dose commitment is a more comprehensive and relevant measure of radiation exposure than acute doses for most of the scenarios studied in this report. The calculated dose commitments should usually not be compared directly with the acute doses just discussed because of the difference in the time periods over which the dose is received. Only for a severe geologic event that totally disperses the waste would the dose be sufficiently large to cause acute effects. Clinical evidence indicates that radiation received over a long time period, such as 50 years, is tolerated better than the same amount of radiation received in a short period of time (NRC, 1974).

The calculated doses are generally very low. They are within the fluctuation of normal background radiation. The maximum individual dose commitment from routine operations at the ICPP is calculated to be 3×10^{-6} rem [Alternatives 2 (glass) and 3 (glass)]. The maximum individual dose commitment from an accident during waste shipment is calculated to be 10 rem (Alternative 4). Thus, acute health effects to the public would not be expected from routine operations or accidents postulated to occur from implementation of any of the waste management alternatives.

4.3.2.2 Long-Term Effects

Long-term health effects considered are latent cancer deaths. These are cancers that could develop 5 to 30 years after exposure.

To estimate health effects, the whole-body equivalent dose for the population in man-rem has been used as a measure of the damage to the exposed group. To estimate the potential number of health effects that might result from the population doses calculated for this report, cancer risk estimates from exposure to low-level radiation published by the National Academy of Sciences Committee on the Biological Effects of Ionizing Radiation (BEIR III Report) have been used (NASNRC, 1980). In the BEIR Report, the number of additional cancers estimated to occur in 1 million people after exposure of each to 1 rem of radiation is 75 to 230 (NASNRC, 1980). This may be a conservative limit because a linear relationship between dose and health effects is assumed even at very low doses and dose rates.

The range of 75 to 230 health effects (cancer deaths) can be compared with the cancer fatalities expected from all possible causes. The American Cancer Society has reported that approximately 16.8 percent of all deaths, 168,000 per million deaths, will result from all causes of cancer (ACS, 1981). Therefore, the number of health effects observed in 1 million people each exposed to 1 rem of radiation would be about 0.14 percent of the number of cancer deaths expected from all causes.

Additional perspective on the small radiation doses calculated in this report can be gained by considering the magnitude of other sources of radiation exposure given in Table 4-2.

4.4 The Concept of Risk

Almost every human activity creates risk. Radiological risks are evaluated in terms of risk to the public; the "public" includes those who, without choice, could be exposed to radiation because of activities at the INEL,

TABLE 4-2

AVERAGE INDIVIDUAL RADIATION EXPOSURE[a]

Sources of Radiation	Radiation Exposure (Rem/Yr)
Background radiation on and near the INEL	0.15[b]
Medical and dental diagnosis	0.07
Brick or stone buildings	0.02
Nuclear weapons tests	0.004
Combustion of coal and natural gas	0.003
Nuclear power production	0.0001

a. McCormack, 1980.
b. This level of radiation is due to the high elevation (5,000 ft) of the INEL.

along the waste shipment route, or at an offsite federal geologic repository. The "public" does not include employees located at the INEL facility.

The purpose of risk analysis is to compare the consequences of events that have different probabilities. However, catastrophic events that have low probabilities will have the same calculated risk as less hazardous events with high probabilities. Thus, the consequences of an event are obscured if only the risk is reported. Therefore, in this report, the population dose and the probability of the event's occurrence are given separately so that effects of abnormal events that are not expected to occur can be more realistically compared with effects of routine operations that will indeed occur.

4.4.1 Public Perception of Risk

In general, people accept a certain amount of risk in order to obtain a desired benefit such as the convenience of automobile transportation. Also, some risks cannot be avoided; an example is exposure to natural background

radiation, which has the potential to induce cancer. Ordinarily, mitigative measures are taken to reduce exposure if the risk is too great.

Fatality statistics, such as those presented in Table 4-3, provide some insight into attitudes regarding the perception and acceptance of risk. Within the total population of the United States, there is a probability of 2.70×10^{-4} accidental deaths per person per year from the use of motor vehicles (primarily automobiles). At this comparatively high risk level, society will accept considerable trouble and expense to implement risk reduction measures such as traffic safety programs, automobile inspection, and seat belt installation.

Risks ranging from about 10^{-4} to 10^{-5} deaths per person per year also prompt serious efforts to reduce those risks. For example, public funds are expended for fire and police protection and for extensive programs to comply with occupational safety and health statutes and regulations.

Risks in the range of 10^{-5} to 10^{-6} death per person per year are also considered serious enough to receive some remedial action. Lifeguards are employed at swimming areas. Special bottles with child-resistant caps are used for drugs and chemicals. As the risk level is reduced to 10^{-6} death per person per year, the public begins to accept the risk-associated activity. For example, very few people have adequate tornado shelters even though severe weather warnings are issued to encourage the population at risk to seek adequate shelter. It appears that most people perceive a risk of about 10^{-6} death per person per year as a threshold level below which fatal events seem to cause little concern (ERDA, 1977a). The aircraft impact and severe geologic disruption scenarios evaluated in this report have probabilities of 10^{-7} and 10^{-8} event per year, respectively.

4.4.2 Calculation of Risk

To arrive at a meaningful numerical indicator for risk comparisons, three factors must be taken into account: the frequency with which a particular event is likely to occur, the population exposed to the potential risk, and the consequence. The probability that an event will occur is defined as the

TABLE 4-3

SELECTED DEATH STATISTICS FOR THE UNITED STATES DURING 1970[a]

Cause of Death	Total Deaths	Risk of Death per Person per Year for Total U.S. Population[b]
All Causes	1,921,031	9.45×10^{-3}
Disease (total)	1,766,065	8.69×10^{-3}
Cardiovascular Disease	1,007,984	4.96×10^{-3}
Cancer	330,730	1.63×10^{-3}
Accidents (total)	114,638	5.64×10^{-4}
Road and Highway	54,890	2.70×10^{-4}
Water Transport	1,651	8.12×10^{-6}
Air and Space Transport	1,612	7.93×10^{-6}
Railway	852	4.19×10^{-6}
Falls	16,926	8.33×10^{-5}
Drowning	6,391	3.14×10^{-5}
Fire	6,718	3.31×10^{-5}
Firearms	2,406	1.18×10^{-5}
Poisoning (total)	5,299	2.61×10^{-5}
Medical Procedure Complications	3,581	1.76×10^{-5}
Inhalation and Ingestion of Objects	2,753	1.35×10^{-5}
Industrial Accidents	5,968	2.94×10^{-5}
All Other Accidents	5,591	2.75×10^{-5}
Cataclysm[c]	162	7.97×10^{-7}
Lightning	129	6.35×10^{-7}

a. From Statistical Abstract of the United States, 1978, and Reader's Digest 1979 Almanac and Yearbook, 1979.

b. Total 1970 U.S. population is 203,235,298 (1970 United States Census).

c. Deaths reported for 1968.

frequency divided by the population exposed to the risk. Risk is then defined in terms of the event probability and the event consequence by the equation

$$\text{risk} = (\text{event consequence}) \times (\text{event probability}).$$

Using the example of cancer mortality in the United States, the probability given in Table 4-3 is obtained from the equation

$$\text{event probability} = \frac{\text{event frequency}}{\text{affected population}} = \frac{330{,}730 \text{ events/year}}{203{,}000{,}000 \text{ persons}}$$

$$= 0.00163 \text{ event/person/year}$$

$$= 1.63 \times 10^{-3} \text{ event/person/year}.$$

The consequence of contracting a fatal cancer is one death per event. Substituting these values in the equation for risk gives

$$\text{risk of cancer death} = (1 \text{ death/event}) \times (1.63 \times 10^{-3} \text{ event/person/year})$$

$$= 1.63 \times 10^{-3} \text{ death/person/year}.$$

4.4.2.1 Event Frequency

The method of stating an event frequency as events per year is used throughout this document because it is convenient for describing the frequency of recurring events separated by long time periods. An example of this type of event is the beginning of an ice age, which is believed to occur about once in 50,000 years. The frequency of glaciation can therefore be stated as one event divided by 50,000 years or 2.0×10^{-5} event per year.

In order to determine the risk from the release scenarios evaluated in this document, it is necessary to estimate the probability that certain events will occur. The frequency of a system failure that might affect the environment and the public can be estimated by accumulating failure data for a number of similar operating systems. The total number of failures of a given type, divided by the total number of years of operation, approximates the

probability of a given type of system failure. Probabilities are expressed as decimal fractions and lie between 0 and 1. Zero probability means the event cannot occur; a probability of 1 means the event does occur; a probability greater than 0 but less than 1 means the event may occur. If the event is certain to happen each year (routine exposure to workers, for example), the probability is expressed as 1.0 event per year. Probabilities may, therefore, be substituted directly for the frequency term in the event probability equation. It should be emphasized that stating a failure probability does not allow prediction of when or even if a particular system will fail. For instance, assuming that the probability of failure for a particular system has been estimated as 0.01 failure per year, the implication is that among a large number of identically operating systems, one failure may be anticipated for every 100 systems operating for 1 year, or for every 50 systems operating for 2 years.

In many instances, including the operation of remotely operated nuclear processing systems, very few long-term failure data are available. Since this study of waste management alternatives is comparative in nature and the processing systems for all of the alternatives are similar, conservative estimates of failure probabilities are made and applied to each alternative. Consequently, absolute risks associated with equipment failures are probably overestimated but comparisons between alternatives should be valid.

4.4.2.2 Event Consequences

The consequences of waste releases evaluated in this report depend on the following factors:

- radioactive and nonradioactive waste inventory,
- fraction released to the environment,
- mechanisms by which the population is exposed, and
- number of persons exposed.

The fraction of total cancer fatalities caused by exposure to low levels of radiation cannot accurately be determined. A discussion of cancer risk

cannot be based on actual mortality data, but must rely on statistical predictions of health effects estimated to occur in the exposed population as discussed in Subsection 4.3.

4.5 Environmental Consequences of Alternatives

The environmental effects of each waste management alternative are identified in order to determine both their absolute and relative importance. The information about environmental consequences is determined by evaluating a series of release scenarios. In this subsection, each scenario is described, and the potential causes of environmental effects are illustrated to aid in focusing the discussion on relevant consequences.

The data presented are based on the source terms and calculational methodology given in Appendix A. A sample calculation of the maximum individual whole-body equivalent dose and associated health effects for each scenario is provided in Appendix A. The data summarize the results of the dose commitment calculations and nonradiological pollutant concentrations in air and water given in Appendix B.

Environmental effects are divided into two major categories: short-term effects that would occur during the assumed period of institutional control (approximately 100 years) and long-term effects that would occur after institutional control is assumed to cease (up to 1 million years). The short-term versus long-term grouping of effects provides a mechanism for assessing effects on future generations. For purposes of evaluation in the delayed retrieval alternative (Alternative 5), the short-term period of institutional control is assumed to last throughout the delay period. The retrieval date is delayed in order to evaluate the effects of radionuclide decay and to provide a relevant comparison between Alternatives 3 and 5. Should institutional control cease during the delay period, potential effects of Alternative 5 would be similar to the effects identified for Alternative 1.

The short- and long-term categories are further divided into effects which are certain to occur if an alternative is implemented and effects which

result from abnormal events. The division into effects which are certain to occur and effects which result from abnormal events has been done to emphasize the consequences of implementing an alternative. The division enables a decisionmaker to give appropriate consideration to a wide range of effects when only a few will happen.

Both nonradiological and radiological effects on the public and waste management workers are described. The public consists of the maximum individual and the population residing within the study area. The maximum individual is a hypothetical person who is assumed to live his entire life at a location where the radiation dose would be maximal. It is further assumed that his food and water supply are obtained from this location. Thus, the maximum individual dose is a very conservative estimation of potential radiation effects. The population dose is important in estimating health effects predicted to occur in an exposed population group which is involuntarily at risk from radiation. Waste management workers assume a greater risk of exposure to radiation than the general public. However, workers are trained in radiation safety, and the exposure they receive is carefully controlled to minimize exposure. Occupational exposures are important in assessing the overall implications of implementing a waste management program.

Events and environmental effects in the short term would occur during four phases: construction phase, operation phase, decontamination and decommissioning (D&D) phase, and disposal phase. Events and environmental effects in the long term would occur only in the disposal phase. Effects of offsite waste shipment are discussed as part of the operations phase. The project phases and events for which environmental effects are evaluated are given in Table 4-4.

Many of the effects evaluated in this subsection have very minor environmental consequences. However, the most significant effects from each project phase, even though they are minor, are compared in Section 2.

TABLE 4-4
MODES OF ENVIRONMENTAL EFFECTS

		EVENTS CERTAIN TO OCCUR		ABNORMAL EVENTS	
	PROJECT PHASE	NONRADIOLOGICAL	RADIOLOGICAL	NONRADIOLOGICAL	RADIOLOGICAL
SHORT-TERM EFFECTS	CONSTRUCTION	Vehicle Exhaust, Dust	None	None	None
		Worker Injuries	None	None	None
	OPERATIONS AND WASTE SHIPMENT	Routine Stack Releases	Routine Stack Releases, Routine Waste Shipment Exposure, Calcine Spill, and Decontamination Solution Spill	None	Extraction Solvent Fire During Actinide Removal, Waste Shipment Accident, Aircraft Impact
		Worker Injuries		None	
	DECONTAMINATION AND DECOMISSIONING (D&D)	Routine Stack Releases Vehicle Exhaust, Dust	Routine Stack Releases	None	None
		Worker Injuries		None	
	DISPOSAL				
	INEL	None	None	None	None
	FEDERAL REPOSITORY	None	None	None	Waste Canister Drop
LONG-TERM EFFECTS	CONSTRUCTION	None	None	None	None
	OPERATIONS AND WASTE SHIPMENT	None	None	None	None
	DECONTAMINATION AND DECOMMISSIONING (D&D)	None	None	None	None
	DISPOSAL				
	INEL	None	Living Over Waste Intrusion into Waste, and Living at Contaminated Site	Waste Migration into Groundwater	Waste Migration into Groundwater and Severe Geologic Disruption
	FEDERAL REPOSITORY	None	None	Solution Mining, and Fault and Flooding	Solution Mining, Fault and Flooding, and Exploratory Drilling

4.5.1 Short-Term Effects

4.5.1.1 Short-Term Effects of Events Certain to Occur

Events that are certain to occur during the short term cause both nonradiological and radiological effects. The scenarios that are evaluated for each project phase are shown in Table 4-4. The nonradiological effects that would occur during the construction, operation, and D&D phases are primarily minor effects on air quality. All airborne emissions and any minor wastewater discharges would be within applicable regulations (40 CFR 50 and 141).

Certain-to-occur radiological effects would result during the operations and D&D phases of alternative implementation. All routine radionuclide releases and accidents postulated to occur during facility operations would be within applicable regulations (ERDAM, 1977) and within the annual fluctuation of background radiation.

4.5.1.1.1 Construction Phase

Construction would take place within the present ICPP boundary. Fuel-burning equipment and fugitive dust would affect air quality. All consequences of construction would be minor and of short duration, ceasing upon completion of construction.

Construction activities and resource use for each alternative are shown in Table 4-5. Construction of calcine disposal facilities would be required for Alternatives 1, 2, 4, and 5. This additional bin space is required for disposal of calcine produced from present and future high-level liquid waste inventories. Modifying the waste form to pellets or glass would increase the volume of the final waste form to about 1.5 times the original calcine volume, thereby requiring disposal space in addition to the disposal capacity required for continuing present operations (Alternative 1).

Typical construction activity required to implement the waste management alternatives is illustrated on Page 4-25.

TABLE 4-5

ESTIMATED CONSTRUCTION ACTIVITIES AND RESOURCE COMMITMENTS[a]

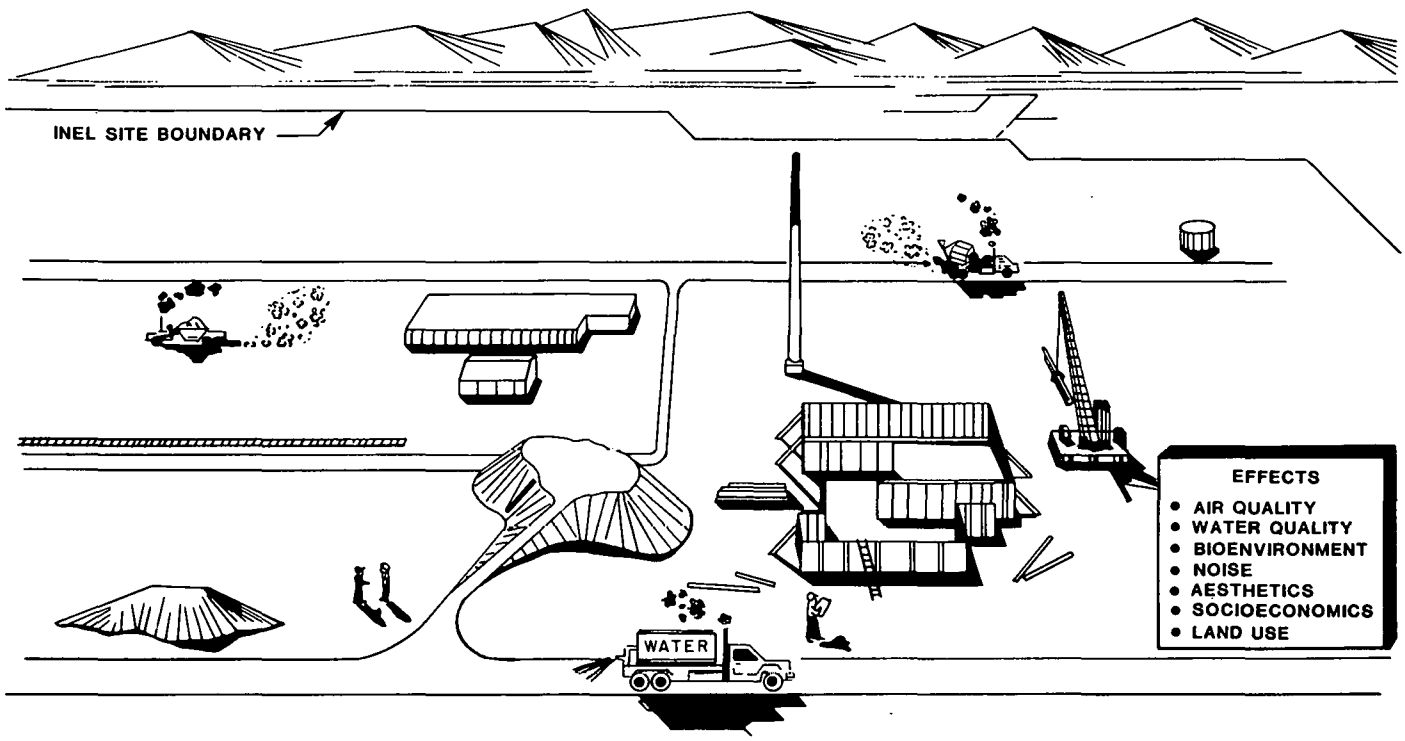
Alternative	Duration (Mo)	Pieces of Heavy Equipment (Average)	Diesel Fuel (10^3 Gal)	Concrete (10^3 Yd^3)	Fabricated[b] Equipment (10^6 Dollars)	Labor Force (Man-Yr)	Land (acres) Processing Facility	Land (acres) Disposal Facility	Water (10^6 Gal)
1. Leave-in-Place	18	25	375	40	1.0	800	NA[c]	1	1.5
2. Retrieve, Modify Calcine, Dispose at the INEL									
Pelletize Calcine	21	30	275	70	1.5	2,000	1	2	3.0
Convert Calcine to Glass	36	50	575	50	3.0	1,000	1	180	2.0
3. Retrieve, Modify Calcine, Dispose Offsite									
Stabilize Calcine	21	35	325/550	10	3.0	200/1100	1	175	0.5/6.2
Convert Calcine to Glass	24	35	390/550	15	3.0	200/1100	1	175	0.5/6.2
4. Retrieve, Separate Actinides, Dispose of Actinides Offsite, Dispose of Depleted Calcine at the INEL	40	50	1,110/5	60	7.0	2750/5	1	1/1	3.0/0.3
5. Delay Retrieval, Modify Calcine, Dispose Offsite									
100 Years	24	35	390/55	50	3.0	1000/110	1	18[d]	2.0/0.6
300 Years	24	35	390/5	50	3.0	1000/5	1	1[d]	2.0
500 Years	24	35	390/5	50	3.0	1000/5	1	1[d]	2.0

a. Resources committed at the INEL are listed first; resources committed to repository construction are listed after the slash mark.

b. Cost (in 1980 dollars) of fabricating specialty equipment from stainless steel for operations at the INEL.

c. NA, not applicable.

d. One acre of land at the INEL would be required for calcine storage during the period of delay.



WASTE MODIFICATION FACILITY CONSTRUCTION

Construction of processing facilities would be required for waste form modification (Alternatives 2, 3, and 5) and actinide separation (Alternative 4).

Actinide separation (Alternative 4) would require the largest construction effort. Additional storage space would be needed for onsite disposal of actinide-depleted calcine. Facilities would be required for calcine dissolution, actinide separation, and calcination of actinide-depleted waste. Increased waste processing costs in Alternative 4 are attributable to the cost of equipment fabricated from specialty alloys which is more than twice the cost of equipment fabricated for the other alternatives.

Onsite disposal of pellets (Alternative 2) would be nearly as labor intensive as actinide separation (Alternative 4). Even though onsite disposal of vitrified calcine would require construction of new disposal facilities, these silos would not be as complex as the additional bins that would be

constructed for disposal of pelletized calcine. Onsite disposal of vitrified calcine would substantially increase present land use requirements.

Construction activities would affect air quality through vehicle and equipment exhaust and dust generation as shown in Table 4-6. Air quality impacts and diesel fuel use are directly related to the pieces of heavy equipment in operation. Concentrations are calculated for all air pollutants controlled by federal and state standards. The concentrations are based on recommended emission factors for construction activity and are calculated from the atmospheric dispersion factor for ground-level releases at the southern INEL boundary (1.7×10^{-8} second per cubic meter). The concentrations are expected to be at a maximum at this location. The calculated increases at site boundaries for all alternatives would be below the detection limits of the monitoring equipment. Consequently, effects on air quality would be negligible.

Mitigative measures would consist of the use of dust suppressants, limiting disturbances of vegetative cover to areas necessary for construction of facilities, and the use of erosion control and restorative procedures to minimize wind-generated dust.

Construction activity would take place near the ICPP where there is no surface water. Wastewater generated during construction would be managed to conform to all applicable federal and state water quality standards and effluent guidelines.

Water for concrete would be provided primarily by the ICPP production well. The expected increase in water consumption would not appreciably affect either the aquifer or other water users. During 1974, the total groundwater usage at the INEL was 2.9 billion gallons, which was 0.1 percent of the estimated total annual discharge of the Snake River Plain Aquifer (ERDA, 1977b). Maximum water use at the ICPP [Alternatives 2 (pellets) and 4] would be only 0.1 percent of the total INEL use.

Solid waste generated during construction would be disposed at the INEL in a sanitary landfill constructed and operated in accordance with federal and state regulations.

TABLE 4-6

CALCULATED CONCENTRATION INCREASES
OF AIR POLLUTANTS FROM CONSTRUCTION ACTIVITYY[a,b]
(micrograms per cubic meter)

Alternative	Particulates (Annual Geometric Mean)	Nitrogen Oxides (Annual Arithmetic Mean)	Carbon Monoxide (1-Hr Average)	Sulfur Dioxide (Annual Arithmetic Mean)	Hydrocarbons (3-Hr Average)
1. Leave-in-Place	0.04	0.12	11.0	0.009	3.4
2. Retrieve, Modify Calcine, Dispose at the INEL					
Pelletize Calcine	0.07	0.07	6.9	0.006	2.2
Convert Calcine to Glass	0.07	0.09	8.3	0.007	2.5
3. Retrieve, Modify Calcine, Dispose Offsite					
Stabilize Calcine	0.04	0.09	8.3	0.007	2.6
Convert Calcine to Glass	0.04	0.09	9.0	0.007	2.7
4. Retrieve, Separate Actinides, Dispose of Actinides Offsite, Dispose of Depleted Calcine at the INEL	0.20	0.15	15.0	0.010	4.4
5. Delay Retrieval, Modify Calcine, Dispose Offsite					
100 Years	0.04	0.09	9.0	0.007	2.7
300 Years	0.04	0.09	9.0	0.007	2.7
500 Years	0.04	0.09	9.0	0.007	2.7
Federal Standard[c]	60.00	100.00	40,000.0	80.0	160.0

a. At southern INEL boundary.

b. All calculated concentrations are below instrument detection limits. Detection limit: sulphur dioxide, 7.2 $\mu g/m^3$; nitrogen oxides, 4.3 $\mu g/m^3$; particulates, 1 $\mu g/m^3$; hydrocarbons, 16 $\mu g/m^3$.

c. The most restrictive standard (40 CFR 50) is listed. It is the primary standard for sulfur dioxide and the secondary standard for particulates, nitrogen oxides, carbon monoxide, and hydrocarbons.

The ambient noise levels at the INEL are generally very low. Construction activities would result in increased noise levels in proportion to the number of pieces of construction equipment operating (Table 4-5). Because of the isolation of the INEL, increases in noise levels would not affect the public. Workers exposed to high noise levels would be provided with hearing protection devices.

Land use requirements would be met within the present INEL boundary. Alternative 2 (glass) would require the largest additional subsurface area (180 acres) for disposal. Alternative 2 (pellets) would require an additional 2 acres, and Alternative 4 would require an additional 1 acre of land for disposal at the INEL. Alternatives 2, 3, 4, and 5 would require about 1 acre of land for construction of processing facilities.

Archaeological surveys of the INEL have found fossils and artifacts (see Subsection 3.4.1). A site reconnaissance project would be conducted before construction to determine the presence of antiquities and their value. During construction, a qualified archaeologist would be on call to inspect any unforeseen finds.

Effects on wildlife and vegetation would be minor because potential construction sites are near the ICPP and already affected by man's activities. Disturbed land and wildlife habitats would be restored after facility decommissioning. No rare or endangered species would be affected by construction activities at the ICPP.

Socioeconomic impacts can be evaluated by examining current construction employment projections. Employment for other INEL construction projects peaked at 1,592 in 1980 and is expected to drop to 572 in 1982. The decline of 1,020 jobs suggests that more than enough workers could be available for the construction of waste management facilities. Alternative 4 would require the greatest level of effort (2750 man-years at the INEL). It is estimated that the maximum level of effort projected for the construction of processing and disposal facilities would require a peak of about 700 construction workers. A labor force of this size has been accommodated in the past and is

within the normal fluctuation of the INEL work force. Consequently, socio-economic effects of the construction labor force would probably not be noticeable in the communities surrounding the INEL.

Compared to applicable standards and regulations, the environmental consequences of construction activities are minor for all the waste management alternatives. With the exception of stainless steel, resource commitments are typical of any industry of similar size and complexity. Stainless steel would be required for the manufacture of specialty equipment necessary for the handling, shipment, and disposal of high-level radioactive waste. Stainless steel requirements are given in terms of dollar cost instead of tons to more realistically reflect the fabrication costs of equipment from specialty alloys.

4.5.1.1.2 Operations Phase

Routine Operations

The environmental effects of routine operations at the ICPP and waste shipment to a federal geologic repository would cause both nonradiological and radiological effects. Nonradiological effects are discussed first, followed by a discussion of radiological effects. Radiological effects are discussed for the public and for waste management workers.

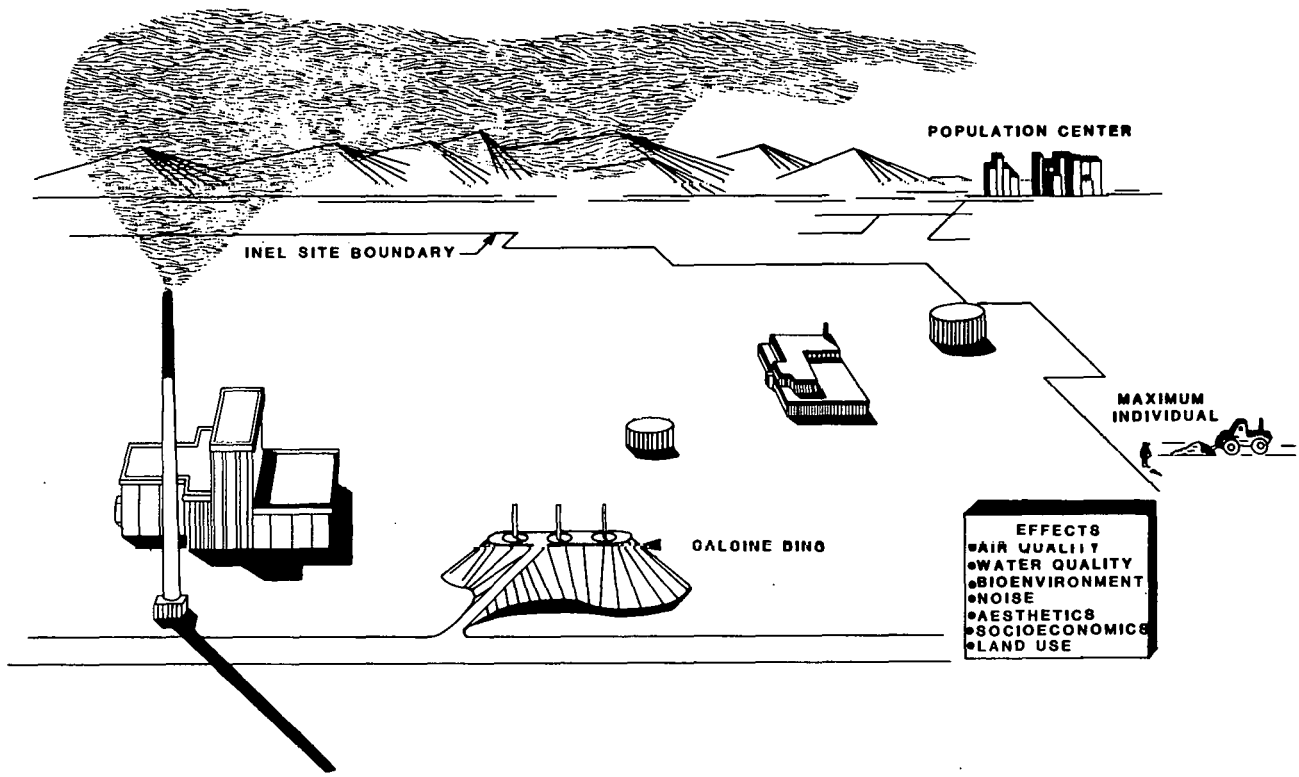
Each alternative is assumed to begin at the point at which calcined waste is in the storage bins. Alternatives 2, 3, 4, and 5 would require processing in addition to the continuing production of calcine. The effects of calcination have been described elsewhere (ERDA, 1977b; AEC, 1973; AEC, 1974). Pertinent effects of current calcining operations are discussed briefly below to provide perspective in considering the effects of the alternatives evaluated in this report. However, since each alternative is assumed to begin with calcined waste, the effects are the same for each alternative and have not been included in Tables 4-7, 4-8, 4-9, or 4-11. The following brief summary of calcination effects is provided for the reader's information.

Current ICPP operations result in slightly elevated emissions of nitrogen oxides and carbon monoxide at the southern INEL boundary; however, these increases are below instrument detection limits. The calculated average annual

increase in nitrogen oxides concentration is 0.80 micrograms per cubic meter and the calculated average hourly increase in carbon monoxide concentration is 0.42 micrograms per cubic meter. Water use is 1000 gallons per minute. The maximum energy demand at the ICPP has been 4.3 megawatts which is equivalent to the electrical demand of 675 households.

About 500 employees are exposed to radiation from all ICPP activities which results in an annual whole-body equivalent dose that ranges from 375 to 650 man-rem. Each worker receives an average annual dose of 1 rem. The population (165,000) within 50 miles of the ICPP receives an annual whole-body equivalent dose of about 0.005 man-rem from ICPP activities. This is an extremely low dose compared to the annual dose received from background radiation of 24,750 man-rem.

As depicted in the illustration below, environmental effects would be caused primarily by airborne emissions. Small amounts of wastewater would be



ROUTINE OPERATIONS

generated during waste form modification and actinide separation, but liquid effluents produced by these operations would be treated before release and would be within applicable drinking water standards.

Nonradiological Effects of Routine Operations

Effects on ambient air quality of the waste management alternatives from routine operations are shown in Table 4-7. It is estimated that waste retrieval and processing would take place during a 30-year period. The volume of waste processed during the first 13 years would be twice the volume processed during the last 17 years of the project. Air concentrations are calculated for all pollutants controlled by federal and state standards. They are based on continuous operation of processing facilities for 230 days per year and calculated from the atmospheric dispersion factor for elevated releases at the southern INEL boundary (4.0×10^{-8} second per cubic meter). The concentration is expected to be maximal at this location. Emissions would be controlled by the offgas treatment and atmospheric protection systems described in Subsection 2.3. The primary air pollutant emitted during the operations phase would be nitrogen oxides produced during waste form modification. Small amounts of carbon monoxide would be produced during recalcination of actinide-depleted waste (Alternative 4). Particulate emissions from all alternatives would be negligible. The calculated air pollutant concentration increases that would result from calcine retrieval and processing would be below the detection limit of the monitoring equipment.

Potentially toxic chemicals could be emitted during waste processing (Alternatives 2, 3, 4, and 5). Emission rates are estimated for stack releases of cadmium and mercury. The maximum cadmium emission rate would be very low (40 pounds per day). There are no federal or state air quality standards for cadmium. The calculated maximum annual average concentration of cadmium ($0.01\ \mu g/m^3$) would be comparable to background concentrations ($0.03\ \mu/m^3$). The maximum mercury emission rate (1,700 grams/24 hours) would be about 74 percent of the most restrictive national emission standard (2,300 grams/ 24 hours) for hazardous air pollutants (40 CFR 61). Small amounts of silicon fluoride could be emitted during pelletization. There are no air quality standards for silicon fluoride.

TABLE 4-7

CALCULATED CONCENTRATION INCREASES
OF AIR POLLUTANTS FROM ROUTINE FACILITY OPERATION[a,b]
(micrograms per cubic meter)

Alternative	Nitrogen Oxides (Annual Arithmetic Mean)	Carbon Monoxide (1-Hr Average)
1. Leave-in-Place	0	0
2. Retrieve, Modify Calcine, Dispose at the INEL		
Pelletize Calcine	1.0	0
Convert Calcine to Glass	0.44	0
3. Retrieve, Modify Calcine, Dispose Offsite		
Stabilize Calcine	0.40	0
Convert Calcine to Glass	0.44	0
4. Retrieve, Separate Actinides, Dispose of Actinides Offsite, Dispose of Depleted Calcine at the INEL	2.3	6.4
5. Delay Retrieval, Modify Calcine, Dispose Offsite		
100 Years	0.44	0
300 Years	0.44	0
500 Years	0.44	0
Federal Standard[c]	100	40,000

a. At southern INEL boundary.

b. All calculated concentrations are below instrument detection limits.

c. 40 CFR 50.

Effects of the small amounts of nonradiological air pollutants on the public and waste management workers would be negligible. State-of-the-art pollution control technology would be utilized and environmental monitoring would be conducted throughout the 30-year period of operations to verify compliance with applicable standards.

Small amounts of nonradioactive solid waste would be generated during waste processing. Materials such as packing boxes, crates, chemical containers, office supplies, and scrap would be surveyed for radioactivity prior to packaging for disposal in the INEL sanitary landfill.

Other environmental effects during the operations phase would not significantly differ from effects of current ICPP operations. Ambient noise levels would not affect the public. Nonradiological effects on the bioenvironment would be less than during the construction phase; effects would be so small that they would probably be undetectable. Aesthetic effects of facility operation and maintenance would be an extension of construction effects which would blend with the other ongoing activities at the ICPP.

The potential employment effects of the waste management alternatives can be placed in perspective by examining the overall INEL employment and variations in its level. Employment remained relatively constant at 5,300 to 6,200 from 1967 to 1974, but grew substantially from 1975 to June 1978 when it reached a total of about 9,400 jobs. The number of employees has since leveled off. Within a year, the number of employees typically varies by 600.

Table 4-8 shows the employment requirements for the alternatives during the 30-year processing period. Twice as many employees would be required during the initial 13 years of operation as during the last 17 years. That number of employees would be in addition to the current labor force at the ICPP, and includes surveillance and maintenance personnel. The largest operating work force (100) would be required for actinide separation during the period 1990 to 2003. Effects of this employment level on local communities would not be observed. According to the Idaho Falls Chamber of Commerce, approximately one job is created in eastern Idaho service industries for every three new permanent jobs created in the nonservice industries. (This relationship converts to an employment multiplier of 1.33). Therefore, the operating work force required for actinide separation would result in a maximum of 133 workers and their families who would require accommodation in the communities surrounding the INEL.

TABLE 4-8

ESTIMATED OPERATIONS PHASE RESOURCE COMMITMENTS

Alternative	Water (Gal/Min)	Glass Frit[a] (10^6 Lb)	Chemicals 10^6 Lb	Energy Demand (Megawatts)	Labor Force[b] (Man-Yr)			Diesel Fuel for Waste Shipment (10^6 Gal)
					At INEL	Waste Shipment	At Repository	
1. Leave-in-Place[c]	0	0	0	0	0	NA[d]	NA	NA
2. Retrieve, Modify Calcine, Dispose at the INEL								
Pelletize Calcine	370	0	7.5	1.45	800	NA	NA	NA
Convert Calcine to Glass	350	93	0	1.15	1250	NA	NA	NA
3. Retrieve, Modify Calcine, Dispose Offsite								
Stablize Calcine	280	0	0	0.57	950	2700	1400	1.8
Convert Calcine to Glass	350	93	0	1.15	1100	2700	1400	2.7
4. Retrieve, Separate Actinides, Dispose of Actinides Offsite Dispose of Depleted Calcine at the INEL	625	1	94	1.60	1700	2700	10	0.1
5. Delay Retrieval, Modify Calcine, Dispose Offsite								
100 Years	350	98	0	1.15	1500	2700	140	2.7
300 Years	350	98	0	1.15	1500	2700	10	2.7
500 Years	350	98	0	1.15	1500	2700	10	2.7

a. Materials are used in waste form modification during the 30-year operations period.

b. Includes additional labor force required for the 30-year operations period at the INEL, waste shipment workers, and operations at the repository.

c. There are no resource commitments in addition to resources already committed to the calcination process.

d. NA, not applicable.

An INEL questionnaire (DOE, 1978) showed that the average employee household size is 3.1 persons. Assuming the same household size for newcomers, the maximum population increase from direct employment is calculated to be 412 persons. The Department of Housing and Urban Development (HUD, 1976) considers that impacts on a community are generally recognizable when the in-migrating work force increases the local population by 5 percent or more. Based on the population growth assumptions used in this report, the study area population in 1990 would be about 199,000. Thus, the maximum additional labor force (Alternative 4) would increase the population in the study area by only 0.2 percent.

As shown in Table 4-8, resource use during the operations phase would be similar to other chemical processing industries. Water use would not appreciably affect the aquifer or other users. The maximum electrical power demand (1.60 megawatts) for waste form modification would be 37 percent of ICPP demand in 1980. A new electrical substation and transmission lines from the main site substation would be required to implement Alternatives 2, 3, 4, and 5. The plant would be operated in accordance with applicable federal and state air quality standards and effluent regulations.

Radiological Effects of Routine Operations

The source of radiological effects on the public from routine calcine retrieval and processing operations would be airborne releases from the facility offgas treatment system and ventilation system (Alternatives 2, 3, 4, and 5). Radiological effects on the public from routine releases for each waste management alternative are shown in Table 4-9. The largest dose commitment to the maximum individual (0.000003 rem) from airborne releases of radionuclides during the operations phase would be within the background radiation dose (0.15 rem). Thus, effects on the public would be undetectable.

Alternatives 3, 4, and 5 involve shipping all or part of the waste calcine to an offsite federal geologic repository. The public along the shipment route would receive minor external doses of direct radiation from the shipping casks as shown in the illustration on Page 4-37.

TABLE 4-9

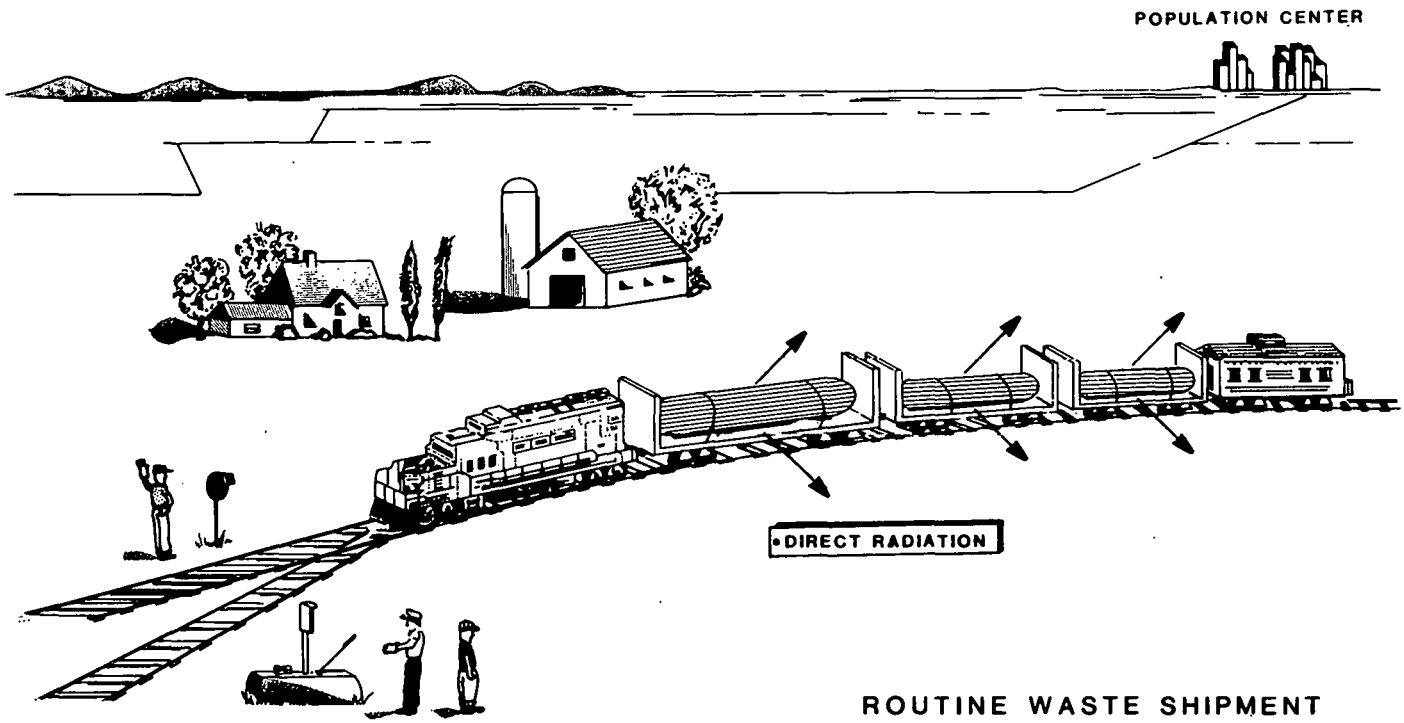
RADIOLOGICAL EFFECTS OF ROUTINE OPERATIONAL RELEASES[a]

Alternative	Maximum Individual Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Population Whole-Body Equivalent Dose (Man-Rem)	Population Range of Health Effects[b] (Number)	Population Probability of Event (Event/Year)	Population Risk (Man-Rem/Year)
1. Leave-in-Place	NA[c]	NA	NA	NA	NA	NA
2. Retrieve, Modify Calcine, Dispose at the INEL						
Pelletize Calcine	3.00×10^{-6}	199,000	2.39×10^{-2}	1.79×10^{-6} to 5.49×10^{-6}	1.0	2.39×10^{-2}
Convert Calcine to Glass	3.00×10^{-6}	199,000	2.39×10^{-2}	1.79×10^{-6} to 5.49×10^{-6}	1.0	2.39×10^{-2}
3. Retrieve, Modify Calcine, Dispose Offsite						
Stabilize Calcine	6.54×10^{-9}	199,000	5.21×10^{-5}	3.90×10^{-9} to 1.20×10^{-8}	1.0	5.21×10^{-5}
Convert Calcine to Glass	3.00×10^{-6}	199,000	2.39×10^{-2}	1.79×10^{-6} to 5.49×10^{-6}	1.0	2.39×10^{-2}
4. Retrieve, Separate Actinides, Dispose of Actinides Offsite Dispose of Depleted Calcine at the INEL	7.35×10^{-9}	199,000	5.85×10^{-5}	4.39×10^{-9} to 1.35×10^{-8}	1.0	5.85×10^{-5}
5. Delay Retrieval, Modify Calcine, Dispose Offsite						
100 Years	1.63×10^{-10}	546,000	3.56×10^{-6}	2.67×10^{-10} to 8.19×10^{-10}	1.0	3.56×10^{-6}
300 Years	8.61×10^{-12}	650,000	2.24×10^{-7}	1.68×10^{-11} to 5.15×10^{-11}	1.0	2.24×10^{-7}
500 Years	4.27×10^{-12}	650,000	1.11×10^{-7}	8.33×10^{-12} to 2.55×10^{-11}	1.0	1.11×10^{-7}

a. Based on 50-year dose commitment from 1 year of operation in 1990 (Alternatives 2, 3, and 4) and in 2090, 2290, and 2490 (Alternative 5).

b. Health effects are cancer deaths.

c. NA, not applicable.



ROUTINE WASTE SHIPMENT

In this report, the waste is assumed to be shipped by rail for a distance of 1,500 miles. Waste canisters would be packaged in shipping casks that would reduce excessive amounts of radiation. Federal shipping regulations (49 CFR 173.393) specify that exposure rates measured 6 feet from the surface of the shipping vehicles shall not exceed 10 millirem per hour.

In estimating the effects of routine shipping operations, waste is assumed to be shipped to the repository along a maximum population route (see Subsection 2.2.3). Since the population is assumed to increase for a 150-year period, the radiation effects of delayed waste retrieval and shipment (Alternative 5) on the public residing along the waste shipment route will also increase. The waste is also assumed to be shipped in containers that comply with federal shipping regulations. Consequently, the decrease in direct radiation for the delayed retrieval alternative is not as great as might be expected. The doses delivered to the general public residing along the route and associated health effects are given in Table 4-10.

TABLE 4-10

RADIOLOGICAL EFFECTS ON THE PUBLIC FROM ROUTINE WASTE SHIPMENT[a]

Alternative	Maximum Individual Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Population Whole-Body Equivalent Dose (Man-Rem)	Population Range of Health Effects[b] (Number)	Population Probability of Event (Event/Year)	Population Risk (Man-Rem/Year)
1. Leave-in-Place	NA[c]	NA	NA	NA	NA	NA
2. Retrieve, Modify Calcine, Dispose at the INEL						
Pelletize Calcine	NA	NA	NA	NA	NA	NA
Convert Calcine to Glass	NA	NA	NA	NA	NA	NA
3. Retrieve, Modify Calcine, Dispose Offsite						
Stabilize Calcine	1.90×10^{-2}	125,000	237	1.78×10^{-2} to 5.46×10^{-2}	1.0	237
Convert Calcine to Glass	2.90×10^{-2}	125,000	362	2.72×10^{-2} to 8.34×10^{-2}	1.0	362
4. Retrieve, Separate Actinides, Dispose of Actinides Offsite, Dispose of Depleted Calcine at the INEL	1.00×10^{-3}	125,000	12.5	9.37×10^{-4} to 2.87×10^{-3}	1.0	12.5
5. Delay Retrieval, Modify Calcine, Dispose Offsite						
100 Years	2.15×10^{-3}	209,000	449	3.37×10^{-2} to 1.03×10^{-1}	1.0	449
300 Years	1.96×10^{-3}	250,000	490	3.67×10^{-2} to 1.13×10^{-1}	1.0	490
500 Years	1.96×10^{-3}	250,000	490	3.67×10^{-2} to 1.13×10^{-1}	1.0	490

a. Based on exposure from 1 year of waste shipment in 1990 (Alternatives 3 and 4) and in 2090, 2290, and 2490 (Alternative 5).

b. Health effects are cancer deaths.

c. NA, not applicable. Effects apply to alternatives that involve offsite shipment.

Occupational exposure is a consequence of waste management activities. Workers who accept employment in waste management projects are assumed to accept exposure to radiation. Occupational exposure is minimized wherever possible by using special shielding, protective clothing, special-use masks, and self-contained or air-supplied breathing equipment. Time spent in radiation areas is carefully monitored to ensure that allowable time limits are not exceeded. Worker exposures are monitored and controlled by a corps of health physicists. Also, workers wear personal dosimeters and radiation badges which are analyzed routinely to ensure compliance with the occupational exposure limit of 5 rem per year (ERDAM, 1977).

Because of these precautions, occupational exposures at the ICPP average less than 1 rem per year. Future improvements in remote maintenance techniques should reduce this level even more. It is assumed that the average occupational exposure would be 1 rem per year, except in Alternative 5 in which retrieval of calcine is delayed. Because beta-gamma decay occurs during the delay period, the average occupational exposure is estimated to be 0.5, 0.3, and 0.1 rem per year for the 100-, 300-, and 500-year delays, respectively.

Train crew members would be exposed to low levels of radiation during waste shipment. Exposures would be proportional to the number of crew members, the annual volume of waste shipped, and the length of time a train crew member remained in close proximity to the shipping cask. Estimated doses to waste management workers resulting from operations at the INEL, waste shipment, and operations at the repository are given in Table 4-11.

Operational Accidents

Nonradiological Effects of Accidents

The operations involved in waste management are similar to other industrial practices; the only major difference is that the materials being handled are radioactive. Because of this similarity, occupational injury and fatality rates for comparable industries were used to quantify the expected impact of nonradiological accidents during the construction, operations, waste shipment, and D&D phases of alternative implementation.

TABLE 4-11

RADIOLOGICAL EFFECTS ON WASTE MANAGEMENT WORKERS FROM FOUTINE OPERATIONS AND WASTE SHIPMENT[a]

Alternative	Operations[b]			Waste Shipment		Repository
	Years of Exposure (Number)	Workers Exposed (Number)	Total Whole-Body Equivalent Dose (Man-Rem)	Workers Exposed (Number)	Total Whole-Body Equivalent Dose (Man-Rem)	Total Whole-Body Equivalent Dose (Man-Rem)
1. Leave-in-Place	0	0	0	NA[c]	NA	NA
2. Retrieve, Modify Calcine, Dispose at the INEL[d]						
Pelletize Calcine	10	40	400	NA	NA	NA
	20	20	400	NA	NA	NA
Convert Calcine to Glass	10	55	500	NA	NA	NA
	20	35	700	NA	NA	NA
3. Retrieve, Modify Calcine, Dispose Offsite						
Stabilize Calcine	10	45	450	90	270	140
	20	25	500			
Convert Calcine to Glass	10	50	500	90	270	140
	20	30	600			
4. Retrieve, Seperate Actinides, Dispose of Actinides Offsite						
Dispose of Depleted Calcine at the INEL[d]	10	100	1,000	90	27	1
	20	35	700			
5. Delay Retrieval, Modify Calcine, Dispose Offsite						
100 Years	30	50	750	90	135	14
300 Years	30	50	450	90	81	1
500 Years	30	50	150	90	27	1

a. Total effects for 30-year operations period.

b. Includes waste disposal at the INEL.

c. NA, not applicable.

d. A larger operating work force to process the existing backlog of calcine is required during the first 10 years of alternative implementation.

The data from related industries provide perspective on the expected magnitude of the hazards. However, the differences in injury and fatality rates between waste management operations and similar industries may be substantial with waste management operations being safer. For instance, all waste management operations would be designed to minimize worker hazards. Workers would be trained in safety techniques. Retrieval operations and waste form modification would be conducted by remote control. Compared to similar industries, these precautions would greatly reduce the hazards to workers. Therefore, the projected injuries and fatalities are expected to be conservative.

Projected worker injuries and fatalities are shown in Table 4-12. Construction, operation, and D&D injuries and fatalities are based on National Safety Council data for 1976 (NSC, 1977). Operations effects have been calculated using data for the manufacturing industry. Construction and D&D effects are based on calculations using data for the construction industry. Waste shipment accidents and injuries are based on data used to estimate effects of waste shipment in the Savannah River EIS (DOE, 1979). Repository injuries and fatalities are based on estimates in the EIS for commercially generated radioactive waste (DOE, 1980a).

Radiological Effects of Accidents

Two postulated accidents with radiological effects have occurrence probabilities that make it very likely they will occur during the 30-year period of facility operation. These are a calcine spill and a decontamination solution spill.

Calcine Spill

A calcine spill could occur during retrieval and waste form modification (Alternatives 2, 3, 4, and 5) as shown in the illustration on Page 4-43.

TABLE 4-12

PROJECTED NONRADIOLOGICAL (INDUSTRIAL) INJURIES AND FATALITIES TO WORKERS [a,b]

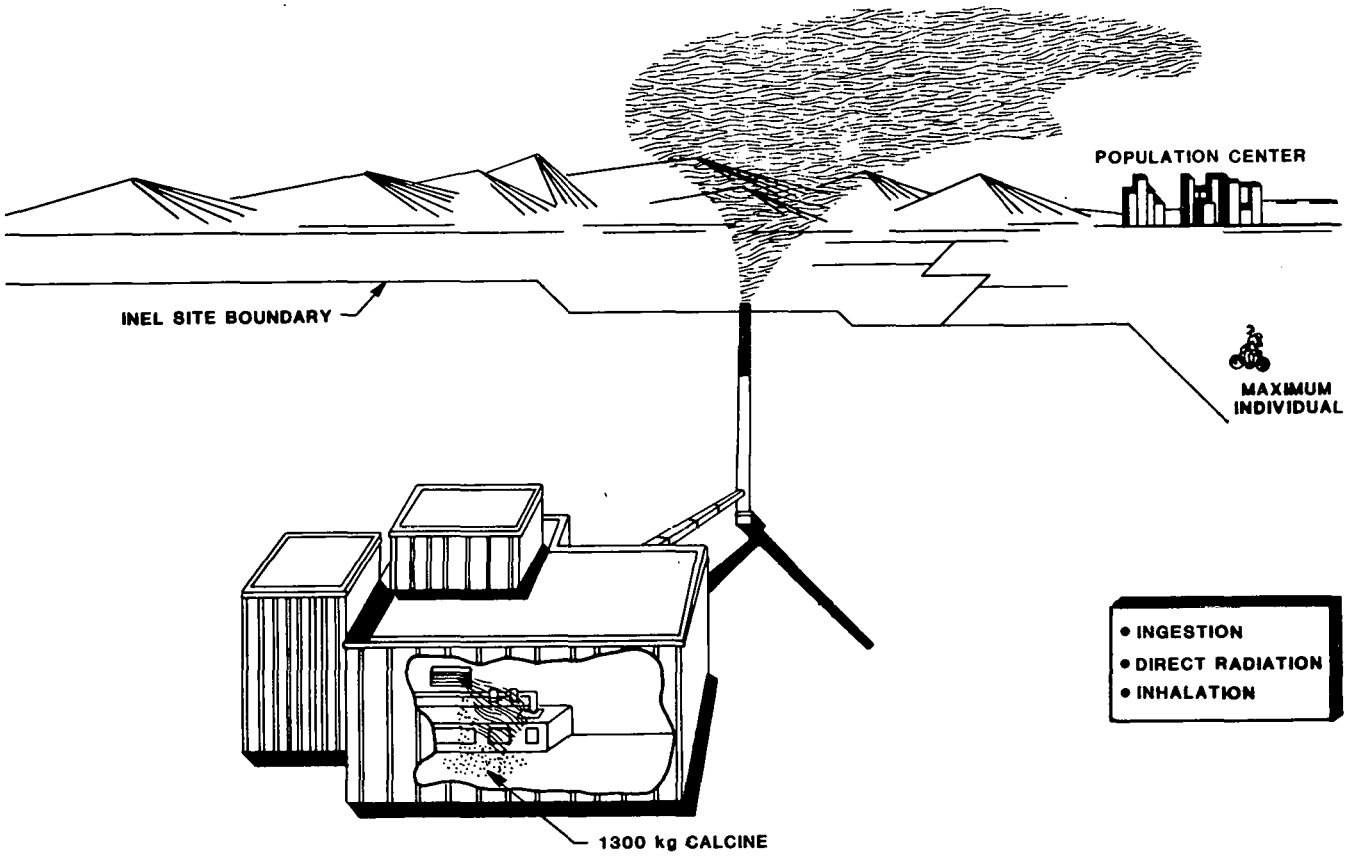
Alternative	Project Phase									
	Construction		Operation[c]		Waste Shipment[d]		D&D		Repository Construction	
	I	F	I	F	I	F	I	F	I	F
1. Leave-in-Place	17	0.2	0.4	0.001	NA	NA	0.5	0.006	NA	NA
2. Retrieve, Modify Calcine, Dispose at INEL										
Pelletize Calcine	51	0.5	20	0.07	NA	NA	0.8	0.009	NA	NA
Convert Calcine to Glass	23	0.2	31	0.1	NA	NA	2	0.02	NA	NA
3. Retrieve, Modify Calcine, Dispose Offsite										
Stabilize Calcine	11	0.1	24	0.09	4	0.3	2	0.02	44	0.9
Convert Calcine to Glass	11	0.1	28	0.1	5	0.4	2	0.02	44	0.9
4. Retrieve, Separate Actinides, Dispose of Actinides Offsite, Dispose of Depleted Calcine at INEL	78	0.8	44	0.2	0.2	0.01	3	0.03	0.2	Negligible
5. Delay Retrieval, Modify Calcine, Dispose Offsite										
100 Years	11	0.1	37	0.14	5	0.4	2	0.02	4	0.1
300 Years	11	0.1	37	0.14	5	0.4	2	0.02	0.2	Negligible
500 Years	11	0.1	37	0.14	5	0.4	2	0.02	0.2	Negligible

a. Abbreviations: I, injuries; F, fatalities; NA, not applicable.

b. Actual calculated values are reported. Fractional values have meaning only for comparison purposes.

c. Includes waste disposal at the INEL.

d. Calculations based on 8.68×10^6, 1.3×10^7 and 4.8×10^5 railcar miles for Alternative 3 (stabilize calcine), Alternative 3 (glass), and Alternative 4, respectively.



CALCINE SPILL

This scenario is based on a similar accident that occurred at the ICPP during the calcination process. Should calcine spill onto the cell floor where the calcine receiver vessel is located, the fine calcine particles could become airborne. They would enter the facility ventilation system where most of the radioactive material would be removed by the atmospheric protection system. However, some of the material would be released through the facility stack and dispersed. Effects on the maximum individual and the population resulting from inhalation of trace amounts of radionuclides are given in Table 4-13.

The meteorologic conditions that exist at the time of the accident would determine the population that would be affected. Only persons located downwind would be exposed to radiation. Since calm weather has been assumed to exist at the time of the accident, the effects shown in Table 4-13 would be even smaller under more turbulent weather conditions. The very small maximum

TABLE 4-13

SHORT-TERM RADIOLOGICAL EFFECTS OF OPERATIONAL ACCIDENTS
CALCINE SPILL[a]

Alternative	Maximum Individual	Population				
	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range of Health Effects[b] (Number)	Probability of Event (Event/Year)	Population Risk (Man-Rem/Year)
1. Leave-in-Place	NA[c]	NA	NA	NA	NA	NA
2. Retrieve, Modify Calcine, Dispose at the INEL						
Pelletize Calcine	9.10×10^{-10}	107,000	3.89×10^{-6}	2.92×10^{-10} to 8.96×10^{-10}	0.20	7.79×10^{-7}
Convert Calcine to Glass	9.10×10^{-10}	107,000	3.89×10^{-6}	2.92×10^{-10} to 8.96×10^{-10}	0.20	7.79×10^{-7}
3. Retrieve, Modify Calcine, Dispose Offsite						
Stabilize Calcine	9.10×10^{-10}	107,000	3.89×10^{-6}	2.92×10^{-10} to 8.96×10^{-10}	0.20	7.79×10^{-7}
Convert Calcine to Glass	9.10×10^{-10}	107,000	3.89×10^{-6}	2.92×10^{-10} to 8.96×10^{-10}	0.20	7.79×10^{-7}
4. Retrieve, Separate Actinides, Dispose of Actinides Offsite, Dispose of Depleted Calcine at the INEL	9.10×10^{-10}	107,000	3.89×10^{-6}	2.92×10^{-10} to 8.96×10^{-10}	0.20	7.79×10^{-7}
5. Delay Retrieval, Modify Calcine, Dispose Offsite						
100 Years	4.77×10^{-11}	230,000	4.39×10^{-7}	3.29×10^{-11} to 1.01×10^{-10}	0.20	8.78×10^{-8}
300 Years	5.49×10^{-12}	230,000	5.05×10^{-8}	3.79×10^{-12} to 1.16×10^{-11}	0.20	1.01×10^{-8}
500 Years	3.57×10^{-12}	230,000	3.28×10^{-8}	2.46×10^{-12} to 7.55×10^{-12}	0.20	6.57×10^{-9}

a. Based on 50-year dose commitment from 1 year of exposure in 2020 (Alternatives 2, 3, and 4) and in 2120, 2320, and 2520 (Alternative 5).

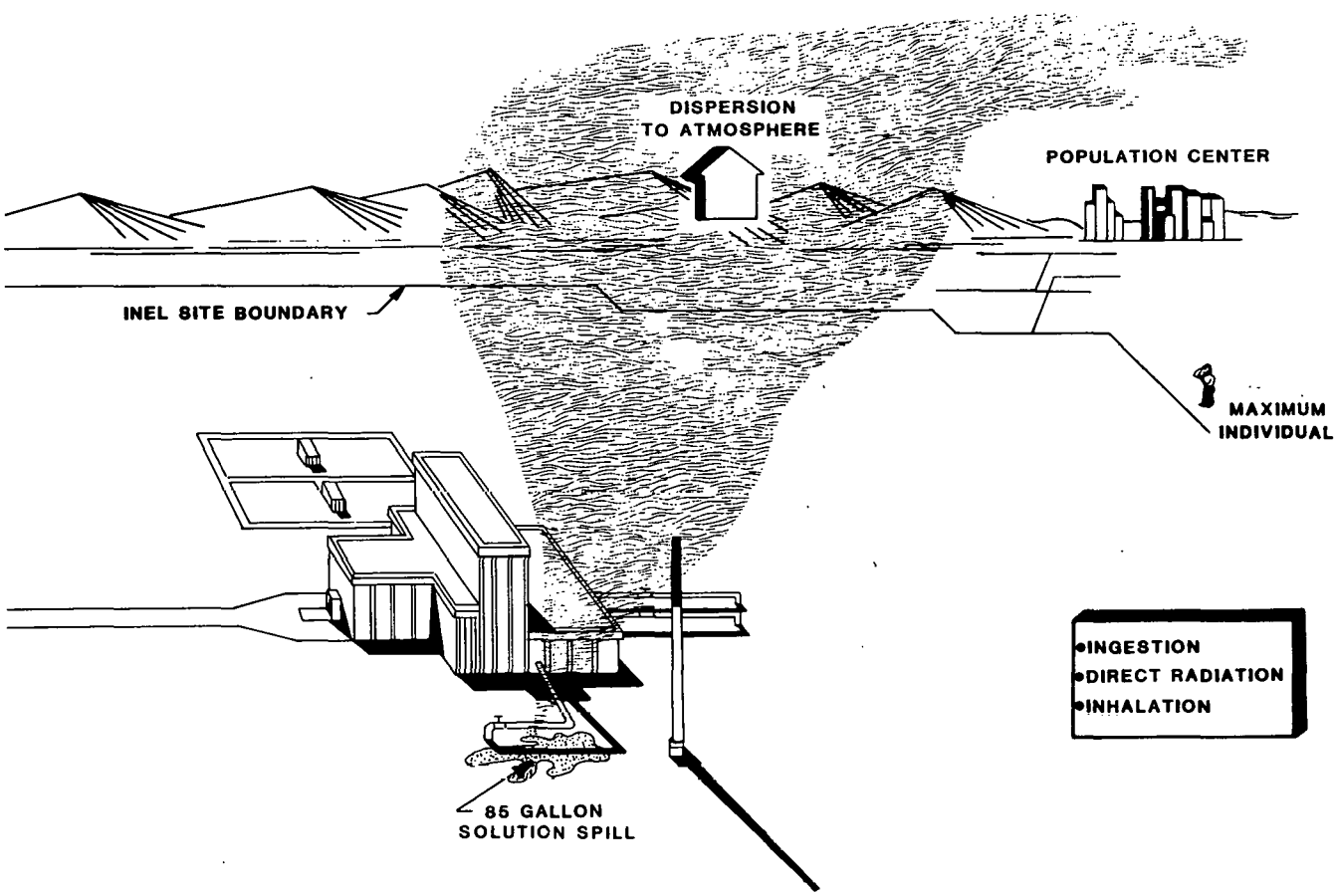
b. Health effects are cancer deaths.

c. NA, not applicable. Calcine spill does not apply to the leave-in-place alternative.

individual dose (9.10×10^{-10} rem) would be the same for Alternatives 2, 3, and 4, and would be indistinguishable from background radiation (0.15 rem). The dose would be about 20 to 300 times smaller if retrieval were delayed (Alternative 5).

Decontamination Solution Spill

Maintenance of retrieval and processing facilities would be required during the operations phase (Alternatives 2, 3, 4, and 5). The equipment would be cleaned periodically with a solution that dissolves the calcine. After decontamination of equipment, the transfer line for the solution containing high-level waste is assumed to leak or allow a spill to occur outside the processing facility as shown in the accompanying illustration.



DECONTAMINATION SOLUTION SPILL

In the case of an outside spill, there would be no removal of radionuclides by the atmospheric protection system. Most of the spilled solution would be absorbed by the soil and be removed as solid waste. However, some of the radionuclides would become airborne and dispersed in the direction of the prevailing winds. Inhalation of trace amounts of nuclides would cause the effects shown in Table 4-14.

The doses for the decontamination solution spill would be a maximum for Alternatives 2, 3, and 4 (0.061 rem). Since the spill is assumed to occur outside the processing facility, the doses for this accident would be larger than the doses for the calcine spill or extraction solvent fire. However, the effects would be less than the effects of background radiation (0.15 rem).

4.5.1.1.3 Decontamination and Decommissioning (D&D)

All waste management alternatives would require D&D. During D&D of the calcine bins (Alternative 1), only minor nonradiological effects similar to those resulting from construction activities would occur. The vaults would be filled with a concrete-like material about the year 2100 after heat from radioactive decay had been sufficiently reduced. During the lifetime of the material, the possibility of accidental intrusion into the waste, or migration of the waste away from the bins should the disposal site become flooded, would be significantly reduced by encapsulation of the bins. Encapsulation would also prevent the release of radionuclides in the event that an aircraft impact occurred at the site after the bins had disintegrated.

As a result of contamination during operations, all retrieval and processing facilities would require D&D. Radionuclide releases during D&D would be less than 1 percent of operational releases. All waste retrieval and processing facilities would be designed to make D&D as simple and inexpensive as feasible. Included would be such features as the use of easily decontaminated surfaces and equipment designed for dismantling into easily handled components.

TABLE 4-14

SHORT-TERM RADIOLOGICAL EFFECTS OF OPERATIONAL ACCIDENTS
DECONTAMINATION SOLUTION SPILL[a]

Alternative	Maximum Individual	Population				
	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range of Health Effects[b] (Number)	Probability of Event (Event/Year)	Population Risk (Man-Rem/Year)
1. Leave-in-Place	NA[c]	NA	NA	NA	NA	NA
2. Retrieve, Modify Calcine, Dispose at the INEL						
Pelletize Calcine	6.10×10^{-2}	107,000	1,310	9.79×10^{-2} to 3.00×10^{-1}	0.10	131
Convert Calcine to Glass	6.10×10^{-2}	107,000	1,310	9.79×10^{-2} to 3.00×10^{-1}	0.10	131
3. Retrieve, Modify Calcine, Dispose Offsite						
Stabilize Calcine	6.10×10^{-2}	107,000	1,310	9.79×10^{-2} to 3.00×10^{-1}	0.10	131
Convert Calcine to Glass	6.10×10^{-2}	107,000	1,310	9.79×10^{-2} to 3.00×10^{-1}	0.10	131
4. Retrieve, Separate Actinides, Dispose of Actinides Offsite, Dispose of Depleted Calcine at the INEL	6.10×10^{-2}	107,000	1,310	9.79×10^{-2} to 3.00×10^{-1}	0.10	131
5. Delay Retrieval, Modify Calcine, Dispose Offsite						
100 Years	3.21×10^{-3}	230,000	148	1.11×10^{-2} to 3.40×10^{-2}	0.10	14.8
300 Years	3.73×10^{-4}	230,000	17.2	1.29×10^{-3} to 3.95×10^{-3}	0.10	1.72
500 Years	2.41×10^{-4}	230,000	11.1	8.31×10^{-4} to 2.55×10^{-3}	0.10	1.11

a. Based on 50-year dose commitment from 1 year of exposure in 2020 (Alternative 2, 3, and 4) and in 2120, 2320, and 2520 (Alternative 5).

b. Health effects are cancer deaths.

c. NA, not applicable. Decontamination solution spill does not apply to the leave-in-place alternative.

Because of the necessity of working inside contaminated areas during the D&D phase, the potential for contamination of the D&D workers is higher during the D&D phase than it is during the operations phase. The workers would wear protective clothing and in some cases would be supplied with breathing air from an external source. They would also be closely monitored to preclude unacceptable exposures. Standard radiological safety procedures would be followed to ensure that hazards are adequately identified and appropriate preventive measures taken.

The technology for D&D is generally well established, and current research should improve remote handling techniques. The effects on the public and waste management workers from D&D activities are given in Table 4-15.

Decontamination and decommissioning for actinide separation (Alternative 4) would cause the highest worker doses. Health effects in the population would be indistinguishable from the effects of background radiation for all alternatives.

Radioactive solid waste produced during D&D would consist of protective clothing, absorbent paper, used tools, process equipment, and demolition debris. This low-level waste would be segregated and sent to the radioactive waste management complex at the INEL for disposal.

Manpower and materials requirements for D&D would be minor. Resource commitments for D&D activities are given in Table 4-16.

4.5.1.1.4 Disposal

During the short-term period of disposal at the INEL, maintenance and surveillance of the disposal site would continue. The present environmental monitoring program (Subsection 3.5) would be continued and expanded. No major use of resources or materials would be required.

TABLE 4-15

RADIOLOGICAL EFFECTS ON THE PUBLIC AND WASTE MANAGEMENT WORKERS FROM DECONTAMINATION AND DECOMMISSIONING ACTIVITIES[a,b]

Alternative	Maximum Individual	Population			Workers		
	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range of Health Effects[c] (Number)	Maximum Individual Whole-Body Equivalent Dose (Rem)	Workers Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)
1. Leave-in-Place	0	0	0	0	0	0	0
2. Retrieve, Modify Calcine, Dispose at the INEL							
Pelletize Calcine	1.06×10^{-8}	303,000	1.28×10^{-4}	9.63×10^{-9} to 2.95×10^{-8}	1	13	25
Convert Calcine to Glass	1.06×10^{-8}	303,000	1.28×10^{-4}	9.63×10^{-9} to 2.95×10^{-8}	1	25	50
3. Retrieve, Modify Calcine, Dispose Offsite							
Stabilize Calcine	2.52×10^{-11}	303,000	3.05×10^{-7}	2.29×10^{-11} to 7.02×10^{-11}	1	25	50
Convert Calcine to Glass	1.06×10^{-8}	303,000	1.28×10^{-4}	9.63×10^{-9} to 2.95×10^{-8}	1	25	50
4. Retrieve, Seperate Actinides, Dispose of Actinides Offsite Dispose of Depleted Calcine at the INEL	3.04×10^{-11}	303,000	3.68×10^{-7}	2.76×10^{-11} to 8.47×10^{-11}	1	38	75
5. Delay Retrieval, Modify Calcine, Dispose Offsite							
100 Years	1.63×10^{-12}	650,000	4.24×10^{-8}	3.18×10^{-12} to 9.75×10^{-12}	0.5	30	30
300 Years	8.61×10^{-14}	650,000	2.24×10^{-9}	1.68×10^{-13} to 5.15×10^{-13}	0.3	30	18
500 Years	4.27×10^{-14}	650,000	1.11×10^{-9}	8.33×10^{-14} to 2.55×10^{-13}	0.1	30	6

a. Based on 50-year dose commitment from 1 year of activities beginning in 2020 (Alternatives 2, 3, and 4) and in 2120, 2320, and 2520 (Alternative 5).

b. The D&D campaign is assumed to require 2 years; encapsulation is the assumed mode of D&D.

c. Health effects are cancer deaths.

TABLE 4-16

DECONTAMINATION AND DECOMMISSIONING ACTIVITIES AND RESOURCE COMMITMENTS[a]

Alternative	Labor Force (Man-Yr)	Concrete (10^3 Yd^3)	Water (10^6 Gal)	Chemicals (10^3 Lb)
1. Leave-in-Place	0[b]	50	2.0	80
2. Retrieve, Modify Calcine, Dispose Offsite				
Pelletize Calcine	25	90	3.6	195
Convert Calcine to Glass	50	9	3.6	278
3. Retrieve, Modify Calcine, Dispose Offsite				
Stabilize Calcine	50	9	3.6	203
Convert Calcine to Glass	50	9	3.6	278
4. Retrieve, Separate Actinides, Dispose of Actinides Offsite, Dispose of Depleted Calcine at the INEL	75	60	2.4	690
5. Delay Retrieval, Modify Calcine, Dispose Offsite				
100 Years	60	80	3.2	379
300 Years	60	80	3.2	379
500 Years	60	80	3.2	379

a. Resources are for encapsulation of bins.

b. No manpower would be required in addition to the present labor force.

Effects of the leave-in-place alternative (Alternative 1) would be minimal because existing calcine storage would be upgraded. The disposal of either pellets, glass, or actinide-depleted calcine at the INEL (Alternatives 2 and 4) would require the construction of disposal space in addition to that required for Alternative 1.

The effects of a federal geologic repository are described in other environmental documents (DOE, 1980a; DOE, 1980b). The effects of offsite disposal at a federal geologic repository would occur regardless of the disposal of INEL waste, and would, therefore, be independent of the INEL waste. The volume of INEL waste would be small compared to the volume of commercially generated waste that would be disposed there. Costs of disposal at a repository have been estimated and are discussed in Subsection 2.5.5.

4.5.1.2 Short-Term Effects of Abnormal Events

This subsection describes the potential radiological consequences of accidents postulated to occur in the short term up to 100 years after alternative implementation (see Table 4-4). There are no radiological effects from abnormal events during the short term.

Radiological effects on the public are discussed for the following abnormal events:

- extraction solvent fire during actinide separation,
- waste shipment accident,
- waste canister drop, and
- aircraft impact.

The radiological consequences of an accident during waste shipment are discussed for train crew members.

Short-term radiological effects from accidental releases of radionuclides at the INEL and at the offsite federal geologic repository are discussed according to the project phase in which each could occur (see Table 4-4). Operational effects are discussed for accidents during solvent extraction, waste shipment, and emplacement in a geologic repository. Effects of waste disposal at the INEL are discussed for an aircraft impact. These events have probabilities of 1×10^{-2} or less so their occurrence during the 30-year period of operation is unlikely.

The mitigative measures that would be used after accidental releases of radionuclides will be discussed in safety documents prepared during the design of waste retrieval and processing facilities. Emergency preparedness, evacuation procedures, and cleanup operations will be addressed when the facility design and operating procedures can be determined with greater accuracy.

Extraction Solvent Fire

This scenario applies only to actinide separation (Alternative 4) where a kerosene-like solvent is used to separate the actinides from the fission products. Since the solvent is flammable, it is assumed that during processing high-level waste is spilled at the same time a solvent leak occurs.

The airborne radionuclides would be carried with the smoke and pass through the cell ventilation system. Most of the radionuclides would be removed by the atmospheric protection system, but some of the material would be released through the facility stack and dispersed. Effects on the maximum individual and the population resulting from inhalation of trace amounts of radionuclides are given in Table 4-17.

The maximum individual dose (2.41×10^{-7} rem) would be indistinguishable from the dose received from background radiation (0.15 rem). This event is more severe than the calcine spill because the actinides present in the waste have been concentrated.

A solution of flammable solvent and radionuclides is assumed to ignite as shown on the page following Table 4-17.

Waste Shipment Accident

Waste shipment to a federal geologic repository would be required to implement Alternatives 3, 4, and 5. The waste would be packaged in containers and placed in shipping casks that meet Department of Transportation specifications for radiation and container integrity. A Type B cask must survive certain severe hypothetical accident conditions that demonstrate resistance to impact, puncture, fire, and submersion in water (49 CFR 173.398). Under these

TABLE 4-17

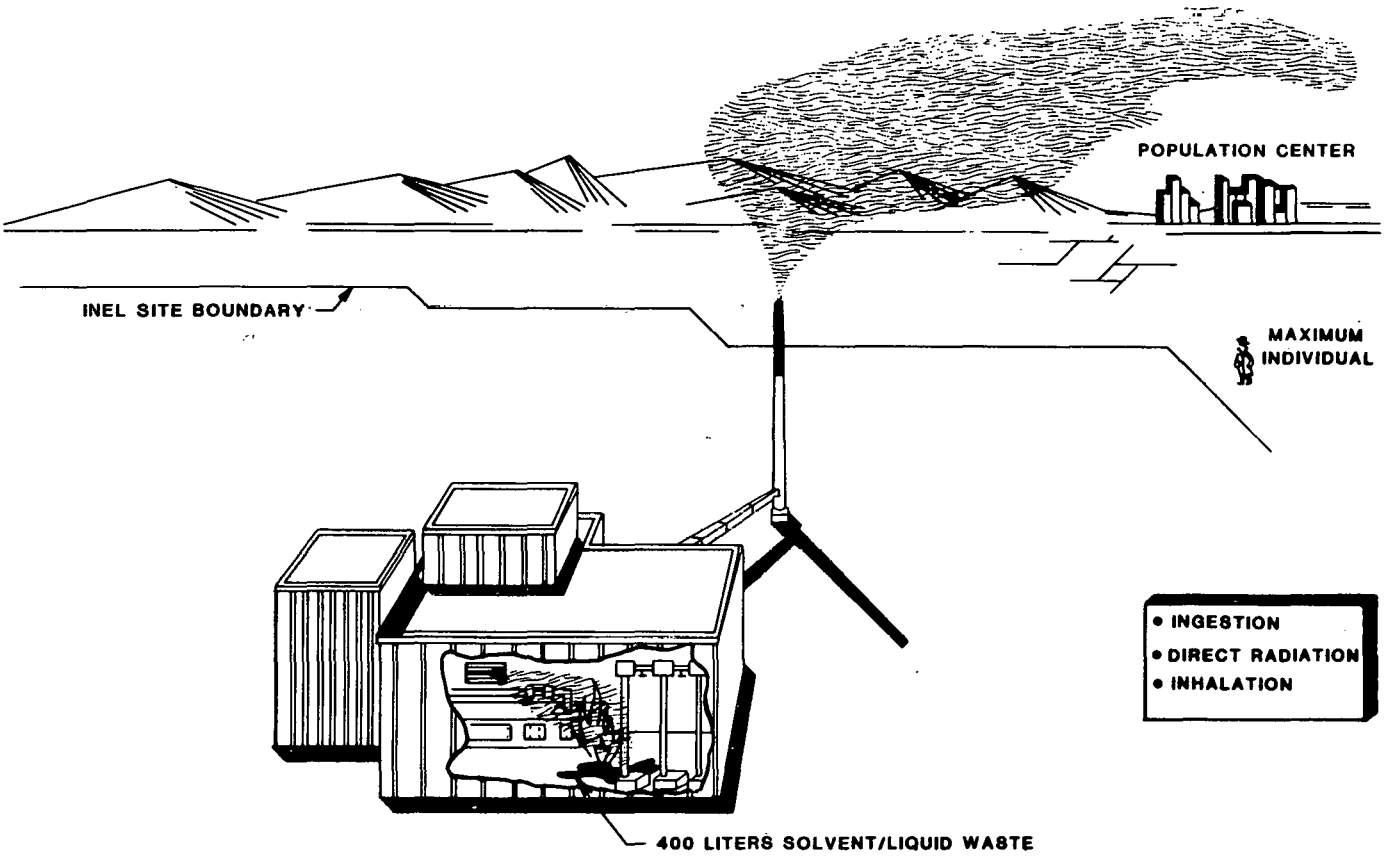
SHORT-TERM RADIOLOGICAL EFFECTS OF OPERATIONAL ACCIDENTS
EXTRACTION SOLVENT FIRE[a]

Alternative	Maximum Individual	Population				
	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range of Health Effects[b] (Number)	Probability of Event (Event/Year)	Population Risk (Man-Rem/Year)
1. Leave-in-Place	NA[c]	NA	NA	NA	NA	NA
2. Retrieve, Modify Calcine, Dispose at the INEL						
Pelletize Calcine	NA	NA	NA	NA	NA	NA
Convert Calcine to Glass	NA	NA	NA	NA	NA	NA
3. Retrieve, Modify Calcine, Dispose Offsite						
Stabilize Calcine	NA	NA	NA	NA	NA	NA
Convert Calcine to Glass	NA	NA	NA	NA	NA	NA
4. Retrieve, Separate Actinides, Dispose of Actinides Offsite, Dispose of Depleted Calcine at the INEL	2.41×10^{-7}	107,000	1.03×10^{-3}	7.74×10^{-8} to 2.37×10^{-7}	0.01	1.03×10^{-5}
5. Delay Retrieval, Modify Calcine, Dispose Offsite						
100 Years	NA	NA	NA	NA	NA	NA
300 Years	NA	NA	NA	NA	NA	NA
500 Years	NA	NA	NA	NA	NA	NA

a. Based on 50-year dose commitment from 1 year of exposure in 2020.

b. Health effects are cancer deaths.

c. NA, not applicable. Extraction solvent fire applies to actinide separation only.

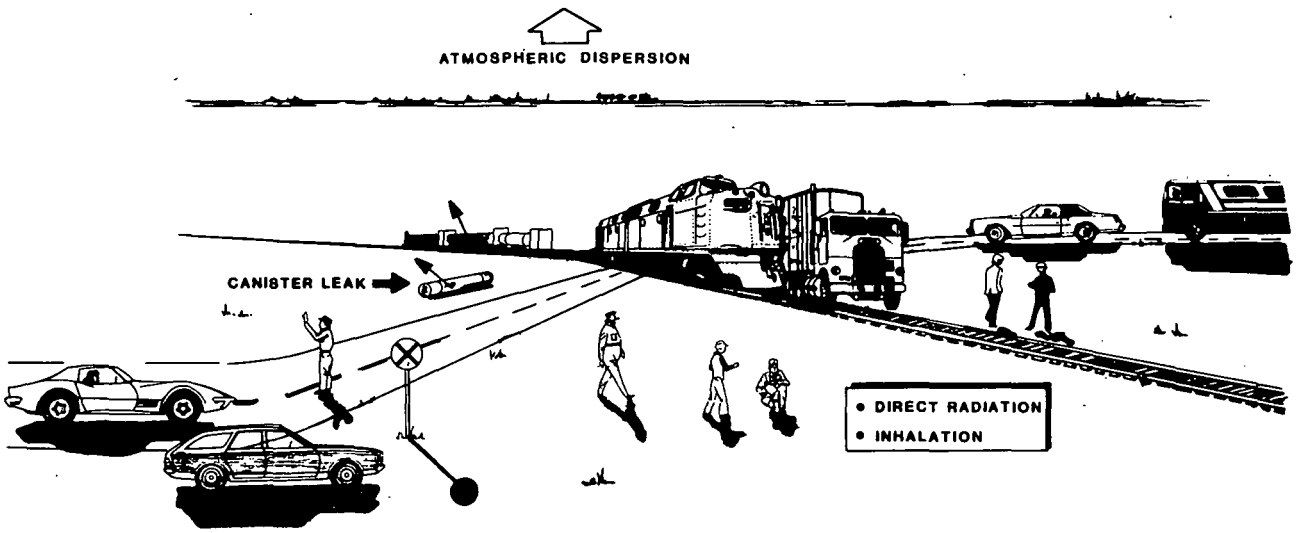


EXTRACTION SOLVENT FIRE

conditions, the Type B package must not release any of its radioactive contents. However, based on the conservative approach used in this report, it is assumed that a train carrying radioactive waste collides with a truck at a railroad crossing. A shipping cask is assumed to break open as shown in the illustration on the following page.

It is assumed that waste containing radioactivity is released and a fraction becomes airborne. Traffic is shown to back up on both sides of the crossing. The general public, spectators, clean-up personnel, and train crew members would be exposed to radioactive material, inhalation of airborne radionuclides, and also to direct radiation.

Accident effects depend on many factors: waste form, shipment method, travel distance, and population distribution along the route. The waste form significantly affects the amount of waste released. In Alternative 3, it is estimated that 370 curies of stabilized calcine would be released compared to



WASTE SHIPMENT ACCIDENT

4.8 curies of vitrified calcine. Actinide separation (Alternative 4) would result in the release of 9.1 curies during a waste shipment accident. Delayed retrieval (Alternative 5) significantly affects the amount of radioactivity released. If the accident occurred in 2090, 2290, or 2490, the radioactivity released would be 0.33, 0.0048, or 0.00072 curies, respectively. The effects of exposure from a waste shipment accident are given in Table 4-18. The dose commitments (Alternative 3) are nearly 100 times higher for stabilized calcine than for calcine that has been converted to a glass. The doses are highest for Alternatives 3 and 4. Stabilized calcine is more easily dispersed than vitrified calcine. However, since the volume of waste shipped is smallest for Alternative 4, the probability that an accident will occur is lower for Alternative 4 than for Alternative 3. The effect of radionuclide decay is reflected in the lower dose commitments for Alternative 5.

A discussion of sabotage or attempted theft has not been included in this report for security purposes. The risks associated with transporting wastes are recognized, but it is believed that effects of sabotage or theft would be minimal. Studies are being conducted to further increase security measures and reduce accident risks.

Waste Canister Drop

A waste canister drop could occur at a federal geologic repository. This operational accident would affect alternatives that involve disposal in a deep

TABLE 4-18

EFFECTS ON THE POPULATION FROM ACCIDENTAL RADIONUCLIDE RELEASE DURING WASTE SHIPMENT[a]

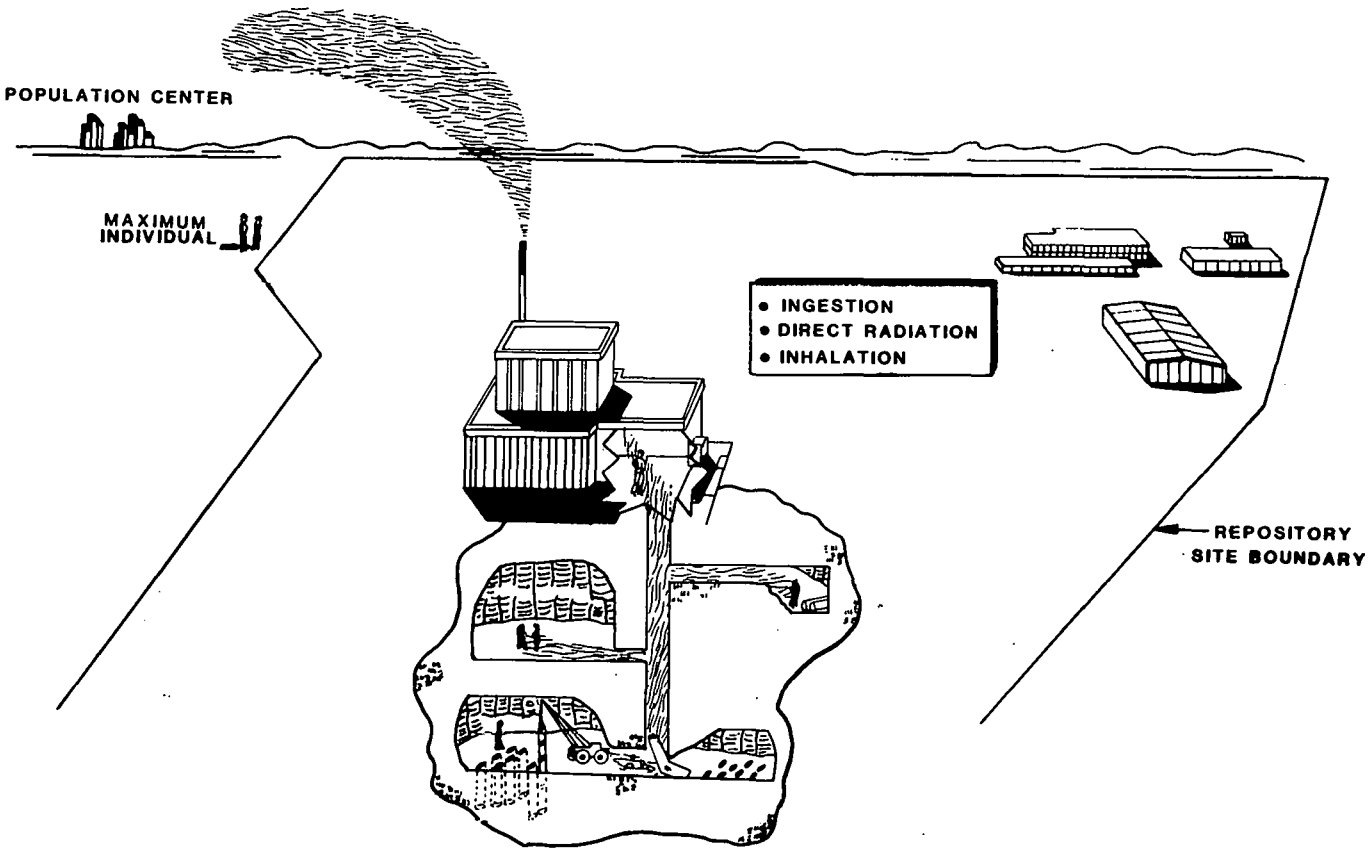
Alternative	Maximum Individual	Population				
	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range of Health Effects[b] (Number)	Probability of Event (Event/Year)	Population Risk (Man-Rem/Year)
1. Leave-in-Place	NA[c]	NA	NA	NA	NA	NA
2. Retrieve, Modify Calcine, Dispose at the INEL						
Pelletize Calcine	NA	NA	NA	NA	NA	NA
Convert Calcine to Glass	NA	NA	NA	NA	NA	NA
3. Retrieve, Modify Calcine, Dispose Offsite						
Stabilize Calcine	9.78	500	4,890	3.67×10^{-1} to 1.12	2.0×10^{-5}	9.78×10^{-2}
Convert Calcine to Glass	0.127	500	63.5	4.76×10^{-3} to 1.46×10^{-2}	3.0×10^{-5}	1.90×10^{-3}
4. Retrieve, Separate Actinides, Dispose of Actinides Offsite, Dispose of Depleted Calcine at the INEL	10	500	500	3.75×10^{-1} to 1.15	7.0×10^{-8}	3.50×10^{-4}
5. Delay Retrieval, Modify Calcine, Dispose Offsite						
100 Years	4.11×10^{-2}	500	20.5	1.54×10^{-3} to 4.73×10^{-3}	3.0×10^{-5}	6.16×10^{-4}
300 Years	1.14×10^{-2}	500	5.70	4.27×10^{-4} to 1.31×10^{-3}	3.0×10^{-5}	1.71×10^{-4}
500 Years	5.47×10^{-3}	500	2.73	2.05×10^{-4} to 6.29×10^{-4}	3.0×10^{-5}	8.20×10^{-5}

a. Based on 50-year dose commitment from 1 year of exposure in 1990-2000 (Alternatives 3 and 4) and in 2090, 2290, and 2490 (Alternative 5).

b. Health effects are cancer deaths.

c. NA, not applicable. Event applies only to alternatives that require offsite waste shipment.

geologic repository (Alternatives 3, 4, and 5). It is conceivable that a waste canister could be dropped down the shaft during emplacement of the canister in the repository as shown in the accompanying illustration.



CANISTER DROP

It was assumed that the canister would rupture upon impact, allowing the waste to escape. Most of the radioactive material would be removed by the atmospheric protection system. However, the radionuclides that became airborne could affect the public by three exposure pathways: inhalation, ingestion, and direct radiation. The effects of a waste canister drop are shown in Table 4-19.

The waste form would cause a difference of nearly a factor of 10 in the doses from a release of stabilized calcine compared to a release of calcine

TABLE 4-19

RADIOLOGICAL EFFECTS OF A WASTE CANISTER DRCP[a]

Alternative	Maximum Individual: Whole-Body Equivalent Dose (Rem)	Population: Population Exposed (Number)	Population: Whole-Body Equivalent Dose (Man-Rem)	Population: Range of Health Effects[b] (Number)	Population: Probability of Event (Event/Year)	Population: Population Risk (Man-Rem/Year)
1. Leave-in-Place	NA[c]	NA	NA	NA	NA	NA
2. Retrieve, Modify Calcine, Dispose at the INEL						
Pelletize Calcine	NA	NA	NA	NA	NA	NA
Convert Calcine to Glass	NA	NA	NA	NA	NA	NA
3. Retrieve, Modify Calcine, Dispose Offsite						
Stabilize Calcine	9.40×10^{-5}	2,000,000	1.88	1.41×10^{-4} to 4.32×10^{-4}	7.0×10^{-7}	1.32×10^{-6}
Convert Calcine to Glass	1.31×10^{-5}	2,000,000	0.262	1.96×10^{-5} to 6.03×10^{-5}	7.0×10^{-7}	1.83×10^{-7}
4. Retrieve, Separate Actinides, Dispose of Actinides Offsite, Dispose of Depleted Calcine at the INEL	1.02×10^{-4}	2,000,000	2.04	1.53×10^{-4} to 4.69×10^{-4}	7.0×10^{-7}	1.43×10^{-6}
5. Delay Retrieval, Modify Calcine, Dispose Offsite						
100 Years	1.28×10^{-6}	2,000,000	2.56×10^{-2}	1.92×10^{-6} to 5.89×10^{-6}	7.0×10^{-7}	1.79×10^{-8}
300 Years	8.88×10^{-8}	2,000,000	1.78×10^{-3}	1.33×10^{-7} to 4.08×10^{-7}	7.0×10^{-7}	1.24×10^{-9}
500 Years	5.40×10^{-8}	2,000,000	1.08×10^{-3}	8.10×10^{-8} to 2.48×10^{-7}	7.0×10^{-7}	7.56×10^{-10}

a. Based on 50-year dose commitment from 1 year of exposure in 1990-2020 (Alternatives 3 and 4) and in 2090, 2290, and 2490 (Alternative 5)

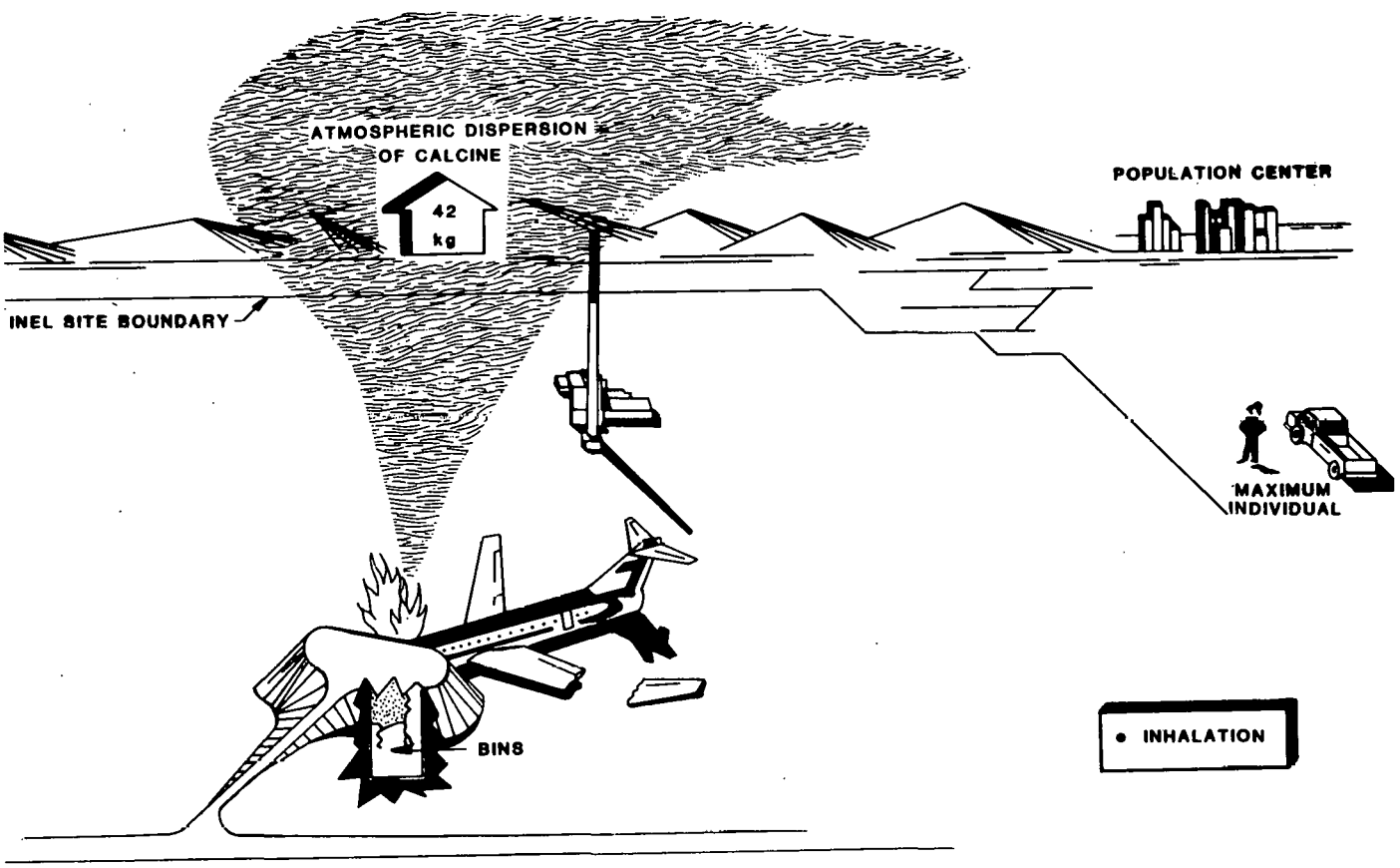
b. Health effects are cancer deaths.

c. NA, not applicable. Event applies to operations at a federal geologic repository.

that had been converted to glass. The vitrified actinides (Alternative 4) would cause a slightly higher dose than stabilized calcine (Alternative 3) because of the concentrated waste form. The doses for all alternatives would be small.

Aircraft Impact

The alternatives affected by a postulated aircraft impact involve waste disposal at the INEL (Alternatives 1, 2, and 4). Inhalation is the exposure pathway by which the maximum individual and the population surrounding the INEL would be affected as indicated in the accompanying illustration.



AIRCRAFT IMPACT

Prior to the end of the first hundred years of disposal when much of the heat generated by radioactive decay will have dissipated, the disposal facilities at the INEL would be immobilized with a concrete-like material. Before filling the bin-vault complexes, the near-surface disposal facilities would be vulnerable to intrusion by a falling aircraft. After about 2100, the immobilization material would prevent an aircraft from striking the waste bins, even after the material disintegrates. Even though this event has an occurrence probability of 1 in 5 million years, it is assumed to occur during the short-term period when the effects of an aircraft impact would be greatest.

In this scenario, it is assumed that an aircraft looses altitude, falls on the disposal facility, and ruptures a waste bin. Should the jet fuel ignite, the waste would become airborne in the smoke from the fire. The population would be affected by inhalation of the dispersed radionuclides. It was calculated that ingestion and direct radiation would not contribute significantly to the dose from an aircraft impact.

The effects of an airborne release of radioactive material from an aircraft impact and fire are shown in Table 4-20. They would be independent of the waste form because it has been assumed that the accident would involve calcine before modification. Therefore, the maximum individual doses would be the same for Alternatives 1, 2, 3, and 4. The effects would be about ten times lower if the event were to occur 200 years in the future.

4.5.2 Long-Term Effects

Long-term effects of implementing the waste management alternatives would occur in the future after institutional control is assumed to cease. Long-term effects are divided into effects which are certain to occur and effects of abnormal events which are not certain to occur (see Table 4-4). The release scenarios considered to be certain to occur at some time during the long term could occur because the INEL disposal facilities are located so near the land surface. Certain-to-occur scenarios evaluated for long-term effects are intrusion into the waste by future generations, living and farming at the contaminated site, and effects of radon gas in houses built over the waste disposal facilities by future generations.

TABLE 4-20

RADIOLOGICAL EFFECTS OF AN AIRCRAFT IMPACT[a]

Alternative	Maximum Individual	Population				
	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range of Health Effects[b] (Number)	Probability of Event (Event/Year)	Population Risk (Man-Rem/Year)
1. Leave-in-Place	5.20	71,000	7.38×10^{4}	5.54 to 17.0	2.0×10^{-7}	1.48×10^{-2}
2. Retrieve, Modify Calcine, Dispose at the INEL						
Pelletize Calcine	5.20	71,000	7.38×10^{4}	5.54 to 17.0	2.0×10^{-7}	1.48×10^{-2}
Convert Calcine to Glass	5.20	71,000	7.38×10^{4}	5.54 to 17.0	2.0×10^{-7}	1.48×10^{-2}
3. Retrieve, Modify Calcine, Dispose Offsite						
Stabilize Calcine	5.20	71,000	7.38×10^{4}	5.54 to 17.0	2.0×10^{-7}	1.48×10^{-2}
Convert Calcine to Glass	5.20	71,000	7.38×10^{4}	5.54 to 17.0	2.0×10^{-7}	1.48×10^{-2}
4. Retrieve, Separate Actinides, Dispose of Actinides Offsite, Dispose of Depleted Calcine at the INEL	5.20	71,000	7.38×10^{4}	5.54 to 17.0	2.0×10^{-7}	1.48×10^{-2}
5. Delay Retrieval, Modify Calcine, Dispose Offsite						
100 Years	2.15	193,000	8.30×10^{4}	6.22 to 19.1	2.0×10^{-7}	1.66×10^{-2}
300 Years	0.60	230,000	2.75×10^{4}	2.06 to 6.32	2.0×10^{-7}	5.49×10^{-3}
500 Years	0.29	230,000	1.32×10^{4}	0.99 to 3.04	2.0×10^{-7}	2.64×10^{-3}

a. Based on 50-year dose commitment from 1 year of exposure in 1990 (Alternatives 1, 2, 3, and 4) and in 2090, 2290, and 2490 (Alternative 5). Effects are independent of the waste form.

b. Health effects are cancer deaths.

The release scenarios that are not considered to be certain to occur, include abnormal events at both the INEL and the federal geologic repository. At the INEL, waste migration into groundwater and a severe geologic disruption that disperses the waste were evaluated. Waste migration into groundwater has both nonradiological and radiological consequences. At the repository, exploratory drilling, fault and flooding, and ingestion of contaminated table salt from solution mining were evaluated.

4.5.2.1 Long-Term Effects of Events Certain to Occur

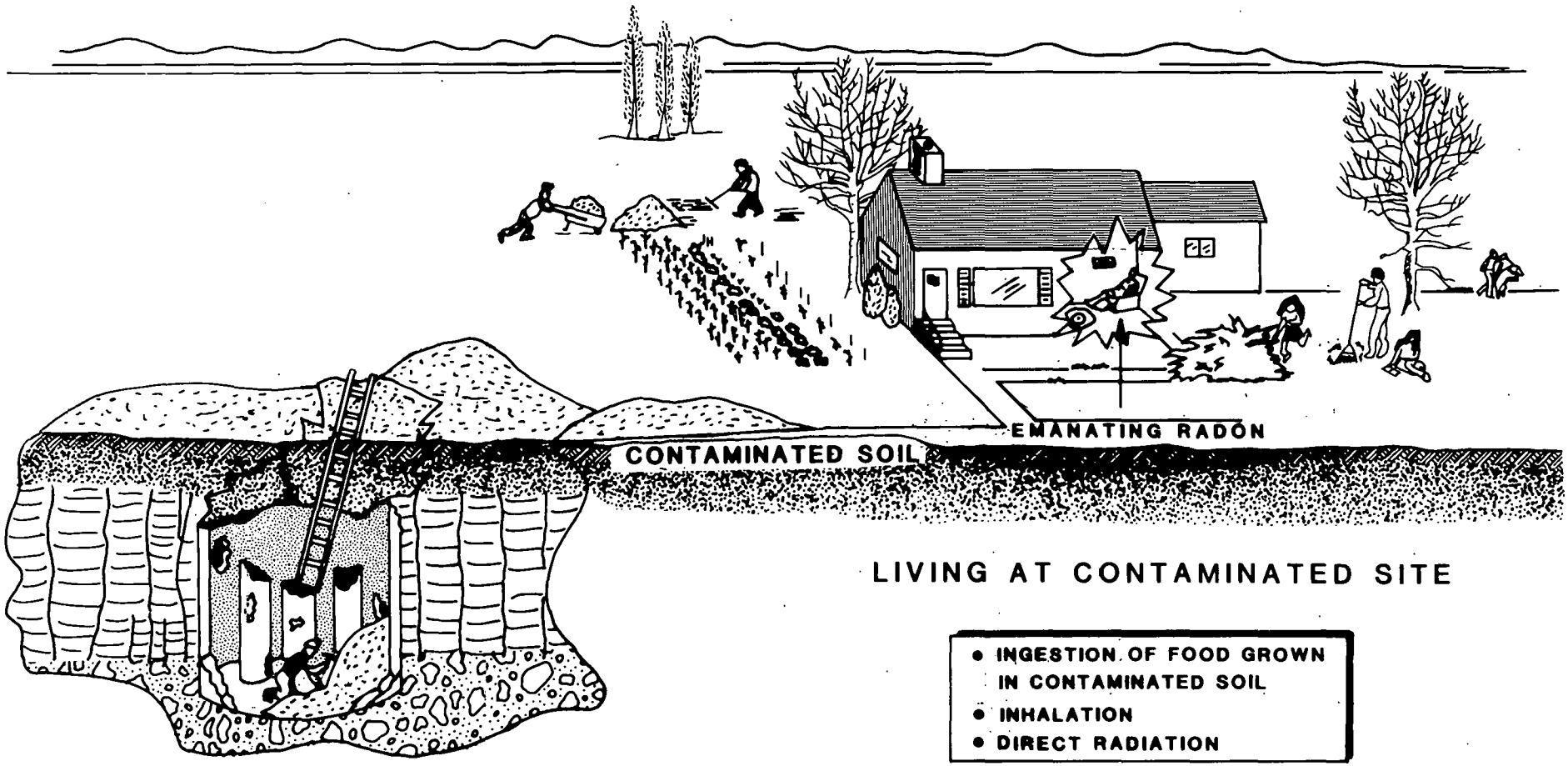
Events certain to occur in the long term are near-surface phenomena. For calculational purposes, intrusion into the waste, living at the contaminated site, and living over the waste are assumed to occur shortly after the minimum estimated life of the disposal facilities (about 2500). The waste disposal area is not far enough below ground surface to prevent radon gas from exceeding natural background concentrations in the region directly over the waste should the waste bins disintegrate.

Intrusion into the Waste

The effects of near-surface waste disposal on future generations were considered by evaluating the effects of individual intrusion into the waste soon after the bins are assumed to have disintegrated. The individual intrusion event would affect only a few individuals (assumed to be 10).

To implement Alternatives 1, 2, and 4, the waste would be placed in disposal facilities just below the ground surface. An archaeologist, prospector, or other individual looking for artifacts or useful materials could conceivably dig in the waste after containment failure as shown in the illustration found on the following page.

Digging in the waste could produce a dust cloud containing radioactive material. Exposure would result from inhalation and direct radiation. The effects of the individual intrusion scenario are given in Table 4-21. The highest dose (43.8 rem) would result from the leave-in-place alternative. Waste form modification [Alternative 2 (glass)] would reduce the dose nearly



LIVING AT CONTAMINATED SITE

- INGESTION OF FOOD GROWN IN CONTAMINATED SOIL
- INHALATION
- DIRECT RADIATION

INTRUSION INTO THE WASTE

- DIRECT RADIATION
- INHALATION

TABLE 4-21

LONG-TERM RADIOLOGICAL EFFECTS OF EVENTS CERTAIN TO OCCUR[a]
INDIVIDUAL INTRUSION INTO THE WASTE

Alternative	Maximum Individual	Population				
	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range of Health Effects[b] (Number)	Probability of Event (Event/Year)	Population Risk (Man-Rem/Year)
1. Leave-in-Place	43.8	10	438	3.28×10^{-2} to 1.01×10^{-1}	0.010	4.38
2. Retrieve, Modify Calcine, Dispose at the INEL						
Pelletize Calcine	10.5	10	105	7.87×10^{-3} to 2.41×10^{-2}	0.010	1.05
Convert Calcine to Glass	0.68	10	6.80	5.10×10^{-4} to 1.56×10^{-3}	0.010	6.80×10^{-2}
3. Retrieve, Modify Calcine, Dispose Offsite						
Stabilize Calcine	NA[c]	NA	NA	NA	NA	NA
Convert Calcine to Glass	NA	NA	NA	NA	NA	NA
4. Retrieve, Separate Actinides, Dispose of Actinides Offsite, Dispose of Depleted Calcine at the INEL	8.51	10	85.1	6.38×10^{-3} to 1.96×10^{-2}	0.010	8.51×10^{-1}
5. Delay Retrieval, Modify Calcine, Dispose Offsite[d]	NA	NA	NA	NA	NA	NA
100 Years						
300 Years						
500 Years						

a. Based on 50-year dose commitment from 1 year of exposure in 2500.

b. Health effects are cancer deaths.

c. NA, not applicable. Event applies to waste disposal at the INEL.

d. If the event were to occur during the period of delay, the effects of Alternative 5 would be no worse than the effects of Alternative 1.

to background level. Intrusion into actinide-depleted calcine (Alternative 4) would result in a maximum individual dose one-fifth that of the dose received from digging in calcine (Alternative 1).

Living at the Contaminated Site

As a result of an individual digging in the waste, some of the radioactive material could be brought to the surface and contaminate the surrounding soil. In this farming scenario, a family or small population group (five people) is assumed to inhabit the INEL after the site has been contaminated by prior intrusions. The family is assumed to farm the contaminated area as shown in the illustration on the preceding page.

Exposure to radiation would result from direct radiation, inhalation of airborne radionuclides, and ingestion of contaminated food. Since the house would be built on contaminated soil, radon gas, and particulate daughter products could accumulate inside the house and contribute to the inhalation dose. It was conservatively assumed that individuals living at the site would obtain all of their food from farming in soil contaminated with radioactive material and that the same group of people would remain on the site for 50 years. The effects of the farming scenario are given in Table 4-22. The maximum doses would result from Alternative 1.

Living Over the Waste

This event would affect waste disposal at the INEL (Alternatives 1, 2, and 4). Radon gas occurs naturally in uranium ore bodies from the decay of uranium. In the case of INEL defense high-level waste, actinides are present that produce radon gas during the course of their decay into harmless materials. Consequently, the concentration of radon in the waste continues to increase until the radon-producing radionuclides no longer exist.

Radon gas concentration increases until it reaches a maximum about 200,000 years after waste disposal. Should waste containment fail, radon emissions would be higher than background levels in the area directly over the waste disposal facilities. Construction of a building, such as a house, over

TABLE 4-22

LONG-TERM RADIOLOGICAL EFFECTS OF EVENTS CERTAIN TO OCCUR[a]
LIVING AT THE CONTAMINATED SITE AND LIVING OVER THE WASTE

Alternative	Maximum Individual	Population				
	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range of Health Effects[b] (Number)	Probability of Event (Event/Year)	Population Risk (Man-Rem/Year)
1. Leave-in-Place						
Living at the Contaminated Site	53.1	5	265	1.99×10^{-2} to 6.11×10^{-2}	0.010	2.65
Living Over the Waste	1.10×10^{-1}	5	5.50×10^{-1}	4.12×10^{-5} to 1.26×10^{-4}	1.0×10^{-2}	5.50×10^{-3}
2. Retrieve, Modify Calcine, Dispose at the INEL						
Living at the Contaminated Site						
Pelletize Calcine	8.08	5	40.4	3.03×10^{-3} to 9.29×10^{-3}	0.010	4.04×10^{-1}
Living Over the Waste	9.20×10^{-2}	5	4.60×10^{-1}	3.45×10^{-5} to 1.06×10^{-4}	1.0×10^{-2}	4.60×10^{-3}
Convert Calcine to Glass						
Living at the Contaminated Site	7.75	5	38.8	2.91×10^{-3} to 8.91×10^{-3}	0.010	3.87×10^{-1}
Living Over the Waste	1.50×10^{-2}	5	7.50×10^{-2}	5.62×10^{-6} to 1.72×10^{-5}	1.0×10^{-2}	7.50×10^{-4}
3. Retrieve, Modify Calcine, Dispose Offsite						
Stabilize Calcine	NA[c]	NA	NA	NA	NA	NA
Convert Calcine to Glass	NA	NA	NA	NA	NA	NA
4. Retrieve, Separate Actinides, Dispose of Actinides Offsite, Dispose of Depleted Calcine at the INEL						
Living at the Contaminated Site	27.0	5	135	1.01×10^{-2} to 3.10×10^{-2}	0.010	1.35
Living Over the Waste	2.20×10^{-3}	5	1.10×10^{-2}	8.25×10^{-7} to 2.53×10^{-6}	1.0×10^{-2}	1.0×10^{-4}
5. Delay Retrieval, Modify Calcine, Dispose Offsite[d]	NA	NA	NA	NA	NA	NA
100 Years						
300 Years						
500 Years						

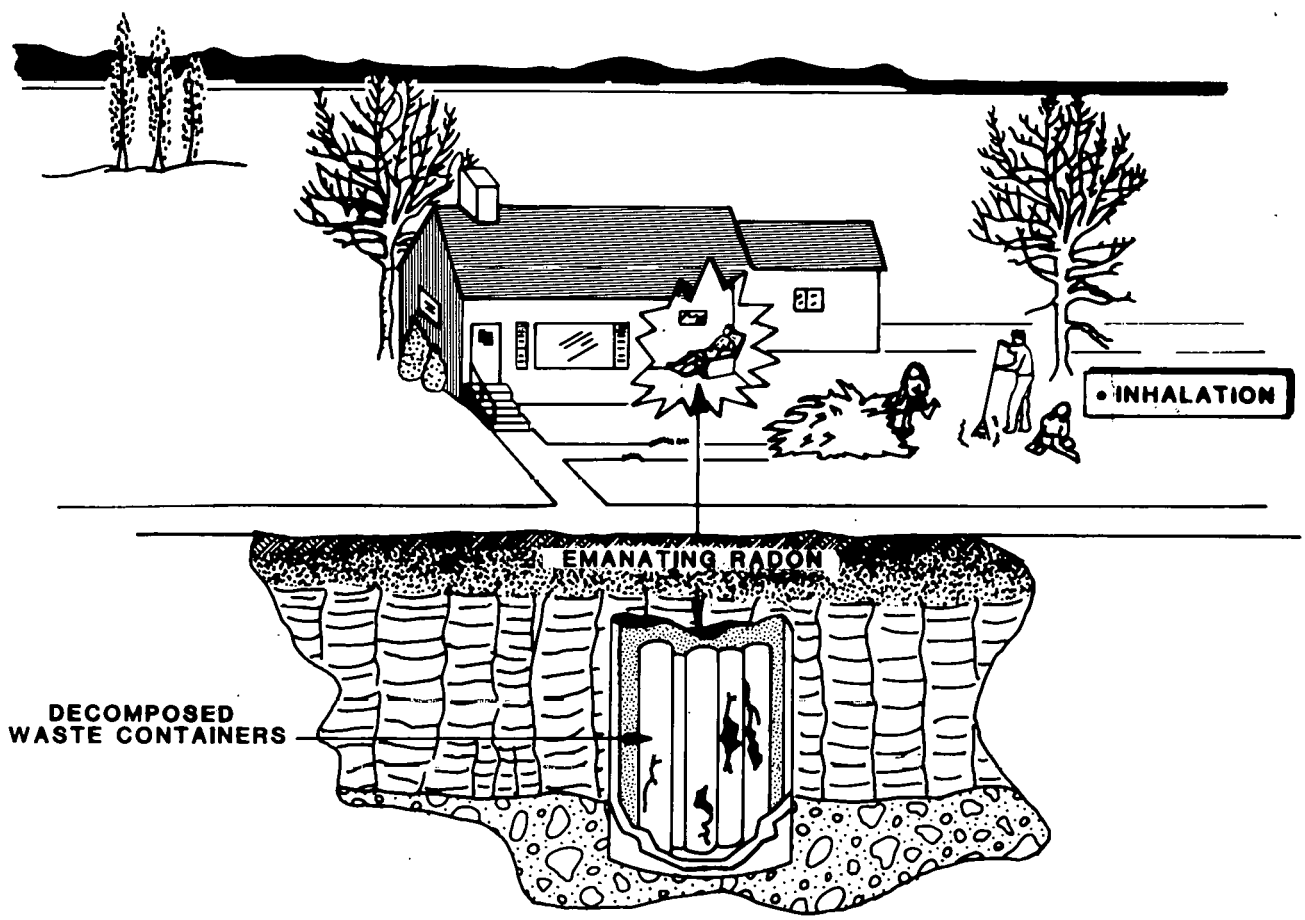
a. Based on 50-year dose commitment from 1 year of exposure in 2500.

b. alth effects are cancer deaths.

the radon source provides a confined area which traps the gas and allows the concentration of decay products to increase. The radon daughter products are solids which can be inhaled, thus contributing to the radiation dose received by persons living or working in the enclosed area.

In the living-over-the-waste scenario, it is assumed that individuals move onto the INEL without knowing the location of the waste disposal facilities. Dose commitments and health effects from radon inhalation are given in Table 4-22. Doses in any one year are small and would be less than annual background radiation (0.15 rem).

Exposure to radon gas of individuals whose homes are built over disintegrated waste containers is shown in the accompanying illustration.



LIVING OVER THE WASTE

4.5.2.2 Long-Term Effects of Abnormal Events

Long-term effects of abnormal events are postulated to occur at the INEL and at a federal geologic repository. They would be radiological and non-radiological in nature. At the INEL, the effects of waste migration into groundwater were evaluated. The effects of a severe geologic disruption, such as a volcano erupting through the waste, were evaluated to determine the worst effects of an atmospheric release of high-level waste at the INEL.

Abnormal events were evaluated at a federal geologic repository to determine the long-term effects of INEL waste disposal. The most significant events evaluated in the EIS for commercially generated high-level waste (DOE, 1980a) were selected for consideration in this report. The scenarios evaluated are solution mining for recovery of table salt, fault and flooding of the repository which causes surface water contamination, and exploratory drilling.

Waste Migration Into Groundwater

The waste contains toxic chemicals and radionuclides which could be harmful if ingested. The Snake River Plain Aquifer is a source of drinking water, irrigation water, and water used by commercial fish hatcheries (Section 3). Pollution of the aquifer depends on several factors. Radionuclide and toxic chemical migration would require filtration of flood waters into the waste disposal area; leaching of hazardous material from disintegrated containers; percolation of the leached material through approximately 450 feet of basalt and sediment into the aquifer; waste migration through the aquifer to wells; and, finally, use of the contaminated well water. Engineered barriers, such as the disposal bins, should remain intact for a sufficiently long time to allow radioactive decay to reach harmless levels. However, toxic chemicals could always present a potential hazard to the aquifer in the event of containment failure.

A conservative subsurface migration model was used to calculate effects of waste migration on the aquifer. Toxic chemical and radionuclide migration to the aquifer was assumed to occur instantaneously after passing through

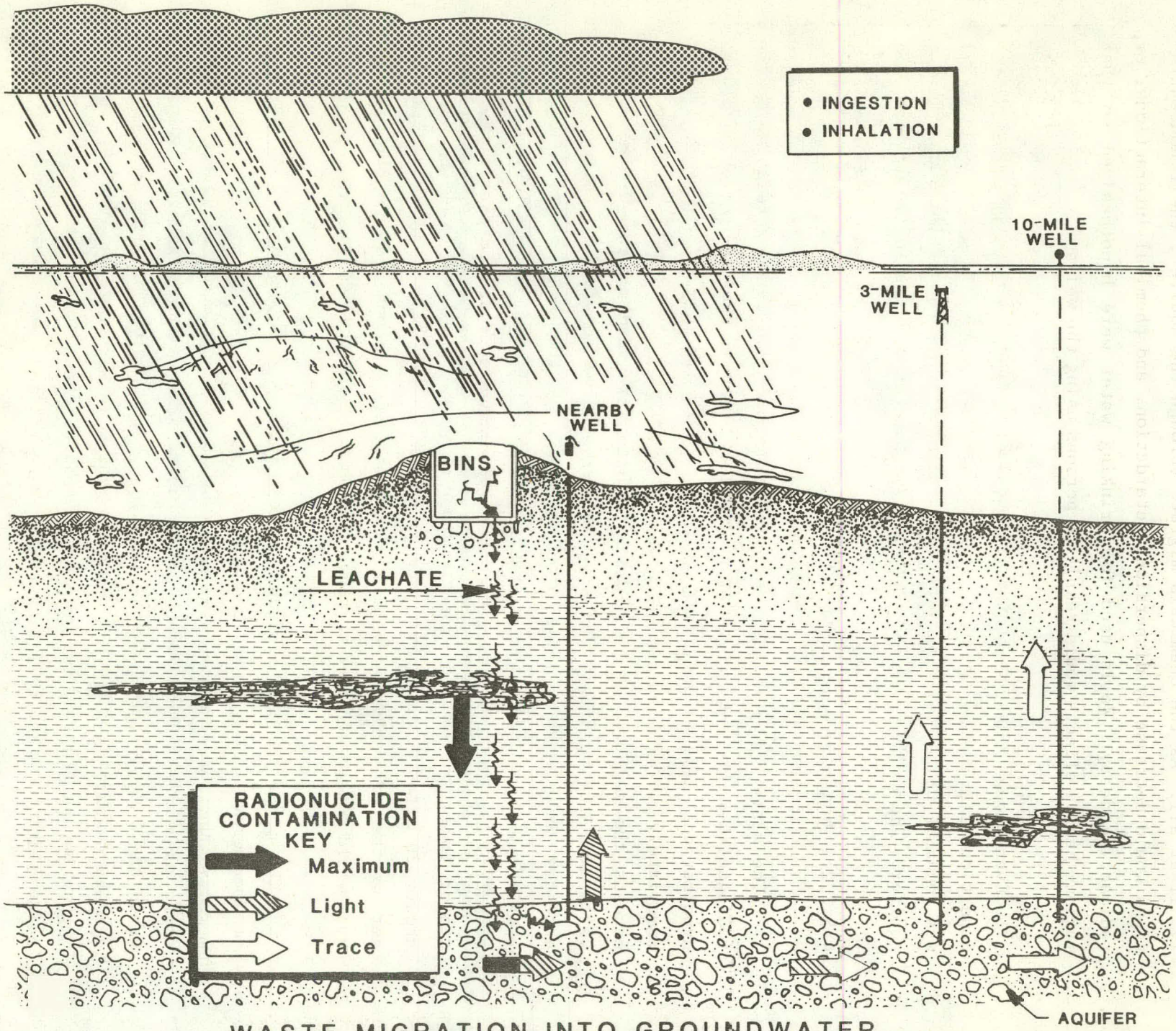
50 feet of sediments. In reality, migration to the aquifer would occur slowly, if at all. As the chemicals migrate through the aquifer, their concentrations would decrease by dispersion, retardation, and chemical interactions, or radioactive decay. Wells used for drinking water were hypothesized so that maximum health effects would result to persons using the wells.

Even though flooding of the site would not occur if climatic and geologic conditions remain similar to the conditions that have existed in the past, it was assumed that conditions would be adequate to transport the waste to the aquifer. The waste migration scenario is illustrated on the following page.

4.5.2.2.1 Nonradiological Effects

The waste contains large amounts of cadmium and mercury relative to the radionuclides present. Potential concentrations of these toxic chemicals in hypothetical wells are given in Table 4-23. The 0-mile well is located immediately downgradient of the discharge point. The cadmium concentration exceeds the national primary drinking water standard at the 0- and 3-mile wells for Alternatives 1 and 4. The drinking water standard for mercury is exceeded only at the point of discharge. At the 10-mile well, which is located just outside the present southern INEL boundary, drinking water standards are not exceeded for either toxic chemical. The nearest population center today that could use contaminated water is Hagerman, Idaho, located about 120 miles downgradient from the ICPP. (Idaho Falls and Pocatello are not in the aquifer flow path.) Commercial fish hatcheries in the Hagerman area would not be affected by waste migration in the aquifer.

The primary pathway by which toxic levels would be reached is ingestion of food grown using contaminated water. Food sources concentrate cadmium and mercury; thus, food rather than drinking water is the dominant source of these toxic chemicals. Consequently, the effect of cadmium and mercury pollution would be to render groundwater unusable for irrigation for a distance of about 5 miles downgradient of the discharge point in Alternatives 1 and 4. At distances beyond 5 miles downgradient of the discharge point, the aquifer would be available for all drinking water, agricultural, and aquaculture uses. The



WASTE MIGRATION INTO GROUNDWATER

TABLE 4-23

NONRADIOLOGICAL EFFECTS OF WASTE MIGRATION INTO GROUNDWATER [a]

Alternative	Population Exposed (Number)	Cadmium Concentration in Hypothetical Wells (Milligrams per Liter)			Mercury Concentration in Hypothetical Wells (Milligrams per Liter)			Health Effects (Number)		
		0-Mile	3-Mile	10-Mile[b]	0-Mile	3-Mile	10-Mile[b]	0-Mile	3-Mile	10-Mile
1. Leave-in-Place	5	2.1	1.2×10^{-2}	3.6×10^{-3}	6.9×10^{-2}	3.9×10^{-4}	1.2×10^{-4}	5	5	0
2. Retrieve, Modify Calcine, Dispose at the INEL										
Pelletize Calcine	5	3.1×10^{-1}	1.7×10^{-3}	5.3×10^{-4}	1.0×10^{-2}	5.7×10^{-5}	1.8×10^{-5}	5	0	0
Convert Calcine to Glass	5	5.2×10^{-5}	3.0×10^{-7}	9.0×10^{-8}	1.7×10^{-6}	9.9×10^{-9}	3.0×10^{-9}	0	0	0
3. Retrieve, Modify Calcine, Dispose Offsite	NA[c]		NA			NA			NA	
Stabilize Calcine										
Convert Calcine to Glass										
4. Retrieve, Separate Actinides, Dispose of Actinides Offsite, Dispose of Depleted Calcine at the INEL	5	2.1	1.2×10^{-2}	3.6×10^{-3}		NA		5	5	0
5. Delay Retrieval, Modify Calcine, Dispose Offsite	NA		NA			NA			NA	
100 Years										
300 Years										
500 Years										
Federal and State Drinking Water Standards[d]			1.0×10^{-2}			2.0×10^{-3}				

a. Zero-mile well is located immediately downgradient of the discharge point prior to mixing of the leachate with groundwater.

b. It is assumed that the 10-mile well would be used by 100 persons, which is about 5 times the present population in the area.

c. NA, not applicable. Event applies to waste disposal at the INEL. In Alternative 4, mercury would be removed during actinide separation.

d. 40 CFR 141 and State of Idaho, 1977.

use of groundwater would be restricted only until dispersion and chemical reactions in the aquifer reduced toxic chemical concentrations to harmless levels.

Modification of the waste form (Alternative 2) would further reduce the potential hazard from aquifer contamination by cadmium and mercury. Mercury would be removed during actinide separation; thus actinide-depleted waste (Alternative 4) would contain only cadmium.

4.5.2.2.2 Radiological Effects

Radiological effects of waste migration depend on the waste form, rate of decay, and migration characteristics of the radionuclides present in the waste. Because of the sediment and basalt characteristics at the INEL, the potential for radionuclides to migrate to the aquifer in signficant concentrations is very low as long as the surface of the ICPP remains free of standing water.

Certain radionuclides present in the calcine waste (e.g., Cs-137, Sr-90, Pu-239, Am-241, Bi-214, Pb-214, Th-232, and Pu-238) tend to have a moderate to high affinity for various minerals which constitute the INEL soil. Measurement of ion-exchange capacities of selected radionuclides stored at the INEL indicates that these minerals indeed have a high rate of sorption by clay minerals in the INEL sediments (Barraclough, et al., 1976). Therefore, the amount of waste movement in the unsaturated zone would probably be slight.

Laboratory experiments (Fried, et al., 1976) indicate that basalts at the INEL appear to strongly retard the migration of plutonium. Mineralogic analyses of the basalt material were not made. However, it is believed that the preparation techniques used ensured that the retardation was because of the basalt and not because of clay or zeolite that may be present on weathered basalt surfaces. Dose commitments given in Table 4-24 are, therefore, conservatively high because retardation was not considered in the calculations.

TABLE 4-24

LONG-TERM RADIOLOGICAL EFFECTS OF ABNORMAL EVENTS
WASTE MIGRATION INTO GROUNDWATER[a]

Alternative	Maximum Individual	Population				
	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range of Health Effects[b] (Number)	Probability of Event[c] (Event/Year)	Population Risk (Man-Rem/Year)
1. Leave-in-Place	0.63	5	3.15	2.36×10^{-4} to 7.24×10^{-4}	1.0×10^{-6}	3.15×10^{-6}
2. Retrieve, Modify Calcine, Dispose at the INEL						
Pelletize Calcine	6.30×10^{-3}	5	3.15×10^{-2}	2.36×10^{-6} to 7.24×10^{-6}	1.0×10^{-6}	3.15×10^{-8}
Convert Calcine to Glass	1.39×10^{-6}	5	6.95×10^{-6}	5.21×10^{-10} to 1.60×10^{-9}	1.0×10^{-6}	6.95×10^{-12}
3. Retrieve, Modify Calcine, Dispose Offsite						
Stabilize Calcine	NA[d]	NA	NA	NA	NA	NA
Convert Calcine to Glass	NA	NA	NA	NA	NA	NA
4. Retrieve, Separate Actinides, Dispose of Actinides Offsite, Dispose of Depleted Calcine at the INEL	0.62	5	3.12	2.34×10^{-4} to 7.18×10^{-4}	1.0×10^{-6}	3.12×10^{-6}
5. Delay Retrieval, Modify Calcine, Dispose Offsite[e]	NA	NA	NA	NA	NA	NA
100 Years						
300 Years						
500 Years						

a. Effects are for a hypothetical well located 3 miles downgradient of the point of discharge to the aquifer; effects are base on a 50-year dose commitment from 1 year of exposure in 2500. Effects for 0-mile, 10-mile, and 120-mile wells are given in Tables B-51 through B-66.

b. Health effects are cancer deaths.

c. The event was assumed to occur during the 1-million-year period of evaluation.

d. NA, not applicable. Event applies to waste disposal at the INEL.

e. If the event were to occur during the period of delay, the effects of Alternative 5 would be no worse than the effects of Alternative 1.

The radiological effects of groundwater contamination would decrease with time as radioactive decay occurs. Individual radionuclides migrate at different rates; consequently, several peak radionuclide concentrations would occur in a well as the radionuclides became dispersed in the aquifer. Dose commitments given in Table 4-24 are the maximum doses that would occur at any time in a well located 3 miles downgradient of the discharge point. The 0.63-rem maximum individual dose (Alternatives 1 and 4) is a 50-year dose commitment. The dose received in any single year of exposure would be below the 0.5-rem dose allowed for persons in unrestricted areas (ERDAM, 1977).

Severe Geologic Disruption

A severe geologic event could affect alternatives involving waste disposal at the INEL (Alternatives 1, 2, and 4). However, it is impossible to predict what significant changes will occur to the earth over the period of time discussed in this report. Geologic studies show that major changes occur to the surface of the earth as ice ages come and go, glaciers form new lakes, erosion occurs, and volcanoes and earthquakes change surface features. Certain formations below the surface, however, are known to have remained relatively unchanged throughout very long periods of time.

Because of the uncertainties associated with geologic changes on the surface of the earth, it is impossible to determine all the effects on the waste that could occur if it is left in near-surface disposal. Unforeseen changes in geologic conditions could cause earthquakes and volcanic activity which would destroy waste containment and disperse the calcine. Rather than attempt to evaluate these many potential scenarios, one major abnormal event is analyzed to determine the maximum potential effects of any abnormal event. To estimate the effects of a severe geologic disruption at the INEL, the event is assumed to have the same probability of occurrence as a volcano erupting through the waste (1×10^{-8}). Since the purpose of evaluating a severe geologic disruption is to determine the worst conceivable effects of waste dispersion, the event is assumed to occur at several times in the future. Effects are discussed for the event's occurrence at the beginning of the long-term period (2100) when the waste would have had only a short time to decay.

The effects of other abnormal events of nature, such as volcanos, earthquakes, tornadoes, and floods, have been considered in this report. The probability of occurrence can be more reliably predicted for these relatively common natural phenomena than for geologic or climatic changes. The probabilities cited in the following discussion are based on documented knowledge of past events.

One of the greatest hazards would be related to volcanic activity on the INEL (see Subsection 3.1.2). Two types of volcanic activity have been considered, but dose commitments and health effects were not calculated because they would be less than the effects of a severe geologic disruption.

The possibility of a volcanic eruption through the waste, or near enough to the disposal area to cause radionuclide release, is about 1×10^{-8} per year or once every 100 million years. High temperatures accompanying the eruption could volatilize some of the waste, but much of the material would settle in the immediate vicinity of the eruption. Depending on the force of the eruption and wind conditions at the time, contaminated ash and gaseous emissions could cover an extensive area.

Lava flows at the INEL are much more likely events than an explosive volcano. The estimated probability of a lava flow on the INEL site is about 3.3×10^{-4} per year, or once every 3,000 years. Based on the characteristics of other lava flows in the area, a lava flow at the ICPP would entomb the waste, forming a natural protective cover. The dose commitments and health effects would be negligible, and any subsequent lava flows would further entomb the waste.

Based on past earthquake activity in the INEL area, the design of the waste disposal complex would provide adequate protection against earthquake damage. No destructive earthquakes have been recorded in the eastern part of the Snake River Plain (see Subsection 3.1.4).

The largest estimated ground acceleration recorded in the seismic zone that includes the INEL is 0.09 gravity. Waste management facilities would be designed to withstand an earthquake of a modified Mercalli intensity of X

(approximate magnitude 7.75 on the Richter scale), a maximum horizontal ground acceleration of 0.24 gravity, and a vertical acceleration of 0.16 gravity (Exxon Nuclear Idaho, Inc., 1979) (see Subsection 2.3). Consequently, an earthquake at the ICPP should not cause a release of radioactive material.

Tornadoes pose only a minor risk during calcine retrieval and processing operations and no risk after disposal of the waste. Tornadoes in the area have been small (Fujita, 1971). All but one have affected an area of less than 0.01 square mile. Waste management facilities would be designed to protect against tornado damage (see Subsection 2.3).

After decontamination and decommissioning of the surface facilities, the waste would be located underground in long-term disposal facilities where tornado winds would not affect waste containment.

The flooding potential of the site has been evaluated. Assuming that hydrogeologic conditions at the ICPP are relatively constant throughout the 1-million-year period of evaluation, flooding of the waste disposal area would be highly unlikely. The geologic and hydraulic characteristics of the ICPP area appear to prevent flooding. While specific studies have not been conducted on the flooding potential at the ICPP, it is possible to evaluate the consequences of this event based on studies conducted upstream of the ICPP (Druffel, 1979).

The severe geologic disruption scenario was evaluated in order to determine the effects of unforeseen geologic changes. The event would affect alternatives involving waste disposal at the INEL (Alternatives 1, 2, and 4) as shown in the illustration on Page 4-79.

In the severe geologic disruption scenario, it is assumed that 1 percent of the waste is dispersed. (If all of the waste became airborne, the effects would be 100 times greater than the effects shown in Table 4-25.) Radiological effects on the public would result from inhalation of airborne radioactive material, direct radiation from the contaminated plume, and ingestion of contaminated food and water. The maximum individual and the population dose commitments for the year 2100 are shown in Table 4-25. The nonradiological consequences of a severe geologic disruption would probably be

TABLE 4-25

LONG-TERM RADIOLOGICAL EFFECTS OF ABNORMAL EVENTS[a,b]

Alternative and Scenario	Maximum Individual: Whole-Body Equivalent Dose (Rem)	Population: Population Exposed (Number)	Population: Whole-Body Equivalent Dose (Man-Rem)	Population: Range of Health Effects[c] (Number)	Probability of Event (Event/Year)	Population Risk (Man-Rem/Year)
1. Leave-in-Place						
Severe Geologic Disruption	1.58×10^{1}	206,000	1.95×10^{6}	1.46×10^{2} to 4.49×10^{2}	1.0×10^{-8}	1.95×10^{-2}
2. Retrieve, Modify Calcine, Dispose at the INEL						
Pelletize Calcine						
Severe Geologic Disruption	1.58×10^{1}	206,000	1.95×10^{6}	1.46×10^{2} to 4.49×10^{2}	1.0×10^{-8}	1.95×10^{-2}
Convert Calcine to Glass						
Severe Geologic Disruption	1.58×10^{1}	206,000	1.95×10^{6}	1.46×10^{2} to 4.49×10^{2}	1.0×10^{-8}	1.95×10^{-2}
3. Retrieve, Modify Calcine, Dispose Offsite						
Stablize Calcine						
Fault and Flooding	1.78	2,000,000	3.56×10^{4}	2.67 to 8.19	2.0×10^{-13}	7.12×10^{-9}
Solution Mining	1.71×10^{-2}	40,000,000	6.84×10^{5}	5.13×10^{1} to 1.57×10^{2}	1.0×10^{-6}	6.84×10^{-1}
Exploratory Drilling	2.36	25	5.90×10^{1}	4.42×10^{-3} to 1.36×10^{-2}	5.0×10^{-7}	2.95×10^{-5}
Convert Calcine to Glass						
Fault and Flooding	1.78×10^{-4}	2,000,000	3.56	2.67×10^{-4} to 8.19×10^{-4}	2.0×10^{-13}	7.12×10^{-13}
Solution Mining	1.71×10^{-2}	40,000,000	6.84×10^{5}	5.13×10^{1} to 1.57×10^{2}	1.0×10^{-6}	6.84×10^{-1}
Exploratory Drilling	1.55	25	3.87×10^{1}	2.91×10^{-3} to 8.91×10^{-3}	5.0×10^{-7}	1.94×10^{-5}
4. Retrieve, Separate Actinides, Dispose of Actinides Offsite, Dispose of Depleted Calcine at the INEL						
Dispose of the Depleted Calcine at the INEL						
Severe Geologic Disruption	1.11×10^{1}	206,000	1.37×10^{6}	1.03×10^{2} to 3.16×10^{2}	1.0×10^{-8}	1.37×10^{-2}
Dispose of Actinides Offsite						
Fault and Flooding	1.78×10^{-6}	2,000,000	3.56×10^{-2}	2.67×10^{-6} to 8.19×10^{-6}	2.0×10^{-13}	7.12×10^{-15}
Solution Mining	1.71×10^{-2}	40,000,000	6.84×10^{5}	5.13×10^{1} to 1.57×10^{2}	1.0×10^{-6}	6.84×10^{-1}
Exploratory Drilling	2.71×10^{2}	25	6.78×10^{3}	5.08×10^{-1} to 1.56	5.0×10^{-7}	3.39×10^{-3}

TABLE 4-25

LONG-TERM RADIOLOGICAL EFFECTS OF ABNORMAL EVENTS[a,b]
(concluded)

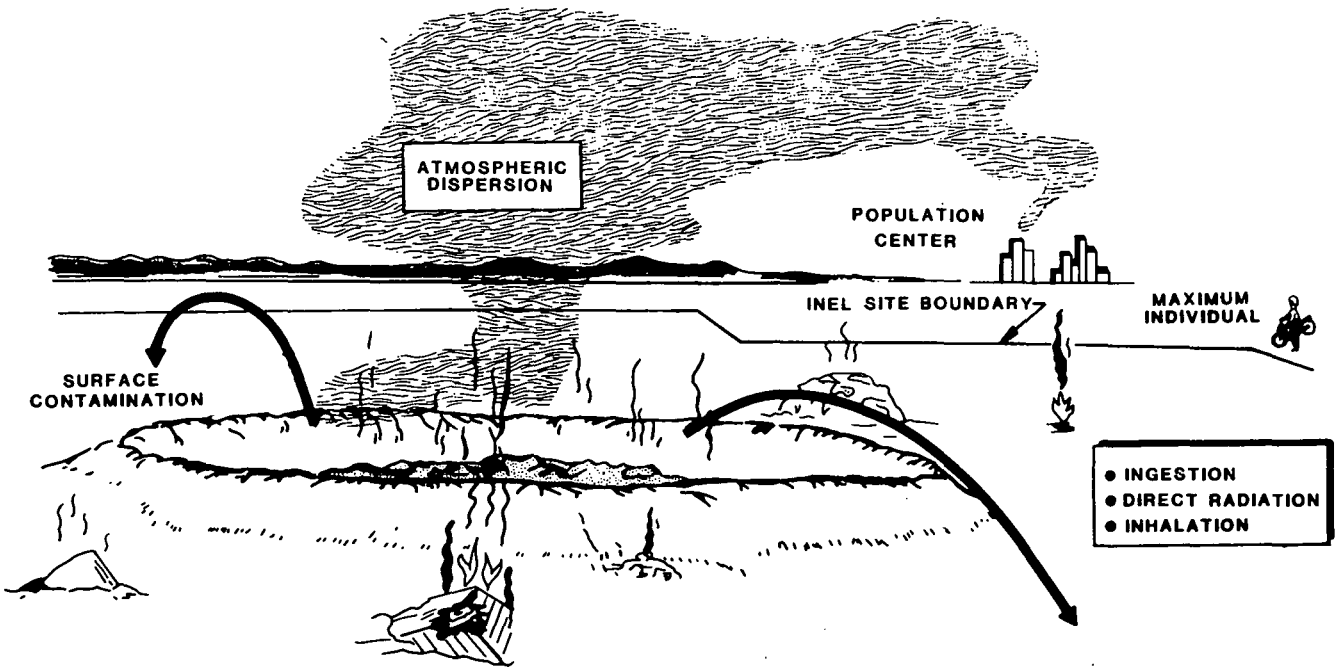
Alternative and Scenario	Maximum Individual: Whole-Body Equivalent Dose (Rem)	Population: Population Exposed (Number)	Population: Whole-Body Equivalent Dose (Man-Rem)	Population: Range of Health Effects[c] (Number)		Population: Probability of Event (Event/Year)	Population: Population Risk (Man-Rem/Year)
5. Delay Retrieval, Modify Calcine, Dispose Offsite[d]							
100 Years							
Solution Mining	1.45×10^{-2}	40,000,000	5.80×10^{5}	4.35×10^{1}	to	1.0×10^{-6}	5.80×10^{-1}
				1.33×10^{2}			
Fault and Flooding	1.78×10^{-4}	2,000,000	3.56	2.67×10^{-4}	to	2.0×10^{-13}	7.12×10^{-13}
				8.19×10^{-4}			
Exploratory Drilling	1.13	25	2.82×10^{1}	2.12×10^{-3}	to	5.0×10^{-7}	1.41×10^{-5}
				6.50×10^{-3}			
300 Years							
Solution Mining	1.06×10^{-2}	40,000,000	4.24×10^{5}	3.18×10^{1}	to	1.0×10^{-6}	4.24×10^{-1}
				9.75×10^{1}			
Fault and Flooding	1.78×10^{-4}	2,000,000	3.56	2.67×10^{-4}	to	2.0×10^{-13}	7.12×10^{-13}
				8.19×10^{-4}			
Exploratory Drilling	9.65×10^{-1}	25	2.41×10^{1}	1.81×10^{-3}	to	5.0×10^{-7}	1.21×10^{-5}
				5.55×10^{-3}			
500 Years							
Solution Mining	7.83×10^{-3}	40,000,000	3.13×10^{5}	2.35×10^{1}	to	1.0×10^{-6}	3.13×10^{-1}
				7.20×10^{1}			
Fault and Flooding	1.78×10^{-4}	2,000,000	3.56	2.67×10^{-4}	to	2.0×10^{-13}	7.12×10^{-13}
				8.19×10^{-4}			
Exploratory Drilling	8.80×10^{-1}	25	2.20×10^{1}	1.65×10^{-3}	to	5.0×10^{-7}	1.10×10^{-5}
				5.06×10^{-3}			

a. Scenarios that apply to Alternatives 1 and 2 and the same scenarios that apply to Alternative 4 would occur at the INEL. Scenarios that apply to Alternatives 3 and 5 and the same scenarios that apply to Alternative 4 would occur at the offsite federal geologic repository.

b. Severe geologic disruption; 2100. Solution mining, 2500 (Alternatives 3 and 4), 2600, 2800, 3000 (Alternative 5). Fault and flooding, 2600 (Alternatives 3 and 4), 2700, 2900, 3100 (Alternative 5). Exploratory drilling, 2500 (Alternatives 3 and 4), 2600, 2800, 3000 (Alternative 5).

c. Health effects are cancer deaths.

d. If the severe geologic disruption were to occur during the period of delay, the effects of Alternative 5 would be no worse than the effects of Alternative 1.



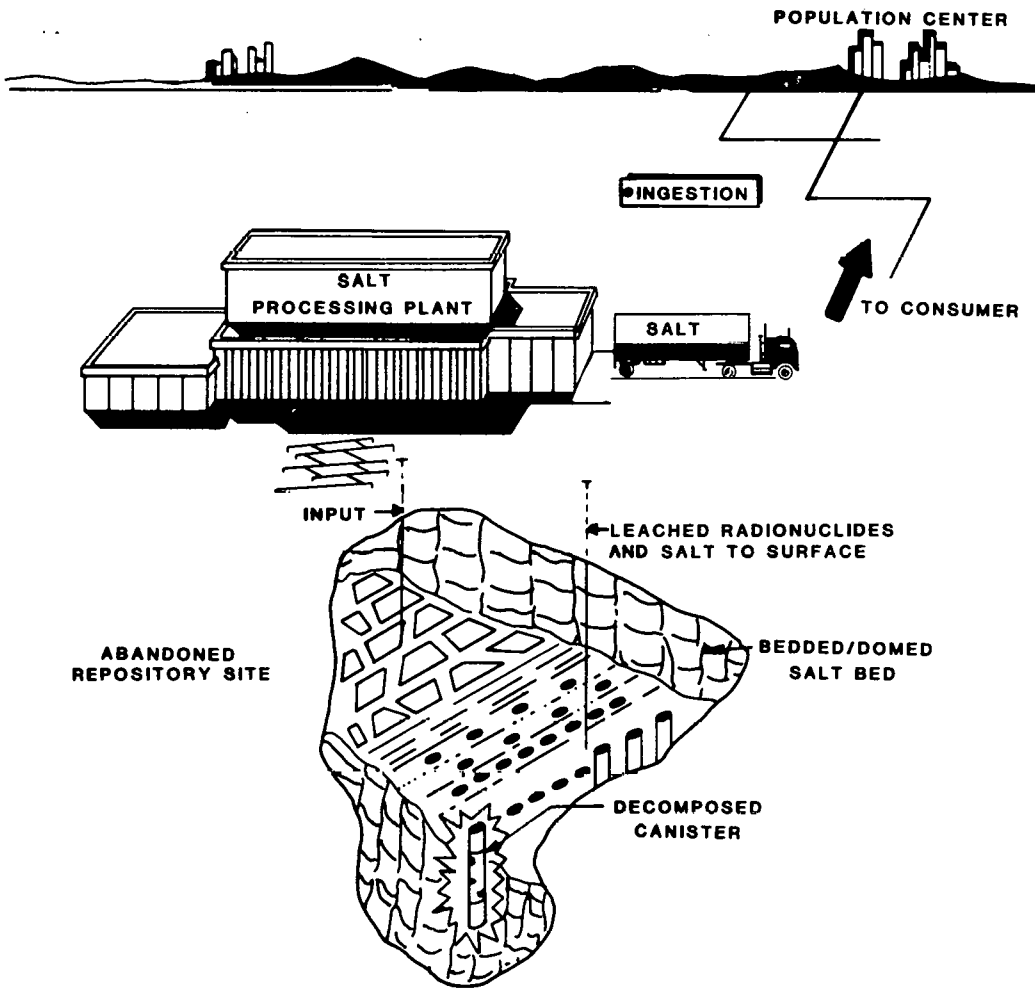
SEVERE GEOLOGIC DISRUPTION

fatal to persons in the immediate vicinity of the INEL. Effects from acute radiation exposure would not be expected. Land use at the INEL would be restricted until the extent of contamination was determined and, if necessary, decontamination was complete. Should the event occur several hundred years in the future, radiological effects would be reduced about ten times; if the event were to occur several thousand years in the future, radiological effects would be reduced about 100 times.

Solution Mining

This event would affect waste disposal at a federal geologic repository (Alternatives 3, 4, and 5) located in bedded or domed salt formations. The scenario would not apply to other types of mined repositories. Since salt formations are being considered as possible locations for a federal repository, solution mining after institutional control is assumed to cease could expose large population groups to radiation by ingestion of table salt. In this scenario, it is assumed that waste containment fails and the salt processor is unaware of the radioactive waste. Exploratory drilling in the area could identify commercial salt deposits that would be recovered by a solution

mining operation. During the mining process, radionuclides would be leached and enter the food chain in table salt as shown in the accompanying illustration.



SOLUTION MINING

A large population could be affected by this event. The population assumed to be exposed to contaminated table salt (40,000,000) was based on the current distribution of table salt supplies. Calculated dose commitments and health effects for the ingestion of table salt are given in Table 4-25. Effects are for the year 2500 for Alternatives 3 and 4, and for the years 2600, 2800, and 3000 for Alternative 5. The maximum radiation dose received by individuals is small (0.017 rem); however, the number of individuals

TABLE 4-26

NONRADIOLOGICAL EFFECTS OF LONG-TERM ABNORMAL EVENTS

Alternative and Scenario	Population Exposed (Number)	Cadmium Concentration (mg/ℓ)	Mercury Concentration (mg/ℓ)	Health Effects (Number)
1. Leave-in-Place	NA[a]	NA	NA	NA
2. Retrieve, Modify Calcine, Dispose at the INEL				
Pelletize Calcine	NA	NA	NA	NA
Convert Calcine to Glass	NA	NA	NA	NA
3. Retrieve, Modify Calcine, Dispose Offsite				
Stabilize Calcine				
Solution Mining	40,000,000	1.4×10^{-4}	4.7×10^{-6}	0
Fault and Flooding	2,000,000	2.0×10^{-3}	7.0×10^{-5}	0
Convert Calcine to Glass				
Solution Mining	40,000,000	1.4×10^{-4}	4.7×10^{-6}	0
Fault and Flooding	2,000,000	4.9×10^{-5}	1.6×10^{-6}	0
4. Retrieve, Separate Actinides, Dispose of Actinides Offsite, Dispose of Depleted Calcine at the INEL	NA	NA	NA	NA
5. Delay Retrieval Modify Calcine, Dispose Offsite				
100 Years				
Solution Mining	40,000,000	1.4×10^{-4}	4.7×10^{-6}	0
Fault and Flooding	2,000,000	4.9×10^{-5}	1.6×10^{-6}	0
300 Years				
Solution Mining	40,000,000	1.4×10^{-4}	4.7×10^{-6}	0
Fault and Flooding	2,000,000	4.9×10^{-5}	1.6×10^{-6}	0
500 Years				
Solution Mining	40,000,000	1.4×10^{-4}	4.7×10^{-6}	0
Fault and Flooding	2,000,000	4.9×10^{-5}	1.6×10^{-6}	0
Federal and State Drinking Water Standards[b]		1.0×10^{-2}	2.0×10^{-3}	0

a. NA, not applicable. Alternatives 1, 2, and 4 do not involve disposal at a federal geologic repository.

b. 40 CFR 141 and State of Idaho, 1977.

exposed in the scenario is very large which accounts for the large number of health effects. No single individual would receive a dose that could be distinguished from background radiation (0.15 rem).

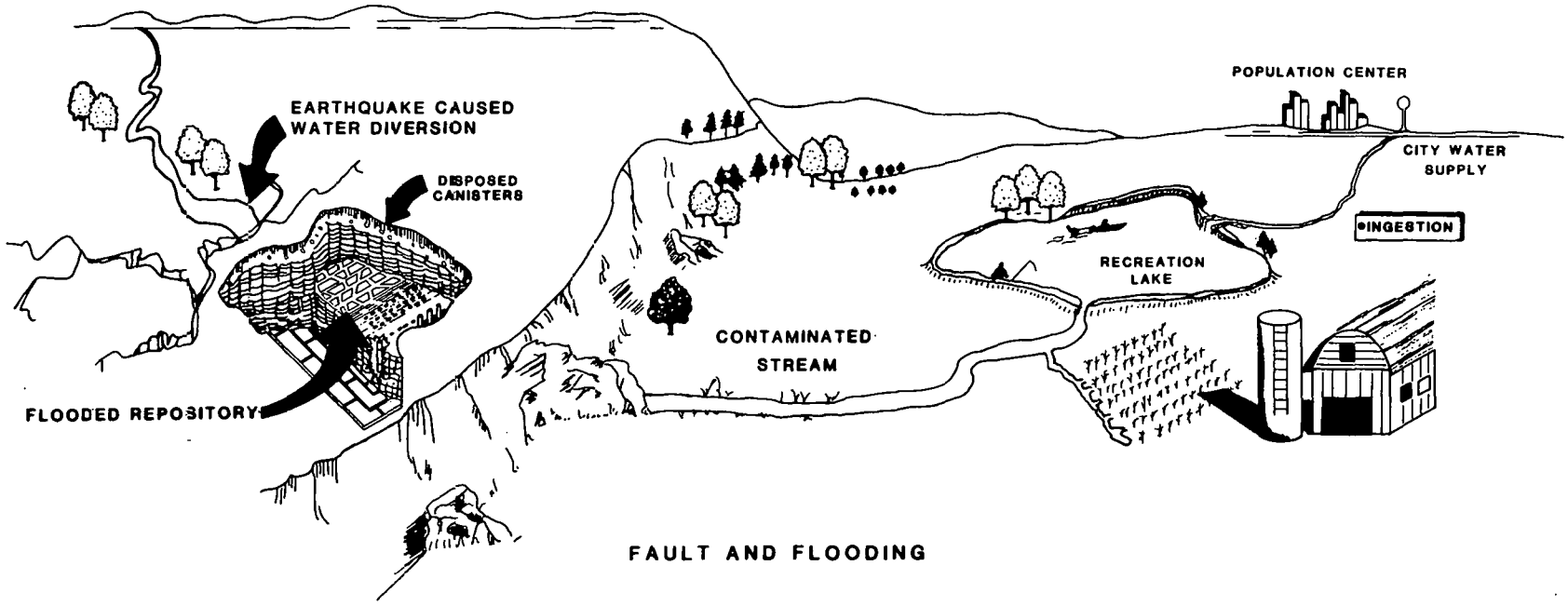
The nonradiological effects of cadmium and mercury present in INEL waste were evaluated for the solution mining scenario. Calculated concentrations of these potentially toxic chemicals would be less than drinking water standards in the salt solution. There would be no health effects from ingesting table salt recovered in the solution mining process. Concentrations of cadmium and mercury in the solution mining scenario are given in Table 4-26.

Fault and Flooding

Waste disposal at a geologic repository could cause contamination of surface water should a stream or aquifer be diverted through the repository. Geologic changes over long time periods could cause a fault to form and allow water to flow through the repository as shown in the illustration found following Table 4-26.

It was assumed that the contaminated stream would be used as a water supply by the population in the surrounding area. The event is assumed to occur in 2500 but about a hundred years would be required for the waste to migrate from the repository to surface water supplies. Since maximum effects are discussed, dose commitments and health effects for the fault and flooding scenario are given in Table 4-25 for the year 2600 for Alternatives 3, and 4, and the years 2700, 2900, and 3100 for Alternative 5. The doses for all alternatives except Alternative 3 (stabilize calcine) would be very small. Stabilized calcine would result in a dose that is about 12 times the background radiation dose (0.15 rem).

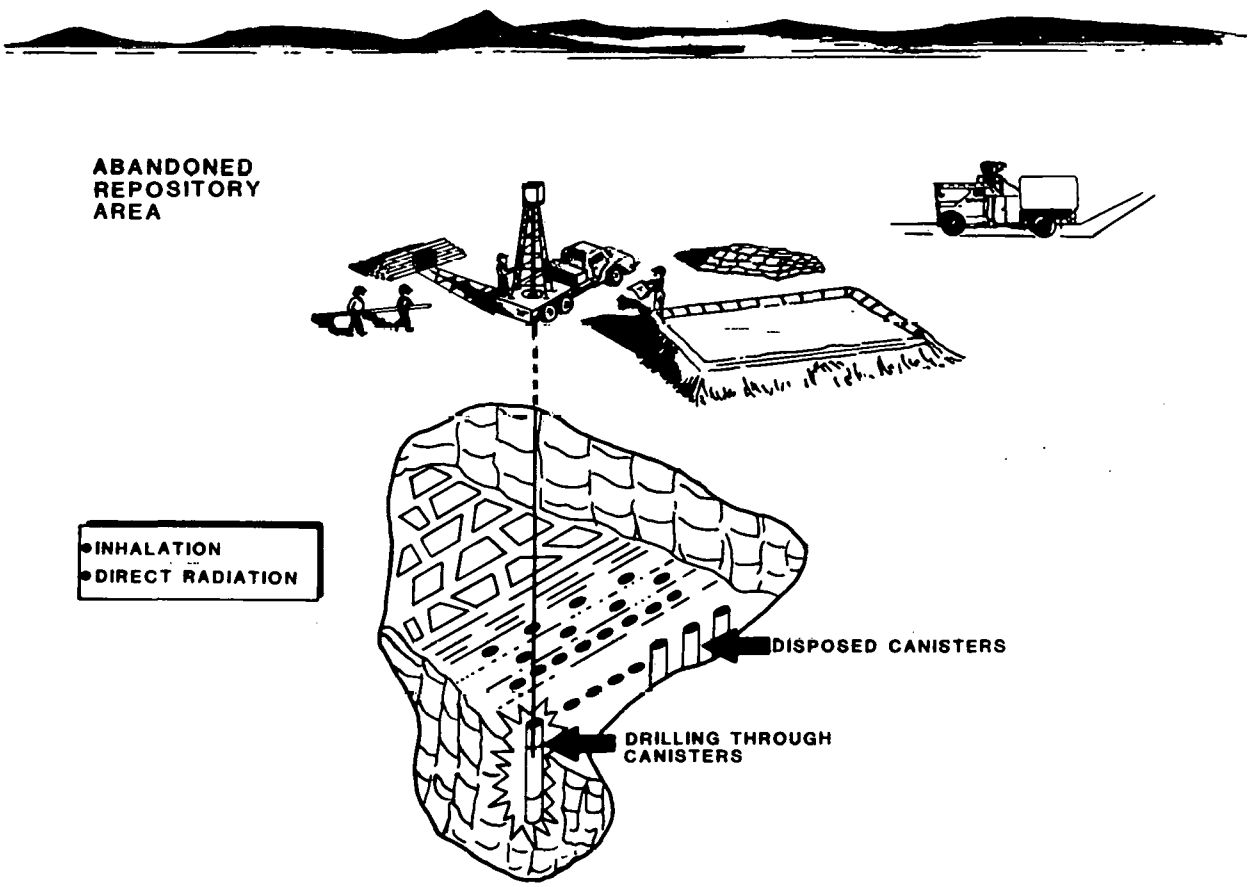
The nonradiological effects of cadmium and mercury present in INEL waste were evaluated for the fault and flooding scenario. The scenario would be very similar to the waste-migration-into-groundwater scenario, but there would be fewer effects. Because of the larger volume of water available, cadmium and mercury concentrations in the river would not exceed drinking water standards and there would be no health effects. Concentrations for cadmium and mercury in the fault and flooding scenario are given in Table 4-26.



FAULT AND FLOODING

Exploratory Drilling

This event would affect waste disposal at a federal geologic repository (Alternatives 3, 4, and 5). Only a limited number of people would be affected by this event as shown in the accompanying illustration.



EXPLORATORY DRILLING

An area of significant mineral reserves would not be selected as a suitable location for a geologic repository. However, since future exploratory drilling could occur in the repository area, the effects of this event were evaluated. The repository would be at a substantial depth. It was assumed that exploratory drilling could penetrate a waste canister and bring radioactive material to the surface.

It was assumed that radiation exposure would result from direct radiation, inhalation of airborne radionuclides, and ingestion of food grown in soil contaminated by the waste brought to the surface.

The calculated dose commitments and health effects for the exploratory drilling scenario are given in Table 4-25 for 2500 (Alternatives 3 and 4), and 2600, 2800, and 3000 (Alternative 5). A significant dose (271 rem) would result from Alternative 4 since the waste would be highly concentrated.

4.6 Summary of Effects by Alternative

The effects of the waste management alternatives discussed in Subsection 4.5 are summarized for each alternative in this subsection. Effects are divided into nonradiological effects and radiological effects for the short-term and long-term periods of evaluation and include effects at the repository. Dose commitments and health effects are given for each scenario evaluated in this report. Nonradiological effects of the construction and operation phases of alternative implementation have been summarized by selecting only the most representative of the many effects that were evaluated. Detailed information on nonradiological effects of construction and operation is given in Subsection 4.5.

4.6.1 Alternative 1

Nonradiological effects of leaving the waste in place are summarized in Table 4-27. During the construction phase, effects on air quality would be undetectable. Diesel fuel use would be about 22 percent of the diesel fuel used at the INEL in 1978. Labor force requirements would be well within current fluctuations of the total INEL labor force. Thus, socioeconomic effects could be easily accommodated by the communities surrounding the INEL. Effects during the operations phase would consist primarily of routine maintenance and surveillance activities. The only significant effect would occur during the disposal phase. The waste-migration-into-groundwater scenario could result in contamination of the Snake River Plain Aquifer by toxic chemicals present in the waste. Concentrations of cadmium and mercury could exceed public drinking water standards for a distance of about 5 miles downgradient of the discharge

TABLE 4-27

SUMMARY OF NONRADIOLOGICAL ENVIRONMENTAL EFFECTS
ALTERNATIVE 1

Phase and Scenario	Land Use (Acres)	Air Quality[a] (μg/m³)	Water Quality[b] Cadmium (mg/ℓ)	Water Quality[b] Mercury (mg/ℓ)	Labor Force (Man-Yr)	Diesel Fuel (10^3 Gal)	Energy Demand (Megawatts)	Worker Injuries/ Fatalities
CERTAIN-TO-OCCUR EVENTS								
Short-Term								
Construction Activities	NA	0.12	NA[c]		800	375	NA	17/0.2
Routine Operations	NA	0	NA		0	NA	0	0.4/0.001
Decontamination and Decommissioning	NA	NA	NA		0	NA	NA	0.5/0.006
Disposal at INEL	NA	NA	NA		NA	NA	NA	e
Long-Term								
Disposal at INEL	1	NA	NA		NA	NA	NA	NA
ABNORMAL EVENTS[d]								
Short-Term								
Construction Activities	NA	NA	NA		NA	NA	NA	NA
Routine Operations	NA	NA	NA		NA	NA	NA	NA
Decontamination and Decommissioning	NA	NA	NA		NA	NA	NA	NA
Long-Term								
Waste Migration into Groundwater	NA	NA	0.012	0.00039	NA	NA	NA	NA

a. Ambient air concentrations given are in addition to background. During construction, the concentration is given for particulates. During operations, the concentration is given for nitrogen oxides. Federal standard: particulates, 60 μg/m³; nitrogen oxides, 100 μg/m³; (40 CFR 50).

b. Concentration at hypothetical 3-mile well. Federal standard: cadmium, 0.010 mg/ℓ; mercury, 0.002 mg/ℓ (40 CFR 141).

c. NA, not applicable.

d. No nonradiological abnormal effects in the long-term period.

e. Injury/fatality values are included in Routine Operations.

point until chemical reactions and dispersion in the aquifer reduced the concentrations to harmless levels.

Radiological effects are summarized in Table 4-28. It is extremely unlikely that any health effects would be caused by implementation of Alternative 1. Only two abnormal events would result in health effects in the population exposed to radiation. The aircraft impact scenario could cause 17 health effects in a population of 71,000 people, which is within the fluctuation of the 11,900 health effects that would be expected from all causes of cancer. The consequences of a severe geologic disruption could cause 449 health effects in an estimated population of 206,000 people. These radiological health effects would be less than 2 percent of the 34,600 health effects that would be expected from all causes of cancer.

4.6.2 Alternative 2

Nonradiological effects of waste retrieval, waste form modification (pellets and glass), and disposal at the INEL are given in Table 4-29 for pellets and in Table 4-30 for calcine converted to glass. While the nonradiological effects of waste form modification are generally minor, the effects of pelletization differ markedly from the effects of vitrification. Waste form modification is relatively energy intensive. However, the labor force required for pelletization would be about twice the labor force required for vitrification because construction of the disposal facilities for pellets is more labor intensive than construction of the silos required for disposal of glass. The subsurface area required for glass disposal would be about 50 times the area required for disposal of pellets.

The waste form would significantly affect the potential for contamination of the Snake River Plain Aquifer by toxic chemicals present in the waste. Pelletized calcine could cause public drinking water standards to be exceeded at the point of discharge into the aquifer. Vitrified calcine would not be as leachable as pellets, and concentrations of cadmium and mercury in the aquifer would not exceed applicable standards.

TABLE 4-28

SUMMARY OF RADIOLOGICAL ENVIRONMENTAL EFFECTS
ALTERNATIVE 1

Scenario	Maximum Individual: Whole-Body Equivalent Dose (Rem)	Population: Population Exposed (Number)	Population: Whole-Body Equivalent Dose (Man-Rem)	Population: Range of Health Effects[a,b] (Number)	Population: Probability of Event (Event/Year)	Population: Population Risk (Man-Rem/Year)
CERTAIN-TO-OCCUR EVENTS[c]						
Long-Term						
Disposal at INEL						
Living Over the Waste	1.10×10^{-1}	5	0.55	4.12×10^{-5} to 1.26×10^{-4}	1.0×10^{-2}	5.50×10^{-3}
Intrusion into Waste	4.38×10^{1}	10	4.38×10^{2}	3.28×10^{-2} to 1.01×10^{-1}	1.0×10^{-2}	4.38
Living at Contaminated Site	5.31×10^{1}	5	2.65×10^{2}	1.99×10^{-2} to 6.11×10^{-2}	1.0×10^{-2}	2.65
ABNORMAL EVENTS						
Short-Term						
Disposal at INEL						
Aircraft Impact	5.20	71,000	7.38×10^{4}	5.54 to 1.70×10^{1}	2.0×10^{-7}	1.48×10^{-2}
Long-Term						
Disposal at INEL						
Waste Migration into Groundwater	6.30×10^{-1}	5	3.15	2.36×10^{-4} to 7.24×10^{-4}	1.0×10^{-6}	3.15×10^{-6}
Severe Geologic Disruption	1.58×10^{1}	206,000	1.95×10^{6}	1.46×10^{2} to 4.49×10^{2}	1.0×10^{-8}	1.95×10^{-2}

a. Health effects are cancer deaths.

b. Health effects (cancer deaths) from all causes: 16.8% per 100,000 population (ACS, 1981).

c. No certain-to-occur radiological effects in the short-term period.

TABLE 4-29

SUMMARY OF NONRADIOLOGICAL ENVIRONMENTAL EFFECTS
ALTERNATIVE 2 - PELLETIZE CALCINE

Phase and Scenario	Land Use (Acres)	Air Quality[a] ($\mu g/m^3$)	Water Quality[b] Cadmium (mg/ℓ)	Water Quality[b] Mercury (mg/ℓ)	Labor Force (Man-Yr)	Diesel Fuel (10^3 Gal)	Energy Demand (Megawatts)	Worker Injuries/ Fatalities
CERTAIN-TO-OCCUR EVENTS								
Short-Term								
Construction Activities	1	0.07	NA[c]		2,000	275	NA	51/0.5
Routine Operations	NA	1.0	NA		800	NA	1.45	20/0.07
Decontamination and Decommissioning	NA	NA	NA		26	NA	NA	0.8/0.009
Disposal at INEL	NA	NA	NA		NA	NA	NA	e
Long-Term								
Disposal at INEL	2	NA	NA		NA	NA	NA	NA
ABNORMAL EVENTS[d]								
Short-Term								
Construction Activities	NA	NA	NA		NA	NA	NA	NA
Routine Operations	NA	NA	NA		NA	NA	NA	NA
Decontamination and Decommissioning	NA	NA	NA		NA	NA	NA	NA
Long-Term								
Waste Migration into Groundwater	NA	NA	1.7×10^{-3}	5.7×10^{-5}	NA	NA	NA	NA

a. Ambient air concentrations given are in addition to background. During construction, the concentration is given for particulates. During operations, the concentration is given for nitrogen oxides. Federal standard: particulates, 60 $\mu g/m^3$; nitrogen oxides, 100 $\mu g/m^3$; (40 CFR 50).

b. Concentration at hypothetical 3-mile well. Federal standard: cadmium, 0.010 mg/ℓ; mercury, 0.002 mg/ℓ (40 CFR 141).

c. NA, not applicable.

d. No nonradiological abnormal effects in the long-term period.

e. Injury/fatality values are included in Routine Operations.

TABLE 4-30

SUMMARY OF NONRADIOLOGICAL ENVIRONMENTAL EFFECTS
ALTERNATIVE 2 - CONVERT CALCINE TO GLASS

Phase and Scenario	Land Use (Acres)	Air Quality[a] ($\mu g/m^3$)	Water Quality[b] Cadmium (mg/ℓ)	Water Quality[b] Mercury (mg/ℓ)	Labor Force (Man-Yr)	Diesel Fuel (10^3 Gal)	Energy Demand (Megawatts)	Worker Injuries/ Fatalities
CERTAIN-TO-OCCUR EVENTS								
Short-Term								
Construction Activities	1	0.07	NA[c]		1,000	575	NA	23/0.2
Routine Operations	NA	0.44	NA		1,250	NA	1.15	31/0.1
Decontamination and Decommissioning	NA	NA	NA		50	NA	NA	2/0.02
Disposal at INEL	NA	NA	NA		NA	NA	NA	e
Long-Term								
Disposal at INEL	180	NA	NA		NA	NA	NA	NA
ABNORMAL EVENTS[d]								
Short-Term								
Construction Activities	NA	NA	NA		NA	NA	NA	NA
Routine Operations	NA	NA	NA		NA	NA	NA	NA
Decontamination and Decommissioning	NA	NA	NA		NA	NA	NA	NA
Long-Term								
Waste Migration into Groundwater	NA	NA	3.0×10^{-7}	9.9×10^{-9}	NA	NA	NA	NA

a. Ambient air concentrations given are in addition to background. During construction, the concentration is given for particulates. During operations, the concentration is given for nitrogen oxides. Federal standard: particulates, 60 $\mu g/m^3$; nitrogen oxides, 100 $\mu g/m^3$; (40 CFR 50).

b. Concentration at hypothetical 3-mile well. Federal standard: cadmium, 0.010 mg/ℓ; mercury, 0.002 mg/ℓ (40 CFR 141).

c. NA, not applicable.

d. No nonradiological abnormal effects in the long-term period.

e. Injury/fatality values are included in Routine Operations.

Radiological effects of Alternative 2 are given in Table 4-31 for pellets and in Table 4-32 for calcine converted to glass. The most probable number of health effects caused by implementation of Alternative 2 would be zero, regardless of waste form. Releases of the more stable waste form (glass) would cause significantly lower dose commitments for such events as waste migration into groundwater and intrusion into the waste by future generations. However, the most probable number of health effects would be zero for all scenarios evaluated except for the aircraft impact and severe geologic disruption scenarios. These events would cause effects identical to the effects of Alternative 1. The maximum number of health effects would result from a severe geologic disruption; they would be less than 2 percent of the 34,600 health effects that would be expected from all causes of cancer.

4.6.3 Alternative 3

Nonradiological effects of waste retrieval, waste form modification, and disposal at an offsite federal geologic repository are given in Table 4-33 for stabilized calcine and in Table 4-34 for calcine converted to glass. The nonradiological effects of producing stabilized calcine and glass are very similar. The only significant difference would be in energy use. Twice as much energy would be required to convert calcine to glass than would be required to stabilize the calcine. Electrical power demand for vitrification would be about 27 percent of the ICPP demand in 1980. Diesel fuel required for shipment of glass would exceed the fuel requirement for shipment of stabilized calcine by 33 percent because of the larger volume of glass.

Radiological effects of Alternative 3 are given in Table 4-35 for stabilized calcine and in Table 4-36 for vitrified calcine. It is very unlikely that any radiological health effects would be caused by implementation of Alternative 3, regardless of waste form. Releases during processing of the more stable waste form (glass) would cause dose commitments from routine operations that would be 500 times smaller than the doses calculated for stabilized calcine. However, the routine operations dose commitments for stabilized calcine would be so small that they would be indistinguishable from the dose received from background radiation. For both waste forms, aircraft impact during waste processing and solution mining at the federal repository would cause a maximum

TABLE 4-31

SUMMARY OF RADIOLOGICAL ENVIRONMENTAL EFFECTS
ALTERNATIVE 2 - PELLETIZE CALCINE

Phase and Scenario	Maximum Individual	Population				
	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range of Health[a] Effects (Number)	Probability of Event (Event/Year)	Population Risk (Man-Rem/Year)
CERTAIN-TO-OCCUR EVENTS						
Short-Term						
Operations Phase						
Routine Operations	3.00×10^{-6}	199,000	2.39×10^{-2}	1.79×10^{-6} to 5.49×10^{-6}	1.0	2.39×10^{-2}
Calcine Spill	9.10×10^{-10}	107,000	3.89×10^{-6}	2.92×10^{-10} to 8.96×10^{-10}	2.0×10^{-1}	7.79×10^{-7}
Decontamination Solution Spill	6.10×10^{-2}	107,000	1.31×10^{3}	9.79×10^{-2} to 3.00×10^{-1}	1.0×10^{-1}	1.31×10^{2}
Decontamination and Decommissioning	1.06×10^{-8}	303,000	1.28×10^{-4}	9.63×10^{-9} to 2.95×10^{-8}	1.0	1.28×10^{-4}
Long-Term						
Disposal at INEL						
Living Over the Waste	9.20×10^{-3}	5	4.60×10^{-11}	3.45×10^{-5} to 1.06×10^{-3}	1.0×10^{-2}	4.60×10^{-3}
Intrusion into Waste	1.05×10^{1}	10	1.05×10^{2}	7.87×10^{-2} to 2.41×10^{-3}	1.0×10^{-2}	1.05
Living at Contaminated Site	8.08	5	4.04×10^{1}	3.03×10^{-3} to 9.29×10^{-3}	1.0×10^{-2}	4.04×10^{-1}
ABNORMAL EVENTS						
Short-Term						
Disposal at INEL						
Aircraft Impact[b]	5.20	71,000	7.38×10^{4}	5.54 to 1.70×10^{1}	2.0×10^{-7}	1.48×10^{-2}
Long-Term						
Disposal at INEL						
Waste Migration into Groundwater	6.30×10^{-3}	5	3.15×10^{-2}	2.36×10^{-6} to 7.24×10^{-6}	1.0×10^{-6}	3.15×10^{-8}
Severe Geologic Disruption	1.58×10^{1}	206,000	1.95×10^{6}	1.46×10^{2} to 4.49×10^{2}	1.0×10^{-8}	1.95×10^{-2}

a. ealth effects (cancer deaths) from all causes: 16.8% per 100,000 population (ACS, 1981).

b. Aircraft impact is assumed to occur in the year 1990 prior to completion of processing and shipment of waste offsite.

TABLE 4-32

SUMMARY OF RADIOLOGICAL ENVIRONMENTAL EFFECTS
ALTERNATIVE 2 - CONVERT CALCINE TO GLASS

Phase and Scenario	Maximum Individual: Whole-Body Equivalent Dose (Rem)	Population: Population Exposed (Number)	Population: Whole-Body Equivalent Dose (Man-Rem)	Population: Range of Health Effects[a,b] (Number)	Population: Probability of Event (Event/Year)	Population: Population Risk (Man-Rem/Year)
CERTAIN-TO-OCCUR EVENTS						
Short-Term						
Operations Phase						
Routine Operations	3.00×10^{-6}	199,000	2.39×10^{-2}	1.79×10^{-6} to 5.49×10^{-6}	1.0	2.39×10^{-2}
Calcine Spill	9.10×10^{-10}	107,000	3.89×10^{-6}	2.92×10^{-10} to 8.96×10^{-10}	2.0×10^{-1}	7.79×10^{-7}
Decontamination Solution Spill	6.10×10^{-2}	107,000	1.31×10^{3}	9.79×10^{-2} to 3.00×10^{-1}	1.0×10^{-1}	1.31×10^{2}
Decontamination and Decommissioning	1.06×10^{-8}	303,000	1.28×10^{-4}	9.63×10^{-9} to 2.95×10^{-8}	1.0	1.28×10^{-4}
Long-Term						
Disposal at INEL						
Living Over the Waste	1.50×10^{-2}	5	7.50×10^{-2}	5.62×10^{-6} to 1.72×10^{-5}	1.0×10^{-2}	7.50×10^{-4}
Intrusion into Waste	6.80×10^{-1}	10	6.80	5.10×10^{-4} to 1.56×10^{-3}	1.0×10^{-2}	6.80×10^{-2}
Living at Contaminated Site	7.75	5	3.88×10^{1}	2.91×10^{-3} to 8.91×10^{-3}	1.0×10^{-2}	3.87×10^{-1}
ABNORMAL EVENTS						
Short-Term						
Disposal at INEL						
Aircraft Impact[c]	5.20	71,000	7.38×10^{4}	5.54 to 1.70×10^{1}	2.0×10^{-7}	1.48×10^{-2}
Long-Term						
Disposal at INEL						
Waste Migration into Groundwater	1.39×10^{-6}	5	6.95×10^{-6}	5.21×10^{-10} to 1.60×10^{-9}	1.0×10^{-6}	6.95×10^{-12}
Severe Geologic Disruption	1.58×10^{1}	206,000	1.95×10^{6}	1.46×10^{2} to 4.49×10^{2}	1.0×10^{-8}	1.95×10^{-2}

a. Health effects are cancer deaths.

b. Health effects (cancer deaths) from all causes: 16.8% per 100,000 population (ACS, 1981).

c. Aircraft impact is assumed to occur in the year 1990 prior to completion of processing and shipment of waste offsite.

TABLE 4-33

SUMMARY OF NONRADIOLOGICAL ENVIRONMENTAL EFFECTS
ALTERNATIVE 3 - STABILIZE CALCINE

Phase and Scenario	Land Use (Acres)	Air Quality[a] ($\mu g/m^3$)	Water Quality[b] Cadmium (mg/ℓ)	Water Quality[b] Mercury (mg/ℓ)	Labor Force (Man-Yr)	Diesel Fuel (10^3 Gal)	Energy Demand (Megawatts)	Worker Injuries/ Fatalities
CERTAIN-TO-OCCUR EVENTS								
Short-Term								
Construction Activities	1	0.04	NA[c]		1,300	875	NA	55/1.0
Routine Operations	NA	0.40	NA		2,350	NA	0.57	24/0.09
Routine Waste Shipment	NA	NA	NA		2,700	1,800	NA	4/0.3
Decontamination and Decommissioning	NA	NA	NA		50	NA	NA	2/0.02
Disposal at INEL	NA	NA	NA		NA	NA	NA	d
ABNORMAL EVENTS								
Short-Term								
Construction Activities	NA	NA	NA		NA	NA	NA	NA
Routine Operations	NA	NA	NA		NA	NA	NA	NA
Waste Shipment Accident	NA	NA	NA		NA	NA	NA	NA
Decontamination and Decommissioning	NA	NA	NA		NA	NA	NA	NA
Long-Term								
Disposal at Federal Geologic Repository	175	NA	NA		NA	NA	NA	NA
Solution Mining	NA	NA	1.4×10^{-4}	4.7×10^{-6}	NA	NA	NA	NA
Fault and Flooding	NA	NA	2.0×10^{-3}	7.0×10^{-5}	NA	NA	NA	NA

a. Ambient air concentrations given are in addition to background. During construction, the concentration is given for particulates. During operations, the concentration is given for nitrogen oxides. Federal standard: particulates, 60 $\mu g/m^3$; nitrogen oxides, 100 $\mu g/m^3$; (40 CFR 50).

b. Concentration at hypothetical 3-mile well. Federal standard: cadmium, 0.010 mg/ℓ; mercury, 0.002 mg/ℓ (40 CFR 141).

c. NA, not applicable.

d. Injury/fatality values are included in Routine Operations.

TABLE 4-34

SUMMARY OF NONRADIOLOGICAL ENVIRONMENTAL EFFECTS
ALTERNATIVE 3 - CONVERT CALCINE TO GLASS

Phase and Scenario	Land Use (Acres)	Air Quality[a] ($\mu g/m^3$)	Water Quality[b] Cadmium (mg/ℓ)	Water Quality[b] Mercury (mg/ℓ)	Labor Force (Man-Yr)	Diesel Fuel (10^3 Gal)	Energy Demand (Megawatts)	Worker Injuries/ Fatalities
CERTAIN-TO-OCCUR EVENTS								
Short-Term								
Construction Activities	1	0.04	NA[c]		1,300	940	NA	55/1.0
Routine Operations	NA	0.44	NA		2,500	NA	1.15	28/0.1
Routine Waste Shipment	NA	NA	NA		2,700	2,700	NA	5/0.4
Decontamination and Decommissioning	NA	NA	NA		50	NA	NA	2/0.02
Disposal at INEL	NA	NA	NA		NA	NA	NA	d
ABNORMAL EVENTS[d]								
Short-Term								
Construction Activities	NA	NA	NA		NA	NA	NA	NA
Routine Operations	NA	NA	NA		NA	NA	NA	NA
Waste Shipment Accident	NA	NA	NA		NA	NA	NA	NA
Decontamination and Decommissioning	NA	NA	NA		NA	NA	NA	NA
Long-Term								
Disposal at Federal Geologic Repository	175	NA	NA		NA	NA	NA	NA
Solution Mining	NA	NA	1.4×10^{-4}	4.7×10^{-6}	NA	NA	NA	NA
Fault and Flooding	NA	NA	4.9×10^{-5}	1.6×10^{-6}	NA	NA	NA	NA

a. Ambient air concentrations given are in addition to background. During construction, the concentration is given for particulates. During operations, the concentration is given for nitrogen oxides. Federal standard: particulates, 60 $\mu g/m^3$; nitrogen oxides, 100 $\mu g/m^3$; (40 CFR 50).

b. Concentration at hypothetical 3-mile well. Federal standard: cadmium, 0.010 mg/ℓ; mercury, 0.002 mg/ℓ (40 CFR 141).

c. NA, not applicable.

d. Injury/fatality values are included in Routine Operations.

TABLE 4-35

SUMMARY OF RADIOLOGICAL ENVIRONMENTAL EFFECTS
ALTERNATIVE 3 - STABILIZE CALCINE

Phase and Scenario	Maximum Individual	Population				
	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range of Health Effects[a,b] (Number)	Probability of Event (Event/Year)	Population Risk (Man-Rem/Year)
CERTAIN-TO-OCCUR EVENTS						
Short-Term						
Operations Phase						
Routine Operations	6.54×10^{-9}	199,000	5.21×10^{-5}	3.90×10^{-9} to 1.20×10^{-8}	1.0	5.21×10^{-5}
Calcine Spill	9.10×10^{-10}	107,000	3.89×10^{-6}	2.92×10^{-10} to 8.96×10^{-10}	2.0×10^{-1}	7.79×10^{-7}
Decontamination Solution Spill	6.10×10^{-2}	107,000	1.31×10^{3}	9.79×10^{-2} to 3.00×10^{-1}	1.0×10^{-1}	1.31×10^{2}
Routine Waste Shipment	1.90×10^{-2}	125,000	2.37×10^{2}	1.78×10^{-2} to 5.46	1.0	2.37×10^{2}
Decontamination and Decommissioning	2.52×10^{-11}	303,000	3.05×10^{-7}	2.29×10^{-11} to 7.02×10^{-11}	1.0	3.05×10^{-7}
Long-Term						
Disposal at Federal Geologic Repository	0	0	0	0	0	0
ABNORMAL EVENTS						
Short-Term						
Waste Shipment Accident	9.78	500	4.89×10^{3}	3.67×10^{-1} to 1.12	2.0×10^{-5}	9.78×10^{-2}
Disposal at INEL						
Aircraft Impact[c]	5.20	71,000	7.38×10^{4}	5.54 to 1.70×10^{1}	2.0×10^{-7}	1.48×10^{-2}
Disposal at Federal Geologic Repository						
Waste Canister Drop	9.40×10^{-5}	2,000,000	1.88	1.41×10^{-4} to 4.32×10^{-4}	7.0×10^{-7}	1.32×10^{-6}
Long-Term						
Disposal at Federal Geologic Repository						
Solution Mining	1.71×10^{-4}	40,000,000	6.84×10^{5}	5.13×10^{1} to 1.57×10^{2}	1.0×10^{-6}	6.84×10^{-1}
Fault and Flooding	1.78	2,000,000	3.56×10^{4}	2.67 to 8.19	2.0×10^{-13}	7.12×10^{-9}
Exploratory Drilling	2.36	25	5.90×10^{1}	4.42×10^{-3} to 1.36×10^{-2}	5.0×10^{-7}	2.95×10^{-5}

a. Health effects are cancer deaths.

b. Health effects (cancer deaths) from all causes: 16.8% per 100,000 population (ACS, 1981).

c. Aircraft impact is assumed to occur in the year 1990 prior to the completion of processing and shipment of waste offsite.

TABLE 4-36

SUMMARY OF RADIOLOGICAL ENVIRONMENTAL EFFECTS
ALTERNATIVE 3 - CONVERT CALCINE TO GLASS

Phase and Scenario	Maximum Individual: Whole-Body Equivalent Dose (Rem)	Population: Population Exposed (Number)	Population: Whole-Body Equivalent Dose (Man-Rem)	Population: Range of Health Effects[a,b] (Number)	Population: Probability of Event (Event/Year)	Population: Population Risk (Man-Rem/Year)
CERTAIN-TO-OCCUR EVENTS						
Short-Term						
Operations Phase						
Routine Operations	3.00×10^{-6}	199,000	2.39×10^{-2}	1.79×10^{-6} to 5.49×10^{-6}	1.00	2.39×10^{-2}
Calcine Spill	9.10×10^{-10}	107,000	3.89×10^{-6}	2.92×10^{-10} to 8.96×10^{-10}	2.00×10^{-1}	7.79×10^{-7}
Decontamination Solution Spill	6.10×10^{-2}	107,000	1.31×10^{3}	9.79×10^{-2} to 3.00×10^{-1}	1.00×10^{-1}	1.31×10^{2}
Routine Waste Shipment	2.90×10^{-2}	125,000	3.62×10^{2}	2.72×10^{-2} to 8.34×10^{-2}	1.00	3.62×10^{2}
Decontamination and Decommissioning	1.06×10^{-8}	303,000	1.28×10^{-4}	9.63×10^{-9} to 2.95×10^{-8}	1.00	1.28×10^{-4}
Long-Term						
Disposal at Federal Geologic Repository	0	0	0	0	0	0
ABNORMAL EVENTS						
Short-Term						
Waste Shipment Accident	1.27×10^{-1}	500	6.35×10^{1}	4.76×10^{-3} to 1.46×10^{-2}	3.00×10^{-5}	1.90×10^{-3}
Disposal at INEL						
Aircraft Impact[c]	5.20	71,000	7.38×10^{-4}	5.54 to 1.70×10^{1}	2.00×10^{-7}	1.48×10^{-2}
Disposal at Federal Geologic Repository						
Waste Canister Drop	1.31×10^{-5}	2,000,000	2.62×10^{-1}	1.96×10^{-5} to 6.03×10^{-5}	7.00×10^{-7}	1.83×10^{-7}
Long-Term						
Disposal at Federal Geologic Repository						
Solution Mining	1.71×10^{-2}	40,000,000	6.84×10^{5}	5.13×10^{1} to 1.57×10^{2}	1.00×10^{-6}	6.84×10^{-1}
Fault and Flooding	1.78×10^{-4}	2,000,000	3.56	2.67×10^{-4} to 8.19×10^{-4}	2.00×10^{-13}	7.12×10^{-13}
Exploratory Drilling	1.55	25	3.87×10^{1}	2.91×10^{-3} to 8.91×10^{-3}	5.00×10^{-7}	1.94×10^{-5}

a. Health effects are cancer deaths.

b. Health effects (cancer deaths) from all causes: 16.8% per 100,000 population (ACS, 1981).

c. Aircraft impact is assumed to occur in the year 1990 prior to the completion of processing and shipment of waste offsite.

of 17 and 157 health effects, respectively. The 157 health effects are estimated to occur as a result of ingestion of contaminated table salt by a population of 40,000,000 people. In a population of 40,000,000 people, 6,700,000 health effects can be expected to occur from all causes. The health effects that could result from radionuclide exposure in these scenarios would be difficult to identify.

4.6.4 Alternative 4

Nonradiological effects of waste retrieval, actinide separation, disposal of the actinides at an offsite federal geologic repository, and disposal of the actinide-depleted calcine at the INEL are given in Table 4-37. During the construction and operation phases, effects on air quality would be undetectable. Diesel fuel used for construction would be 66 percent of diesel fuel use at the INEL in 1978. Diesel fuel used for waste shipment would be 37 percent of the fuel used to ship glass in Alternative 3. Actinide separation would be relatively energy intensive; electricity requirements would be 3.7 percent of the electrical power demand at the ICPP in 1980. Labor force requirements, while moderately labor intensive, would be within current fluctuations of the total INEL labor force. Thus, socioeconomic effects could be accommodated by the communities surrounding the INEL.

During the disposal phase, the waste-migration-into-groundwater scenario could result in contamination of the Snake River Plain Aquifer by cadmium for a distance of about 5 miles downgradient of the discharge point. Mercury would be removed during the actinide separation process.

Radiological effects of Alternative 4 are given in Table 4-38. It is very unlikely that radiological health effects would be caused by implementation of Alternative 4. Three abnormal events would result in health effects in the population exposed to radiation: the aircraft impact and the severe geologic disruption scenarios at the INEL, and the solution mining scenario at a federal geologic repository in a salt formation. The aircraft impact scenario could cause 17 radiological health effects in a population of 71,000 people. These effects are comparable to 11,900 health effects that would be expected from all causes of cancer. (The effects of an aircraft impact are

TABLE 4-37

SUMMARY OF NONRADIOLOGICAL ENVIRONMENTAL EFFECTS
ALTERNATIVE 4

Phase and Scenario	Land Use (Acres)	Air Quality[b] ($\mu g/m^3$)	Water Quality[c] Cadmium (mg/ℓ)	Water Quality[c] Mercury (mg/ℓ)	Labor Force (Man-Yr)	Diesel Fuel (10^3 Gal)	Energy Demand (Megawatts)	Worker Injuries/ Fatalities
CERTAIN-TO-OCCUR EVENTS								
Short-Term								
Construction Activities	1	0.2		NA[a]	2,755	1,115	NA	78.2/0.8
Routine Operations	NA	2.3		NA	1,710	NA	1.60	44/0.2
Routine Waste Shipment	NA	NA		NA	2,700	100	NA	0.2/0.01
Decontamination and Decommissioning	NA	NA		NA	76	NA	NA	3/0.03
Disposal at INEL	NA	NA		NA	NA	NA	NA	e
Long-Term								
Disposal at INEL	1	NA		NA	NA	NA	NA	NA
Disposal at Federal Geologic Repository	1	NA		NA	NA	NA	NA	NA
ABNORMAL EVENTS[d]								
Short-Term								
Construction Activities	NA	NA		NA	NA	NA	NA	NA
Routine Operations	NA	NA		NA	NA	NA	NA	NA
Waste Shipment Accident	NA	NA		NA	NA	NA	NA	NA
Decontamination and Decommissioning	NA	NA		NA	NA	NA	NA	NA
Long-Term								
Waste Migration into Groundwater	NA	NA	0.012	NA	NA	NA	NA	NA

a. NA, not applicable.

b. Ambient air concentrations given are in addition to background. During construction, the concentration is given for particulates. During operations, the concentration is given for nitrogen oxides. Federal standard: particulates, 60 $\mu g/m^3$; nitrogen oxides, 100 $\mu g/m^3$; (40 CFR 50).

c. Concentration at hypothetical 3-mile well. Federal standard: cadmium, 0.010 mg/ℓ; mercury, 0.002 mg/ℓ (40 CFR 141).

d. No nonradiological abnormal effects in the long-term period.

e. Injury/fatality values are included in Routine Operations.

TABLE 4-38

SUMMARY OF RADIOLOGICAL ENVIRONMENTAL EFFECTS
ALTERNATIVE 4

Phase and Scenario	Maximum Individual: Whole-Body Equivalent Dose (Rem)	Population: Population Exposed (Number)	Population: Whole-Body Equivalent Dose (Man-Rem)	Population: Range of Health Effects[a,b] (Number)	Population: Probability of Event (Event/Year)	Population: Population Risk (Man-Rem/Year)
CERTAIN-TO-OCCUR EVENTS						
Short-Term						
Operations Phase						
Routine Operations	7.35×10^{-9}	199,000	5.85×10^{-5}	4.39×10^{-9} to 1.35×10^{-8}	1.00	5.85×10^{-5}
Calcine Spill	9.10×10^{-10}	107,000	3.89×10^{-6}	2.92×10^{-10} to 8.96×10^{-10}	2.00×10^{-1}	7.79×10^{-7}
Decontamination Solution Spill	6.10×10^{-2}	107,000	1.31×10^{3}	9.79×10^{-2} to 3.00×10^{-1}	1.00×10^{-1}	1.31×10^{2}
Routine Waste Shipment	1.00×10^{-3}	125,000	1.25×10^{1}	9.37×10^{-4} to 2.87×10^{-3}	1.00	1.25×10^{1}
Decontamination and Decommissioning	3.04×10^{-11}	303,000	3.68×10^{-7}	2.76×10^{-11} to 8.47×10^{-11}	1.00	3.68×10^{-7}
Long-Term						
Disposal at INEL						
Living Over the Waste	2.20×10^{-3}	5	1.10×10^{-2}	8.25×10^{-7} to 2.53×10^{-6}	1.00×10^{-2}	1.10×10^{-4}
Intrusion into Waste	8.51	10	8.51×10^{1}	6.38×10^{-3} to 1.96×10^{-2}	1.00×10^{-2}	8.51×10^{-1}
Living at Contaminated Site	2.70×10^{1}	5	1.35×10^{2}	1.01×10^{-2} to 3.10×10^{-2}	1.00×10^{-2}	1.35
Disposal at Federal Geologic Repository	0	0	0	0	0	0
ABNORMAL EVENTS						
Short-Term						
Operations Phase						
Extraction Solvent Fire	2.41×10^{-7}	107,000	1.03×10^{-3}	7.74×10^{-8} to 2.37×10^{-7}	1.00×10^{-2}	1.03×10^{-5}
Waste Shipment Accident	1.00×10^{1}	500	5.00×10^{2}	3.75×10^{-1} to 1.15	7.00×10^{-8}	3.50×10^{-4}
Disposal at INEL						
Aircraft Impact[c]	5.20	71,000	7.38×10^{4}	5.54 to 1.70×10^{1}	2.00×10^{-7}	1.48×10^{-2}
Disposal at Federal Geologic Repository						
Waste Canister Drop	1.02×10^{-4}	2,000,000	2.04	1.53×10^{-4} to 4.69×10^{-4}	7.00×10^{-7}	1.43×10^{-6}
Long-Term						
Disposal at INEL						
Waste Migration into Groundwater	6.20×10^{-1}	5	3.12	2.34×10^{-4} to 7.18×10^{-4}	1.00×10^{-6}	3.12×10^{-6}
Severe Geologic Disruption	1.11×10^{1}	206,000	1.37×10^{6}	1.03×10^{2} to 3.16×10^{2}	1.00×10^{-8}	1.37×10^{-2}
Disposal at Federal Geologic Repository						
Solution Mining	1.71×10^{-2}	40,000,000	6.84×10^{5}	5.13×10^{1} to 1.57×10^{2}	1.00×10^{-6}	6.84×10^{-1}
Fault and Flooding	1.78×10^{-6}	2,000,000	3.56×10^{-2}	2.67×10^{-6} to 8.19×10^{-6}	2.00×10^{-13}	7.12×10^{-15}
Exploratory Drilling	2.71×10^{2}	25	6.78×10^{3}	5.08×10^{-1} to 1.56	5.00×10^{-7}	3.39×10^{-3}

a. Health effects are cancer deaths.

b. Health effects (cancer deaths) from all causes: 16.8% per 100,000 population (ACS, 1981).

c. Aircraft impact is assumed to occur in the year 1990 prior to the completion of processing and shipment of waste offsite.

the same for each alternative because the event is assumed to occur prior to waste shipment.) Maximum health effects (cancer deaths) would result from the severe geologic disruption scenario. The radiological consequences of a severe geologic disruption would be about 70 percent of the radiological health effects from a severe geologic disruption involving Alternatives 1 and 2. Solution mining could expose a large population to contaminated table salt. Consequently, even though the maximum individual dose is small (0.017 rem), health effects range from 51.3 to 157.

4.6.5 Alternative 5

Nonradiological effects of delayed waste retrieval, waste form modification, and disposal at an offsite federal geologic repository are given in Table 4-39. The nonradiological effects of implementing Alternative 5 are similar to the combined effects of Alternatives 1 and 3 (convert calcine to glass) with the exception of cadmium and mercury. The construction of storage facilities would be completed in Alternative 5 as described for Alternative 1; the bin-vault complex would be encapsulated in a concrete-like material, and surveillance and monitoring would be continued until the calcine is retrieved for final processing. All nonradiological effects would be minor. Surveillance and maintenance costs would be as high for Alternative 5 as for Alternative 1.

Radiological effects of delayed retrieval are given in Table 4-40 for 100-year delay, in Table 4-41 for 300-year delay, and in Table 4-42 for 500-year delay. The radiological effects of implementing Alternative 5 would, of course, be less than Alternative 3. However, the most probable number of health effects for Alternative 3 is zero, and the most probable number of health effects for Alternative 5 would also be zero. Should an extremely unlikely event such as solution mining occur at the federal respository after the delayed disposal of vitrified calcine, health effects in the exposed population of 40,000,000 people would be indistinguishable from the health effects expected from all causes of cancer.

To summarize the discussion of effects, none of the alternatives would cause significant environmental effects during the construction phase.

TABLE 4-39

SUMMARY OF NONRADIOLOGICAL ENVIRONMENTAL EFFECTS
ALTERNATIVE 5

Phase and Scenario	Land Use (Acres)	Air Quality[a] ($\mu g/m^3$)	Water Quality[b] Cadmium (mg/ℓ)	Water Quality[b] Mercury (mg/ℓ)	Labor Force (Man-Yr)	Diesel Fuel (10^3 Gal)	Energy Demand (Megawatts)	Worker Injuries/ Fatalities
CERTAIN-TO-OCCUR EVENTS								
Short-Term								
Construction Activities	1	0.04	NA[c]		1,110[d]	445[e]	NA	15/0.2
Routine Operations	NA	0.44	NA		1,640[f]	NA	1.15	37/0.14
Routine Waste Shipment	NA	NA	NA		2,700	2,700	NA	2/0.02
Decontamination and Decommissioning	NA	NA	NA		60	NA	NA	NA
Disposal at INEL	NA	NA	NA		NA	NA	NA	i
ABNORMAL EVENTS								
Short-Term								
Construction Activities	NA	NA	NA		NA	NA	NA	NA
Routine Operations	NA	NA	NA		NA	NA	NA	NA
Decontamination and Decommissioning	NA	NA	NA		NA	NA	NA	NA
Long-Term								
Disposal at Federal Geologic Repository	18[g]	NA	NA		NA	NA	NA	NA
Solution Mining	NA	NA	1.4×10^{-4}	4.7×10^{-6}	NA	NA	NA	NA
Fault and Flooding	NA	NA	4.9×10^{-5}	1.6×10^{-6}	NA	NA	NA	NA

a. Ambient air concentrations given are in addition to background. During construction, the concentration is given for particulates. During operations, the concentration is given for nitrogen oxides. Federal standard: particulates, 60 $\mu g/m^3$; nitrogen oxides, 100 $\mu g/m^3$; (40 CFR 50).

b. Concentration at hypothetical 3-mile well. Federal standard: cadmium, 0.010 mg/ℓ; mercury, 0.002 mg/ℓ (40 CFR 141).

c. NA, not applicable.

d. Value is for 100-year delay; 1005 man-years would be required for the 300- and 500-year delay periods.

e. Value is for 100-year delay; 395,000 gallons would be required for the 300- and 500-year delay periods.

f. Value is for 100-year delay; 1,510 man-years would be required for the 300- and 500-year delay periods.

g. Value is for 100-year delay; 1 acre would be required for the 300- and 500-year delay periods.

h. Value is for 100-year delay; 11.2/0.1 injuries/fatalities are projected for the 300- and 500-year delay periods.

i. Injury/fatality values are included in routine operations.

TABLE 4-40

SUMMARY OF RADIOLOGICAL ENVIRONMENTAL EFFECTS
ALTERNATIVE 5 (100 years)

Phase and Scenario	Maximum Individual	Population				
	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range of Health Effects[a,b] (Number)	Probability of Event (Event/Year)	Population Risk (Man-Rem/Year)
CERTAIN-TO-OCCUR EVENTS						
Short-Term						
Operations Phase						
Routine Operations	1.63×10^{-10}	546,000	3.56×10^{-6}	2.67×10^{-10} to 8.19×10^{-10}	1.0	3.56×10^{-6}
Calcine Spill	4.77×10^{-11}	230,000	4.39×10^{-7}	3.29×10^{-11} to 1.01×10^{-10}	2.0×10^{-1}	8.78×10^{-8}
Decontamination Solution Spill	3.21×10^{-3}	230,000	1.48×10^{2}	1.11×10^{-2} to 3.40×10^{-2}	1.0×10^{-1}	1.48×10^{1}
Routine Waste Shipment	2.15×10^{-3}	209,000	4.48×10^{2}	3.37×10^{-2} to 1.03×10^{-1}	1.0	4.49×10^{2}
Decontamination and Decommissioning	1.63×10^{-12}	650,000	4.24×10^{-8}	3.18×10^{-12} to 9.75×10^{-12}	1.0	4.24×10^{-8}
Long-Term						
Disposal at Federal Geologic Repository	0	0	0	0	0	0
ABNORMAL EVENTS						
Short-Term						
Waste Shipment Accident	4.11×10^{-2}	500	2.05×10^{1}	1.54×10^{-3} to 4.73×10^{-3}	3.0×10^{-5}	6.16×10^{-4}
Disposal at INEL						
Aircraft Impact[c]	2.15	193,000	8.30×10^{4}	6.22 to 1.91×10^{1}	2.0×10^{-7}	1.66×10^{-2}
Disposal at Federal Geologic Repository						
Waste Canister Drop	1.28×10^{-6}	2,000,000	2.56×10^{-2}	1.92×10^{-6} to 5.89×10^{-6}	7.0×10^{-7}	1.79×10^{-8}
Long-Term						
Disposal at Federal Geologic Repository						
Solution Mining	1.45×10^{-2}	40,000,000	5.80×10^{5}	4.35×10^{1} to 1.33×10^{2}	1.0×10^{-6}	5.80×10^{-1}
Fault and Flooding	1.78×10^{-4}	2,000,000	3.56	2.67×10^{-4} to 8.19×10^{-4}	2.0×10^{-13}	7.12×10^{-13}
Exploratory Drilling	1.13	25	2.82×10^{1}	2.12×10^{-3} to 6.50×10^{-3}	5.0×10^{-7}	1.41×10^{-5}

a. Health effects are cancer deaths.

b. Health effects (cancer deaths) from all causes; 16.8% per 100,000 population (ACS, 1981).

c. Aircraft impact is assumed to occur in the year 1990 prior to completion of processing and shipment of waste offsite.

TABLE 4-41

SUMMARY OF RADIOLOGICAL ENVIRONMENTAL EFFECTS
ALTERNATIVE 5 (300 years)

Phase and Scenario	Maximum Individual	Population				
	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range of Health Effects[a,b] (Number)	Probability of Event (Event/Year)	Population Risk (Man-Rem/Year)
CERTAIN-TO-OCCUR EVENTS						
Short-Term						
Operations Phase						
Routine Operations	8.61×10^{-12}	650,000	2.24×10^{-7}	1.68×10^{-11} to 5.15×10^{-11}	1.0	2.24×10^{-7}
Calcine Spill	5.49×10^{-12}	230,000	5.05×10^{-8}	3.79×10^{-12} to 1.16×10^{-11}	2.0×10^{-1}	1.01×10^{-8}
Decontamination Solution Spill	3.73×10^{-4}	230,000	1.72×10^{1}	1.29×10^{-3} to 3.95×10^{-3}	4.0×10^{-4}	1.72
Routine Waste Shipment	1.96×10^{-3}	250,000	4.90×10^{2}	3.67×10^{-2} to 1.13×10^{-1}	1.0	4.90×10^{2}
Decontamination and Decommissioning	8.61×10^{-14}	650,000	2.24×10^{-9}	1.68×10^{-13} to 5.15×10^{-13}	1.0	2.24×10^{-9}
Long-Term						
Dispose at Federal Geologic Repository	0	0	0	0	0	0
ABNORMAL EVENTS						
Short-Term						
Waste Shipment Accident	1.14×10^{-2}	500	5.70	4.27×10^{-4} to 1.31×10^{-3}	3.0×10^{-5}	1.71×10^{-4}
Disposal at INEL						
Aircraft Impact	6.00×10^{-1}	230,000	2.75×10^{4}	2.06 to 6.32	2.0×10^{-7}	5.49×10^{-3}
Disposal at Federal Geologic Repository						
Waste Canister Drop	8.88×10^{-8}	2,000,000	1.78×10^{-3}	1.33×10^{-7} to 4.08×10^{-7}	7.0×10^{-7}	1.24×10^{-9}
Long-Term						
Disposal at Federal Geologic Repository						
Solution Mining	1.06×10^{-2}	40,000,000	4.24×10^{5}	3.18×10^{1} to 9.75×10^{1}	1.0×10^{-6}	4.24×10^{-1}
Fault and Flooding	1.78×10^{-4}	2,000,000	3.56	2.67×10^{-4} to 8.19×10^{-4}	2.0×10^{-13}	7.12×10^{-13}
Exploratory Drilling	9.65×10^{-1}	25	2.41×10^{1}	1.81×10^{-3} to 5.55×10^{-3}	5.0×10^{-7}	1.21×10^{-5}

a. Health effects are cancer deaths.

b. Health effects (cancer deaths) from all causes; 16.8% per 100,000 population (ACS, 1981).

TABLE 4-42

SUMMARY OF RADIOLOGICAL ENVIRONMENTAL EFFECTS
ALTERNATIVE 5 (500 years)

Phase and Scenario	Maximum Individual	Population				
	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range of Health Effects[a,b] (Number)	Probability of Event (Event/Year)	Population Risk (Man-Rem/Year)
CERTAIN-TO-OCCUR EVENTS						
Short-Term						
Operations Phase						
Routine Operations	4.27×10^{-12}	650,000	1.11×10^{-7}	8.33×10^{-12} to 2.55×10^{-11}	1.0	1.11×10^{-7}
Calcine Spill	3.57×10^{-12}	230,000	3.28×10^{-8}	2.46×10^{-12} to 7.55×10^{-12}	2.0×10^{-1}	6.57×10^{-9}
Decontamination Solution Spill	2.41×10^{-4}	230,000	1.11×10^{1}	8.31×10^{-4} to 2.55×10^{-3}	1.0×10^{-1}	1.11
Routine Waste Shipment	1.96×10^{-3}	250,000	4.90×10^{2}	3.67×10^{-2} to 1.13×10^{-1}	1.0	4.90×10^{2}
Decontamination and Decommissioning	4.27×10^{-14}	650,000	1.11×10^{-9}	8.33×10^{-14} to 2.55×10^{-13}	1.0	1.11×10^{-9}
Long-Term						
Disposal at Federal Geologic Repository	0	0	0	0	0	0
ABNORMAL EVENTS						
Short-Term						
Waste Shipment Accident	5.47×10^{-3}	500	2.73	2.05×10^{-4} to 6.29×10^{-4}	3.0×10^{-5}	8.20×10^{-5}
Disposal at INEL						
Aircraft Impact	2.90×10^{-1}	230,000	1.32×10^{4}	9.90×10^{-1} to 3.04	2.0×10^{-7}	2.64×10^{-3}
Disposal at Federal Geologic Repository						
Waste Canister Drop	5.4×10^{-8}	2,000,000	1.08×10^{-3}	8.10×10^{-8} to 2.48×10^{-7}	7.0×10^{-7}	7.56×10^{-10}
Long-Term						
Disposal at Federal Geologic Repository						
Solution Mining	7.83×10^{-3}	40,000,000	3.13×10^{5}	2.35×10^{1} to 7.20×10^{1}	1.0×10^{-6}	3.13×10^{-1}
Fault and Flooding	1.78×10^{-4}	2,000,000	3.56	2.67×10^{-4} to 8.19×10^{-4}	2.0×10^{-13}	7.12×10^{-13}
Exploratory Drilling	8.80×10^{-1}	25	2.20×10^{1}	1.65×10^{-3} to 5.06×10^{-3}	5.0×10^{-7}	1.10×10^{-5}

a. Health effects are cancer deaths.

b. Health effects (cancer deaths) from all causes; 16.8% per 100,000 population (ACS, 1981).

Radiological effects on the human environment from routine operations, waste shipment, D&D, and disposal would also be insignificant compared to applicable standards and effects of background radiation. Abnormal events such as a severe geologic disruption at the INEL would cause land use to be restricted until the extent of contamination was determined and, if necessary, remedial action was complete. However, doses would not be high enough to cause acute radiation effects in the exposed population. Exploratory drilling at the federal geologic repository could cause health effects in 8 percent of the drilling crew if actinide waste (Alternative 4) were disposed at the repository. The no-action alternative (Alternative 1) and the actinide separation alternative (Alternative 4) present potentially significant adverse nonradiological effects at the INEL due to the cadmium and mercury present in calcine. In Alternative 1, groundwater contamination by cadmium and mercury could exceed public drinking water standards for a distance of about 5 miles downgradient of the aquifer discharge point until chemical reactions in the aquifer reduced the concentrations to acceptable levels. In Alternative 4, groundwater contamination could result only from cadmium since mercury is removed in the actinide-separation process.

4.7 Environmental Monitoring

Environmental monitoring and sampling procedures for the ICPP and perimeter areas are described in Subsection 3.5. These procedures will be continued and updated as technology advances. The monitoring programs focus on the radiological contamination of the soil, air, water, and biota that results from the ICPP and other INEL activities. Also measured routinely are various nonradiological parameters: water level, water quality, and particulates suspended in the air. In addition, studies are being conducted to learn more about the vegetation and wildlife at the INEL and about the effects of man's activities on a cool desert ecosystem. These studies will provide data useful in developing future mitigative actions.

4.8 Unavoidable Adverse Effects

The implementation of any waste management alternative would cause some unavoidable adverse effects on the local environment.

Construction is required for all of the alternatives. Effects would be nonradiological in nature and would be minor, ceasing after construction is complete.

Operation of retrieval and processing facilities would cause primarily radiological effects. Adverse effects on the public would occur during the short-term period of waste processing and would be extremely small. Waste management workers, including train crews, would be exposed to radiation, but exposure would be within the allowable occupational limit of 5 rem per year (ERDAM, 1977).

The decontamination and decommissioning of a retrieval and processing facility would generate additional waste that would be accommodated at the INEL or shipped to the federal geologic repository for disposal.

The estimated resource use for the waste management alternatives is given in Table 4-5 for construction, in Table 4-8 for operations and waste shipment, and in Table 4-16 for D&D activities. The resources used compare with other industrial operations of similar size and technical complexity.

The commitment of the subsurface disposal area (Alternatives 1, 2, and 4) would conform to land use plans and policies at the INEL.

The energy resources consumed would be primarily petroleum products and electricity for waste form modification and waste shipment. In addition to the fuel usage given in Table 4-5, other fuel would be used by miscellaneous equipment and commuting workers. If the maximum fuel use during construction (1.1 million gallons, Alternative 4) occurred in 1 year, this would be about a 35 percent increase over the fuel used at the INEL in 1978. The diesel fuel required for waste shipment [Alternative 3 (glass) and Alternative 5] would heat 5400 houses in Idaho Falls, Idaho, for 1 year.

Modifying the waste form by vitrification or pelletization of calcine would be moderately energy intensive. The maximum energy demand is estimated to be 1.60 megawatts (Alternative 4), which is 37 percent of the electrical demand at the ICPP in 1980. This energy demand is equivalent to the electrical demand of 250 houses.

Although the labor hours and monies committed for the design, construction, and operation of facilities would not be available for other uses, local economies would benefit from the continuation of current levels of spending and employment. The construction and operation of the retrieval and processing facilities would not cause significant population increases. The labor force required to implement any waste management alternative would be within current fluctuations of the INEL labor force.

The potential for adverse air quality effects from the retrieval and processing facilities would be mitigated by equipping these facilities with effective air-filtration and treatment systems. Emissions of nonradiological air pollutants and radiological contaminants would be well within applicable standards.

There would be no significant long-term effects associated with the construction, operation, waste shipment, or D&D phases of alternative implementation. During the disposal phase, the significant long-term effect would be the potential contamination of the Snake River Plain Aquifer by cadmium and mercury. Should the bins disintegrate, flooding of the site could cause waste migration to the aquifer. Concentrations of cadmium and mercury [Alternatives 1 and 2 (pellets)] and cadmium (Alternative 4) could exceed federal drinking water standards for about 5 miles downgradient of the discharge point until chemical reactions and dispersion in the aquifer reduced the concentrations to harmless levels.

The magnitude of long-term effects caused by accidental intrusion or abnormal natural events is difficult to quantify because of the uncertainty that the events would occur and the many variables involved. The risk assessment indicates that the alternative of maximum long-term risk (Alternative 1) would result in less than 2 percent of the number of cancers normally expected from all causes unrelated to the waste.

4.9 Relationship Between Short-Term Uses of the Environment and Long-Term Productivity

No significant cumulative effect on the environment or on its long-term productivity would result from construction and operation of any of the facilities required to implement high-level waste management alternatives.

The environmental effects described in Subsection 4.5 indicate that radiological effects on the surrounding population from the implementation of any of the five alternatives would be significantly fewer than effects caused by natural background radiation. Wastewater discharges to the ICPP disposal well would be within applicable federal and state standards. Airborne releases from the proposed facilities would not inhibit future uses of land surrounding the ICPP.

Calcine modification would preempt the use of a limited land area during facility construction and operation. However, after facility decontamination and decommissioning, the land would be returned to its original condition and would be available for other uses.

No mineral deposits or other extractable resources have been identified at the INEL. The long-term dedication of the subsurface disposal area (Alternatives 1, 2, and 4) would not foreclose future surface land use options. However, the potential pollution of the Snake River Plain Aquifer by cadmium and mercury present in the waste [Alternatives 1 and 2 (pellets)] and by cadmium (Alternative 4) could require the installation of water treatment systems by future water users for a distance of about 5 miles downgradient of the discharge point. Use of the aquifer for agricultural and aquaculture purposes would be preempted for this distance.

The relationship between short-term uses and long-term productivity for Alternative 1 is discussed in more detail in other environmental documents (AEC, 1974).

4.10 Irreversible and Irretrievable Commitment of Resources

The resources consumed during all phases of alternative implementation represent resource commitments that are irretrievable. Commitments that could not be changed or altered at some future time are irreversible.

In general, the resources that may be irreversibly or irretrievably committed by the construction, operation, waste shipment, or decontamination and decommissioning activities are

- biota that may be destroyed,
- construction materials that cannot be recovered or recycled,
- materials consumed or reduced to unrecoverable waste forms,
- labor hours expended,
- capital expenditures not available for other types of investment, and
- land areas not available for other uses.

The irretrievable resource commitments for each waste management alternative are given in Table 4-43 for each waste management alternative. The table shows the resources committed during all phases of project implementation, including resource commitments at the federal repository. Repository commitments are based on the space required by INEL waste disposal as described in the environmental impact statement for commercially generated radioactive waste (DOE, 1980a).

4.11 Relationship to Land Use Plans, Policies, and Procedures

Local, state, and federal agencies have been contacted to determine whether the waste management alternatives would conflict with existing land use plans or policies. There are no conflicts with any written state, local, or regional land-use plans, policies, or procedures under consideration by these agencies.

The East-Central Idaho Planning and Development Association is a regional economic planning agency serving a nine-county region comprised mostly of the

TABLE 4-43

IRRETRIEVABLE RESOURCES USED TO IMPLEMENT WASTE MANAGEMENT ALTERNATIVES

Alternative	Construction					Operations				Decontamination and Decommissioning		
	Diesel Fuel[a] (10^3 Gal)	Concrete (10^3 Yd^3)	Fabricated Equipment[b] (10^6 Dollars)	Land[a] (Acres)	Labor Force[a] (Man-Yr)	Materials[c] (10^6 Lb)	Energy Demand (Megawatts)	Labor Force[d] (Man-Yr)	Diesel Fuel for Waste Shipment (10^6 Gal)	Concrete (10^3 Yd^3)	Chemicals (10^3 Lb)	Labor Force (Man-Yr)
1. Leave-in-Place	375	40	1.0	1	800	0	0	0[e]	NA	50	80	0[e]
2. Retrieve, Modify Calcine, Dispose at the INEL												
Pelletize Calcine	275	70	1.5	3	2,000	7.5	1.45	800	NA	90	195	26
Convert to Glass	575	50	3.0	181	1,000	98	1.15	1,250	NA	9	278	50
3. Retrieve, Modify Calcine, Dispose Offsite												
Stabilize Calcine	875	10	3.0	176	1,300	0	0.57	5,050	1.8	9	203	50
Convert to Glass	940	15	3.0	176	1,300	98	1.15	5,200	2.7	9	278	50
4. Retrieve, Separate Actinides, Dispose of Actinides Offsite, Dispose of Depleted Calcine at the INEL	1,115	60	7.0	3	2,755	95	1.60	4,410	0.1	60	690	76
5. Delay Retrieval, Modify Calcine,[a] Dispose Offsite												
100 Years	445	50	3.0	19	1,110	98	1.15	4,340	2.7	80	379	60
300 Years	395	50	3.0	2	1,005	98	1.15	4,210	2.7	80	379	60
500 Years	395	50	3.0	2	1,005	98	1.15	4,210	2.7	80	379	60

a. Includes effects at the repository.

b. Cost (1980 dollars) of fabricating specialty equipment from stainless steel for operations at the INEL.

c. Materials are chemicals and glass frit used in waste form modification.

d. Includes additional labor force for operations at the ICPP, waste shipment, and operations at the repository.

e. No manpower would be required in addition to the current labor force at the INEL.

INEL. This association has no policies or plans that involve lands or activities near the INEL. Most of the INEL is in sparsely populated Butte County. The association has no land use policy plan, comprehensive plan, or zoning ordinances involving lands or activities near the INEL.

The State of Idaho Office of Budget and Policy Planning has no plans or policies specifically related to land use either adjacent to or within the boundaries of the INEL.

The Bureau of Land Management administers grazing permits and road and utility rights-of-way for facilities other than those belonging to the INEL.

The relationship of a federal repository site to local land use plans, policies, and procedures will be discussed in a site-specific environmental impact statement.

REFERENCES FOR SECTION 4

ACS (American Cancer Society), "1980 Cancer Facts and Figures," 1981.

AEC (U.S. Atomic Energy Commission), "Environmental Statement, Calcined Solids Storage Additions, National Reactor Testing Station, Idaho," WASH-1529, April 1973.

AEC (U.S. Atomic Energy Commission), "Environmental Statement New Waste Calcining Facility, National Reactor Testing Station, Idaho," WASH-1531, June 1974.

Barraclough, J. T., et al., "Hydrology of the Solid Waste Burial Ground as Related to the Potential Migration of Radionuclides," Idaho National Engineering Laboratory IDO-22056, August 1976.

49 CFR 173.393 (Code of Federal Regulations, Transportation), "General Packaging and Shipping Requirements," 1981.

40 CFR 61 (Code of Federal Regulations, Protection of Environment), "National Emission Standards for Hazardous Air Pollutants," 1978.

40 CFR 141 (Code of Federal Regulations, Protection of Environment), "National Interim Primary Drinking Water Standards," 1979.

40 CFR 50 (Code of Federal Regulations, Protection of Environment), "National Primary and Secondary Ambient Air Quality Standards," 1979.

DOE (U.S. Department of Energy), "Environmental Impact Statement, Management of Commercially Generated Radioactive Waste," DOE/EIS-0046-F, 1980a.

DOE (U.S. Department of Energy), "Final Environmental Impact Statement, Long-Term Management of Defense High-Level Radioactive Wastes, Savannah River Plant, Aiken, South Carolina," DOE/EIS-0023, November 1979.

DOE (U.S. Department of Energy), "Final Environmental Impact Statement, Waste Isolation Pilot Project," DOE/EIS-0026, October 1980b.

DOE (U.S. Department of Energy), Summary of INEL Personnel Data, March 1978, Personnel Questionnaire, INEL, Idaho Falls, Idaho, 1978.

Druffel, et al; "Probable Effects of a Hypothetical Failure of Mackay Dam on the Big Lost River Valley from Mackay, Idaho, to the Idaho National Engineering Laboratory," U.S. Geological Survey, Water Resources Investigation 79-99, September 1979.

EPA (U.S. Environmental Protection Agency), "Criteria for Radioactive Wastes: Recommendations for Federal Radiation Guidance," Federal Register, Part IX, November 15, 1978.

ERDA (U.S. Energy Research and Development Administration), "Alternatives for Long-Term Management of Defense High-Level Radioactive Waste, Idaho Chemical Processing Plant, Idaho Falls, Idaho," ERDA 77-43, September 1977a.

ERDA (U.S. Energy Research and Development Administration), "Final Environmental Impact Statement, Waste Management Operations, Idaho National Engineering Laboratory, Idaho," ERDA-1536, September 1977b.

ERDAM (U.S. Energy Research and Development Administration), "Standards for Radiation Protection," ERDA Manual Chapter 0524, March 1977.

Exxon Nuclear Idaho, Inc., "Architect-Engineering Standards for Idaho National Engineering Laboratory, ENICO Supplement to DOE-ID," December 1979.

Fried S., et al., "Migration of Actinides in Geologic Formations," in Proceedings of the International Symposium on the Management of Wastes from the LWR Fuel Cycle, CONF-76-0701, U.S. Energy Research and Development Administration, 1976.

Fujita, T. T., "Estimates of Maximum Wind Speeds of Tornadoes in Three Northwestern States," Appendix 2 to Review of Tornado Considerations, for FFTF, by D. F. Simpson, HEDL-TME-71-35, Hanford Engineering Development Laboratory, Richland, Washington, 1971.

HUD (Department of Housing and Urban Development), "Rapid Growth From Energy Projects. . . Idea for State and Local Action. . .A Program Guide," Office of Community Planning and Development, Washington, D.C., 203-068/6231, 1976.

Idaho Department of Health and Welfare, Idaho Regulations for Public Drinking Water Systems, Idaho Code, Title 1, Chapter 8, November 1977.

Idaho Department of Health and Welfare, Rules and Regulations for Control of Air Pollution in Idaho, Idaho Code, Title 1, Chapter 8, November 1979.

McCormack, M. (U.S. House of Representatives), slide presentation on low-level waste to National Society of Engineers, 1980.

NASNRC (National Academy of Sciences, National Research Council), "The Effects on Population of Exposure to Low Levels of Ionizing Radiation," The BEIR Report, Washington, D.C., 1980.

NCRP (National Council on Radiation Protection and Measurements), "Review of the Current State of Radiation Protection Philosophy," NCRP-43, Washington, D.C., 1975.

NRC (U.S. Nuclear Regulatory Commission), "Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance With 10 CFR, Part 50, Appendix I," Regulatory Guide 1.109, Washington, D.C., 1974.

NSC (National Safety Council), "Accident Facts," 1977.

Reader's Digest 1979 Almanac and Yearbook, The Reader's Digest Association, Inc., 1979.

USDA (U.S. Department of Agriculture), Soil Conservation Service, "Soil Survey of Jefferson County, Idaho," 1975.

U.S. Department of Commerce, "Statistical Abstract of the United States," 1978.

GLOSSARY

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Actinide - An element in the series of radioactive elements that begins with actinium, element No. 89, and continues through lawrencium, element No. 103. The actinide series includes uranium, element No. 92, and all the manmade transuranic elements.

Activation - The process of making a material radioactive by bombardment with neutrons, protons, other nuclear particles, or radiation.

Activity - A measure of the rate at which a material is emitting nuclear radiation, usually given in terms of the number of nuclear disintegrations occurring in a given quantity of material over a unit of time. A common unit of activity is the curie (Ci), which is equal to 3.7×10^{10} (37 billion) disintegrations per second.

Alluvium - Any sediment deposited by flowing water, such as sediment in a river bed, flood plain, or delta.

Alpha (α) particle - A positively charged particle emitted in the radioactive decay of certain nuclides. Consisting of two protons and two neutrons bound together, it is identical to the nucleus of a helium-4 atom.

Alpha particle emission - Ejection of alpha particles from an atom's nucleus.

Alpha particle emitter - A nuclide which undergoes radioactive decay by emitting a positively charged particle identical to the nucleus of a helium atom (e.g., many transuranics).

Alpha radiation - An emission of alpha particles from a material undergoing nuclear transformation. The particles have a nuclear mass number of 4 and a charge of +2. Alpha radiation is the least penetrating of the three common types of nuclear radiation and can be blocked by a sheet of paper. Since alpha radiation cannot penetrate the skin, it is not harmful to people if the exposure is external. However, it is harmful if inhaled or ingested, as it may become concentrated in a specific organ.

Anion - A negatively charged particle.

Anneal - As used in this document, to heat to the point where crystalline imperfections disappear in order to make the glass less brittle.

Annular - Geometric design of the bins in the first bin set constructed at the ICPP. Each bin consists of concentric, elongated, donut-shaped segments containing calcine, with spaces between each segment to provide cooling.

Aqueous phase - The phase in solvent extraction consisting of materials such as acid and fission products dissolved in water. (See also organic phase.)

Aquifer - A zone of permeable rock or soil which is saturated with water. The water may flow through this zone to emerge as a spring or may be pumped to the surface through a well.

Atom - An electrically neutral particle of matter indivisible by chemical means. It consists of an atomic nucleus, which contains most of the atom's mass, and carries a positive electric charge and a number of electrons to neutralize the positive charge of the nucleus.

Atomic mass - Mass of an atom frequently expressed in atomic mass units (u), where 1 u = 1.660566×10^{27} kg. By this definition, the atomic mass of carbon-12 = 12 u.

Atomic number - The number of protons within the atomic nucleus of each chemical element. This number is also equal to the number of electrons in the atom.

Atomic weight - A number used to identify a specific isotope which is numerically equal to the number of protons and neutrons in the isotope. For example, the "90" in Sr-90 indicates that there are a total of 90 protons and neutrons in the atom.

Background radiation - The levels of ionizing radiation received in man's natural environment, including cosmic rays, radiation from naturally occurring radioactive elements, and fallout from nuclear weapons testing. Background doses in the U.S. vary between about 0.1 to 0.2 rem/year, depending on location. The background radiation dose monitored at the INEL is 0.15 rem/year.

Basalt - A dark-colored, fine-grained rock produced by the cooling of lava.

Bedded salt - Salt formations deposited in layered sequence.

Beta (β) particle - An elementary particle emitted from a nucleus during radioactive decay. It has a single electrical charge and a mass equal to 1/1836 that of a proton. The negatively charged beta particle is identical to an electron.

Beta radiation - Essentially weightless, charged particles (electrons and positrons) emitted from the nucleus of atoms undergoing nuclear transformation. Beta radiation may cause skin burns, but can be stopped by a thin sheet of metal about the thickness of foil.

Billet - As used in this document, a short, thick bar of material.

Bin - Cylindrical or annular vertical stainless steel container for the storage of calcine. Three to seven bins are clustered in a reinforced concrete vault.

Binder - As used in the pelletization process described in this document, a binder is a substance that causes calcine particles to adhere to each other. In the pelletization process, phosphoric acid and clay can be used as binders.

Biosphere - Life-sustaining portions of the earth, bodies of water, and the atmosphere.

Biota - The plant and animal life of a given region; flora and fauna, collectively.

Borosilicate glass - A strong, chemically resistant glass whose main ingredients are sand and borax. In this document, one of the processes for modifying calcine is by incorporation in a leach-resistant matrix of borosilicate glass.

Btu - Abbreviation for British thermal unit. The quantity of heat required to raise the temperature of 1 pound of water by 1 degree Fahrenheit.

Calcareous - Describes a substance that contains calcium.

Calcination - A process whereby liquefied waste is sprayed onto the surface of hot granular particles as they are being agitated in a vessel. The liquid evaporates and most of the salts adhere to the particles as oxides and fluorides. The granules increase in size, layer by layer, and are eventually discharged from the fluidized bed to be transported to the storage bins.

Calcine - (n.) Solids having the consistency of sand mixed with powder produced from liquid waste by the calcination process; (v.) to produce calcine material from liquid waste.

Canister - As used in this document, a metal container for solid radioactive waste. A canister provides physical containment, but no shielding against penetrating gamma radiation. During shipment, shielding is provided by a cask.

Cask - A massive shipping container that holds one or more canisters and provides shielding for highly radioactive materials.

Ceramic - Material formed from clay or clay-like matter which is similar to a brick or unglazed china.

Curie (Ci) - A unit of activity (decay rate of a radioactive substance) defined as 3.7×10^{10} (37 billion) disintegrations per second.

Decay - The spontaneous transformation of one nuclide into a different nuclide or into a different energy state of the same nuclide. The process results in the emission of nuclear radiation (i.e., alpha, beta, or gamma radiation).

Decay (or daughter) product - A nuclide resulting from a single or a series of radioactive decays. A decay product may be either radioactive or stable.

Decommissioning - Decommissioning of obsolete nuclear facilities is defined as an orderly and well planned procedure to accomplish the following: decontamination of structures; removal of sources of radiation; dismantling and salvaging of uncontaminated equipment; and return of the area to a condition suitable for unrestricted use whenever possible; or provision for surveillance to protect public health and safety if it is technically or economically infeasible to decontaminate the facility to acceptable levels for unrestricted use.

Decontamination - The selective removal of radioactive material from a surface or from within another material.

Defense waste - Nuclear waste generated from government defense programs as opposed to waste generated by commercial reactors and medical facilities.

Denitration - Removal of nitrates or nitrogen. A one-step process for converting the highly purified uranyl-nitrate [$UO_2(NO_3)_2$] solution, the product of fuel-reprocessing at the ICPP, to a solid granular uranium trioxide (UO_3) suitable for safe shipment.

Diluent - In this document, an organic compound used to dilute the solvent in a solvent extraction process. It usually does not enter into the reaction but is merely a carrier for the active solvent.

Disposal - In this document, the permanent isolation of radioactive waste from the biosphere with no plans for retrieval after emplacement.

Diurnal - Having daily cycles.

Dose - As used in this document, the word "dose" is used interchangeably with "dose equivalent." It is the radiation exposure received from outside the body and is measured in rem.

Dose commitment - As used in this document, the phrase "dose commitment" is used interchangeably with "committed dose equivalent." It is the dose which an organ or tissue would receive during the 50 years after intake of a radionuclide. Dose commitment refers to organ exposures from radionuclides ingested or inhaled into the body over a 1-year period.

Dosimeter (personal) - A small device carried by a radiation worker or other person for measuring the quantity of radiation to which he has been exposed.

Electron - An elementary atomic particle with a negative charge and an extremely small mass. Electrons surround the nucleus of an atom.

Electropolishing - Cleaning of contaminated metal equipment by use of a solution in which the parent metal becomes positively charged. The solution removes the outer layer of the metal and the contaminant along with it.

Extraction cycle - In this document, a process used in Alternative 4 (retrieve calcine, separate actinides, dispose of actinides offsite, dispose of actinide-depleted calcine at the INEL) to separate the actinides (and lanthanides) from liquefied calcine. In this process, a series of three extraction columns is used. An extraction column is a long thin pipe in which an ascending stream of organic solvent is brought into contact with a descending stream of aqueous solution containing the actinides. The actinides are transferred from the aqueous stream to the organic stream and are removed from the top of the column. The organic stream is then washed in a second column to remove the impurities. In a third column the actinides are transferred from the organic stream back to a new aqueous stream. This completes the extraction cycle.

Fallout - Particulate matter, which may be radioactive, deposited on the ground from the air.

Fault - A fracture, or a zone of fractures, within a rock formation along which vertical, horizontal, or transverse slippage occurs.

Federal geologic repository (mined geologic repository) - In this document, a federally operated facility for the disposal of nuclear waste. The waste is isolated by placing it within a continuous geologic formation at depths of about 1000 feet. Two or three such repositories are contemplated and will accommodate both commercial and defense waste.

Fines - Calcine dust having the consistency and flow properties of talcum powder.

Fission (nuclear) - The splitting of a heavy nucleus into two approximately equal parts, each the nucleus of a lighter element, accompanied by the release of a large amount of energy and generally by several neutrons. Fission can occur spontaneously or be induced by absorption of a nuclear particle or radiation. In practical applications, fission usually follows neutron absorption.

Fission products - A nuclide produced by the fission of a heavy element, or the daughter(s) resulting from the radioactive decay of the nuclide thus formed.

Fluidized bed - A bed of granular material expanded and agitated by an upflow of gas. Used as a means of calcining (solidifying) radioactive waste.

Fuel cycle - The complete series of steps involved in supplying fuel for nuclear reactors. It includes mining, refining, enrichment, fabrication of fuel elements, use in a reactor, chemical processing to recover the fissionable material remaining in the spent fuel, reenrichment of the fuel material, refabrication of new fuel elements, and management of radioactive waste.

Fuel element - Component of a nuclear reactor containing the fissile fuel material. It can have a variety of forms, but is most often an assembled bundle of thin tubes filled with nuclear fuel.

Fuel reprocessing - At the ICPP, recovery by a sequence of chemical processes of highly valuable unused fissile fuel from spent (used) fuel elements. The recovered fuel can then be used for fabricating new fuel elements. At the ICPP, the fuel material being recovered is uranium.

Gamma-ray spectrometry - Technique used to measure gamma ray energies emanating from a radioactive source.

Gamma (γ) rays - High energy, short-wavelength electromagnetic radiation emitted during the radioactive decay of certain nuclides; similar to but more penetrating than x-rays. Gamma radiation frequently accompanies alpha and beta emissions and always accompanies fission. Gamma rays are very penetrating and are best attenuated by dense materials such as lead. Synonyms often used are gamma photons and gamma radiation.

Generic site - A theoretical location having certain characteristics attributed to it such as population of the surrounding area, elevation, stream flows, annual rainfall, temperatures, and all other attributes of a given

site. Such an imaginary location is used to describe the environmental effects at a definite but as yet undetermined repository location.

Geologic time scale - A time scale portraying geologic ages.

Glacial till - Generally unconsolidated sand, soil, and rocks deposited by a glacier.

Glass frit - Ground or powdered glass.

Granules - Particles having the consistency and flow of sand.

Groundwater - Water beneath the earth's surface between saturated soil and rock that may supply wells and springs.

Half-life - A measure of the longevity of radioactive materials. The half-life is the time required for one-half the atoms of a particular nuclide to disintegrate by radioactive decay. After a period of 10 half-lives, the radioactivity has decreased to less than 0.1% of its original value. Each nuclide has a characteristic half-life.

HEPA (high-efficiency particulate air) filter - An air filter capable of removing at least 99.97% of particulate material as small as 0.3 micrometers from an air stream. (Three-tenths of a micrometer is approximately the size of the particulate material in tobacco smoke.)

High-level liquid waste - The aqueous waste resulting from the operation of the first-cycle extraction system, or equivalent concentrated wastes from subsequent extraction cycles, or equivalent wastes from a process not using solvent extraction, in a facility for processing irradiated reactor fuels.

High-level waste (HLW) - (a) High-level liquid waste, or (b) the products from solidification of high-level liquid waste.

High sodium wastes - Concentrates from waste evaporators and other sources containing large amounts of sodium such as ion exchange, decontamination, and regeneration solutions.

Homologs - Elements or compounds having similar structure and/or similar chemical properties.

Hydromagmatic eruptions - A type of volcanic eruption that occurs when magma encounters groundwater at relatively shallow levels (400-2000 feet) or at the earth's surface.

Igneous - Describes rock or minerals that have solidified from molten or partly molten material, i.e., from a magma. Igneous rocks constitute one of the three main classes into which rocks are divided. (The others are metamorphic and sedimentary.)

Immobilization - Treatment and/or emplacement of the wastes.

Index - (v.) To multiply the amount of a price, wage, or other cost by a given number which reflects a percent increase over the original amount. For example, if a tax on an item is 6% of its cost, the total can be computed by

multiplying the original cost by 1.06. This is the same as multiplying the cost by 6% and adding it to the original cost. (n.) In the above example, the index number is 1.06.

Injection well - Well through which process cooling water is returned to the aquifer.

Institutional control - Management of a disposal site by any governmental body. In this document, restriction of public entry into disposal areas for 100 years from the date of cessation of operations, except in Alternative 5 where control has been assumed throughout the delayed retrieval period of 500 years.

Intrusion - Accidental or intentional entry into a vessel or structure by a person or tool. In this document, it includes breaching a waste container in a disposal facility.

Ion - An atom or group of atoms with an electrical charge from either the loss or attachment of one or several electrons.

Ion exchange - A process whereby an ion in solution is adsorbed by a solid such as clay, and, in turn, an ion in the solid is displaced into the liquid (water).

Ionizing radiation - Any form of radiation (such as x-rays, alpha, beta, and gamma radiation) that transfers energy by stripping electrons from atoms or molecules, thereby producing ions. Ionizing radiation absorbed in living tissue can produce damage by triggering biochemical reactions. Severity of damage and health effects increases with increasing doses.

Isotope - A form of the same atom having a different atomic weight.

Lanthanides - The series of elements of very similar chemical properties beginning with lanthanum, element No. 57, and continuing through lutetium, element No. 71. The lanthanides are chemically similar (homologs) to the actinides and are extracted with the actinides in the solvent extraction system described in Alternative 4 (retrieve calcine, separate actinides, dispose actinides offsite, dispose of actinide-depleted calcine at the INEL).

Leach - To remove or separate soluble components from a solid by contact with water or other liquids.

Loam - A rich permeable soil usually containing organic material.

Loess - A fine-grained calcareous silt or clay deposited by the wind.

Long-term period - The period of time after the first 100 years of disposal through 1 million years. (In Alternative 5 only, the long-term period begins after the 500-year delay period.)

Magma - Molten or partially molten material originating beneath the earth's crust.

Man-rem - The radiation dose received by an average individual multiplied by the number of individuals in the population group.

Matrix - In this document, a solid material, such as concrete or metal, in which calcine is incorporated to create a less dispersible, monolithic form.

Maximum individual dose - Largest possible dose an individual can receive from all pathways at any one time and location.

Maximum permissible concentration - The highest concentration of a radionuclide or other material allowable in air, food, or beverages.

Micrometer (μm) - A unit of length equal to one one-millionth (10^6) of a meter.

Migration - The natural travel of a material through the air, soil, or groundwater.

Modified Mercalli intensity (MMI) - An arbitrary scale of earthquake intensity ranging from I (detectable only instrumentally) to XII (causing almost total destruction). To convert from the Mercalli to the Richter scale, multiply the Mercalli scale intensity by the approximate conversion factor of 0.75.

Nucleation - The formation of new crystals from a solution.

Nuclide - A species of atom characterized by the number of neutrons and protons in the nucleus and the energy content of its nucleus. These factors determine the other properties of the element, including its radioactivity.

Offgas - Gas released by any industrial process, such as fuel reprocessing.

Organic phase - The phase in the solvent extraction process consisting of carbon-containing compounds similar to kerosene; the organic phase is specifically selected for separating the target material from the aqueous phase.

Oxide - A chemical compound of oxygen and another element or elements.

Particulates - Fine solid or liquid particles dispersed in air, gases (e.g., stack emissions), and water.

Pelletize - To produce pellets by combining calcine fines with a liquid binder and heating to form ceramic pellets about the size of an aspirin tablet.

Penetrating radiation - Forms of energy which are capable of passing through thicknesses of material; these include gamma rays, x-rays, and neutrons.

Phase separation - The separation of one material phase from another, such as separation of a solid from a liquid. Phase separation occurs, for example, when dissolved sugar begins to crystallize, or when oil which has been mixed with water is allowed to separate.

Playa - A dry, flat area at the lowest part of an undrained desert basin. As used in this document, playas on the Snake River Plain are those areas where water will pond and eventually seep into the soil.

Pneumatic transport - Transport of granular solids by a moving air stream in a pipe.

Prefilter - A filter used to remove large particulates from a gas stream before the stream enters the HEPA filter.

Proton - A particle with a single positive charge and a mass approximately 1836 times that of an electron (equal to about 1.7×10^{27} kg) found in the nucleus of each atom.

Rad - Acronym for radiation absorbed dose. A basic unit of absorbed dose of ionizing radiation. A dose of 1 rad means the absorption of 100 erg of radiation energy per gram of absorbing material.

Radiation - Particles and electromagnetic energy emitted by nuclear transformations which are capable of producing ions when interacting with matter; gamma rays and alpha and beta particles are primary examples.

Radiolytic decomposition - Decomposition of a material by the absorption of radiation energy. For example, radiolytic decomposition of water produces hydrogen gas and hydrogen peroxide.

Radionuclide - An unstable nuclide which spontaneously disintegrates, emitting ionizing radiation.

Raffinate - The waste stream from an extraction column.

Reference process - The process against which other processes are measured.

Rem - Acronym for roentgen equivalent in man. A unit for measuring a dose of radiation. A rem is equivalent to the amount of ionizing radiation required to produce the same biological effect in man as one roentgen of high-penetration x-rays.

Rhyolitic volcanism - Groups of extensive igneous rocks of volcanic origin.

Rift zone - Area where volcanic activity has occurred or is occurring. It is characterized by open cracks, cracks which have been filled with lava and from which lava has oozed, and cinder cones, buttes, and other lava formations.

Riparian - Living or located on a river bank.

Risk - Risk is calculated by multiplying probability (number of events per year) by the consequence (number of rems resulting from the event), yielding a measure of the potential for injury caused by the event.

Scarp - A line of cliffs produced by faulting or by erosion.

Scrubbing system - A system of devices for the removal or washing out of suspended liquid droplets or dust, or for the removal of an undesired gas component, from process gas streams. A second type of scrubbing system consists of a column in a solvent extraction system where impurities are removed from the extracting medium.

Seismicity - Pertaining to an earthquake or earth vibrations, including those that are artificially induced.

Shield volcano - A volcano in the shape of a flattened dome, broad and low, built by flows of very fluid basaltic lava or by rhyolitic ash flows.

Short-term period - The first 100 years after waste disposal during which institutional controls are in effect. (In Alternative 5 only, institutional control remains in effect through the 500-year delayed retrieval period.)

Sinter - To form a coherent, bonded mass by heating powders without melting.

Site - Idaho National Engineering Laboratory.

Solvent extraction - In this document, a process by which a selected material is removed from an acid solution. The solution (aqueous phase) is mixed with an organic mixture (organic phase). These two liquids behave similarly to water and oil when mixed. Since the material to be extracted (usually uranium or actinides) has a greater affinity for the organic solvent, it is taken up in the organic phase and removed from the acid solution when the two liquids are separated.

Sorption - A general term used in physical chemistry to encompass several processes involving the binding on a microscopic scale of one substance to another. Included in these processes are absorption, adsorption, and ion exchange.

Stabilization - A process where calcine is heated above the calcination temperature to remove residual water and nitrates.

Steppe - An extensive, treeless, grassland area.

Storage - Retention of radioactive waste in a man-made device, such as a tank or a vault, in a manner permitting retrieval. Interim storage indicates storage up to 100 years.

Strategy - As used in this document, all the components of a long-range plan leading to the ultimate goal of permanent isolation of radioactive waste from the biosphere.

Tectonic - Pertaining to, causing, or resulting from structural deformation in the earth's crust.

Temperature gradient - A continuous temperature difference between two points. In this document, temperature distribution is of concern in cooling glass because extreme temperature variations can result in high internal stress. A temperature gradient in the storage bins is also of concern because of the need to avoid high or sintering temperatures in the calcine.

Transmutation - Conversion of a radioisotope to a shorter-lived or stable isotope by bombarding it with nuclear particles.

Transuranic - The designation of elements above atomic No. 92 (uranium). There are 13 known transuranic elements, all man-made and all radioactive. This term is used (not quite correctly) as a substitute for actinides.

Transuranic (TRU) waste - Waste material measured or assumed to contain more than a specified concentration of transuranic elements. For purposes of

this report, TRU waste is waste from locations that might cause contamination levels above 10 nanocuries of transuranic alpha activity per gram of waste.

Unsaturated zone - A subsurface zone capable of holding more water.

Vault - A reinforced concrete structure enclosing three to seven stainless steel bins in which calcine is stored. Also a structure for enclosing large stainless steel tanks containing liquid waste. The underground vaults are anchored in bed rock.

Vortex - A whirling or circular motion of air (or water) that tends to form a cavity or vacuum in the center of the circle and to draw toward this cavity or vacuum bodies subject to its action.

Waste management - A general term encompassing the several aspects of nuclear waste control, e.g., processing, storage, and disposal.

Whole-body equivalent dose - The summation of the weighted committed dose equivalents of all organs within the body from intake of a radionuclide. The weighting factors used to convert the organ dose commitments to a common risk equivalent so that they can be summed are from ICRP-26.

Worst-site boundary - The site boundary which receives the largest possible dose based on nearby population and meteorological conditions.

Zeolite - A generic term for a large group of white or colorless minerals which typically have good ion exchange capacities.

SCIENTIFIC NOTATION

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SCIENTIFIC NOTATION

When dealing with very large or very small numbers, the conventional notation is awkward and cumbersome. Writing 0.000000000000001, for example, is undesirable, as is calling this number "a millionth of a billionth." To overcome this problem, a notation system in general use throughout the scientific community has been employed in this report. Using this system, 0.000000000000001 is expressed as 1×10^{-15}. This notation can then be converted back to the original number by moving the decimal point according to the power of ten (the superscript number above the ten) that is indicated. If the power of ten is positive, the decimal is moved to the right the number of places indicated by the power. If the power of ten is negative, the decimal is moved to the left the number of places indicated by the power. Examples of positive and negative powers of ten follow:

$$1.25 \times 10^{5} = 125{,}000$$
$$1.25 \times 10^{-4} = 0.000125$$

Prefixes are often added to units (such as curies or grams) to indicate the magnitude of the value. Common prefixes, their values, and their abbreviations are as follow:

Prefix	Power	Value	Symbol
mega	10^{6}	1,000,000	M
kilo	10^{3}	1,000	k
centi	10^{-2}	0.01	c
milli	10^{-3}	0.001	m
micro	10^{-6}	0.000001	μ
nano	10^{-9}	0.000000001	η

Thus, 1 kilogram (kg) = 10^{3} grams = 1,000 grams, and 1 microcurie (μCi) = 10^{-6} curie = 0.000001 curie.

The tables in Appendixes A and B use different notation because they are based on a system used in computers. For example, Appendix B would express the number of years during which an individual would be exposed to radiation

via a given pathway as 5E+03. In this expression, E represents "exponent," thus,

$$5E+03 = 5 \times 10^{3} = 5000$$

The negative expression,

$$4E-04 = 4 \times 10^{-4} = 0.0004$$

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APPENDIX A

METHODS USED TO CALCULATE RADIOLOGICAL AND NONRADIOLOGICAL EFFECTS

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APPENDIX A

METHODS USED TO CALCULATE RADIOLOGICAL AND NONRADIOLOGICAL EFFECTS

A. Assessment of Effects

The evaluation of waste management alternatives presented in this report is based on a comprehensive analysis of potential environmental effects that might be expected from implementation of the alternatives considered in this report. The method used to evaluate the alternatives was to develop a series of release scenarios for routine and abnormal events postulated to occur during all waste management phases. The scenarios include events which are readily predicted to occur based on Idaho Chemical Processing Plant (ICPP) and related nuclear industry experience (DOE, 1980). The scenarios also include highly unusual events which are less predictable because of uncertainties in institutional and geologic conditions over a period of thousands of years. While the scenarios may not realistically represent the types of waste releases that might occur in the future, the conservative assumptions on which the scenarios are based ensure that the widest possible range of potential effects has been considered. Consequently, waste management decisions based on this type of evaluation can be made with a high level of confidence that waste disposal will be accomplished in a safe and environmentally acceptable manner.

The use of a consistent set of scenarios and assumptions allows an accurate comparison of alternatives even though the results may be overly conservative for any particular scenario. However, every effort has been made to calculate effects that are as realistic as possible. The quantities of radionuclide and toxic chemical releases during calcine retrieval and waste form modification are based on proven offgas treatment and atmospheric protection system technology. The quantities of radionuclides released in hypothetical accidents are derived from the radionuclide inventory present at the time of the accident. The event probabilities (frequencies) and release fractions are based, where possible, on ICPP experience or documented data for similar or related events. Where data on probabilities and release fractions are inadequate, engineering judgment has been used.

INEL defense high-level waste contains both radioactive materials and toxic chemicals (cadmium and mercury). All potentially significant pathways by which the waste could affect people and the environment are considered for each scenario. The major exposure pathways are atmospheric dispersion and transport for airborne releases, and migration into the aquifer and transport by groundwater to drinking water wells for waterborne releases. To put the waste releases in perspective, health effects estimated to result from exposure to radionuclides and poisoning by heavy metals are cited.

Appendix A contains all of the information needed to reproduce the dose commitments and health effects calculated in this report. A sample calculation is given for each type of radiological and nonradiological release. For radionuclide releases, the sample calculation is based on the most hazardous radionuclide present at the time of release. The sample calculation includes a separate calculation for each significant contributing pathway, converts the organ doses for the maximum individual to the whole-body equivalent dose, calculates the population dose commitments, and finally converts the population dose commitment to the expected range of health effects.

The results of the radiological calculations presented in this report are given in Appendix B. Appendix B is intended to be used in conjunction with Appendix A and the sample calculations.

A.1 Radiological Effects

The calculation of radiological effects is based on a set of variables and calculational methodology which are presented in this subsection. The material is organized so that data and information required to calculate radiological effects are given in Subsections A.1.1 through A.1.7. Values for such parameters as atmospheric dispersion factors, populations at risk from a release of radioactive material, and radionuclide inventories are basic to all of the calculations. Therefore, they are presented first.

The release scenarios and the sample calculations used to determine the estimated dose commitments and health effects are presented in Subsection A.1.8. Detailed information about the scenarios, such as the alternatives to

which the scenario applies, the waste release fraction, the exposed population, and the event probability, are given for each scenario. The mathematical models required to perform the calculations are given in Subsection A.1.9.

The scenarios are discussed in the order of their occurrence. Operational releases occur in the short term (up to 100 yr) and are presented first. Migrational and intrusional releases occur in the long term (after 100 yr) and are presented last. Since migrational and intrusional releases occur during the disposal phase of alternative implementation, these events are discussed for disposal at the Idaho National Engineering Laboratory (INEL) and at an offsite geologic repository.

A.1.1 Source Terms

A.1.1.1 Mass Quantities of Waste Processed at the ICPP

The first step in this analysis requires the determination of the high-level waste inventories as a function of time. This study begins by determining the inventory of both high-level liquid and calcined waste at the ICPP in the year 1980. It is assumed that between 1965 and 1980 the waste accumulated at a constant rate. From 1980 to 1990, it is assumed that reprocessing of fuels will continue producing additional liquid waste. It is assumed that sometime during the decade a new waste calcining facility will become operational, permitting conversion to calcine of all liquid wastes produced and accumulated prior to the year 1990, except for a working backlog of approximately 1.2 million gal. After the year 1990, there will be no waste in liquid form except for a comparatively small amount produced during normal operations. It is assumed that an alternative for waste management will have been selected and that its implementation will begin in 1990. For the purposes of this study, it is also assumed that fuel reprocessing at the ICPP will continue through the year 2020. During this period, production and processing of wastes are assumed to continue at a constant rate.

The mass rates of waste assumed to be processed at the ICPP are compiled in Table A-1. During the assumed 30-yr period of operation, the quantity of waste is expected to increase by the addition of new processing waste at the

TABLE A-1

MASS RATES OF WASTE PROCESSED AT ICPP FOR VARIOUS TIME PERIODS

Source of Material		Mass Rate (kg/yr)[a] Processed in Time Period				
		1965-1980	1980-1990	990-2000	2000-2010	2010-2020
Alternative 1: Calcine at INEL						
Plant Production	Calcine	1.55×10^5	3.55×10^5	4.22×10^5	4.22×10^5	4.22×10^5
Plant Production	Liquid Storage[b]	1.38×10^5	-	-	-	-
Liquid Storage	Calcine[b]	-	2.07×10^5	-	-	-
Alternative 2: Pellets or Glass at INEL						
Plant Production	Calcine	1.55×10^5	3.55×10^5	4.22×10^5	4.22×10^5	4.22×10^5
Plant Production	Liquid Storage[b]	1.38×10^5	-	-	-	-
Liquid Storage	Calcine[b]	-	2.07×10^5	-	-	-
Retrieved Calcine	Pellets or Glass	-	-	7.75×10^5	-	-
Fresh Calcine	Pellets or Glass	-	-	4.22×10^5	4.22×10^5	4.22×10^5
Alternative 3: Stabilized Calcine or Glass to Repository						
Plant Production	Calcine	1.55×10^5	3.55×10^5	4.22×10^5	4.22×10^5	4.22×10^5
Plant Production	Liquid Storage[b]	1.38×10^5	-	-	-	-
Liquid Storage[b]	Calcine	-	2.07×10^5	-	-	-
Retrieved Calcine	Stabilized or Glass Calcine	-	-	7.75×10^5	-	-
Fresh Calcine	Stabilized or Glass Calcine	-	-	4.22×10^5	4.22×10^5	4.22×10^5
Stabilized or Glass Calcine	Federal Repository	-	-	1.20×10^6	4.22×10^5	4.22×10^5
Alternative 4: Actinides to Repository						
Plant Production	Calcine	1.55×10^5	3.55×10^5	-	-	-
Plant Production	Liquid Storage[b]	1.38×10^5	-	-	-	-
Liquid Storage	Calcine[b]	-	2.07×10^5	-	-	-
Retrieved Calcine	Actinide-Depleted Calcine	-	-	7.75×10^5	-	-
Plant Production	Actinide-Depleted Calcine	-	-	4.22×10^5	4.22×10^5	4.22×10^5
Actinide Glass[c]	Federal Repository	-	-	1.20×10^6	4.22×10^5	4.22×10^5
Alternative 5: Glass to Repository After Delay						
Plant Production	Calcine	1.55×10^5	3.55×10^5	4.22×10^5	4.22×10^5	4.22×10^5
Plant Production	Liquid Storage[b]	1.38×10^5	-	-	-	-
Liquid Storage	Calcine[b]	-	2.07×10^5	-	-	-
Retrieved Calcine	Glass	-	-	7.75×10^6	-	-
Fresh Calcine	Glass	-	-	4.22×10^5	4.22×10^5	4.22×10^5
Glass	Federal Repository	-	-	1.20×10^6	4.22×10^5	4.22×10^5

a. See Scientific Notation section.

b. All these entries represent the same waste material: $(1.38 \times 10^5$ kg/yr) × (15 yr) = 2.07×10^6 kg in liquid storage by 1980 and $(2.07 \times 10^5$ kg/yr) × (10 yr) = 2.07×10^6 kg converted to calcine by 1990.

c. Values given represent the calcine-equivalent mass of the actinide inventory; the actual mass of the vitrified waste shipment is much smaller.

mass rates given in Table A-1. In the year 2020, further processing of liquid waste is assumed to cease. Thus it is assumed that no new waste will be generated after 2020; thereafter, the total waste inventory is projected to remain constant.

A.1.1.2 Initial Radionuclide Concentrations in Waste

For simplicity and ease of calculation, all waste produced during the entire time period from 1965 to 2020 is assumed to have the same chemical and isotopic composition. The concentration of radionuclides in the calcined waste is estimated from the expected composition of liquid radioactive waste before calcination. Only radionuclides with significant initial concentrations and sufficiently long half-lives, or those with particular biological significance, are included in the initial inventory. Radionuclides which volatilize during fuel dissolution and calcination (e.g., tritium, krypton-85, and iodine-129) are no longer present in the calcine and therefore are not included in the radionuclide inventory.

The concentrations of the fission products and their daughters are based on estimates of the radionuclide content of the various future fuels to be processed at the ICPP. This approach slightly overestimates the fission product inventory because the fuel processed during the first 15 yr contains fewer fission products than waste processed subsequently.

Actinide concentrations are determined from actual samples of current liquid wastes normalized to future fuel element compositions. Uranium isotopes are present in the liquid waste in very low concentrations. Therefore, individual uranium isotope concentrations are calculated using known ratios of uranium nuclides in the waste and the total amount of uranium present. Because calcined wastes will always be cooled at least 3 yr after removal from a reactor before any postcalcination treatment, the radionuclide concentrations for 3-yr-cooled waste shown in Table A-2 are used for this environmental analysis.

TABLE A-2

RADIONUCLIDE CONCENTRATIONS OF 3-YEAR-COOLED CALCINED WASTES

Nuclide	Activity (Ci/kg)[a,b]	Nuclide	Activity (Ci/kg)	Nuclide	Activity (Ci/kg)
Se-79	6.4×10^{-5}	Rb-87	3.6×10^{-9}	Sr-90	1.3×10^{1}
Y-90	1.3×10^{1}	Zr-93	3.1×10^{-4}	Nb-93m	7.5×10^{-5}
Tc-99	2.1×10^{-3}	Ru-106	9.7×10^{-1}	Rh-106	9.7×10^{-1}
Pd-107	2.0×10^{-6}	Sn-126	3.2×10^{-5}	Sb-126m	3.2×10^{-5}
Sb-126	3.2×10^{-5}	Cs-134	3.3	Cs-135	7.5×10^{-5}
Cs-137	1.3×10^{1}	Ba-137m	1.2×10^{1}	Ce-144	8.2
Pr-144m	0	Pr-144	8.2	Nd-144	0
Pm-147	1.2×10^{1}	Sm-147	0	Sm-151	1.7×10^{-1}
Eu-154	1.8×10^{-1}	Tl-207	0	Tl-208	0
Tl-209	0	Tl-210	0	Pb-209	0
Pb-210	0	Pb-211	0	Pb-212	0
Pb-214	0	Bi-210	0	Bi-211	0
Bi-212	0	Bi-213	0	Bi-214	0
Bi-215	0	Po-210	0	Po-211	0
Po-212	0	Po-213	0	Po-214	0
Po-215	0	Po-216	0	Po-218	0
At-217	0	At-218	0	At-219	0
Rn-217	0	Rn-218	0	Rn-219	0
Rn-220	0	Rn-222	0	Fr-221	0
Fr-223	0	Ra-223	0	Ra-224	0
Ra-225	0	Ra-226	0	Ra-228	0
Ac-225	0	Ac-227	0	Ac-228	0
Th-227	0	Th-228	0	Th-229	0
Th-230	0	Th-231	0	Th-232	0
Th-234	0	Pa-231	0	Pa-233	0
Pa-234m	0	Pa-234	0	U-233	1.2×10^{-12}
U-234	4.3×10^{-10}	U-235	1.8×10^{-9}	U-236	1.0×10^{-8}
U-237	4.8×10^{-12}	U-238	1.0×10^{-14}	Np-237	4.8×10^{-8}
Np-239	0	Pu-238	7.0×10^{-2}	Pu-239	7.0×10^{-4}
Pu-240	6.5×10^{-4}	Pu-241	1.6×10^{-1}	Pu-242	1.8×10^{-6}
Am-241	9.1×10^{-4}	Am-243	8.3×10^{-6}	Cm-242	6.5×10^{-4}
Cm-244	5.2×10^{-4}				

a. See Scientific Notation section.

b. The isotopes shown to have initial concentrations of zero are those which have been removed during fuel production processes. Over long periods of time, the parent uranium present in the waste again produces these daughter products.

A.1.1.3 Radionuclide Inventories as a Function of Time

Because of radioactive decay, the radionuclide inventory will change as a function of time. Some isotopes, such as yttrium-90, decay to stable isotopes and are removed from the radionuclide inventory. Others decay into daughter nuclides which are also radioactive. The quantity of the radioactive daughters may increase as a function of time. For example, Figure A-1 shows the parent isotopes which contribute to the production of radium-226 and its radionuclide daughter, radon-222, a radioactive gas. (Radon is also produced in nature from the uranium-238 distributed throughout the earth's crust.) Inventories of total radionuclide activity thus calculated are presented in Figure A-2 for the time period from 1980 to 10^6 yr. The values given in Figure A-2 are for the entire quantity of calcine present which, after the year 2020, is assumed to remain constant at 2.04×10^7 kg.

A.1.2 Dose Factors

Each individual radionuclide presents a separate and unique contribution to the radiation dose to either the whole body or organ under consideration. Dose contributions result from processes which may be quite complex. Calculation of dose contributions can be simplified by using specific dose factors computed for each isotope. Once the quantity of a radionuclide is determined, the dose commitment can be calculated by multiplying that quantity by the appropriate dose factor according to the following equation:

$$D_i = Q_i \times DF_i$$

where

D_i = dose due to isotope i (rem)
Q_i = quantity of isotope i (μCi)
DF_i = dose conversion factor for isotope i (rem/μCi).

The total dose is determined by summing the component doses received from each isotope i.

$$D = \Sigma_i D_i$$

where D is the total dose from all isotopes.

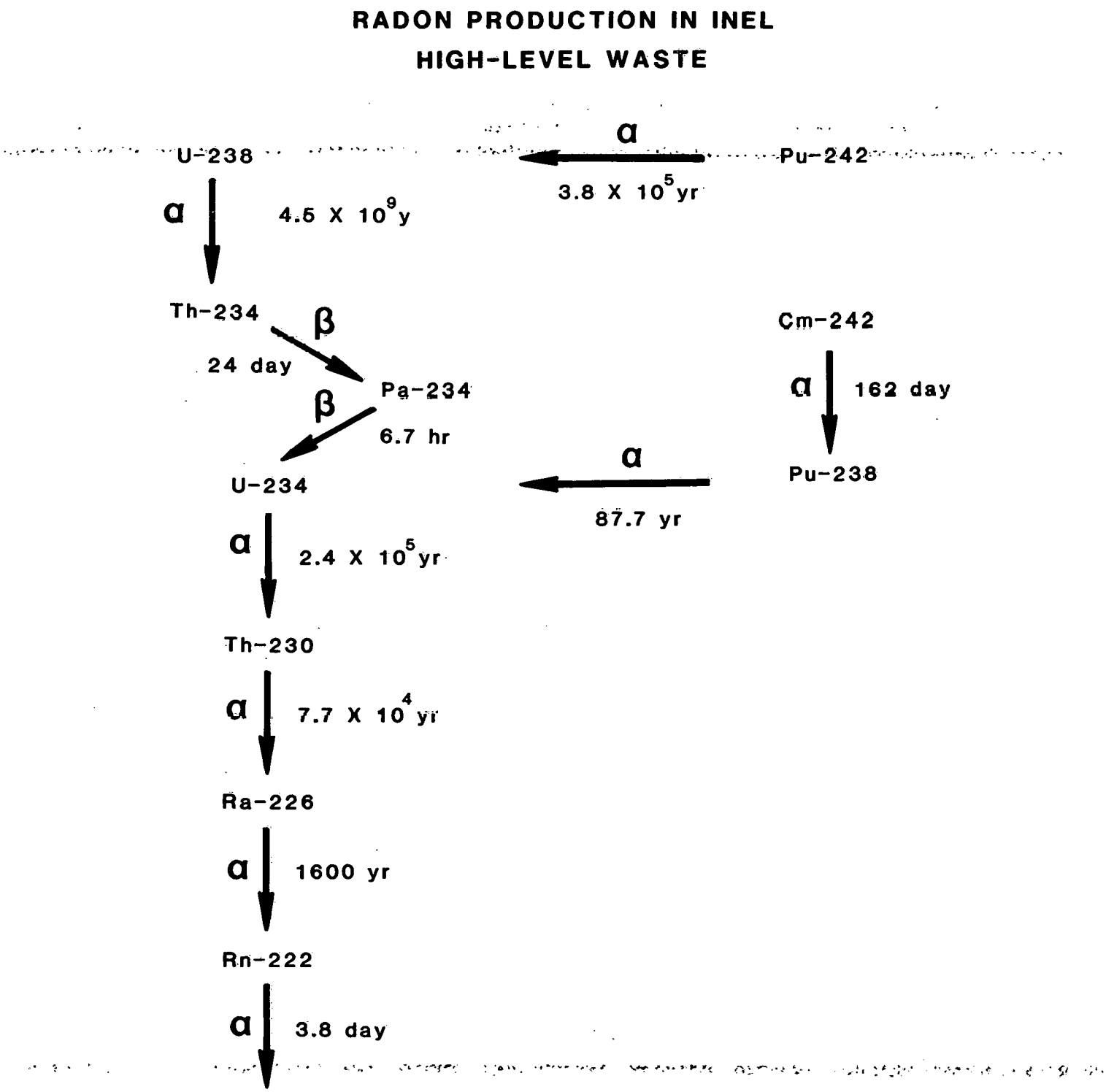


Figure A-1. Radon Production in INEL High-Level Waste

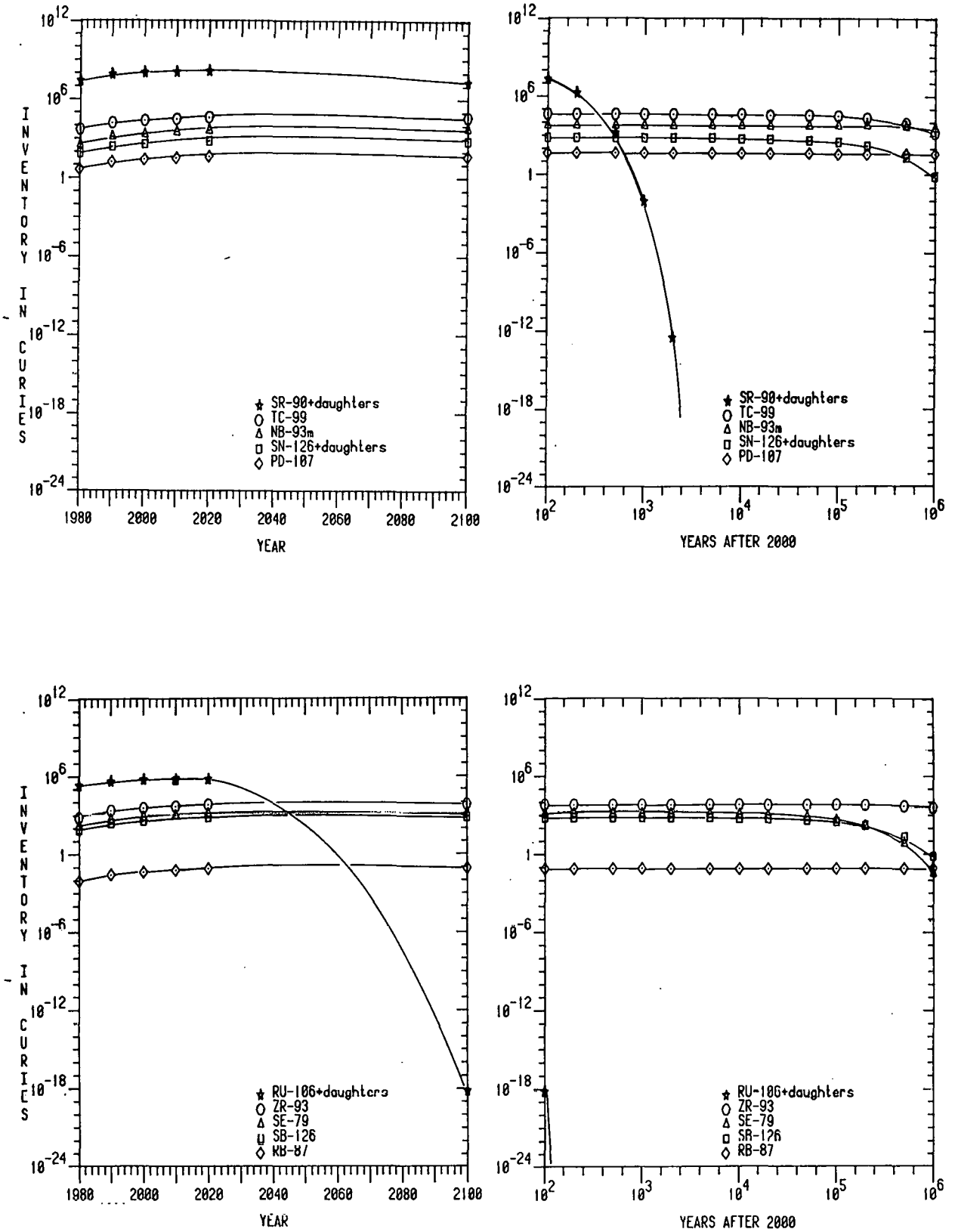


Figure A-2. Radionuclide Inventories as a Function of Time

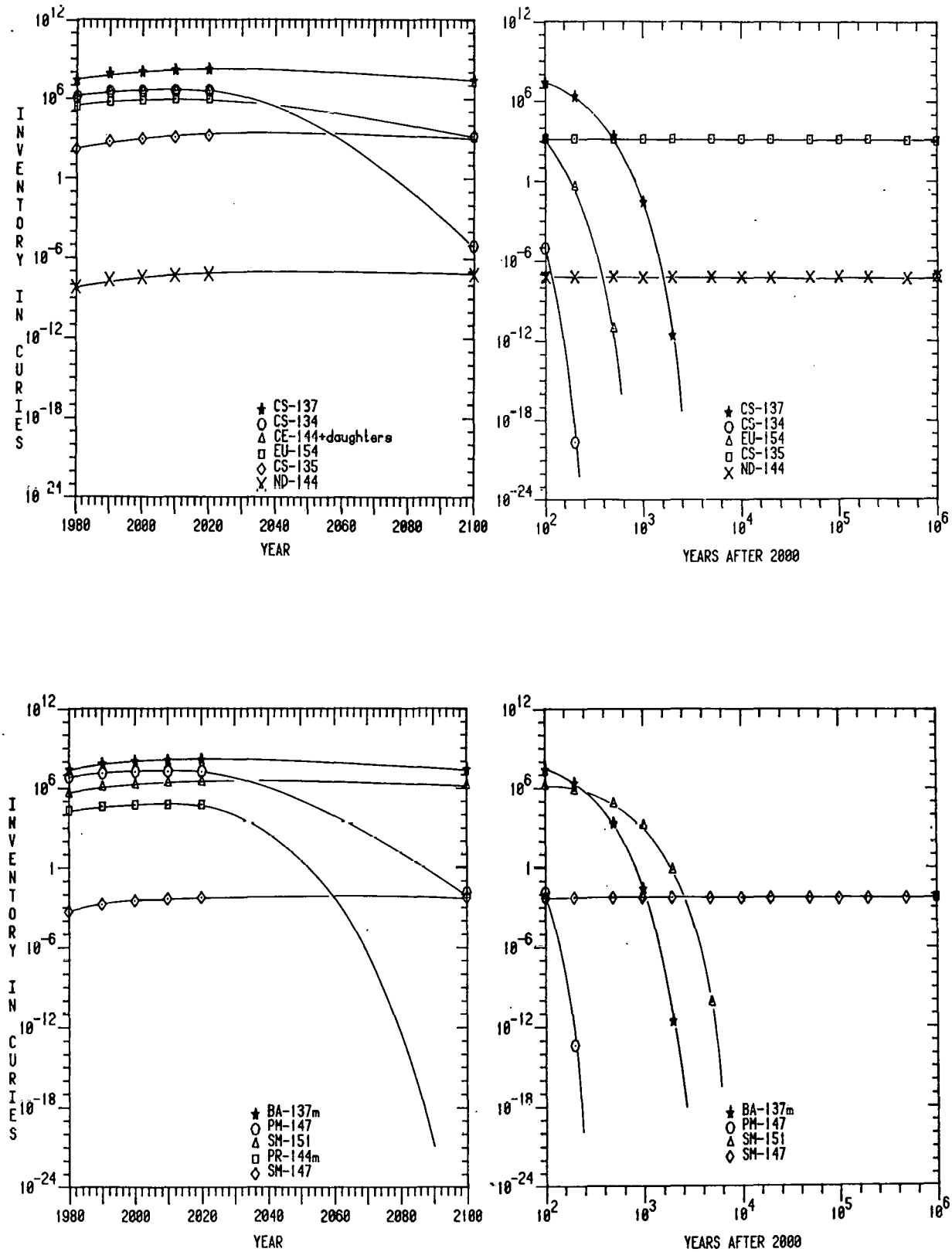


Figure A-2. Radionuclide Inventories as a Function of Time (continued)

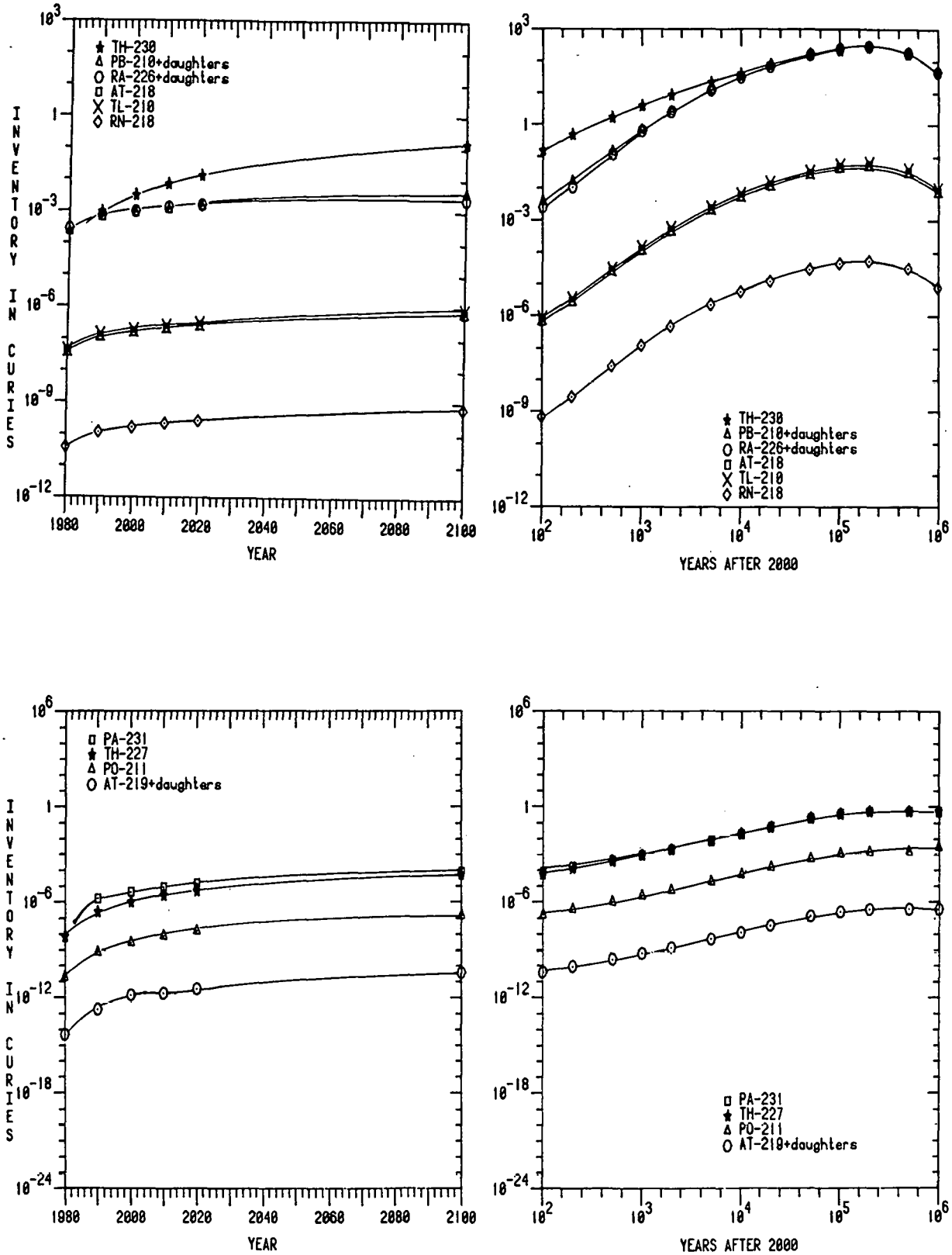


Figure A-2. Radionuclide Inventories as a Function of Time (continued)

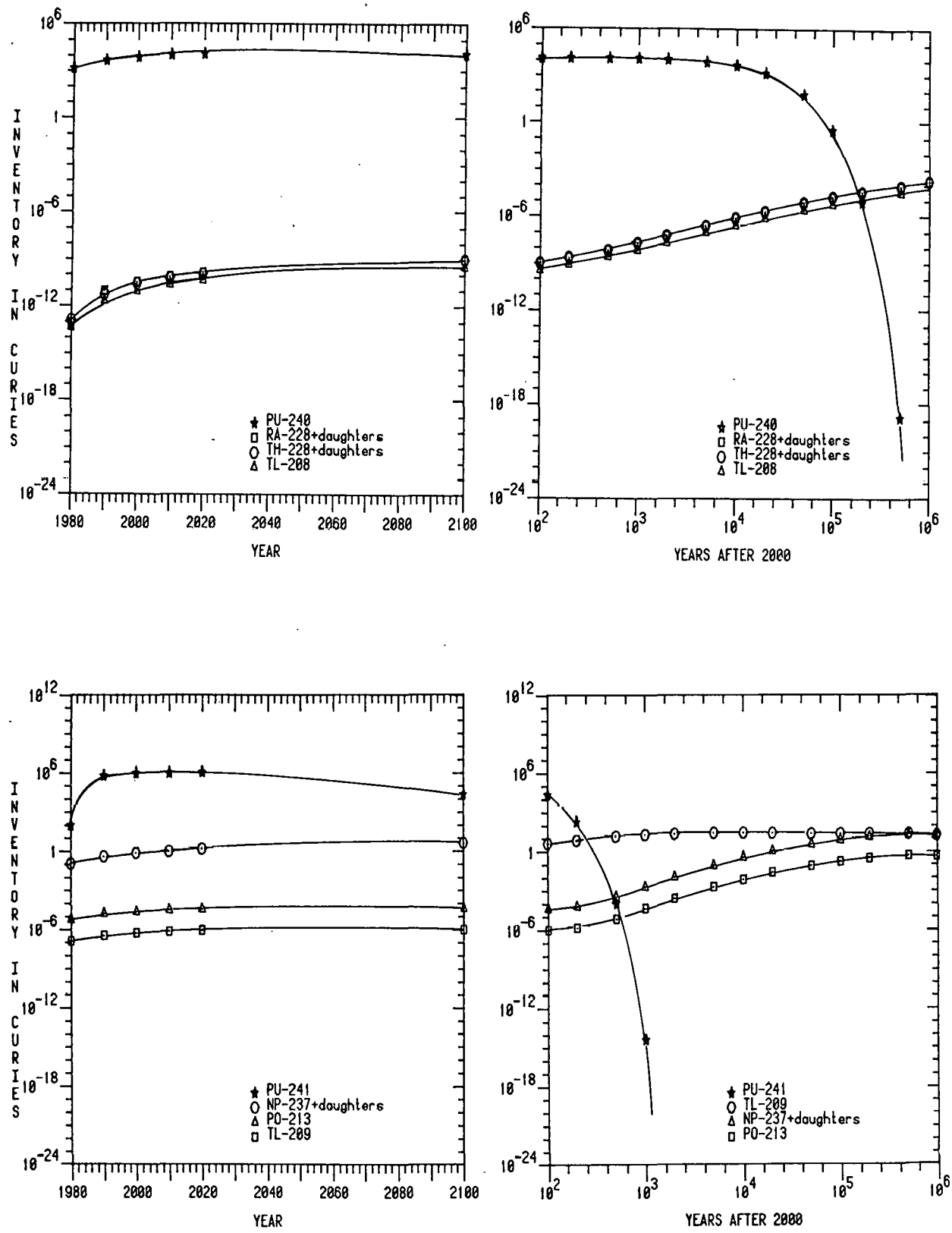


Figure A-2. Radionuclide Inventories as a Function of Time (continued)

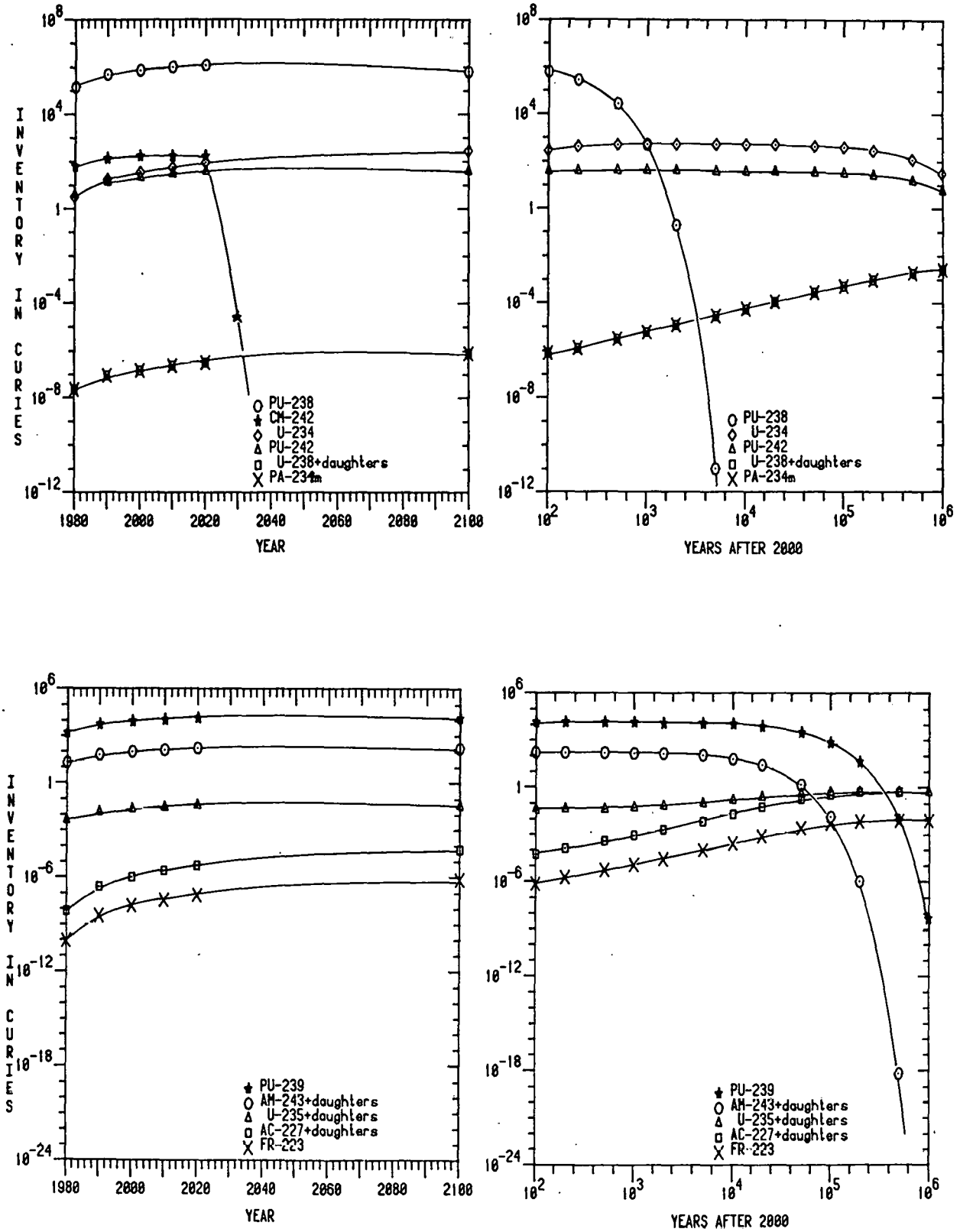


Figure A-2. Radionuclide Inventories as a Function of Time (continued)

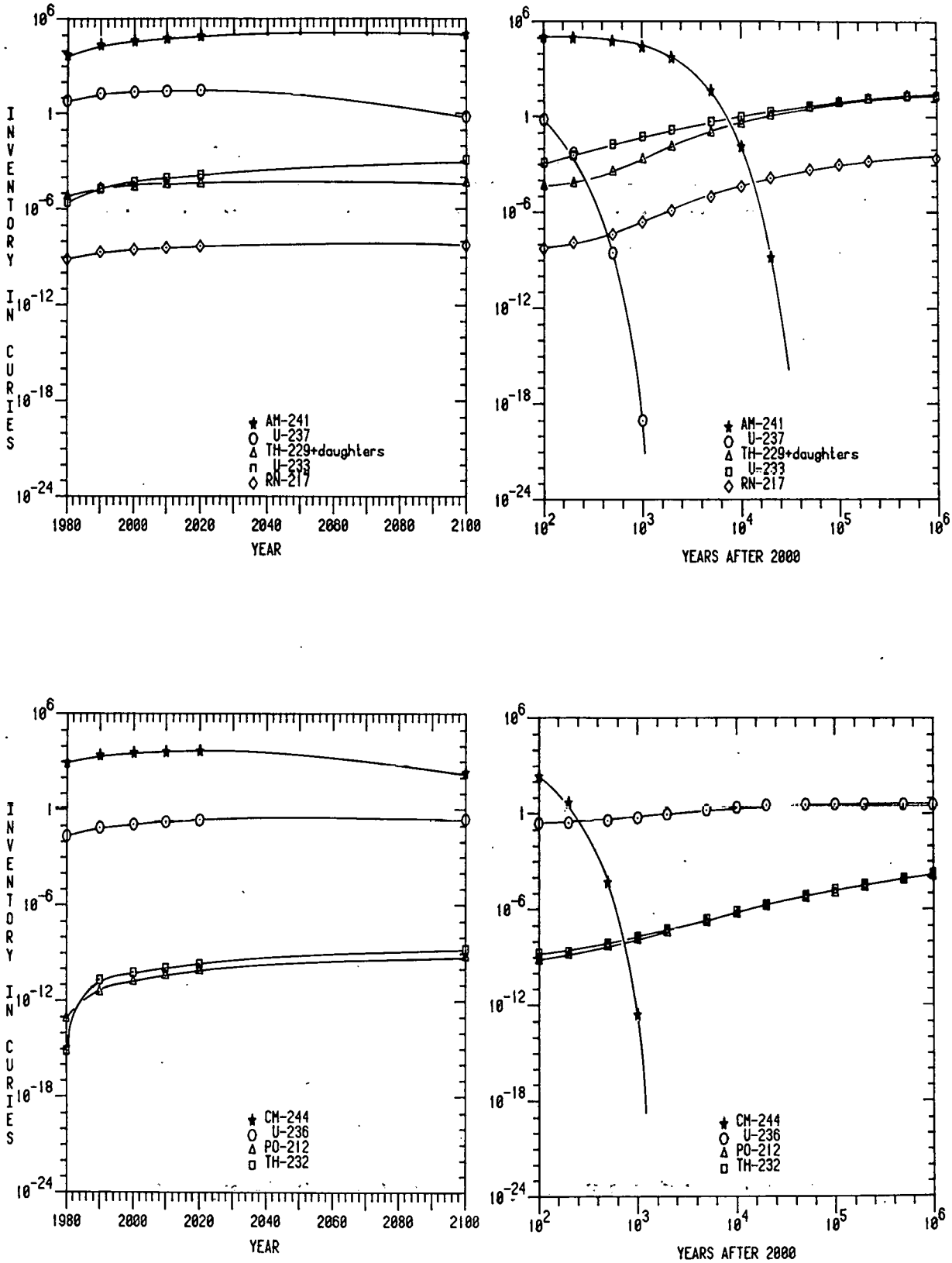


Figure A-2. Radionuclide Inventories as a Function of Time (concluded)

A.1.2.1 Internal Dose Conversion Factors

Dose conversion factors for radionuclides taken into the body vary depending upon the route of entry into the body and upon the age and size of the person receiving the dose. Those used in this document are for the adult 70-kg reference man (ICRP, 1977).

Internal dose conversion factors used to calculate 50-yr dose commitments result from radionuclides received internally from 1 yr of exposure. The calculated dose is for 50 yr, but the exposure received in any single year is only a fraction of the 50-yr dose commitment. A first approximation is that about 1/50 of the calculated dose will be received each year from the long-lived isotopes present in the calcine.

A.1.2.1.1 Inhalation Dose Conversion Factors

The inhalation dose conversion factors shown in Table A-3 were taken from "Estimates of Internal Dose Equivalent to 22 Target Organs for Radionuclides Occurring in Routine Releases from Nuclear Fuel-Cycle Facilities (NUREG/CR-0150)," (Dunning, et al., 1979). Dose conversion factors are shown for only the most significant isotopes. In order to calculate a conservative estimate of the dose from the significant isotopes, the dose conversion factor used from Table A-3 corresponds to the minimum solubility class for each radionuclide species as currently determined (Dunning, et al., 1979). This approach results in the highest dose for each species. To reduce the number of calculations, only one particle size of an average mean aerodynamic diameter (AMAD) of 1 μm was used.

A.1.2.1.2 Ingestion Dose Conversion Factors

The ingestion dose conversion factors for representative radionuclides are shown in Table A-4. They were taken from NUREG/CR-0150.

TABLE A-3

INHALATION DOSE CONVERSION FACTORS (rem/μCi)*

Nuclide	Lungs	Total Body	Stomach	Small Intestine	Upper Level Intestine	Lower Level Intestine	Breast	Adrenals	Bladder	Kidneys
Sr-90	8.50	1.50×10^{-1}	2.86×10^{-2}	6.87×10^{-2}	3.60×10^{-1}	8.90×10^{-1}	1.50×10^{-1}	3.65×10^{-13}	1.83×10^{-3}	3.65×10^{-3}
Y-90	3.93×10^{-2}	8.90×10^{-4}	1.39×10^{-3}	3.32×10^{-3}	1.71×10^{-2}	4.09×10^{-2}	8.90×10^{-4}	9.07×10^{-5}	4.92×10^{-5}	9.07×10^{-5}
Tc-99	5.22×10^{-2}	8.87×10^{-4}	5.70×10^{-4}	9.35×10^{-5}	5.53×10^{-4}	1.66×10^{-3}	8.87×10^{-4}	2.12×10^{-4}	1.06×10^{-4}	3.07×10^{-4}
Ru-106	3.80	6.18×10^{-2}	6.96×10^{-3}	8.82×10^{-3}	4.69×10^{-2}	1.40×10^{-1}	6.18×10^{-2}	1.15×10^{-2}	3.85×10^{-3}	8.95×10^{-3}
Rh-106	2.32×10^{-5}	3.44×10^{-7}	5.01×10^{-8}	3.52×10^{-9}	4.49×10^{-9}	9.41×10^{-10}	3.44×10^{-7}	2.74×10^{-8}	9.63×10^{-10}	1.19×10^{-8}
Cs-134	3.38×10^{-2}	4.55×10^{-2}	3.26×10^{-2}	3.49×10^{-2}	3.64×10^{-2}	3.71×10^{-2}	4.55×10^{-2}	6.51×10^{-2}	5.11×10^{-2}	6.77×10^{-2}
Cs-137	1.62×10^{-2}	3.26×10^{-2}	1.39×10^{-2}	1.48×10^{-2}	1.56×10^{-2}	1.60×10^{-2}	3.26×10^{-2}	5.01×10^{-2}	3.30×10^{-2}	5.13×10^{-2}
Ba-137m	7.09×10^{-6}	3.21×10^{-7}	9.70×10^{-7}	9.89×10^{-8}	1.03×10^{-7}	3.77×10^{-8}	3.21×10^{-7}	4.09×10^{-7}	3.78×10^{-8}	2.06×10^{-7}
Ra-226	5.60×10^{1}	1.90×10^{1}	3.81×10^{-3}	7.47×10^{-3}	4.42×10^{-2}	1.80×10^{-1}	1.90×10^{1}	6.70×10^{-1}	3.30×10^{-1}	6.60×10^{-1}
Pu-238	6.08×10^{2}	1.40×10^{2}	2.90×10^{-3}	7.01×10^{-3}	4.09×10^{-2}	1.20×10^{-1}	1.40×10^{2}	5.10	2.50	9.00×10^{1}
Pu-239	5.80×10^{2}	1.69×10^{2}	2.72×10^{-3}	6.58×10^{-3}	3.82×10^{-2}	1.10×10^{-1}	1.69×10^{2}	5.80	2.90	1.03×10^{2}

INHALATION DOSE CONVERSION FACTORS (rem/μCi)*

Nuclide	Liver	Ovaries	Pancreas	Red Marrow	Bone Surface	Spleen	Testes	Thymus	Thyroid	Uterus
Sr-90	1.90×10^{-2}	3.65×10^{-3}	3.65×10^{-3}	1.20×10^{-1}	2.30×10^{-1}	3.65×10^{-3}	3.65×10^{-3}	3.65×10^{-3}	3.65×10^{-3}	3.65×10^{-3}
Y-90	2.64×10^{-4}	9.07×10^{-5}	9.07×10^{-5}	5.32×10^{-4}	9.32×10^{-4}	9.07×10^{-5}	9.07×10^{-5}	9.07×10^{-5}	9.07×10^{-5}	9.07×10^{-5}
Tc-99	4.21×10^{-4}	2.12×10^{-4}	2.12×10^{-4}	2.15×10^{-4}	2.75×10^{-4}	2.12×10^{-4}	2.12×10^{-4}	2.12×10^{-4}	9.46×10^{-3}	2.12×10^{-4}
Ru-106	1.15×10^{-2}	7.67×10^{-3}	1.20×10^{-2}	9.37×10^{-3}	1.00×10^{-2}	1.10×10^{-2}	6.97×10^{-3}	1.15×10^{-2}	9.19×10^{-3}	4.82×10^{-3}
Rh-106	2.70×10^{-8}	1.93×10^{-9}	3.03×10^{-8}	1.43×10^{-8}	1.14×10^{-8}	2.43×10^{-8}	4.34×10^{-10}	4.31×10^{-8}	1.41×10^{-8}	1.32×10^{-9}
Cs-134	6.99×10^{-2}	6.45×10^{-2}	7.42×10^{-2}	6.16×10^{-2}	5.89×10^{-2}	6.55×10^{-2}	5.13×10^{-2}	7.73×10^{-2}	5.19×10^{-2}	1.00×10^{-1}
Cs-137	5.23×10^{-2}	5.00×10^{-2}	5.43×10^{-2}	4.91×10^{-2}	5.31×10^{-2}	5.04×10^{-2}	4.44×10^{-2}	5.66×10^{-2}	4.47×10^{-2}	6.55×10^{-2}
Ba-137m	4.07×10^{-7}	5.96×10^{-8}	5.32×10^{-7}	2.22×10^{-7}	1.74×10^{-7}	4.14×10^{-7}	2.67×10^{-8}	6.23×10^{-7}	2.18×10^{-7}	6.78×10^{-8}
Ra-226	1.10×10^{1}	6.70×10^{-1}	6.70×10^{-1}	2.30×10^{1}	2.27×10^{2}	6.60×10^{-1}	6.60×10^{-1}	6.60×10^{-1}	6.60×10^{-1}	6.60×10^{-1}
Pu-238	7.00×10^{2}	3.50×10^{1}	5.10	2.61×10^{2}	3.27×10^{3}	5.10	3.50×10^{1}	5.10	5.10	5.10
Pu-239	7.97×10^{2}	4.00×10^{1}	5.80	3.03×10^{2}	4.16×10^{3}	5.80	4.00×10^{1}	5.80	5.80	5.80

* NUREG/CR-0150.

TABLE A-4

INGESTION DOSE CONVERSION FACTORS (rem/μCi)*

Nuclide	Lungs	Total Body	Stomach	Small Intestine	Upper Level Intestine	Lower Level Intestine	Breast	Adrenals	Bladder	Kidneys
Sr-90	5.94×10^{-9}	9.45×10^{-2}	8.76×10^{-4}	2.10×10^{-3}	1.79×10^{-2}	7.78×10^{-2}	9.45×10^{-2}	5.99×10^{-3}	3.00×10^{-3}	5.99×10^{-3}
Y-90	9.80×10^{-9}	5.07×10^{-4}	3.93×10^{-3}	9.40×10^{-4}	4.86×10^{-2}	1.20×10^{-3}	5.07×10^{-4}	1.18×10^{-7}	6.42×10^{-8}	1.18×10^{-7}
Tc-99	0.00	2.14×10^{-4}	9.30×10^{-4}	1.80×10^{-3}	1.07×10^{-3}	3.20×10^{-1}	2.14×10^{-4}	3.17×10^{-4}	1.58×10^{-4}	4.58×10^{-4}
Ru-106	2.17×10^{-4}	5.94×10^{-3}	6.41×10^{-3}	1.56×10^{-2}	8.73×10^{-2}	2.60×10^{-1}	5.94×10^{-3}	8.20×10^{-3}	4.44×10^{-3}	8.23×10^{-3}
Rh-106	3.22×10^{-8}	1.89×10^{-7}	7.20×10^{-5}	5.85×10^{-7}	6.44×10^{-8}	2.42×10^{-8}	1.89×10^{-7}	3.85×10^{-8}	8.85×10^{-9}	5.79×10^{-8}
Cs-134	4.68×10^{-2}	6.84×10^{-2}	4.99×10^{-2}	5.28×10^{-2}	5.55×10^{-2}	5.75×10^{-2}	6.84×10^{-2}	9.78×10^{-2}	7.69×10^{-2}	1.00×10^{-1}
Cs-137	1.99×10^{-2}	4.19×10^{-2}	2.18×10^{-2}	2.25×10^{-2}	2.41×10^{-2}	2.59×10^{-2}	4.91×10^{-2}	7.54×10^{-2}	4.97×10^{-2}	7.73×10^{-2}
Ba-137m	4.60×10^{-7}	5.12×10^{-7}	2.87×10^{-5}	1.70×10^{-6}	1.16×10^{-6}	4.27×10^{-7}	5.12×10^{-7}	5.48×10^{-7}	1.63×10^{-7}	8.61×10^{-7}
Ra-226	1.76×10^{-3}	1.60×10^{1}	5.37×10^{-3}	1.17×10^{-2}	7.93×10^{-2}	3.30×10^{-1}	1.60×10^{1}	5.90×10^{-1}	3.00×10^{-3}	5.90×10^{-1}
Pu-238	1.14×10^{-7}	8.50×10^{-2}	4.71×10^{-3}	1.18×10^{-2}	6.99×10^{-2}	2.10×10^{-1}	8.50×10^{-2}	3.23×10^{-3}	1.62×10^{-3}	5.72×10^{-2}
Pu-239	9.35×10^{-8}	9.51E-02	4.42×10^{-3}	1.10×10^{-2}	6.50×10^{-2}	2.60×10^{-1}	9.51×10^{-2}	3.63×10^{-3}	1.82×10^{-3}	6.33×10^{-2}

INGESTION DOSE CONVERSION FACTORS (rem/μCi)*

Nuclide	Liver	Ovaries	Pancreas	Red Marrow	Bone Surface	Spleen	Testes	Thymus	Thyroid	Uterus
Sr-90	5.71×10^{-3}	5.99×10^{-3}	5.99×10^{-3}	4.30×10^{-1}	8.60×10^{-1}	5.99×10^{-3}	5.99×10^{-3}	5.99×10^{-3}	5.99×10^{-3}	5.99×10^{-3}
Y-90	3.45×10^{-7}	1.25×10^{-7}	1.18×10^{-7}	6.94×10^{-7}	1.22×10^{-6}	1.18×10^{-7}	1.18×10^{-7}	1.18×10^{-7}	1.18×10^{-7}	1.18×10^{-7}
Tc-99	6.28×10^{-4}	3.17×10^{-4}	3.17×10^{-4}	3.22×10^{-4}	4.10×10^{-4}	3.17×10^{-4}	3.17×10^{-4}	3.17×10^{-4}	1.41×10^{-2}	3.17×10^{-4}
Ru-106	8.27×10^{-3}	8.96×10^{-3}	8.29×10^{-3}	8.31×10^{-3}	9.57×10^{-3}	8.23×10^{-3}	8.14×10^{-3}	5.13×10^{-3}	8.06×10^{-3}	5.54×10^{-3}
Rh-106	3.57×10^{-8}	1.46×10^{-8}	3.01×10^{-7}	1.86×10^{-8}	1.07×10^{-8}	1.66×10^{-7}	1.15×10^{-9}	6.64×10^{-9}	2.80×10^{-9}	1.79×10^{-8}
Cs-134	1.00×10^{-1}	9.74×10^{-2}	1.10×10^{-1}	9.26×10^{-2}	8.86×10^{-2}	9.84×10^{-2}	7.73×10^{-2}	1.20×10^{-1}	7.81×10^{-2}	1.50×10^{-1}
Cs-137	7.87×10^{-2}	7.54×10^{-2}	8.17×10^{-2}	7.38×10^{-2}	7.99×10^{-2}	7.58×10^{-2}	6.68×10^{-2}	8.50×10^{-2}	6.72×10^{-2}	9.86×10^{-2}
Ba-137m	5.29×10^{-7}	3.47×10^{-7}	4.29×10^{-6}	2.93×10^{-7}	1.61×10^{-7}	2.33×10^{-6}	2.40×10^{-8}	1.09×10^{-7}	4.07×10^{-8}	3.59×10^{-7}
Ra-226	5.90×10^{-1}	5.90×10^{-1}	5.90×10^{-1}	2.00×10^{1}	2.02×10^{2}	5.90×10^{-1}	5.90×10^{-1}	5.90×10^{-1}	5.90×10^{-1}	5.90×10^{-1}
Pu-238	4.40×10^{-1}	2.21×10^{-2}	3.23×10^{-3}	1.70×10^{-1}	2.10	3.23×10^{-3}	2.12×10^{-2}	3.23×10^{-3}	3.23×10^{-3}	3.23×10^{-3}
Pu-239	4.90×10^{-1}	2.48×10^{-2}	3.63×10^{-3}	1.90×10^{-1}	2.60	3.63×10^{-3}	2.48×10^{-2}	3.63×10^{-3}	3.63×10^{-3}	3.63×10^{-3}

* NUREG/CR-0150.

A.1.2.2 External Dose Conversion Factors

Direct external radiation exposure results in a whole-body radiation dose. There are three primary sources of direct radiation: immersion in a radioactive cloud, radiation from radionuclides distributed on ground surfaces, and specific concentrations of radionuclides in storage or process areas.

Immersion and ground-plane sources lend themselves to dose conversion factor calculations which reduce the complexity of the dose analyses. Radiation doses from other specific concentrations are calculated using case-by-case analyses.

External dose conversion factors for both immersion situations and ground-plane surface depositions were taken from "ISOSHLD, A Computer Code for General Purpose Isotope Shielding Analysis" (Engle, 1966), and, as with internal dose conversion factors, are calculated for the 70-kg reference man. External radiation doses are the acute type and are received during the exposure time only. They do not contribute to long-term dose commitments.

A.1.3 Calculation of Maximum Individual, Population, and Worker Doses

Two distinct groups are considered in the analysis of radiological effects on people: the population living outside the INEL boundaries within a distance of 50 mi of the ICPP (see Figure A-4) and the radiation workers.

The effects on the public are analyzed by first calculating the dose to an individual who would receive the maximum dose from a given event. An average population dose factor is then multiplied by the maximum individual dose and the total population exposed to radiation to obtain the population dose commitment.

The average dose factors are calculated from the atmospheric dispersion factors weighted by the population for each sector. Atmospheric dispersion factors and the exposed population are discussed by sector in Subsections A.1.5 and A.1.6, respectively. The dose factors used for each scenario evaluation are listed in Table A-5.

TABLE A-5

POPULATION, PROBABILITY, AND AVERAGE POPULATION DOSE FACTORS

Scenario and Year of Exposure	Population Exposed (Number)	Probability (Event/Year)	Average Population Dose Factors
	AT THE ICPP		
Routine Release (Alternatives 2, 3, 4; Tables B-1 to B-5)			
1990	199,000	1.0	0.04
2000	234,000	1.0	0.04
2010	269,000	1.0	0.04
2020	303,000	1.0	0.04
Routine Release (Alternative 5; Tables B-6 to B-8)			
2090	546,000	1.0	0.04
2100	581,000	1.0	0.04
2110	615,000	1.0	0.04
2120-2520	650,000	1.0	0.04
Routine Waste Shipment (Alternatives 3, 4; Tables B-9 to B-11)			
1990	125,000	1.0	0.1*
2000	133,000	1.0	0.1
2010	142,000	1.0	0.1
2020	150,000	1.0	0.1
Routine Waste Shipment (Alternative 5; Tables B-12 to B-14)			
2090	209,000	1.0	0.1*
2100	217,000	1.0	0.1
2110	225,000	1.0	0.1
2120	234,000	1.0	0.1
2290-2520	250,000	1.0	0.1
Routine Occupational Exposure (Alternative 1; Table B-15)			
1990-2020	0	1.0	1.0
Routine Occupational Exposure (Alternative 2; Tables B-16 and B-17)			
1990-2020	20-55	1.0	1.0
Routine Occupational Exposure (Alternative 3; Tables B-18 and B-19)			
1990-2020	115-140	1.0	1.0

TABLE A-5

POPULATION, PROBABILITY, AND AVERAGE POPULATION DOSE FACTORS
(continued)

Scenario and Year of Exposure	Population Exposed (Number)	Probability (Event/Year)	Average Population Dose Factors
Routine Occupational Exposure (Alternative 4; Table B-20)			
1990-2020	125-190	1.0	1.0
Routine Occupational Exposure (Alternative 5; Tables B-21 and B-23)			
2090-2520	140	1.0	1.0
Calcine Spill (Alternatives 2, 3, 4; Tables B-24 to B-28)			
1990	71,000	2.0×10^{-1}	0.04
2000	83,000	2.0×10^{-1}	0.04
2010	95,000	2.0×10^{-1}	0.04
2020	107,000	2.0×10^{-1}	0.04
Calcine Spill (Alternative 5; Tables B-29 to B-31)			
2090	193,000	2.0×10^{-1}	0.04
2100	206,000	2.0×10^{-1}	0.04
2110	218,000	2.0×10^{-1}	0.04
2120-2520	230,000	2.0×10^{-1}	0.04
Decontamination Solution Spill (Alternatives 2, 3, 4; Tables B-32 to B-36)			
1990	71,000	1.0×10^{-1}	0.20
2000	83,000	1.0×10^{-1}	0.20
2010	95,000	1.0×10^{-1}	0.20
2020	107,000	1.0×10^{-1}	0.20
Decontamination Solution Spill (Alternative 5; Tables B-37 to B-39)			
2090	193,000	1.0×10^{-1}	0.20
2100	206,000	1.0×10^{-1}	0.20
2110	218,000	1.0×10^{-1}	0.20
2120-2520	230,000	1.0×10^{-1}	0.20
Extraction Solvent Fire (Alternative 4; Table B-40)			
1990	71,000	1.0×10^{-2}	0.04
2000	83,000	1.0×10^{-2}	0.04
2010	95,000	1.0×10^{-2}	0.04
2020	107,000	1.0×10^{-2}	0.04

TABLE A-5

POPULATION, PROBABILITY, AND AVERAGE POPULATION DOSE FACTORS
(continued)

Scenario and Year of Exposure	Population Exposed (Number)	Probability (Event/Year)		Average Population Dose Factors
Waste Shipment Accident (Alternative 3; Tables B-41 and B-42)				
		Glass	Calcine	
1990-2000	500	3.0×10^{-5}	2.0×10^{-5}	1.0
2010-2020	500	5.0×10^{-6}	3.0×10^{-6}	1.0
Waste Shipment Accident (Alternative 4; Table B-43)				
1990-2000	500	7.0×10^{-8}		1.0
2010-2020	500	2.0×10^{-8}		1.0
Waste Shipment Accident (Alternative 5; Tables B-44 to B-46)				
2090-2520	500	3.0×10^{-5}		1.0
Living Over the Waste (Alternatives 1, 2, 4; Tables B-47 to B-50)				
2500-1,002,000	5	1.0×10^{-2}		1.0
Waste Migration into Groundwater (Alternatives 1, 4; Tables B-51 and B-54)				
	Discharge Point / 3-mi Well / 10-mi Well / 120-mi Well			
2500-24,500	5 / 5 / 100 / 5000	1.0×10^{-6}		1.0
Waste Migration into Groundwater (Alternative 2; Tables B-52 and B-53)				
2500-1,002,000	5 / 5 / 100 / 5000	1.0×10^{-6}		1.0
Individual Intrusion (Alternatives 1, 2, 4; Tables B-55 to B-58)				
2500-1,002,000	10	1.0×10^{-2}		1.0
Living at Contaminated Site (Alternatives 1, 2, 4; Tables B-59 to B-62)				
2500-1,002,000	5	1.0×10^{-2}		1.0

TABLE A-5

POPULATION, PROBABILITY, AND AVERAGE POPULATION DOSE FACTORS
(continued)

Scenario and Year of Exposure	Population Exposed (Number)	Probability (Event/Year)	Average Population Dose Factors
Aircraft Impact (Alternatives 1, 2, 3, 4; Tables B-63 to B-66)			
1990	71,000	2.0×10^{-7}	0.20
2000	83,000	2.0×10^{-7}	0.20
2010	95,000	2.0×10^{-7}	0.20
2020	107,000	2.0×10^{-7}	0.20
2060	156,000	2.0×10^{-7}	0.20
Aircraft Impact (Alternative 5; Tables B-67 to B-69)			
1990	71,000	2.0×10^{-7}	0.20
2000	83,000	2.0×10^{-7}	0.20
2010	95,000	2.0×10^{-7}	0.20
2020	107,000	2.0×10^{-7}	0.20
2060	156,000	2.0×10^{-7}	0.20
2090	193,000	2.0×10^{-7}	0.20
2100	206,000	2.0×10^{-7}	0.20
2200-2490	230,000	2.0×10^{-7}	0.20
Severe Geologic Disruption (Alternatives 1, 2, 4, 5; Tables B-70 to B-76)			
1990	71,000	1.0×10^{-8}	0.60
2000	83,000	1.0×10^{-8}	0.60
2010	95,000	1.0×10^{-8}	0.60
2020	107,000	1.0×10^{-8}	0.60
2060	156,000	1.0×10^{-8}	0.60
2100	206,000	1.0×10^{-8}	0.60
2200-1,002,000	230,000	1.0×10^{-8}	0.60
AT THE REPOSITORY			
Canister Drop (Alternatives 3, 4, 5; Tables B-77 to B-82)			
1990-2520	2,000,000	7.0×10^{-7}	0.01
Fault and Flooding (Alternatives 3, 4, 5; Tables B-83 to B-88)			
2600-536,4000	2,000,000	2.0×10^{-13}	0.01

TABLE A-5

POPULATION, PROBABILITY, AND AVERAGE POPULATION DOSE FACTORS
(concluded)

Scenario and Year of Exposure	Population Exposed (Number)	Probability (Event/Year)	Average Population Dose Factors
Solution Mining (Alternatives 3, 4, 5; Tables B-89 to B-94)			
2100-1,002,000	40,000,000	1.0×10^{-6}	1.0
Exploratory Drilling (Alternatives 3, 4, 5; Tables B-95 to B-100)			
2100-1,002,000	25	5.0×10^{-7}	1.0

* Based on an average population for rural, suburban, and urban areas, and the estimated travel distances through each.

Doses to radiation workers are calculated using data derived from recent ICPP experience under a controlled radiation exposure program. These data indicate that each worker directly involved in operating and maintaining the ICPP receives an average annual exposure of 1 rem. This annual average radiation dose also accounts for the onsite exposure that would occur from minor accident situations. The waste shipment worker who is only incidentally involved in the transport of radioactive materials would receive a much smaller annual dose. This dose is calculated from the estimated amount of time the waste shipment worker spends in the vicinity of a radioactive material shipping container approved by the Department of Transportation (DOT) (49 CFR 173.393).

The main pathways by which radionuclides reach the public are through atmospheric diffusion and through subsurface water transport. In a few cases, fruits, vegetables, or meat produced on contaminated farm areas constitute important pathways. For each scenario, these pathways are evaluated for the maximum individual and then related to the exposed population by using the average population dose factor listed in Table A-5.

A.1.3.1 Calculation of the Dose to the Maximum Individual

The calculation of radiation doses to individuals combines the inventory of radioactive waste with exposure pathway factors to determine the amount of each isotope to which the maximum individual would be exposed. The pathway analysis uses the methods and parameters outlined in "Calculation of Annual Dose to Man from Routine Releases of Reactor Effluents for the Purpose of Compliance with 10 CFR Part 50, Appendix I," Regulatory Guide 1.109 (NRC, 1977). For pathways in which activity may increase (for example, by deposition from routine operations), the dose is calculated for the last year of facility operation to ensure that a maximum dose is obtained.

Because of the comparative nature of this study and the need to avoid unnecessary calculations, doses are calculated for only the adult reference 70-kg man (ICRP, 1977). In each case, the dose applicable to adult female organs is included in the evaluation. For cases where female organs receive a higher dose commitment, the higher value is added to the dose calculation for the reference man. The 50-yr dose commitment is based on a 50-yr life expectancy for the adult population.

Because different radionuclides irradiate different organs and different tissues, a method is needed to express the total radiation risk to an individual. Since there is no universally established approach to this task, two separate methods are reported in this study. In the first method, the individual organ doses for the four organs most likely to be affected by the calcine radionuclide inventory are evaluated. These four organs are the lung, liver, bone surface, and total body. The total body is considered to be comprised of soft tissue and body water with a 70-kg mass. The separate listing of these organs allows intercomparison of the five waste management alternatives on an individual organ basis.

In the second method, an attempt was made to weight the exposure received by individual organs in such a way that the organ doses could be combined to yield a single dose equivalent. This weighted dose equivalent is then used as a single parameter for comparing one alternative to another and to calculate potential health effects in the exposed population.

The weighting method selected is based on the International Commission on Radiological Protection (ICRP-26) model (ICRP, 1977). In this model, doses from 20 different organs are combined by a weighting factor method to yield a single whole-body equivalent dose (WBE) from which potential health effects can be derived. The ICRP-26 method for developing the WBE is described in the following paragraphs.

Whole-Body Equivalent Dose

The ICRP recommends a system for limiting low-level exposure based on the principle that the risk should be the same whether the whole body is irradiated uniformly or whether there is non-uniform irradiation of organs or tissue. This condition is met if

$$\Sigma_T \; W_T \; D_T \leq D_{WB}$$

where

W_T = the weighting factor representing the ratio of risk from tissue (T) irradiation and the total risk from uniform whole-body irradiation

D_T = committed dose equivalent received by tissue (T)

D_{WB} = annual dose equivalent limit for whole-body irradiation.

The whole-body equivalent (WBE) is defined as follows:

$$WBE = \Sigma_T \; D_T \; W_T \quad .$$

Weighting factors recommended by the ICRP are given in Table A-6. For each WBE dose calculation, all 20 organs and tissues listed in Table A-6 are considered. First, the WBE dose for each of the initial six organs specified in Table A-6 is calculated. Next, it is determined from the list of remaining organs which five organs or tissues receive the greatest dose equivalent. These five organs are assigned a W_T value of 0.06 yielding a total of 0.3 which is added to the WBE for the first six organs. Doses to the rest of the remaining organs and tissues are not considered in the WBE dose calculation because it has been determined that they contribute only a negligible fraction of the total.

TABLE A-6

WEIGHTING FACTORS RECOMMENDED BY THE ICRP

Organ or Tissue	Weighting Factor (W_T)
Gonads	0.25
Breast	0.15
Red Bone Marrow	0.12
Lung	0.12
Thyroid	0.03
Bone Surfaces	0.03
Remainder	0.30

The five organs from the following list which contribute the highest dose equivalents constitute the "remainder" organs.

Uterus	0.06
Thymus	0.06
Spleen	0.06
Pancreas	0.06
Liver	0.06
Kidneys	0.06
Bladder	0.06
Adrenals	0.06
Lower Large Intestine	0.06
Upper Large Intestine	0.06
Small Intestine	0.06
Stomach	0.06
Soft Tissue	0.06

A.1.3.2 Calculation of the Dose to the Population

Calculations have been made for several population groups in this report:

- persons residing within 50 mi of the INEL boundary,
- persons living along a waste shipment route between the INEL and a future waste repository,
- persons who might work on or occupy the INEL site after institutional control is assumed to cease,
- persons residing within 50 mi of the federal repository,
- persons who might explore the federal repository site after records of the repository may be lost, and

- persons who might consume salt produced by solution mining at a federal geologic repository site in the distant future.

Some of the pathways described in this document do not result in widespread population exposures. In these instances, the exposure is confined to a single or a few individuals; their exposures have been included in the population totals.

In each population dose determination, the approach is to calculate the dose to the maximum exposed individual. This dose is multiplied by the average population dose factor and the total population to calculate the population dose commitment.

In the routine operational release scenario which affects the entire population within the 50-mi area surrounding the INEL, the average population dose factor is calculated to be 0.04 times the dose to the maximum individual. The average population dose factor was obtained by weighting the population in each radial interval and sector (see Figure A-4) by the corresponding atmospheric dispersion factor (see Table A-8).

Other types of exposure pathways require different dispersion factors appropriate to the circumstances of the radionuclide release. The populations exposed in each scenario analyzed in this document are discussed in Subsection A.1.6 and summarized in Table A-5.

A.1.3.3 Calculation of Worker Dose

Four waste management alternatives result in additional occupational exposure. Alternative 2 involves additional workers for waste form modification at the INEL. Alternatives 3, 4, and 5 involve additional workers for waste form modification and additional train crews for shipment of waste to an offsite repository.

Table A-7 shows the estimated additional workers required for each alternative and the expected additional radiation exposure based on ICPP experience under a controlled radiation program. Radiation doses to train

TABLE A-7

RADIATION WORKER EXPOSURE DATA

Alternative	Additional Operations Personnel 1990-2000	Additional Operations Personnel 2000-2020	Train Crews	Average (Rem/Yr) Operations	Average (Rem/Yr) Train Crews	Total Man-Rem
1 Leave-in-Place	0	0	NA*	1.0	NA	0
2 Retrieve, Modify Calcine, Dispose at the INEL						
Pelletize Calcine	40	20	NA	1.0	NA	800
Convert Calcine to Glass	55	35	NA	1.0	NA	1,250
3 Retrieve, Modify Calcine, Dispose Offsite						
Stabilize Calcine	45	25	90	1.0	0.1	1,220
Convert Calcine to Glass	50	30	90	1.0	0.1	1,370
4 Retrieve, Separate Actinides, Dispose of Actinides Offsite, Dispose of Depleted Calcine at the INEL	100	35	90	1.0	0.01	1,727
5 Delay Retrieval, Modify Calcine, Dispose Offsite						
	2090-2120					
100 yr	50		90	0.5	0.05	885
	2290-2320					
300 yr	50		90	0.3	0.03	531
	2490-2520					
500 yr	50		90	0.1	0.01	177

* NA, not applicable

crews and offsite cask handlers are calculated from DOT limits for radiation from Class B shipping containers (49 CFR 173.393) and the average periods of time crews would be in the vicinity of the cask. In the hypothetical accident situation in which a shipping cask is breached in transit, the waste shipment worker is assumed to receive the largest dose commitment because of his proximity to the cask at the time of the accident.

A.1.4 Radiation Health Effects

Health effects from exposure to radiation were selected as a basis for comparing alternatives because health effects are, in general, easily understood by the reader. In addition, there are a wide variety of activities which involve some degree of risk both in the working environment and at home.

Since waste management evaluations are comparative in nature, only the health effect of death from cancer is considered. Comparison of other types of health effects would result in the same ratios between alternatives without providing additional information.

A.1.4.1 Acute Effects

Exposure to ionizing radiation can cause a variety of health effects depending upon the magnitude of the radiation dose received. These effects are generally divided into acute effects, which occur immediately, and delayed effects, which occur many years after the initial exposure.

The doses predicted for all routine release scenarios evaluated in this study are too low to produce the acute or immediate health effects that appear only at very high dose levels. At very high doses, around 300 rem and above, death could result. At relatively high levels, about 150 to 200 rem, some persons experience symptoms of radiation sickness manifested by vomiting and a decrease in white blood cell count. The lowest doses which produce visible evidence (vomiting) that a person has been affected by radiation are in the range of 75 to 125 rem.

The intrusion scenario during the first 500 yr of the disposal phase could produce exposures sufficiently high to cause acute effects. It is

believed such high exposures are precluded because the bins have a minimum integrity period of 500 yr and will be further reinforced by encapsulation in a concrete-like substance. After 500 yr, the intrusion scenario would produce exposures well below the minimum acute level of 75 to 125 rem.

A.1.4.2 Delayed Effects

The most important long-range effect of low-level radiation exposure is the chance for development of fatal cancer. There are several other delayed effects such as genetic effects and nonfatal malignancies. However, because these effects are poorly understood, criteria for their evaluation have not yet been developed. Therefore, these effects are not considered in this study.

The exact relationship between the amount of low-level radiation absorbed and the number of eventually fatal cancers produced is not known with certainty. It is known that the probability of cancer from low-level radiation is very low. Even when using assumptions which tend to maximize the dose effects, the number of predicted cancer fatalities from low-level radiation is a very small fraction of the total incidence of fatal cancers in the population of the United States.

Inasmuch as the cancer forms from radiation are predicted to be the same forms that occur naturally and spontaneously, the prediction of radiation-induced cancer fatalities cannot be based on actual mortality data. The cancer rate due to radiation can only be statistically inferred, and inferential statistical analyses entail a substantial margin of uncertainty. This uncertainty derives from assumptions made in mathematical models for extrapolation of annual data on known effects from radiation exposure at about 100 rem to effects caused by low-level radiation exposure of less than 5 rem.

Lacking actual comparative data, risk factor estimates made by a consensus of reputable scientists remain the only way to provide estimates of possible radiation health effects. The risk factors for fatal cancer used in this study are derived from the 1980 BEIR (Biological Effects of Ionizing Radiation) III Report (NASNRC, 1980) published by the National Academy of

Sciences after a comprehensive review of information generated since 1972 when the BEIR II Report was issued.

The BEIR III Report projects a range of 75 to 230 fatal cancers for a population of one million persons, each of whom is assumed to receive 1 rem of radiation in 1 yr. The population dose in this situation would be one million man-rem which leads to risk factors of 7.5×10^{-5} to 2.3×10^{-4} cancer fatality per man-rem.

The estimated range of health effects is then calculated by multiplying the population dose from each scenario by these risk factors.

$$\text{Health effects} = \text{population dose (man-rem)} \times 7.5 \times 10^{-5} \frac{\text{(cancer fatality)}}{\text{(man-rem)}}$$

to

$$\text{population dose (man-rem)} \times 2.3 \times 10^{-4} \frac{\text{(cancer fatality)}}{\text{(man-rem)}} .$$

A.1.5 Dispersion Factors

Radiological effects on distant populations due to the release of all or part of the radionuclide inventory will be substantially reduced as a result of dispersion and dilution. The diffusion and dilution factors in atmospheric transport and subsurface migration are discussed in this subsection. These are the two most important exposure pathways by which population groups are affected.

A.1.5.1 Meteorological Data

A.1.5.1.1 Atmospheric Diffusion and Dispersion

The most important mechanism for the transport of radionuclides is wind; it could carry radionuclides to population centers, agricultural areas, or grazing lands at or around the INEL. The data needed for establishing various parameters related to wind transport are derived from INEL meteorological

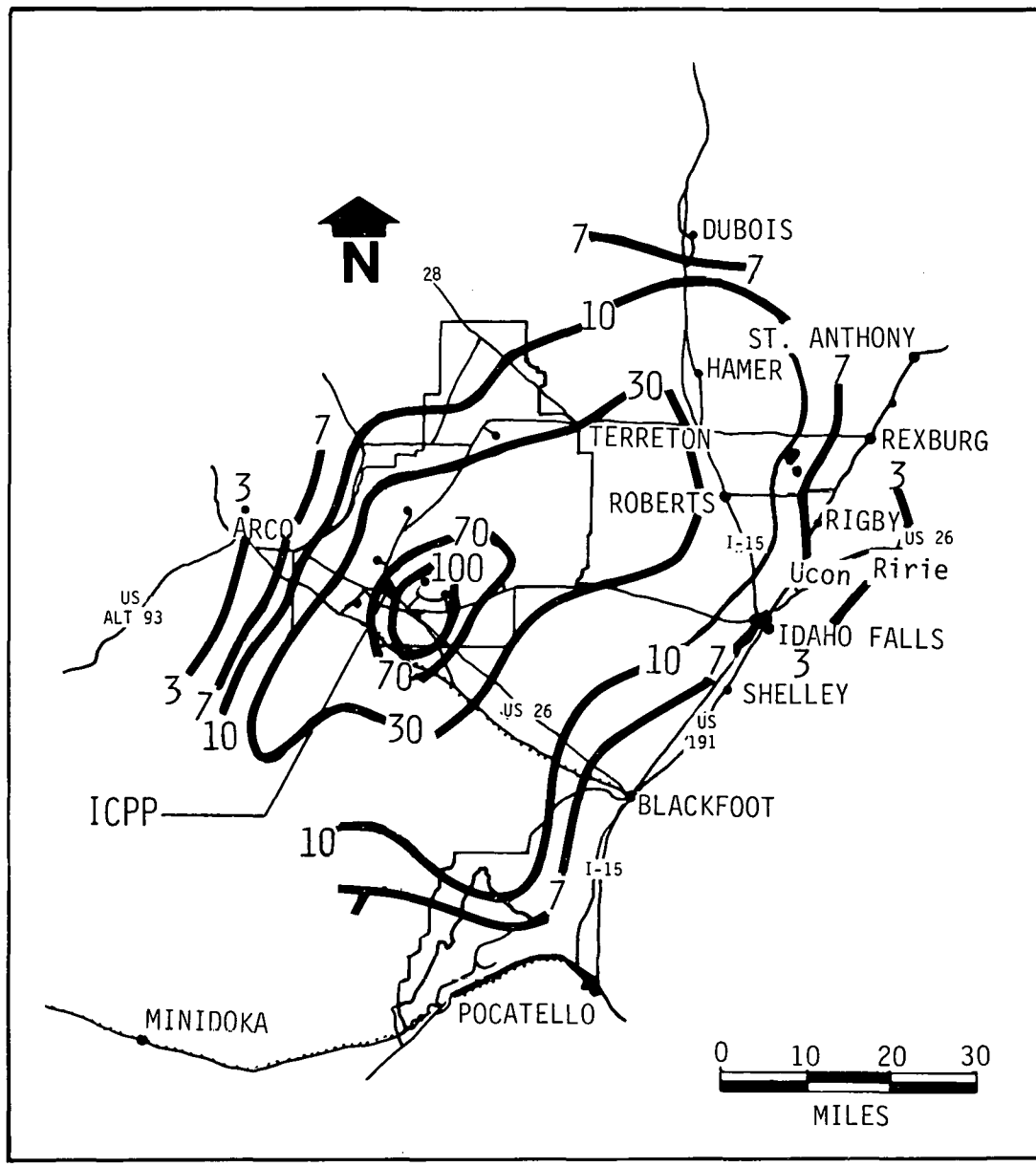
monitoring and research programs which have been conducted for more than 20 yr. In recent years, simultaneous measurements of wind speed and direction have been made at numerous locations on the eastern Snake River Plain. These data were used in modeling the characteristics of atmospheric dispersion for the INEL and surrounding areas.

The model and the associated computer code MESODIF (Start and Wendell, 1974) use a boundary-layer field of wind vectors. Measured variations, over both time and space, in wind speed and direction are used to calculate the transport and dispersion of emissions released from a facility. The influences of local terrain are taken into account indirectly by inclusion of data derived from simultaneous wind measurements at many locations across the plain. The present model has achieved two major improvements over the conventional single-station wind-rose technique. First, because the modeling of the hour-by-hour transport of the effluent is based on actual wind-field data, it includes the higher concentrations that result from stagnation. Second, the values of the atmospheric dispersion factors (χ/Q) are adjusted hourly to reflect changes in atmospheric stability.

In calculating radiation dose commitments, it is necessary to know the average air concentrations of the radionuclides that would be released. This quantity is derived from the atmospheric dispersion factor, χ/Q, which is obtained from the relative time-integrated concentration. The atmospheric dispersion factor is measured in sec/m^3.

The analyses on which this report is based use χ/Q values calculated for gaseous emissions discharged from the ICPP stack at an effective height of 250 ft. Six-year average data (1972 through 1977) are used. The calculated ground-level relative time-integrated concentrations for the INEL and surrounding areas are shown in Figure A-3. The atmospheric dispersion factors for the study area are given in Table A-8. The atmospheric dispersion factors were derived from the time-integrated concentrations by dividing by the number of hours in a year (8,760), and by converting hours to seconds; thus,

$$\chi/Q \ (sec/m^3) = 0.41 \ (\text{time-integrated concentration}) \ \frac{hr^2}{m^3 - yr} \ .$$



Note: Isopleth values should be multiplied by 10^{-9} for the correct magnitude in hr^2/m^3-yr.

Figure A-3. Average Annual Time-Integrated Ground-Level Concentrations

TABLE A-8

ATMOSPHERIC DISPERSION FACTORS (χ/Q) BY SECTOR AND DISTANCE FROM THE ICPP[a,b]

Depleted Mean Annual χ/Q (sec/m^3)

Sector	0-10 mi	10-20 mi	20-30 mi	30-40 mi	40-50 mi
1	2×10^{-8}[c]	6×10^{-9}	2×10^{-9}	2×10^{-9}	1×10^{-9}
2	2×10^{-8}	1×10^{-8}	8×10^{-9}	3×10^{-9}	2×10^{-9}
3	3×10^{-8}	2×10^{-8}	1×10^{-8}	7×10^{-9}	7×10^{-9}
4	3×10^{-8}	2×10^{-8}	1×10^{-8}	1×10^{-8}	2×10^{-9}
5	3×10^{-8}	1×10^{-8}	6×10^{-9}	3×10^{-9}	1×10^{-9}
6	1×10^{-7}	2×10^{-8}	6×10^{-9}	1×10^{-9}	9×10^{-10}
7	1×10^{-7}	2×10^{-8}	8×10^{-9}	3×10^{-9}	2×10^{-9}
8	4×10^{-8}	2×10^{-8}	6×10^{-9}	3×10^{-9}	1×10^{-9}
9	3×10^{-8}	2×10^{-8}	6×10^{-9}	3×10^{-9}	1×10^{-9}
10	3×10^{-8}	2×10^{-8}	1×10^{-8}	3×10^{-9}	1×10^{-9}
11	2×10^{-8}	6×10^{-9}	1×10^{-8}	5×10^{-10}	2×10^{-10}
12	1×10^{-8}	2×10^{-9}	6×10^{-10}	3×10^{-10}	1×10^{-10}
13	1×10^{-8}	1×10^{-9}	6×10^{-10}	3×10^{-10}	1×10^{-10}
14	1×10^{-8}	2×10^{-9}	8×10^{-10}	5×10^{-10}	2×10^{-10}
15	1×10^{-8}	3×10^{-9}	1×10^{-9}	3×10^{-10}	2×10^{-10}
16	2×10^{-8}	6×10^{-9}	3×10^{-9}	1×10^{-9}	2×10^{-10}

Depleted χ/Q Values for Accident Conditions (sec/m^3)[b,d]

Distance (m)	Class F, Ground Release	Class F, Stack Release
1×10^2	2.1×10^{-3}	1.2×10^{-4}
2×10^2	1.0×10^{-3}	6.8×10^{-5}
5×10^2	3.4×10^{-4}	2.9×10^{-5}
1×10^3	1.5×10^{-4}	1.5×10^{-5}
2×10^3	6.3×10^{-5}	7.4×10^{-6}
5×10^3	2.1×10^{-5}	3.1×10^{-6}
1×10^4	1.0×10^{-5}	1.6×10^{-6}
2×10^4	4.9×10^{-6}	8.8×10^{-7}
5×10^4	2.1×10^{-6}	4.1×10^{-7}
1×10^5	1.2×10^{-6}	2.3×10^{-7}

a. Start, 1978.

b. Depleted according to RG 1.111 (NRC, 1977).

c. See Scientific Notation section.

d. Using the Markee Diffusion Parameters and a 2-m/sec wind velocity (Yanskey, et al.; 1966).

A.1.5.1.2 Tabulation of χ/Q Values

The mean annual χ/Q values from the MESODIF code are given in the upper portion of Table A-8 for each of the sixteen 22.5° wind sectors in a 50-mi-radius circle centered at the ICPP. The first sector borders on the north and the sectors are numbered in a clockwise direction. The χ/Q values were determined for the midpoint of each 10-mi interval. These values of χ/Q were used in calculating the airborne dispersion of releases during normal operating conditions. The maximum mean annual χ/Q value at a point on the site boundary is 4.0×10^{-8} sec/m^3.

To evaluate the effects of accidents, atmospheric conditions which cause the least amount of dispersion were used. These are straight-line diffusion factors taken from curves published in "Climatography of the National Reactor Testing Station" (Yanskey, et al., 1966). The χ/Q values used for analysis of accidental radionuclide releases are given in the lower portion of Table A-8 for Pasquill Class F, a very stable atmospheric condition.

Both the mean annual and straight-line dispersion factors have been depleted to account for the loss of material in the contaminated plume as it moves to greater distances from the emission source.

A.1.5.2 Deposition Rate

The deposition of airborne material on ground surfaces can be calculated from the following equation which was originally developed to describe the fallout of radioactive particulates. The average deposition rate is related to the average air concentration by

$$D = (V_d + fr)\chi$$

where

D = deposition rate for particulates (Ci/m^2-sec)

V_d = empirical constant for the dry deposition of airborne particulates (m/sec)

f = empirical constant for the scavenging of airborne particulates by precipitation (m/cm of rain)

r = average rainfall rate (cm/sec)

χ = average air concentration of particulate matter (Ci/m^3).

The rate of change of particulate radionuclide concentration on the surface is computed from the following equation:

$$dS/dt = D - \lambda_r S$$

where

S = the surface concentration of deposited material (Ci/m^2)

λ_r = the radioactive decay constant for the radionuclide (1/sec).

The nominal values for the parameters in the above equations are

V_d = 0.01 m/sec for accident conditions and
0.005 m/sec for normal operating conditions.

The value of 0.01 m/sec is used in this study, and rain scouring is not considered; i.e., f = 0.

A.1.5.3 Subsurface Migration

To evaluate doses from groundwater migration, two processes are considered: first, transport through the soil in a vertical path from the calcine bins during which the various chemical species travel independently of each other; and second, dilution in the aquifer directly beneath the bins as a result of the mixing that occurs in the aquifer due to groundwater movement.

A.1.5.3.1 Aquifer Dilution

Movement of the Snake River Plain Aquifer under the ICPP averages about 3 m/day. The radionuclides that reach the aquifer are assumed to be diluted initially only by the aquifer flow directly beneath the calcine storage bins. This dilution is about 110 m^3/day per meter of bin width. The width of a bin vault is taken to be 15 m, leading to an annual dilution volume of 6.0×10^5 m^3. Additional dilution occurs as this volume moves downgradient.

Measurements of samples from INEL monitor wells indicate that the initial area of contamination spreads through at least 30° for the first 10 mi from the release point. Since measurements at more distant points are not available, the contaminated area, or plume, is assumed to have a constant width thereafter. Using this model, the downgradient dilution for the first 10 mi is given by the equation:

$$\text{dispersion} = \text{distance in meters} \times 0.133 \tan(\theta/2) + 1$$

where

θ = the plume dispersion angle.

The dilution factors for hypothetical wells evaluated in the waste migration scenario are: 3-mi well = 173; 10-mi well = 575; and 120-mi well = 575.

A.1.5.3.2 Soil Retardation

Soil retardation characteristics affect the radionuclide concentration in the aquifer by delaying the time at which various isotopes arrive at the aquifer. Due to the delay in arrival time (which may be years), the radioactivity of many isotopes is reduced by radioactive decay. The most important parameters controlling the transport of isotopes to the aquifer are the distribution coefficients (K_d). K_d values used in this document are presented in Table A-9.

Where they are available, the distribution coefficients are taken from published literature (Burkholder, 1976). For those isotopes not listed in the literature, representative values for that chemical group are used.

The K_d values are assumed to operate through a 15-m layer of soil. The vertical distance down to the aquifer is about 135 m. Well drilling logs indicate 100 to 120 m of the subsurface material is lava. Therefore, calculations are based only on a 15-m layer of material having an effective ion exchange capacity. The remaining 120-m distance is treated as if it were a pipe, with no ion exchange and adsorption assumed to occur on the lava interfaces or in perched water zones above the aquifer.

TABLE A-9

VALUES OF DISTRIBUTION COEFFICIENTS

Element	K_d	Element	K_d
Rb*	500	Sb	10
Cs*	500	Bi	10
Fr	500	Se	0
Sr*	50	Po*	10
Ba	50	At	0
Ra*	50	Ce	1,000
Y*	1,000	Pr	1,000
Zr*	1,000	Nd	1,000
Nb*	1,000	Pm*	1,000
Tc*	0	Sm	1,000
Ru	100	Eu*	1,000
Rh	1,000	Ac	1,000
Pd	1,000	Th*	1,000
Cd	100	Pa*	1,000
Hg	100	U*	1,000
Tl	100	Np*	500
Sn*	100	Pu*	1,000
Pb*	100	Am*	1,000
		Cm*	1,000

* These values are based on data contained in "Nuclear Waste Partitioning Incentives" (Burkholder, 1976).

A.1.6 Demographic Data

Radiological effects from the release of radionuclides during routine operations or from accidental releases are analyzed by evaluating the interaction between the radionuclides and the specific population affected. This section describes the population groups considered in the radiological effects analysis.

A.1.6.1 Population in Study Area

The 1970 population in the 50-mi study area is shown in Figure A-4. The population has been augmented by adding the populations of Pocatello, American Falls, Rigby, and Rexburg because these communities are very close to the 50-mi boundary. The 50-mi-radius circle is centered on the ICPP and divided

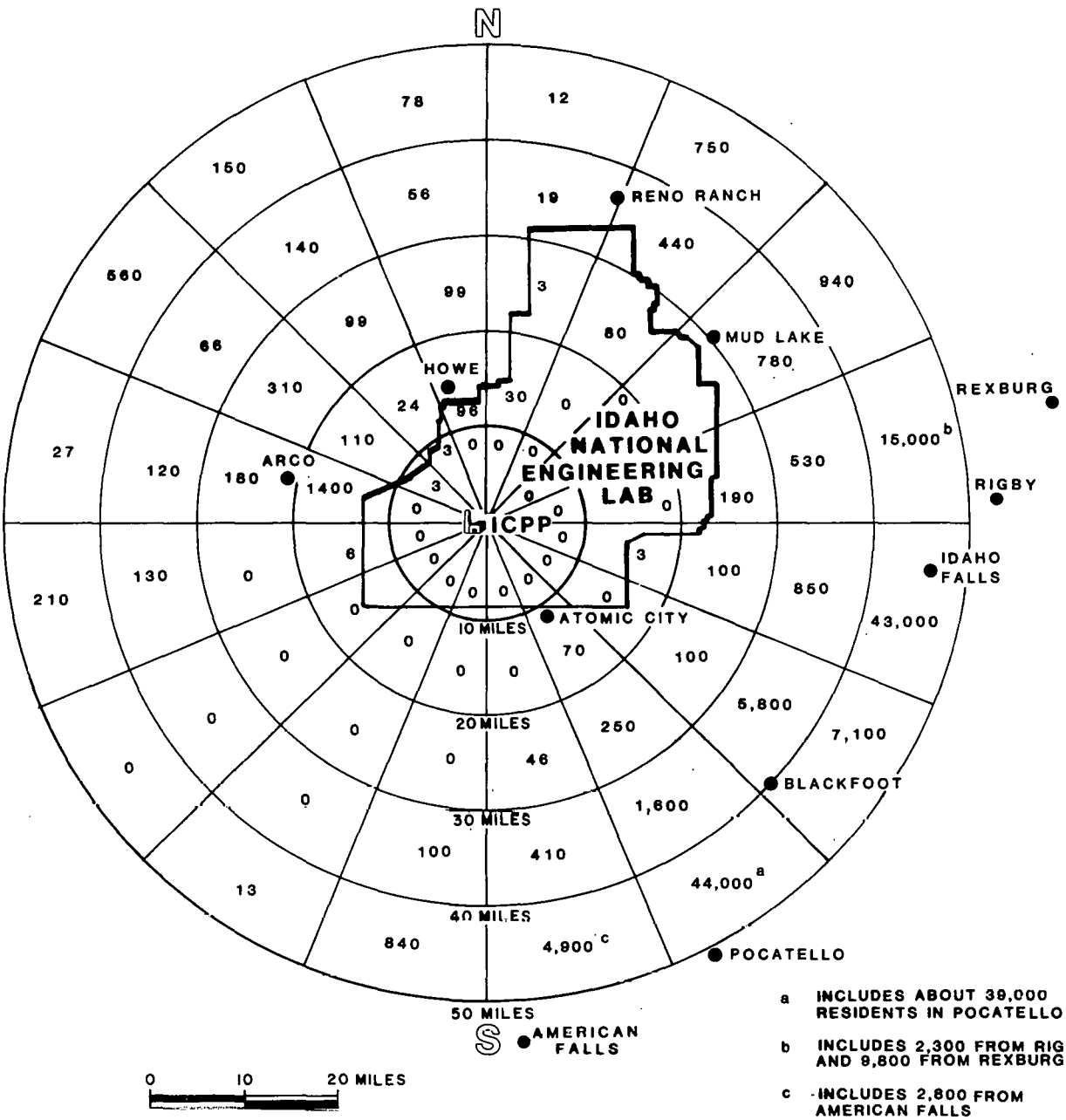


Figure A-4. Distribution of the 1970 Population Around the INEL Centered at the ICPP

into 16 sectors of 22.5° each. Each sector is further divided into 10-mi radial intervals. Sectors are numbered in a clockwise direction beginning with Sector 1 bordering on the north.

To allow for growth, the 1970 population is assumed to increase by a factor of 5 in the next 150 yr and remain constant thereafter. The growth averages 3,500 people per year over the 150-yr period. Population projections used in this document are given in Table A-5. They are based on the 1970 population rounded to 130,000.

A.1.6.2 Populations Affected by Short-Term Releases

Since an accident can occur at any time, it is assumed that accidents occur when atmospheric conditions would cause maximum effects on the population exposed to radionuclide releases. All short-term accidental releases are assumed to occur during very stable atmospheric conditions that correspond to Pasquill Category F and 2 m/sec wind speed conditions. The wind is assumed to transport the radionuclides into Sector 7, the most heavily populated sector (see Figure A-4). Population projections for Sector 7 are based on the 1970 population rounded to 46,000. Population projections used to evaluate accidental releases are given in Table A-5.

A.1.6.3 Populations Affected by Long-Term Releases

The number of individuals affected by events postulated to occur at the INEL after institutional control is assumed to cease is generally estimated to be small.

It is assumed that a family of five would be the largest population group that would permanently inhabit a family farm located directly on the calcine disposal site. The family of five is assumed to obtain its water from a domestic well at the ICPP. The effects of consuming garden vegetables grown on land irrigated with water from the domestic well are included in the evaluation. It is assumed that the small amount of produce that could be marketed from this site would have negligible impact on other populations.

The population affected by waste migration into the aquifer was estimated to increase with distance from the disposal site. The aquifer under the ICPP flows to the southwest. There is essentially no population in the sectors underlain by the aquifer for a distance of 50 mi. To compute radiological effects of aquifer contamination, a series of hypothetical wells located downgradient of the discharge point are evaluated. The population groups assumed to use these wells are given in Table A-5. A 120-mi well is evaluated because the aquifer discharges at this location in the form of springs.

A group of 10 individuals is assumed to be exposed in the intrusion scenarios evaluated at the INEL. These individuals could take an active part in excavating the disposal site, uncover the calcine bins, and remove some of the waste. Another type of intrusion that would cause similar effects is a drilling operation that penetrates the bins, bringing the calcine to the surface.

Population assumptions from the Final Environmental Impact Statement for Management of Commercially Generated Waste (GEIS) (DOE, 1980) were used to evaluate effects at a federal repository. Since a specific federal repository site has not been selected, the surrounding population cannot be precisely defined. An arbitrary population of 2 million is assumed for the fault-and-flooding scenario, 40,000,000 people are assumed to be affected by solution mining, and 25 people are assumed to take part in exploratory drilling.

A.1.7 Accident Probability, Frequency, and Risk

To arrive at a meaningful numerical indicator for risk comparisons, three essential factors must be taken into account: the frequency with which the event of interest is likely to occur; the population exposed to the potential risk; and the consequences of the event should it occur. Risk can then be defined in terms of the event probability and the event consequence by the equation:

$$\text{risk} = (\text{event consequence}) \times (\text{event probability}).$$

Population risk in man-rem per year is the product of the whole-body equivalent dose in rem, the event probability in events per year, the affected population, and the average population dose factor (Table A-5).

A.1.8 Scenario Parameters, Assumptions, and Sample Calculations

To assess the environmental impact of waste management alternatives, scenarios were developed to identify the potential effects of routine operations, accidents, and abnormal events that could cause radionuclide releases.

To allow the reader to reproduce the dose commitment values which appear in Appendix B and are cited throughout this report, sample calculations have been provided along with sufficient descriptive material, mathematical formulas, and other parameters required to perform the calculation.

An illustration is provided at the beginning of each scenario to help the reader visualize the pathways that are significant in calculating the effect of radiation exposure for the scenario. Also included for each scenario is a brief narrative describing the event, the time of occurrence, and the factors that determine the amount of waste released. The narrative is followed by a discussion of the exposure pathways considered, the radionuclide that causes the major part of the dose, and the alternatives affected by the scenario.

In general, the mathematical models and evaluative approach conform to the methodology described in RG 1.109. To eliminate the need to define each parameter and symbol for each scenario, the mathematical models are given separately in Subsection A.1.9. The equations used in the scenarios are identified by number for ease of location in Subsection A.1.9.

All scenario- and pathway-specific parameters used for the dose calculations are accompanied by an explanation of the basic assumptions. Particular care has been taken to assure that any arbitrary judgments (which are sometimes necessary because adequate physical data are lacking) are conservative and tend toward overestimation of the dose commitments. Exposure from resuspension is not considered because the effects were determined to be negligible compared to doses from other pathways. All calculated effects are in addition to background radiation.

The sample calculation given in each scenario guides the reader through a series of calculational steps for each pathway that contributes to the radiation exposure. First, the dose commitments for four representative organs are calculated for the most significant isotope. These values are then followed by the computer-calculated dose commitment from the 94 isotopes present in the waste. These are the values reported in Appendix B.

The dose calculations are performed according to the methods outlined in Subsections A.1.3 and A.1.4, using the mathematical models given in Subsection A.1.9. The following steps are used to calculate the maximum individual and population dose commitments. Each step is identified by number at the point at which it is used in the sample calculation.

Step 1. Compute each organ dose from each isotope (i). There are 20 organs at risk from 94 isotopes. For the sample calculation, only the dose to four representative organs from the most significant radionuclide is calculated. Dose commitments are calculated by multiplying the radionuclide intake by the appropriate dose conversion factor.

Step 2. Sum the dose commitments from each isotope (i) for each organ. The total dose commitment to an organ (D_T) by pathway (j) is determined by:

$$D_{Tj} = \Sigma_i D_{ij} \quad .$$

Step 3. Sum the total dose commitments for each organ from all pathways by:

$$D_T = \Sigma_j D_{Tj} \quad .$$

Step 4. Using the organ dose commitments calculated in Step 3, and appropriate weighting factors (W_T) from Table A-6 for each organ dose, compute the whole-body equivalent (WBE) dose for the maximum individual by:

$$WBE = \Sigma_T D_T W_T \quad .$$

Step 5. Using the WBE dose from Step 4, the average population dose factor, and the exposed population from Table A-5, compute the WBE dose for the population.

Population WBE dose = (maximum individual WBE) × (average population dose factor) × (population).

Step 6. Using the population WBE dose from Step 5 and conversion factors in Subsection A.1.4, compute the range of health effects.

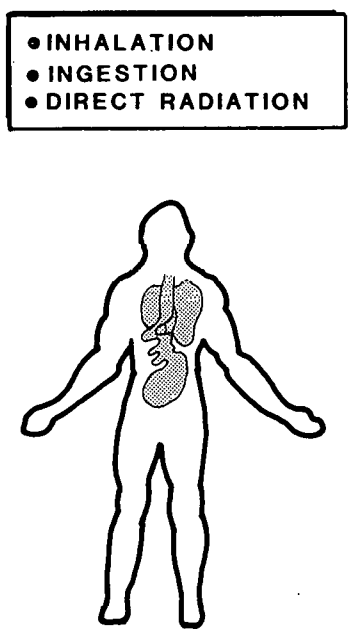
Health effects = (population WBE dose) × (health effect factors).

A.1.8.1 Releases at the ICPP

A.1.8.1.1 Routine Operational Release Scenario

During modification of calcined waste, a small fraction of the total radionuclide inventory is released after passing through the offgas treatment system and plant stack. The dispersed atmospheric contamination is a source of radiation exposure.

The accompanying illustration indicates the contributing pathways for routine releases. The significant pathways for human exposure are inhalation, direct external radiation from ground contaminated by radionuclide deposition, and through the food chain as a consequence of growing food and animal feed in contaminated soil. Effects of facility operation are illustrated in Subsection 4.5.1.1.2. The scenario is based on the following assumptions:



ROUTINE OPERATIONAL RELEASES

- The fraction of radionuclides released is based on past operating experience at the waste calcining facility located at the INEL.

- The probability of occurrence is 1.0 event per year.

- The maximum dose to an individual is calculated for annual average meteorology at the site boundary where the dispersed radionuclide concentration is highest.

- For pathways in which radioactivity on ground surfaces and vegetation increases with time, the final year of operations was used in order to estimate maximum effects.

- A population of 199,000 is exposed to radiation in 1990.

Releases during operations occur from the plant stack after passing through the atmospheric protection filters. Because of the volatility of some of its chemical forms, ruthenium (Ru-106) penetrates the atmospheric protection filters to a higher degree than other radionuclides. The result of this greater penetration is that Ru-106 is the principal dose contributor in the routine operations scenario. General parameters applicable to the exposure pathways for all alternatives are given in Table A-10. The following sample calculation is given for Alternative 3 (glass) in the year 1990. The other alternatives would cause fewer effects.

Calculation of Inhalation Pathway Dose

The contribution of a single radionuclide, isotope i, to the maximum individual 50-yr dose commitment from the inhalation pathway is given by the equation:

$$D_i = C_i \times V \times DF_i \qquad \text{(A-1)}$$

where

$$V = B \times T \qquad \text{(A-2)}$$

$$C_i = Q_i \times \frac{\chi}{Q} \qquad \text{(A-3)}$$

TABLE A-10

GENERAL PARAMETERS
ROUTINE OPERATIONAL RELEASES*

Parameter	Value	Units	Reference
Calcine retrieval rate from bins, Q_r	7.75×10^5	kg/yr	Applies between 1990-2000.
Production rate of fresh calcine, Q_p	4.22×10^5	kg/yr	Table A-1
Nuclide fraction released during calcine retrieval, F_{ri}	5.0×10^{-14}	none	Scenario
Ruthenium fraction released during processing, F_{pi}			
Alternatives 2, 3	6.0×10^{-9}	none	Scenario
Alternatives 4, 5	1.0×10^{-11}	none	Scenario
Other nuclide fractions released during processing, F_{pi}			
Alternatives 2, 3, 5	1.0×10^{-13}	none	Scenario
Alternative 4	1.7×10^{-13}	none	Scenario

* Ground-plane deposition and food pathways are calculated using models from RG 1.109.

where

$$Q_i = (Q_r [F_{ri} + F_{pi}] + Q_p \times F_{pi}) C_{ci} \times 10^6 \quad . \qquad \text{(A-4)}$$

Data for use in these equations are presented in Table A-11.

Substitution of the numerical values from Tables A-10 and A-11 into Equations A-1, A-2, A-3, and A-4 gives the organ dose commitments from the inhalation pathway for Ru-106.

TABLE A-11

DATA FOR INHALATION PATHWAY
ROUTINE OPERATIONAL RELEASE SCENARIO
(Ru-106)

Variable	Quantity	Unit	Reference
Q_r	7.75×10^{5}	kg/yr	Table A-1
Q_p	4.22×10^{5}	kg/yr	Table A-1
C_{ci}	9.70×10^{-1}	Ci/kg	Table A-2
F_{ri}	5.00×10^{-14}	none	Table A-10
F_{pi}	6.00×10^{-9}	none	Table A-10
χ/Q	4.00×10^{-8}	sec/m^3	Figure A-3
B	0.9	m^3/hr	Light work, adult man.
T	8.76×10^{3}	hr	1 yr
DF_i (bone surface)	1.00×10^{-2}	rem/μCi	Table A-3
DF_i (lung)	3.8	rem/μCi	Table A-3
DF_i (liver)	1.15×10^{-2}	rem/μCi	Table A-3
DF_i (total body)	6.18×10^{-2}	rem/μCi	Table A-3

Step 1

D_i (lung) $= 2.69 \times 10^{-7}$ rem
D_i (liver) $= 8.14 \times 10^{-10}$ rem
D_i (bone surface) $= 7.07 \times 10^{-10}$ rem
D_i (total body) $= 4.37 \times 10^{-9}$ rem.

Step 2

The total dose to these four organs from all 94 radionuclides considered was determined by using the values of isotope concentrations in Table A-2 and dose conversion factors from NUREG/CR-0150. The totals are

D_t (lung) $= 2.69 \times 10^{-7}$ rem
D_t (liver) $= 9.03 \times 10^{-10}$ rem
D_t (bone surface) $= 1.12 \times 10^{-9}$ rem
D_t (total body) $= 4.39 \times 10^{-9}$ rem.

Calculation of Ingestion Pathway Dose

The ingestion pathway has three contributing subpathways: direct ingestion of contaminated fruits and vegetables, ingestion of meat from animals grazed on contaminated vegetation, and ingestion of milk from animals grazed on contaminated vegetation.

The maximum individual 50-yr dose commitment from these subpathways has a common factor, C_{iv}, which relates the airborne release to the concentration in vegetable matter.

$$C_{iv} = D_{pi}\left(R\,\frac{[1 - e^{-(\lambda_e + \lambda_i)t_e}]}{Y(\lambda_e + \lambda_i)} + B_{iv}\,\frac{[1 - e^{-\lambda_i t_s}]}{P\lambda_i}\right)e^{-\lambda_i t_c} \qquad \text{(A-5)}$$

where

$$D_{pi} = \frac{\chi}{Q} \times V_d \times Q_i \qquad \text{(A-6)}$$

and

Q_i is derived by using Equation A-4.

Data for calculation of C_{iv} are given in Table A-12. Dose commitments for the three ingestion subpathways are calculated separately as follows.

Calculation of Ingestion Dose Commitment from Fruits and Vegetables Consumption

Dose commitments from eating fruits and vegetables contaminated by airborne radionuclides are given by the equations:

$$D_{fi} = Q_{fi} \times DF_i \qquad \text{(A-7)}$$

where

$$Q_{fi} = U_f \times C_{iv} \quad . \qquad \text{(A-8)}$$

TABLE A-12

DATA FOR RADIONUCLIDE CONCENTRATION IN VEGETATION
ROUTINE OPERATIONAL RELEASE SCENARIO
(Ru-106)

Variable	Quantity	Unit	Reference
R	0.2	none	RG 1.109
$\frac{\chi}{Q}$	5.0×10^{-8}	sec/m^3	Figure A-3
V_d	0.01	m/sec	Engineering judgment.
Q_i	0.794	μCi/hr	Equation A-4b
λ_i	7.8×10^{-5}	1/hr	Ru-106
λ_e	2.1×10^{-3}	1/hr	RG 1.109
t_e	1.44×10^{3}[a] 7.20×10^{2}[b]	hr	RG 1.109
Y	2.0[a] 0.7[b]	kg/m^2	RG 1.109
B_{iv}	5.0×10^{-2}	none	RG 1.109
t_s	8.77×10^{3}	hr	RG 1.109
P	240.0	kg/m^2	RG 1.109
t_c	0	hr	No delay assumed.

a. $C_{iv} = 1.8 \times 10^{-8}$ μCi/kg for fruits and vegetables consumed directly by man.

b. $C_{iv} = 4.2 \times 10^{-8}$ μCi/kg for vegetation consumed by meat- or milk-producing animals.

The data for the calculation of D_{fi} are given in Table A-13.

Step 1

Substitution of the numberical values from Table A-13 into Equations A-7 and A-8 gives the organ doses from stored fruits and vegetables:

TABLE A-13

DATA FOR FRUITS AND VEGETABLES CONSUMPTION
ROUTINE OPERATIONAL RELEASE SCENARIO
(Ru-106)

Variable	Quantity	Unit	Reference
U_f	584	kg/yr	RG 1.109
C_{iv}	1.85×10^{-8}	μCi/kg	Equation A-5
DF_i (total body)	5.94×10^{-3}	rem/μCi	Table A-4
DF_i (bone surface)	9.57×10^{-3}	rem/μCi	Table A-4
DF_i (liver)	8.27×10^{-3}	rem/μCi	Table A-4
DF_i (lung)	2.17×10^{-4}	rem/μCi	Table A-4

D_i (lung) $= 2.38 \times 10^{-9}$ rem
D_i (liver) $= 9.07 \times 10^{-8}$ rem
D_i (bone surface) $= 1.05 \times 10^{-7}$ rem
D_i (total body) $= 6.51 \times 10^{-8}$ rem.

Step 2

The organ dose commitments for all radionuclides from consumption of stored fruits and vegetables are determined by using the values of isotope concentrations in Figure A-2 and the DF_i values given in Table A-4 and NUREG/CR-0150. They are

D_t (lung) $= 2.49 \times 10^{-9}$ rem
D_t (liver) $= 9.10 \times 10^{-8}$ rem
D_t (bone surface) $= 1.08 \times 10^{-7}$ rem
D_t (total body) $= 6.57 \times 10^{-8}$ rem.

Calculation of Ingestion Dose Commitment from Meat Consumption

The dose resulting from consumption of meat produced from animals grazed on contaminated forage is obtained from the following equations:

$$D_{mfi} = Q_{mfi} \times DF_i \qquad \text{(A-9)}$$

where

$$Q_{mfi} = U_{mf} \times A_m \times S_{bi} \times C_{iv} \quad . \qquad \text{(A-10)}$$

The data used to calculate the dose from ingestion of meat produced from consumption of contaminated forage appear in Table A-14.

TABLE A-14

DATA FOR MEAT CONSUMPTION
ROUTINE OPERATIONAL RELEASE SCENARIO
(Ru-106)

Variable	Quantity	Unit	Reference
U_{mf}	110	kg/yr	RG 1.109
A_m	50	kg/day	RG 1.109
S_{bi}	4.0×10^{-1}	day/kg	RG 1.109
C_{iv}	4.2×10^{-8}	μCi/kg	Equation A-5
DF_i (bone surface)	9.57×10^{-3}	rem/μCi	Table A-4
DF_i (liver)	8.27×10^{-3}	rem/μCi	Table A-4
DF_i (lung)	2.17×10^{-4}	rem/μCi	Table A-4
DF_i (total body)	5.94×10^{-3}	rem/μCi	Table A-4

Step 1

Substitution of the numerical values from Table A-14 into Equations A-9 and A-10 gives the organ dose commitments for Ru-106 from ingestion of meat produced from consumption of contaminated forage:

D_i (lung) $= 2.04 \times 10^{-8}$ rem
D_i (liver) $= 7.78 \times 10^{-7}$ rem
D_i (bone surface) $= 9.00 \times 10^{-7}$ rem
D_i (total body) $= 5.59 \times 10^{-7}$ rem.

Step 2

The organ dose commitments from all radionuclides for consumption of meat produced from contaminated forage are determined by using the values of isotope concentrations in Figure A-2 and the DF_i values given in NUREG/CR-0150. They are

D_t (lung) $= 2.04 \times 10^{-8}$ rem
D_t (liver) $= 7.78 \times 10^{-7}$ rem
D_t (bone surface) $= 9.00 \times 10^{-7}$ rem
D_t (total body) $= 5.59 \times 10^{-7}$ rem.

Calculation of Ingestion Dose Commitment from Milk Consumption

The contribution of a single nuclide, isotope i, to the individual 50-yr dose commitment as a result of ingesting milk from animals grazed on contaminated forage is given by the equations:

$$D_{cfi} = Q_{cfi} \times DF_i \qquad \text{(A-11)}$$

where

$$Q_{cfi} = U_{cf} \times A_m \times S_{ci} \times C_{iv} \quad . \qquad \text{(A-12)}$$

The data for calculation of the dose from ingestion of milk produced by animals grazed on contaminated forage appear in Table A-15.

Step 1

Substitution of the numerical values from Table A-15 into Equations A-11 and A-12 gives the organ doses for Ru-106 from milk produced by animals grazed on contaminated forage:

D_i (lung) $= 1.41 \times 10^{-13}$ rem
D_i (liver) $= 5.38 \times 10^{-12}$ rem
D_i (bone surface) $= 6.23 \times 10^{-12}$ rem
D_i (total body) $= 3.84 \times 10^{-12}$ rem.

TABLE A-15

DATA FOR MILK CONSUMPTION
ROUTINE OPERATIONAL RELEASE SCENARIO
(Ru-106)

Variable	Quantity	Unit	Reference
U_{cf}	310	ℓ/yr	RG 1.109
A_m	50	kg/day	RG 1.109
S_{ci}	1.0×10^{-6}	day/ℓ	RG 1.109
C_{iv}	4.2×10^{-8}	μCi/kg	Equation A-5
DF_i (bone surface)	9.57×10^{-3}	rem/μCi	Table A-4
DF_i (lung)	2.17×10^{-4}	rem/μCi	Table A-4
DF_i (liver)	8.27×10^{-3}	rem/μCi	Table A-4
DF_i (total body)	5.94×10^{-3}	rem/μCi	Table A-4

Step 2

The organ doses for all radionuclides from milk produced by animals grazed on contaminated forage are determined by using the values of isotopic concentrations in Figure A-2 and DF_i values given in NUREG/CR-0150. They are

D_t (lung) = 7.73×10^{-11} rem
D_t (liver) = 2.57×10^{-10} rem
D_t (bone surface) = 3.92×10^{-10} rem
D_t (total body) = 1.87×10^{-10} rem.

Calculation of Direct Radiation Pathway Dose

Doses from radionuclides deposited on ground surfaces by airborne releases are calculated using the following equations:

$$D_{gi} = t_x \times S_f \times C_{gi} \times DF_{gi} \qquad \text{(A-13)}$$

and

$$C_{gi} = D_{pi} \frac{(1 - e^{-\lambda_i t_s})}{\lambda_i PL} \quad . \qquad \text{(A-14)}$$

Step 1

Since DF_{gi} for Ru-106 is 0, the total-body contribution from ground-plane deposition of Ru-106 is zero.

Step 2

The ground-plane doses from all isotopes are determined by using isotope concentrations in Figure A-2 and the dose conversion factors from the ISOSHLD code (Engle, et al., 1966). The total whole-body ground-plane deposition dose from routine releases is 8.50×10^{-8} rem.

Calculation of Whole-Body Equivalent Doses and Health Effects

Step 3

Step 3 consists of summing the dose commitments from all pathways, for all isotopes, and for all organs at risk as shown in Table A-16.

TABLE A-16

INDIVIDUAL PATHWAY ORGAN DOSE COMMITMENTS (rem)
ROUTINE OPERATIONAL RELEASE SCENARIO

Organ	Inhalation	Fruits and Vegetables	Meat	Milk	Total
Bone surface	1.12×10^{-9}	1.08×10^{-7}	9.00×10^{-7}	3.92×10^{-10}	1.01×10^{-6}
Liver	1.29×10^{-9}	9.10×10^{-8}	7.78×10^{-7}	2.57×10^{-10}	8.62×10^{-7}
Lung	2.69×10^{-7}	2.49×10^{-9}	2.04×10^{-8}	7.73×10^{-11}	2.92×10^{-7}
Total body	4.39×10^{-9}	6.57×10^{-8}	5.59×10^{-7}	1.87×10^{-10}	6.29×10^{-7}

Step 4

Organ dose commitments calculated in Step 3 are multiplied by the appropriate weighting factor from Table A-6 to calculate the whole-body equivalent dose according to the equation

$$WBE_j = D_j \, W_{Tj}$$

where, for example,

WBE_j (bone surface) = $(1.01 \times 10^{-6})(0.03) = 3.02 \times 10^{-8}$ rem
WBE_j (liver) = $(8.70 \times 10^{-7})(0.06) = 5.17 \times 10^{-8}$ rem
WBE_j (lung) = $(2.92 \times 10^{-7})(0.12) = 3.50 \times 10^{-8}$ rem
WBE_j (total body) = $(6.29 \times 10^{-7})(0.06) = 3.77 \times 10^{-8}$ rem.

Using these WBE doses for all organs and the ground-plane deposition dose (8.50×10^{-8} rem), the maximum individual dose is calculated to be

$$WBE = 3.00 \times 10^{-6} \text{ rem.}$$

Step 5

The population WBE dose is calculated as follows.

Population WBE dose = (maximum individual WBE) × (average population dose factor) × (population);

thus,

$$\text{population WBE dose} = (3.00 \times 10^{-6})(0.04)(199{,}000)$$
$$= 2.39 \times 10^{-2} \text{ man-rem.}$$

Step 6

The health effects associated with the population dose are based on the BEIR III Report in which it is estimated that 1 million man-rem cause between 75 and 230 excess cancer fatalities. Multiplying the population WBE dose by 7.5×10^{-5} and 2.3×10^{-4} gives a range of 1.79×10^{-6} to 5.49×10^{-6} excess cancer fatality from a routine operational release in Alternative 3 (glass) in 1990. This dose is far below the dose from background radiation which is calculated as follows.

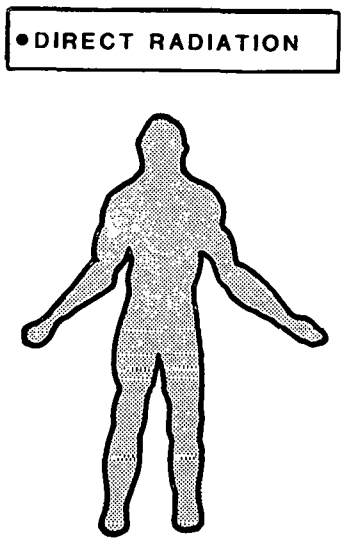
The population WBE dose from background radiation

$$= (1.5 \times 10^{-1})(199{,}000)$$
$$= 2.99 \times 10^{4} \text{ man-rem.}$$

The range of background health effects is 2.24 to 6.88.

A.1.8.1.2 Routine Waste Shipment Exposures

The alternatives that require disposal in an offsite federal geologic repository require shipping all or part of the waste inventory. The effects of waste shipment depend on many factors: the waste form, shipment method (truck or train), travel distance, and population distribution along the shipping route. Waste shipment would expose both train crew members and the general population to direct gamma radiation emitted from the shipping casks. The direct radiation pathway is indicated in the accompanying illustration. The routine waste shipment scenario is illustrated in Subsection 4.5.1.



ROUTINE
WASTE SHIPMENT

The waste shipment scenario applies to Alternatives 3, 4, and 5 and is based on the following assumptions:

- Shipment is by rail.
- The shipping distance is 2400 km (1500 mi).
- The maximum allowable dose rate at 6 ft from the shipping cask is 10×10^{-3} rem/hr; at 300 ft, the dose rate is 1.1×10^{-5} rem/hr (49 CFR 173.393).
- The probability of occurrence is 1 event per year.
- A population of 125,000 is exposed to radiation in 1990.

The general methodology used to evaluate the effects of waste shipment is the same as that used in the Savannah River document (ERDA, 1976b). The dose to an individual from a passing cask is given in Figure A-5. The relationship of dose rate to distance from a cask is given in Figure A-6.

Calculation of Direct Radiation Pathway Dose

Data for the calculation of waste shipment exposures are given in Table A-17.

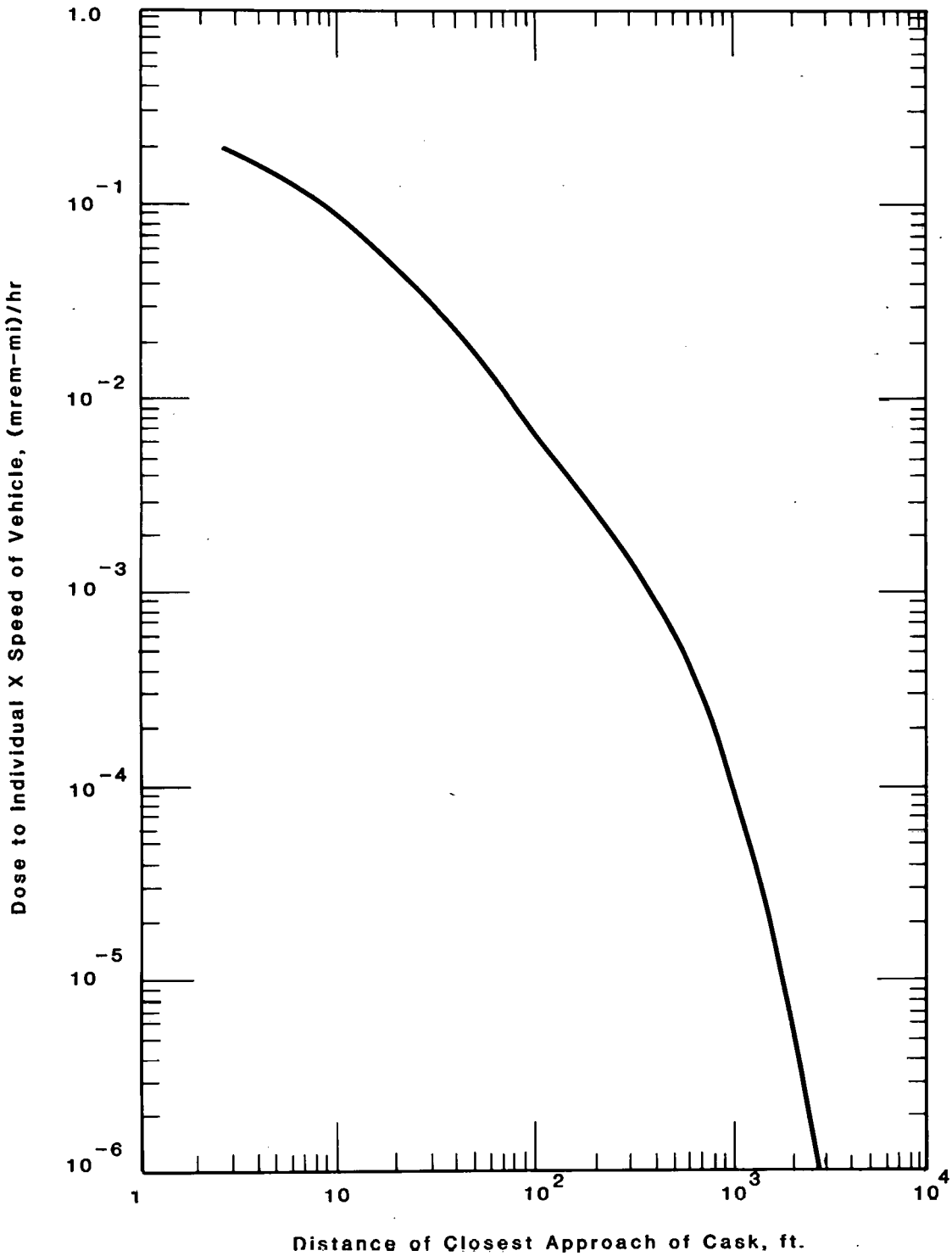


Figure A-5. Dose to Individual from Passage of Cask at 1 mph. [To obtain dose (mrem) to individual, divide ordinate value by vehicle speed in mph.]

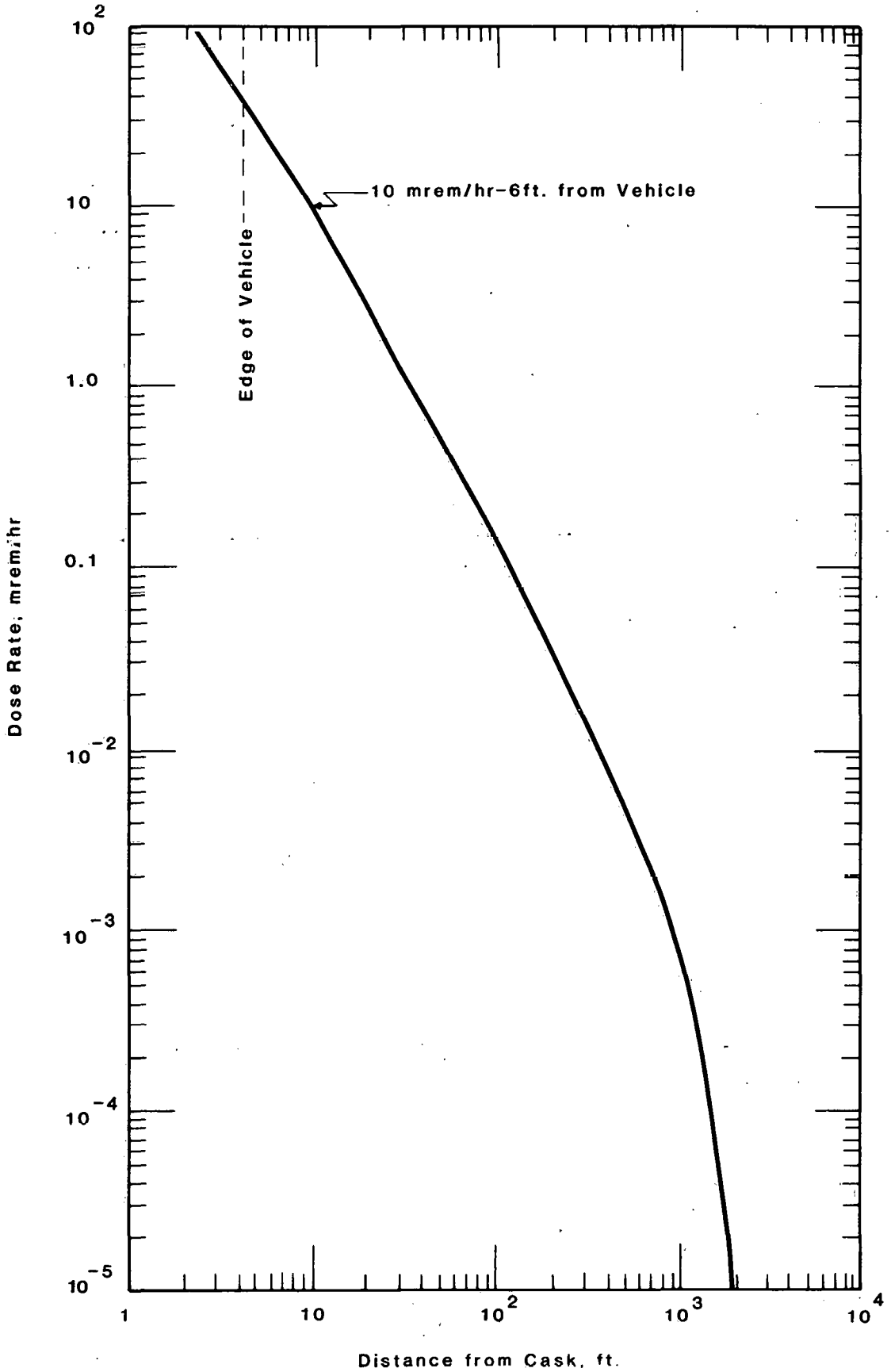


Figure A-6. Relationship of Dose Rate to Distance from Cask

TABLE A-17

GENERAL PARAMETERS
ROUTINE WASTE SHIPMENT SCENARIO

Parameter	Value	Unit
Population densities[a,b]		
Urban	1200	Persons/mi^2
Suburban	140	Persons/mi^2
Rural	30	Persons/mi^2
Train mileage per shipment		
Urban	37	Mi
Suburban	53	Mi
Rural	1410	Mi
Total distance	1500	Mi
Train speed (24 hr/day)	10	Mi/hr
Total railcar mi		
Alt. 3 (stabilize calcine)	8.68×10^6	Railcar-mi
Alt. 3 and 5 (glass)	1.3×10^7	Railcar-mi
Alt. 4	4.8×10^5	Railcar-mi
Casks per railcar[c]	1	Cask/car
Crew size	5	Persons
Cask dose rate	10×10^{-3}	Rem/hr at 6 ft from railcar.
	1.1×10^{-5}	Rem/hr at 300 ft from railcar.
Total number of crew members	90	
(6 days × 3 shifts/day) × 5 men/shift)		

a. Assumes maximum population route.

b. Based on 1990 population figures.

c. ATMX-600 series railroad cars.

Calculations have been performed to assess the effects of radiation from canisters during shipment to an offsite repository on two exposure groups: railroad personnel and the general population. Calculations for the population dose assess separately the doses to three subgroups: urban, suburban, and rural populations. The following sample calculations are given for Alternatives 3 and 4 in 1990, and for Alternative 5 in 2090, 2290, and 2490.

Calculation of Train Crew and Railroad Personnel Dose

In calculating the dose to crew members, it is assumed that:

- A train crew of 3 spends half its time 300 ft from the shipping cask.
- Ten personnel spend 5 min 6 ft from the railroad car for every 1000 mi traveled.

Thus the travel time is

$$\frac{1500 \text{ mi}}{10 \text{ mi/hr}} = 150 \text{ hr/cask}$$

and the time a crew member spends in the vicinity of a cask is

$$3 \text{ crew members} \times 1/2 \text{ time} \times 150 \text{ hr} = 225 \text{ man-hr/cask.}$$

The dose rate 300 ft from the car is

$$1.1 \times 10^{-5} \text{ rem/hr;}$$

therefore, the dose to the train crew is

$$2.5 \times 10^{-3} \text{ man-rem/cask.}$$

The dose to 10 additional railroad personnel each 6 ft from the railroad car for 5 min for each 1000 mi is

$$\frac{10 \text{ people} \times 5 \text{ min} \times 1500 \text{ mi/cask}}{1000 \text{ mi} \times 60 \text{ min/hr}} = 1.25 \text{ man-hr/cask.}$$

The dose rate at 6 ft from the car is

10×10^{-3} rem/hr;

therefore, the dose to other railroad personnel is

12.5×10^{-3} man-rem/cask.

Calculation of the General Population Dose Rate

The dose rate for the general population consists of three components: urban, suburban, and rural. Each of the component contributions is calculated in the following paragraphs.

In calculating the general population dose rate, it is assumed that:

- The closest members of the general population are uniformly distributed starting at 100 ft from the track. The number of people per mile at 100 ft from the track is equivalent to the square root of the population density.

- The next closest set of people is located 100 ft from the track plus the distance obtained from taking the inverse of the square root of the population density.

- The remaining population is located in sets of people at 100 ft from the track plus an integral multiple of the inverse of the square root of the population density.

As an example, by taking the urban population density given in Table A-17 and using the assumptions listed above, the population distribution data in Table A-18 are developed.

The following method is used to calculate the dose to individuals at various distances from the track. The calculation is shown for the urban population.

TABLE A-18

DATA FOR POPULATION DISTRIBUTION ALONG SHIPPING ROUTE
ROUTINE WASTE SHIPMENT SCENARIO

Region	Population Density (people/sq mi)	People per Mi 100 Ft from Track	Distance Between Subsequent Rows of People (mi)	(ft)
Urban	1200	34.6	2.9×10^{-2}	152
Suburban	140	11.8	8.5×10^{-2}	446
Rural	30	5.5	0.2	964

The number of people/mi at 100 ft from the track in an urban region

= $\sqrt{1200/\text{sq mi}}$

= 34.6 people/mi

and the distance between subsequent sets (or rows) of people in the urban region

= 1/34.6 mi

= 2.9×10^{-2} mi

= 152 ft.

The distance from the track to the second set of people in the urban region

= distance from track to first row of people in urban region

+ distance between subsequent rows of people in urban region

= 100 ft + 152 ft

= 252 ft.

The distance from track to n-th row of people in urban region

= distance from the track to the first set of people in the urban region

+ (n-1) distance between subsequent sets of people in the urban region.

For n = 3, the distance from the track to the third row of people in an urban region

$$= 100 \text{ ft} + 2\ (152 \text{ ft})$$
$$= 404 \text{ ft.}$$

This is the method used for developing the data for the "Distance from Individual to Tracks" column in Table A-19. The data for the suburban and rural populations can be found in the same way.

The number of people/mi at 100 ft from the track shown in Table A-18 represents the number on only one side of the track. Asssuming that each track side is a mirror image of the other, this number is doubled to account for the two sides of the track along which the general population can be exposed.

TABLE A-19

DATA FOR URBAN POPULATION DISTRIBUTION ALONG SHIPPING ROUTE
ROUTINE WASTE SHIPMENT SCENARIO

Distance from Individual to Tracks (ft)	Dose to Individual from Passing Cask (rem)	
	Train Speed[a] (1 mi/hr)	Train Speed[b] (10 mi/hr)
100	7×10^{-6}	7×10^{-7}
252	2×10^{-6}	2×10^{-7}
404	1×10^{-6}	1×10^{-7}
556	4×10^{-7}	4×10^{-8}
708	3×10^{-7}	3×10^{-8}
860	2×10^{-7}	2×10^{-8}
1,012	1×10^{-7}	1×10^{-8}

a. Dose values are interpolated from Figure A-5.

b. Dose values for a train speed of 1 mi/hr are multiplied by 10^{-1} to obtain these dose values.

Calculation of the Urban Population Dose Rate

The data in Table A-19 are used to obtain the dose to individuals in a set up to 1,012 ft from the track. The dose is obtained by summing the dose values at 10 mi/hr.

$$\text{Dose} = 1.1 \times 10^{-6} \text{ man-rem/cask.}$$

To calculate the dose to persons in a set at distances of 1,012 ft to 2,987 ft (2,987 ft is the maximum distance for the cut-off dose derived from Figure A-7) from the railroad tracks, it is assumed that the dose is the same as it is at 1,012 ft; that is,

$$\frac{2987 \text{ ft} - 1012 \text{ ft}}{152 \text{ ft/person}} \times 1.0 \times 10^{-8} \text{ rem/cask} = 1.3 \times 10^{-7} \text{ man-rem/cask.}$$

The dose to persons who are more than 2,987 ft from the tracks is assumed to be zero.

The total dose to persons in a set in the urban area is the sum of values previously determined:

$$D_u = 1.1 \times 10^{-6} \text{ man-rem/cask} + 1.3 \times 10^{-7} \text{ man-rem/cask}$$
$$= 1.2 \times 10^{-6} \text{ man-rem/cask.}$$

The number of sets of people on both sides of the track for the urban waste shipment route is obtained using data in Table A-17.

$$N_u = 34.6 \text{ sets/urban mi} \times 37 \text{ urban mi} \times 2$$

and

$$N_u = 2.6 \times 10^{3} \text{ sets.}$$

The total dose to the urban population is obtained as follows:

$$D_{ut} = D_u \times N_u.$$
$$D_{ut} = (1.2 \times 10^{-6} \text{ man-rem/cask}) \ (2.6 \times 10^{3} \text{ sets})$$

and

$$D_u = 3.1 \times 10^{-3} \text{ man-rem/cask.}$$

Calculation of the Suburban Population Dose Rate

The data applied to the calculation of the suburban population dose appear in Table A-20.

TABLE A-20

DATA FOR SUBURBAN POPULATION DISTRIBUTION ALONG SHIPPING ROUTE
ROUTINE WASTE SHIPMENT SCENARIO

Distance from Individual to Tracks[a] (ft)	Dose to Individual from Passing Cask (rem)	
	Train Speed[b] (1 mi/hr)	Train Speed[c] (10 mi/hr)
100	7×10^{-6}	7×10^{-7}
546	4×10^{-7}	4×10^{-8}
992	1×10^{-7}	1×10^{-8}
1438	2×10^{-8}	2×10^{-9}
1884	8×10^{-9}	8×10^{-10}
2330	3×10^{-9}	3×10^{-10}
2776	1×10^{-9}	1×10^{-10}
3222	1×10^{-9}	1×10^{-10}

a. Distances are developed as described for Table A-19.

b. Dose values are interpolated from Figure A-5.

c. Dose values for a train speed of 1 mi/hr are multiplied by 10^{-1} to obtain these values.

The dose to a set of individuals at the distances indicated in Table A-20 is obtained by summing the values at 10 mi/hr:

$$D_s = 7.5 \times 10^{-7} \text{ man-rem/cask.}$$

The dose to persons who are greater than 3,222 ft from the tracks is assumed to be zero. (The maximum distance for the cut-off dose derived from Figure A-7 is 3,222 ft.)

The number of sets of people on both sides of the track for the waste shipment route through a suburban area is obtained using data in Table A-17.

$$N_s = 11.8 \text{ sets/suburban mi} \times 53 \text{ suburban mi} \times 2$$

and

$$N_s = 1.25 \times 10^3 \text{ sets.}$$

The total dose to the suburban population is obtained as follows:

$$D_{st} = D_s \times N_s$$

$$D_{st} = 7.5 \times 10^{-7} \text{ man-rem/cask} \times 1.25 \times 10^3 \text{ sets}$$

and

$$D_s = 9.4 \times 10^{-4} \text{ man-rem/cask.}$$

Calculation of the Rural Population Dose Rate

The data given in Table A-21 are applied to the calculation of the rural population dose.

TABLE A-21

DATA FOR RURAL POPULATION DISTRIBUTION ALONG SHIPPING ROUTE
ROUTINE WASTE SHIPMENT SCENARIO

Distance from Individual to Tracks[a] (ft)	Dose to Individual from Passing Cask (rem)	
	Train Speed[b] (1 mi/hr)	Train Speed[c] (10 mi/hr)
100	7×10^{-6}	7×10^{-7}
1064	1×10^{-7}	1×10^{-8}
2028	8×10^{-9}	8×10^{-10}
2992	1×10^{-9}	1×10^{-10}

a. Distances are developed as described for Table A-19.

b. Dose values are interpolated from Figure A-5.

c. Dose values for a train speed of 1 mi/hr are multiplied by 10^{-1} to obtain these values.

The dose to one set of individuals at the distances indicated in Table A-21 is obtained by summing the values at 10 mi/hr:

$$D_r = 7.1 \times 10^{-7} \text{ man-rem/cask.}$$

The dose to persons who are greater than 2,992 ft from the track is assumed to be zero. (The maximum distance for the cut-off dose derived from Figure A-7 is 2,992 ft.)

The total number of sets of people on both sides of the track along the shipping route is obtained using data in Table A-17 as follows:

$$N_r = 5.5 \text{ sets/rural mi} \times 1410 \text{ rural mi} \times 2$$

and

$$N_r = 1.6 \times 10^{4} \text{ sets.}$$

The total dose to the rural population is obtained as follows:

$$D_{rt} = D_r \times N_r$$
$$= 7.1 \times 10^{-7} \text{ man-rem/cask} \times 1.6 \times 10^{4} \text{ sets}$$

and

$$D_{rt} = 1.1 \times 10^{-2} \text{ man-rem/cask.}$$

Calculation of Passenger Dose Rate

The dose to individuals close to the shipping cask includes the dose to passengers on other trains that pass the cask. It is assumed that:

- Three hundred passengers/day on other trains pass 10 ft from the cask at a relative speed of 30 mph.

$$\frac{8.0 \times 10^{-5} \text{ rem-mi/hr}}{30 \text{ mi/hr}} = 2.7 \times 10^{-6} \text{ rem/cask}$$

where

8.0×10^{-5} rem-mi/hr is obtained by interpolation from Figure A-7.

The number of days in which the cask is in transit is given by

$$\frac{1500 \text{ mi}}{10 \text{ mi/hr} \times 24 \text{ hr/day}} = 6.3 \text{ days.}$$

The dose to passengers on other trains is obtained as follows:

$$= 300 \frac{\text{passengers}}{\text{day}} \times 6.3 \text{ days} \times 2.7 \times 10^{-6} \text{ rem/cask}$$

$$= 5.0 \times 10^{-3} \text{ man-rem/cask.}$$

Calculation of the Onlooker Dose Rate

Next, the dose to onlookers close to the shipping cask is determined. The dose rate to an onlooker 3 ft from the train (7 ft from the cask) is 20×10^{-3} rem/hr. (The dose is obtained by interpolation from Figure A-8.) It is assumed that:

- Ten onlookers spend 3 min 3 ft from the car for every 100 mi traveled.

Thus, the dose to onlookers is calculated:

$$10 \text{ persons} \times \frac{3 \text{ min}}{60 \text{ min/hr}} \times \frac{1000 \text{ mi}}{1500 \text{ mi}}$$

$$= 3.3 \times 10^{-1} \text{ man-hr/cask}$$

and

$$(20 \times 10^{-3} \text{ rem/hr}) \ (3.3 \times 10^{-1} \text{ man-hr/cask})$$

$$= 6.7 \times 10^{-3} \text{ man-rem/cask.}$$

The doses for all individuals exposed to one shipping cask over a transport distance of 1500 mi are summarized in Table A-22.

Calculation of Maximum Individual Dose Rates

The maximum individual dose rate for the train crew is determined from the data given in Table A-17. The dose per cask for railroad personnel is

TABLE A-22

DOSE FROM SHIPPING 1 CASK 1500 MILES
ROUTINE WASTE SHIPMENT SCENARIO

Component	Dose (Man-Rem/Cask)		
Train Crew			
3 crew members at 300 ft half-time			2.5×10^{-3}
10 personnel at 6 ft for 5 min			12.5 × 10-3
General Population			
	1990	2090	2290 and 2490
Urban	3.1×10^{-3}	5.2×10^{-3}	6.2×10^{-3}
Suburban	9.4×10^{-4}	1.6×10^{-3}	2.0×10^{-3}
Rural	1.1×10^{-2}	1.8×10^{-2}	2.2×10^{-2}
Individuals close to passing cask			
Passengers on other trains			5.0×10^{-3}
Onlookers			6.7×10^{-3}
TOTAL*	4.2×10^{-2}	5.2×10^{-2}	5.7×10^{-2}

* Rounded to two significant digits.

2.5×10^{-3} man-rem/cask for 3 crew members at 300 ft
12.5×10^{-3} man-rem/cask for 10 crew members at 6 ft
15×10^{-3} man-rem/cask total.

It is assumed that 15×10^{-3} man-rem/cask affects 90 railroad personnel. The maximum individual dose is

$$\frac{15 \times 10^{-3} \text{ man-rem/cask}}{90 \text{ railroad personnel}} = 1.7 \times 10^{-4} \text{ rem/cask.}$$

For the general population, the maximum individual dose rate is that received by the individual positioned 100 ft from the train. The dose he receives is 7×10^{-7} rem/cask shipped.

For other individuals in close proximity to the shipment, the maximum individual dose rate for a passenger on a passing train is 2.7×10^{-6} rem/cask; the maximum individual dose for an onlooker is 1.0×10^{-3} rem/cask. The onlooker dose is calculated as follows:

$$20 \times 10^{-3} \frac{\text{rem}}{\text{hr}} \times \frac{3 \text{ min/cask}}{60 \text{ min/hr}} = 1 \times 10^{-3} \text{ rem/cask.}$$

The maximum individual dose for each alternative is given in Tables B-9 through B-14.

Calculation of Population Doses and Health Effects

The population doses and health effects from routine waste shipment are given in Table A-23. The doses are calculated using the railcar miles from Table A-17. The total population dose has been calculated for Alternatives 3, 4, and 5, and the results are listed in Table A-23.

TABLE A-23

POPULATION DOSES
ROUTINE WASTE SHIPMENT SCENARIO

Alternative	Casks Shipped[a] (Number)	Population Dose[b] (Man-Rem)	Range of Health Effects (Number)
3 - Stabilize calcine	5.7×10^{3}	2.4×10^{2}	1.78×10^{-2} to 5.46×10^{-2}
3 - Glass	8.7×10^{3}	3.6×10^{2}	2.72×10^{-2} to 8.34×10^{-2}
4 - Actinide glass	3.2×10^{2}	1.3×10^{1}	9.37×10^{-4} to 2.87×10^{-3}
5 - Glass delay 100 yr	8.7×10^{3}	4.5×10^{2}	3.37×10^{-2} to 1.03×10^{-1}
5 - Glass delay 300 yr	8.7×10^{3}	4.9×10^{2}	3.67×10^{-2} to 1.13×10^{-1}
5 - Glass delay 500 yr	8.7×10^{3}	4.9×10^{2}	3.67×10^{-2} to 1.13×10^{-1}

a. Data from Table A-17.

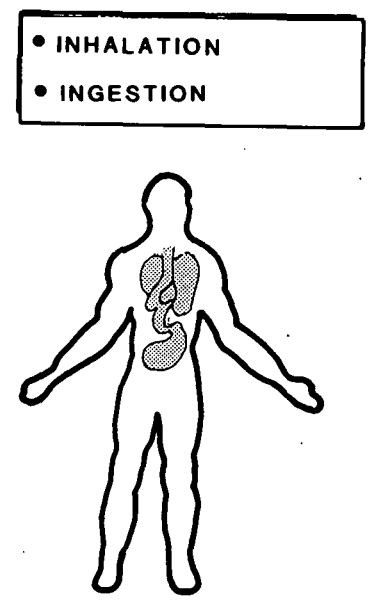
b. Based on doses given in Table A-22.

The health effects associated with the population dose are based on the BEIR III Report in which it is estimated that 1 million man-rem cause between 75 and 230 excess cancer fatalities. (See Appendix B, Tables B-9 through B-14.)

A.1.8.1.3 Accidental Releases

A.1.8.1.3.1 Calcine Spill

Should spillage occur during calcine processing operations, the general public could be exposed to a small increase in radiation by inhalation of contaminated air, ingestion of contaminated food, and direct radiation. Workers would not be affected because operations occur in isolated cells where the air pressure is negative. Calculations show that inhalation and ingestion are the significant pathways as indicated in the accompanying illustration. The calcine spill scenario applies to Alternatives 2, 3, 4, and 5, all of which involve calcine retrieval and processing. The assumed amount of spilled calcine is based on a similar incident which occurred in the ICPP waste calcining facility calciner cell. In that incident, failure of a motor driven delivery valve allowed the contents of the calcine receiver vessel to discharge onto the cell floor. The spilled calcine became airborne and entered the cell ventilation system. The quantity of calcine released to the environment was reduced by a factor of 10^9 after passing through exhaust ducts and HEPA filters. The scenario is illustrated in Subsection 4.5.1.2.2.



CALCINE SPILL

The calcine spill scenario is based on the following assumptions:

- The amount of calcine spilled is 1300 kg (2866 lbs).
- Of the spilled calcine, 0.01% becomes airborne.
- The airborne fraction is reduced by a 10^9 decontamination factor.

- The probability of occurrence is 0.2 event per year.
- A population of 71,000 is exposed to radiation in 1990.

Workers would not be affected by the accident as the spill would occur in a cell which is isolated by negative air pressure within the cell.

The following sample calculation gives the maximum individual whole-body dose commitment for Alternatives 2, 3, and 4 from strontium-90 (Sr-90) in 1990.

Calculation of Inhalation Pathway Dose

The contribution of a single radionuclide, isotope i, to the maximum individual from inhalation is given by the following equations:

$$D_i = C_i \times V \times DF_i \qquad \text{(A-1)}$$

where

$$V = B \times T \qquad \text{(A-2)}$$

$$C_i = Q_i \times \frac{\chi}{Q} \qquad \text{(A-3)}$$

where

$$Q_i = Q_s \times F_i \times C_{ci} \times \frac{1}{3600T} \quad . \qquad \text{(A-4a)}$$

Data for use in these equations are presented in Table A-24.

Step 1

Substitution of the numerical values from Table A-24 into Equations A-1, A-2, A-3, and A-4a gives the maximum individual organ doses from inhalation of Sr-90:

D_i (lung) $= 1.60 \times 10^{-11}$ rem
D_i (liver) $= 3.58 \times 10^{-14}$ rem
D_i (bone surface) $= 4.32 \times 10^{-13}$ rem
D_i (total body) $= 2.82 \times 10^{-13}$ rem.

TABLE A-24

DATA FOR INHALATION PATHWAY
CALCINE SPILL SCENARIO
(Sr-90)

Variable	Quantity	Unit	Reference
Q_s	1.3×10^{3}	kg	Engineering judgment.
C_{ci}	13.0×10^{6}	μCi/kg	Table A-2
F_i	1.0×10^{-13}	none	Engineering judgment.
χ/Q	2.0×10^{-6}	sec/m^3	Table A-7, accident case.
B	2.0	m^3/hr	Working rate.
DF_i (bone surface)	2.30×10^{-1}	rem/μCi	Table A-3
DF_i (lung)	8.50	rem/μCi	Table A-3
DF_i (liver)	1.90×10^{-2}	rem/μCi	Table A-3
DF_i (total body)	1.50×10^{-1}	rem/μCi	Table A-3
T	8.76×10^{3}	hr	1 yr

Step 2

The inhalation organ dose commitments from all radionuclides are determined by using the values of isotope concentrations in Table A-2 and appropriate DF_i values. These total dose commitments are

D_t (lung) $= 2.70 \times 10^{-11}$ rem
D_t (liver) $= 8.07 \times 10^{-12}$ rem
D_t (bone surface) $= 3.71 \times 10^{-11}$ rem
D_t (total body) $= 2.00 \times 10^{-12}$ rem.

Calculation of Ingestion Pathway Dose

The ingestion pathway has three contributing subpathways: ingestion of fruits and vegetables, ingestion of milk, and ingestion of meat from animals

grazed on contaminated forage. Basic to all three ingestion subpathways is the radionuclide concentration in vegetation which is calculated from Equation A-5.

$$C_{iv} = D_{pi}\left(R\,\frac{[1 - e^{-(\lambda_e + \lambda_i)t_e}]}{Y(\lambda_e + \lambda_i)} + B_{iv}\,\frac{[1 - e^{-\lambda_i t_s}]}{P\lambda_i}\right)e^{-\lambda_i t_c} \qquad \text{(A-5)}$$

where

$$D_{pi} = \frac{\chi}{Q} \times V_d \times Q_i \qquad \text{(A-6)}$$

where

$$Q_i = Q_s \times F_i \times C_{ci} \times \frac{1}{T} \quad . \qquad \text{(A-4b)}$$

The data for the calculation of C_{iv} appear in Tables A-24 and A-25. Dose commitments for the three ingestion subpathways are calculated as follows.

Calculation of Dose Commitment from Fruits and Vegetables Consumption

Calculate the radionuclide concentration in fruits and vegetables using Equation A-5 and the data in Tables A-24 and A-25. The result is

$$C_{iv} = 4.93 \times 10^{-12}\ \frac{\mu Ci}{kg} \quad .$$

The dose from ingestion of fruits and vegetables is determined by the equations:

$$D_{fi} = Q_{fi} \times DF_i \qquad \text{(A-7)}$$

where

$$Q_{fi} = U_f \times C_{iv} \quad . \qquad \text{(A-8)}$$

Additional data for calculation of the dose from consumption of fruits and vegetables appear in Table A-26.

TABLE A-25

DATA FOR RADIONUCLIDE CONCENTRATION IN VEGETATION
CALCINE SPILL SCENARIO
(Sr-90)

Variable	Quantity	Unit	Reference
χ/Q	3.0×10^{-6}	sec/m^3	Table A-7
R	2.0×10^{-1}	none	Scenario
λ_e	0	hr^{-1}	RG 1.109
t_e	7.2×10^{2}	hr	RG 1.109
Y	2^a 0.7^b	kg/m^2	RG 1.109
V_d	0.01	m/sec	Engineering judgment.
B_{iv}	1.7×10^{-2}	none	RG 1.109
λ_i	2.73×10^{-6}	hr^{-1}	Sr-90
t_s	8.77×10^{3}	hr	RG 1.109
P	240	kg/m^2	RG 1.109
t_c	0	hr	Maximizes concentration.

a. For fruits and vegetables consumed directly by man.

b. For contaminated forage consumed by meat- or milk-producing animals.

Step 1

Substitution of the numerical values from Table A-26 into Equations A-7 and A-8 gives the organ doses of Sr-90 from consumption of fruits and vegetables:

D_i (lung) $= 1.74 \times 10^{-17}$ rem
D_i (liver) $= 1.67 \times 10^{-11}$ rem
D_i (bone surface) $= 2.52 \times 10^{-9}$ rem
D_i (total body) $= 2.77 \times 10^{-10}$ rem.

TABLE A-26

DATA FOR FRUITS AND VEGETABLES CONSUMPTION
CALCINE SPILL SCENARIO
(Sr-90)

Variable	Quantity	Unit	Reference
U_f	584	kg/yr	RG 1.109
DF_i (bone surface)	8.60×10^{-1}	rem/μCi	Table A-4
DF_i (liver)	5.71×10^{-3}	rem/μCi	Table A-4
DF_i (lung)	5.94×10^{-9}	rem/μCi	Table A-4
DF_i (total body)	9.45×10^{-2}	rem/μCi	Table A-4
C_{iv}	4.93×10^{-12}	μCi/kg	Equation A-5

Step 2

The organ doses from all radionuclides are determined by using the values of isotope concentrations in Table A-2 and the appropriate DF_i from NUREG/CR-0150.

D_t (lung) $= 8.82 \times 10^{-11}$ rem
D_t (liver) $= 3.26 \times 10^{-10}$ rem
D_t (bone surface) $= 2.87 \times 10^{-9}$ rem
D_t (total body) $= 4.70 \times 10^{-10}$ rem.

Calculation of Ingestion Dose Commitment from Meat Consumption

The dose resulting from consumption of meat produced by animals grazed on contaminated forage is obtained using the following equations. Calculate the radionuclide concentration in meat from contaminated forage using Equation A-5 and the data in Tables A-24 and A-25 where Y = 0.7 kg/m^2. The result is

$$C_{iv} = 1.45 \times 10^{-11} \text{ μCi/kg} \quad .$$

The dose from ingestion of meat produced by animals grazed on contaminated forage is given by the equations from Subsection A.1.9:

$$D_{mfi} = Q_{mfi} \times DF_i \quad \text{(A-9)}$$

where

$$Q_{mfi} = U_{mf} \times A_m \times S_{bi} \times C_{iv} \quad . \quad \text{(A-10)}$$

The data for calculation of the dose from ingestion of meat produced by animals grazed on contaminated forage appear in Table A-27.

TABLE A-27

DATA FOR MEAT CONSUMPTION
CALCINE SPILL SCENARIO
(Sr-90)

Variable	Quantity	Unit	Reference
U_{mf}	110	kg/yr	RG 1.109
A_m	50	kg/day	RG 1.109
S_{bi}	6.0×10^{-4}	day/kg	RG 1.109
C_{iv}	1.45×10^{-11}	μCi/kg	Equation A-5
DF_i	Use applicable organ dose conversion factors.	rem/μCi	Table A-4

Step 1

Substitution of the numerical values from Table A-27 into Equations A-9 and A-10 gives the organ doses of isotope i, Sr-90, in meat produced from animals grazed on contaminated forage:

D_i (lung) $= 2.81 \times 10^{-19}$ rem
D_i (liver) $= 2.74 \times 10^{-13}$ rem
D_i (bone surface) $= 4.06 \times 10^{-11}$ rem
D_i (total body) $= 4.46 \times 10^{-12}$ rem.

Step 2

The organ doses from all radionuclides for consumption of meat produced from animals fed on contaminated forage are determined by using the values of

isotope concentrations in Table A-2 and the appropriate DF_i values in NUREG/CR-0150:

D_t (lung) $= 9.86 \times 10^{-12}$ rem
D_t (liver) $= 4.63 \times 10^{-11}$ rem
D_t (bone surface) $= 8.85 \times 10^{-11}$ rem
D_t (total body) $= 3.51 \times 10^{-11}$ rem.

Calculation of Ingestion Dose Commitment from Milk Consumption

The contribution of the significant nuclide, Sr-90, to the maximum individual dose commitment by ingestion of milk from animals grazed on contaminated forage is given by the equations:

$$D_{cfi} = Q_{cfi} \times DF_i \quad \text{(A-11)}$$

where

$$Q_{cfi} = U_{cf} \times A_m \times S_{ci} \times C_{iv} \quad . \quad \text{(A-12)}$$

The data for calculation of the dose from ingestion of milk produced by animals grazed on contaminated forage appear in Table A-28.

TABLE A-28

DATA FOR MILK CONSUMPTION
CALCINE SPILL SCENARIO
(Sr-90)

Variable	Quantity	Unit	Reference
U_{cf}	310	ℓ/yr	RG 1.109
A_m	50	kg/day	RG 1.109
S_{ci}	8.0×10^{-4}	day/ℓ	RG 1.109
C_{iv}	1.45×10^{-11}	μCi/kg	Equation A-5
DF_i	Use applicable organ dose conversion.	rem/μCi	Table A-4

Step 1

Substitution of the numerical values from Table A-28 into Equations A-11 and A-12 gives the organ doses for isotope i, Sr-90, from milk produced by animals grazed on contaminated forage:

D_i (lung) $= 1.05 \times 10^{-18}$ rem
D_i (liver) $= 1.02 \times 10^{-12}$ rem
D_i (bone surface) $= 1.53 \times 10^{-10}$ rem
D_i (total body) $= 1.68 \times 10^{-11}$ rem.

Step 2

The organ doses from all radionuclides from consumption of milk produced by animals fed on contaminated forage are determined by using the values of isotopic concentrations in Table A-2 and the appropriate DF_i values from NUREG/CR-0150:

D_t (lung) $= 8.02 \times 10^{-11}$ rem
D_t (liver) $= 2.69 \times 10^{-10}$ rem
D_t (bone surface) $= 4.17 \times 10^{-10}$ rem
D_t (total body) $= 1.87 \times 10^{-10}$ rem.

Calculation of Direct Radiation Pathway Dose

The direct radiation dose results from material deposited on the ground as the result of a calcine spill. The dose commitment from ground-plane deposition for 1 yr is given by the equations:

$$D_{gi} = t_x \times S_f \times C_{gi} \times DF_{gi} \qquad \text{(A-13)}$$

where

$$C_{gi} = D_{pi} \frac{(1 - e^{-\lambda_i t_s})}{\lambda_i PL} \qquad \text{(A-14)}$$

Step 1

Since DF_{gi} for a beta emitter such as Sr-90 is zero, the total-body contribution from the ground-plane deposition of Sr-90 is zero.

Step 2

The ground-plane doses from all isotopes are determined by using isotope concentrations in Table A-2 and the dose conversion factors from the ISOSHLD code.

The total whole-body ground-plane deposition dose from the calcine spill is 4.10×10^{-12} rem.

Calculation of Whole-Body Equivalent Doses and Health Effects

Step 3

Step 3 consists of summing the dose commitments from all pathways, for all isotopes, and for all organs at risk. The total doses for each pathway are given in Table A-29.

TABLE A-29

INDIVIDUAL PATHWAY ORGAN DOSE COMMITMENTS (rem)
CALCINE SPILL SCENARIO

Organ	Inhalation	Fruits and Vegetables	Meat	Milk	Total
Bone surface	3.71×10^{-11}	2.87×10^{-9}	8.85×10^{-11}	4.17×10^{-10}	3.41×10^{-9}
Liver	8.07×10^{-12}	3.26×10^{-10}	4.63×10^{-11}	2.69×10^{-10}	6.49×10^{-10}
Lung	2.07×10^{-11}	8.82×10^{-11}	9.86×10^{-12}	8.02×10^{-11}	2.05×10^{-10}
Total body	2.00×10^{-12}	4.70×10^{-10}	3.51×10^{-11}	1.87×10^{-10}	6.95×10^{-10}

Step 4

Organ dose commitments calculated in Step 3 are multiplied by the appropriate weighting factor (W_T) from Table A-6 to calculate the whole-body equivalent (WBE) dose.

$$WBE_j = D_j \times W_{Tj}$$

where

WBE_j (bone surface) $= 3.41 \times 10^{-9}$ (0.03) $= 1.02 \times 10^{-10}$ rem
WBE_j (liver) $= 6.49 \times 10^{-10}$ (0.06) $= 3.89 \times 10^{-11}$ rem
WBE_j (lung) $= 2.05 \times 10^{-10}$ (0.12) $= 2.46 \times 10^{-11}$ rem
WBE_j (total body) $= 6.95 \times 10^{-10}$ (0.06) $= 4.17 \times 10^{-11}$ rem.

Using these calculated WBE doses and the procedure outlined in Subsection A.1.3.1 and weighting factors from Table A-6, the maximum individual dose from the calcine spill scenario is

$$WBE = 9.10 \times 10^{-10} \text{ rem.}$$

The WBE dose is sufficiently large that the ground-plane dose of 4.10×10^{-12} rem in 1 yr does not contribute significantly to the total dose.

Step 5

The population dose commitment is calculated from the maximum individual dose as follows.

$$\text{Population WBE dose} = (9.10 \times 10^{-10})(0.04)(71{,}000)$$
$$= 2.58 \times 10^{-6} \text{ man-rem.}$$

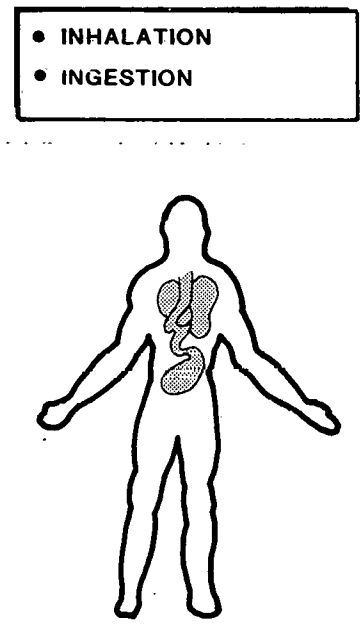
Step 6

The health effects associated with the population dose are based on the BEIR III Report in which it is estimated that 1 million man-rem cause between 75 and 230 excess cancer fatalities. Multiplying the population WBE dose by 7.5×10^{-5} and 2.3×10^{-4} gives a range of 1.94×10^{-10} to 5.94×10^{-10} excess cancer fatality from the calcine spill scenario for Alternatives 2, 3 and 4 in 1990. (See Appendix B, Tables B-24, B-25, B-26, B-27, and B-28.)

For comparison, the population WBE dose from background radiation = $(1.5 \times 10^{-1})(71{,}000) = 1.07 \times 10^{4}$ man-rem, and the range of background health effects is 0.80 to 2.4.

A.1.8.1.3.2 Decontamination Solution Spill

Maintenance-related decontamination activities within the waste form modification facility could result in an accidental spill outside the facility of decontamination solution containing dissolved calcine. Inhalation, ingestion, and direct radiation are the pathways by which the general public would be exposed to radiation from this event. The calculations show that the most significant exposure pathways are ingestion and inhalation, as shown in the accompanying illustration. The scenario is illustrated in Subsection 4.5.1.2.2. The decontamination solution spill scenario applies to Alternatives 2, 3, 4, and 5, all of which require facility maintenance.



DECONTAMINATION SPILL

In this scenario, it is assumed that:

- The spill occurs outside the processing plant when a cap left open on a decontamination solution line causes a spill during transfer of the contaminated solution.
- The amount of the decontamination solution spill is 325 ℓ (85 gal).
- The solution is contained in 250 ft of 3-in. pipe which has a 5-mil-thick scale of calcine dissolved in the solution.
- Of the spilled material, 0.1% becomes airborne; the remainder is absorbed by the soil and treated as a solid waste.
- The probability of occurrence is 0.1 event per year.
- A population of 71,000 is exposed to radiation in 1990.

The following sample calculation gives the maximum individual whole-body dose commitment for Alternatives 2, 3, and 4 from plutonium-238 (Pu-238) in 1990.

Calculation of Inhalation Pathway Dose

The contribution of a single isotope, Pu-238, to the maximum individual dose commitment from the inhalation pathway is given by the equations:

$$D_i = C_i \times V \times DF_i \qquad \text{(A-1)}$$

where

$$V = B \times T \qquad \text{(A-2)}$$

$$C_i = Q_i \times \frac{\chi}{Q} \qquad \text{(A-3)}$$

where

$$Q_i = Q_s \times F_i \times C_{ci} \times \frac{1}{3600T} \quad . \qquad \text{(A-4a)}$$

The data for calculation of the inhalation dose from a decontamination solution spill are given in Table A-30.

Step 1

Substitution of the numerical values from Table A-30 into Equations A-1, A-2, A-3, and A-4a gives the maximum individual organ doses from inhalation of Pu-238:

D_i (lung) $= 4.80 \times 10^{-4}$ rem
D_i (liver) $= 5.52 \times 10^{-4}$ rem
D_i (bone surface) $= 2.58 \times 10^{-3}$ rem
D_i (total body) $= 1.11 \times 10^{-4}$ rem.

Step 2

The inhalation organ dose commitments from all radionuclides are determined by using the values of isotope concentrations in Table A-2 and appropriate DF_i values. These total dose commitments are

TABLE A-30

DATA FOR INHALATION PATHWAY
DECONTAMINATION SOLUTION SPILL SCENARIO
(Pu-238)

Variable	Quantity	Unit	Reference
Q_s	2.9	kg	Engineering judgment.
C_{ci}	7.0×10^{4}	μCi/kg	Table A-2
F_i	1×10^{-3}	none	Engineering judgment.
χ/Q	7.0×10^{-6}	sec/m^3	Table A-7
B	2	m^3/hr	Working rate.
DF_i (bone surface)	3.27×10^{3}	rem/μCi	Table A-3
DF_i (lung)	6.08×10^{2}	rem/μCi	Table A-3
DF_i (liver)	7.00×10^{2}	rem/μCi	Table A-3
DF_i (total body)	1.40×10^{2}	rem/μCi	Table A-3

D_t (lung) = 2.11×10^{-3} rem
D_t (liver) = 6.30×10^{-4} rem
D_t (bone surface) = 2.89×10^{-3} rem
D_t (total body) = 1.56×10^{-4} rem.

Calculation of Ingestion Pathway Dose

The ingestion pathway has three contributing subpathways: ingestion of fruits and vegetables, ingestion of milk, and ingestion of meat from animals grazed on contaminated forage. Basic to all three subpathways is the radionuclide concentration in vegetation is calculated from Equation A-5.

$$C_{iv} = D_{pi}\left(R\,\frac{[1 - e^{-(\lambda_e + \lambda_i)t_e}]}{Y(\lambda_e + \lambda_i)} + B_{iv}\,\frac{[1 - e^{-\lambda_i t_s}]}{P\lambda_i}\right)e^{-\lambda_i t_c} \qquad \text{(A-5)}$$

where

$$D_{pi} = \frac{\chi}{Q} \times V_d \times Q_i \qquad \text{(A-6)}$$

where

$$Q_i = Q_s \times F_i \times C_{ci} \times \frac{1}{T} \quad . \qquad \text{(A-4b)}$$

The data for the calculation of C_{iv} appear in Tables A-30 and A-31. Dose commitments for the three ingestion subpathways are calculated separately as follows.

TABLE A-31

DATA FOR RADIONUCLIDE CONCENTRATION IN DECONTAMINATION SOLUTION SPILL SCENARIO (Pu-238)

Variable	Quantity	Unit	Reference
χ/Q	9×10^{-6}	sec/m^3	Table A-7
R	2.0×10^{-1}	none	RG 1.109
λ_e	0	hr^{-1}	RG 1.109
t_e	8.76×10^3	hr	RG 1.109
Y	2[a] 0.7[b]	kg/m^2	RG 1.109
B_{iv}	2.5×10^{-4}	none	RG 1.109
λ_i	9.15×10^{-7}	hr^{-1}	RG 1.109
t_s	8.76×10^3	hr	RG 1.109
P	240	kg/m^2	RG 1.109
t_c	0	hr	Maximizes concentration.
V_d	0.01	m/sec	RG 1.109

a. For vegetation consumed directly by man.

b. For vegetation consumed by meat- or milk-producing animals.

Calculation of Ingestion Dose Commitment from Fruits and Vegetables Consumption

Calculate the radionuclide concentration in fruits and vegetables using Equation A-5 and the data in Tables A-30 and A-31. The result is

$$C_{iv} = 1.87 \times 10^{-6} \frac{\mu Ci}{kg} .$$

The dose from ingestion of fruits and vegetables is determined by the equations:

$$D_{fi} = Q_{fi} \times DF_i \qquad (A-7)$$

where

$$Q_{fi} = U_f \times C_{iv} . \qquad (A-8)$$

The data for calculation of the dose from consumption of fruits and vegetables appear in Table A-32.

TABLE A-32

DATA FOR FRUITS AND VEGETABLES CONSUMPTION
DECONTAMINATION SOLUTION SPILL SCENARIO
(Pu-238)

Variable	Quantity	Unit	Reference
U_f	584	kg/yr	RG 1.109
DF_i (bone surface)	2.10	rem/μCi	Table A-4
DF_i (liver)	4.40×10^{-1}	rem/μCi	Table A-4
DF_i (lung)	1.14×10^{-7}	rem/μCi	Table A-4
DF_i (total body)	8.50×10^{-2}	rem/μCi	Table A-4
C_{iv}	1.87×10^{-6}	μCi/kg	Equation A-5

Step 1

Substitution of the numerical values from Table A-32 into Equations A-7 and A-8 gives the organ doses of Pu-238 from consumption of fruits and vegetables:

D_i (lung) $= 1.24 \times 10^{-10}$ rem
D_i (liver) $= 4.81 \times 10^{-4}$ rem
D_i (bone surface) $= 2.29 \times 10^{-3}$ rem
D_i (total body) $= 9.28 \times 10^{-5}$ rem.

Step 2

The organ doses from all radionuclides are determined by using the values of isotope concentrations in Table A-2 and the appropriate DF_i values from NUREG/CR-0150.

D_t (lung) $= 5.90 \times 10^{-3}$ rem
D_t (liver) $= 2.18 \times 10^{-2}$ rem
D_t (bone) $= 1.92 \times 10^{-1}$ rem
D_t (total body) $= 3.15 \times 10^{-2}$ rem.

Calculation of Ingestion Dose Commitment from Meat Consumption

The dose resulting from consumption of meat produced by animals grazed on contaminated forage is obtained using the following equations. Calculate the radionuclide concentration in meat from animals grazed on contaminated forage using Equation A-5 and the data in Tables A-30 and A-31 where $Y = 0.7$ kg/m^2. The result is

$$C_{iv} = 5.35 \times 10^{-6} \frac{\mu Ci}{kg} .$$

The dose from ingestion of meat produced by animals grazed on contaminated forage is given by the equations:

$$D_{mfi} = Q_{mfi} \times DF_i \qquad (A\text{-}9)$$

where

$$Q_{mfi} = U_{mf} \times A_m \times S_{bi} \times C_{iv} . \qquad (A\text{-}10)$$

The data for calculation of the dose from ingestion of meat produced by animals grazed on contaminated forage appear in Table A-33.

TABLE A-33

DATA FOR MEAT CONSUMPTION
DECONTAMINATION SOLUTION SPILL SCENARIO
(Pu-238)

Variable	Quantity	Unit	Reference
U_{mf}	110	kg/yr	RG 1.109
A_m	50	kg/day	RG 1.109
S_{bi}	1.40×10^{-5}	day/kg	RG 1.109
C_{iv}	5.35×10^{-6}	μCi/kg	Equation A-5
DF_i	Use applicable organ dose conversion factors.	rem/μCi	Table A-4

Step 1

Substitution of the numerical values from Table A-33 into Equations A-9 and A-10 gives the organ doses of Pu-238 from consumption of meat produced from animals fed on contaminated forage:

D_i (lung) $= 4.56 \times 10^{-14}$ rem
D_i (liver) $= 1.76 \times 10^{-7}$ rem
D_i (bone surface) $= 8.41 \times 10^{-7}$ rem
D_i (total body) $= 3.40 \times 10^{-8}$ rem.

Step 2

The organ doses from all radionuclides are determined by using the values of isotope concentrations in Table A-2 and the appropriate DF_i values from NUREG/CR-0150.

D_t (lung) $= 6.60 \times 10^{-4}$ rem
D_t (liver) $= 3.10 \times 10^{-3}$ rem
D_t (bone surface) $= 5.92 \times 10^{-3}$ rem
D_t (total body) $= 2.35 \times 10^{-3}$ rem.

Calculation of Ingestion Dose Commitment from Milk Consumption

The contribution of a single nuclide, Pu-238, to the maximum individual dose commitment through ingestion of milk from animals grazed on contaminated forage is given by the equations:

$$D_{cfi} = Q_{cfi} \times DF_i \qquad \text{(A-11)}$$

where

$$Q_{cfi} = U_{cf} \times A_m \times S_{ci} \times C_{iv} \quad . \qquad \text{(A-12)}$$

The data for calculation of the dose from ingestion of milk produced by animals grazed on contaminated forage appear in Table A-34.

TABLE A-34

DATA FOR MILK CONSUMPTION
DECONTAMINATION SOLUTION SPILL SCENARIO
(Pu-238)

Variable	Quantity	Unit	Reference
$U_{\mu f}$	310	ℓ/yr	RG 1.109
A_m	50	kg/day	RG 1.109
S_{ci}	2.0×10^{-6}	day/ℓ	RG 1.109
C_{iv}	5.35×10^{-6}	μCi/kg	Equation A-5
DF_i	Use applicable organ dose conversion factors.	rem/μCi	Table A-4

Step 1

Substitution of the numerical values from Table A-34 into Equations A-11 and A-12 gives the organ doses for isotope i, Pu-238, from milk produced by animals grazed on contaminated forage:

D_i (lung) $= 1.84 \times 10^{-14}$ rem
D_i (liver) $= 7.10 \times 10^{-8}$ rem
D_i (bone surface) $= 3.38 \times 10^{-7}$ rem
D_i (total body) $= 1.37 \times 10^{-8}$ rem.

Step 2

The organ doses from all radionuclides are determined by using the values of isotope concentrations in Table A-2 and the appropriate DF_i values from NUREG/CR-0150:

D_t (lung) $= 5.37 \times 10^{-3}$ rem
D_t (liver) $= 1.80 \times 10^{-2}$ rem
D_t (bone surface) $= 2.79 \times 10^{-2}$ rem
D_t (total body) $= 1.25 \times 10^{-2}$ rem.

Calculation of Direct Radiation Pathway Dose

The direct radiation dose results from material deposited on the ground as the result of a decontamination solution spill. The dose commitment from ground-plane deposition for 1 yr is given by the equations:

$$D_{gi} = t_u \times S_f \times C_{gi} \times DF_{gi} \qquad \text{(A-13)}$$

where

$$C_{gi} = D_{pi} \frac{(1 - e^{-\lambda_i T_s})}{\lambda_i PL} \quad . \qquad \text{(A-14)}$$

Step 1

Since DF_{gi} for a beta emitter such as Pu-238 is zero, the total body contribution from the ground-plane deposition of Pu-238 is zero.

Step 2

The ground-plane doses from all isotopes are determined by using the isotope concentrations in Table A-2 and the dose conversion factors from the ISOSHLD code.

The total whole-body ground-plane deposition dose from the decontamination solution spill is 2.75×10^{-4} rem.

Calculation of Whole-Body Equivalent Doses and Health Effects

Step 3

Step 3 consists of summing the dose commitments from all pathways, for all isotopes, and for all organs at risk. The total doses for each pathway are given in Table A-35.

TABLE A-35

INDIVIDUAL PATHWAY ORGAN DOSE COMMITMENTS (rem)
DECONTAMINATION SOLUTION SPILL SCENARIO

Organ	Inhalation	Fruits and Vegetables	Meat	Milk	Total
Liver	6.30×10^{-4}	2.18×10^{-2}	3.10×10^{-3}	1.80×10^{-2}	4.35×10^{-2}
Lung	2.11×10^{-3}	5.90×10^{-3}	6.61×10^{-4}	5.37×10^{-3}	1.40×10^{-2}
Bone surface	2.89×10^{-3}	1.92×10^{-1}	5.92×10^{-3}	2.79×10^{-2}	2.29×10^{-1}
Total body	1.56×10^{-4}	3.15×10^{-2}	2.35×10^{-3}	1.25×10^{-2}	4.65×10^{-2}

Step 4

Organ dose commitments calculated in Step 3 are multiplied by the appropriate weighting factor from Table A-6 to calculate the whole-body equivalent (WBE) dose.

$$WBE_j = D_j \times W_{Tj}$$

where

$$\begin{aligned}
WBE_j \text{ (lung)} &= 1.40 \times 10^{-2} \ (0.12) = 1.68 \times 10^{-3} \text{ rem} \\
WBE_j \text{ (liver)} &= 4.35 \times 10^{-2} \ (0.06) = 2.61 \times 10^{-3} \text{ rem} \\
WBE_j \text{ (bone surface)} &= 2.29 \times 10^{-1} \ (0.03) = 6.87 \times 10^{-3} \text{ rem} \\
WBE_j \text{ (total body)} &= 4.65 \times 10^{-2} \ (0.06) = 2.79 \times 10^{-3} \text{ rem.}
\end{aligned}$$

Using these calculated WBE doses and the procedures outlined in Subsection A.1.3.1 and weighting factors from Table A-6, the maximum individual dose from the decontamination solution spill scenario is

$$WBE = 6.10 \times 10^{-2} \text{ rem.}$$

The WBE is sufficiently large that the ground-plane dose of 1.92×10^{-5} rem in 1 yr does not contribute significantly to the total dose.

Step 5

The population dose commitment is calculated from the maximum individual dose as follows.

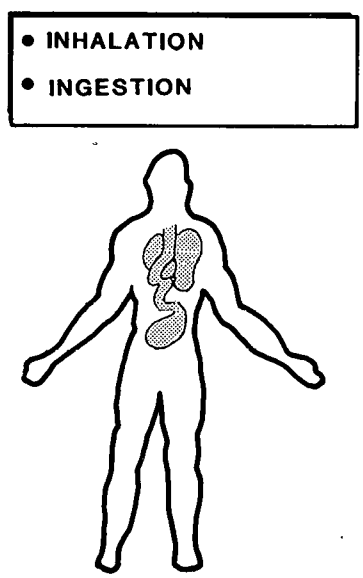
$$\text{Population WBE dose} = (6.10 \times 10^{-2})\ (0.2)\ (71{,}000)$$
$$= 8.66 \times 10^{2} \text{ man-rem.}$$

Step 6

The health effects associated with the population dose are based on the BEIR III Report in which it is estimated that 1 million man-rem cause between 75 and 230 excess cancer fatalities. Multiplying the WBE dose by 7.5×10^{-5} and 2.3×10^{-4} gives a range of 6.5×10^{-2} to 2.0×10^{-1} health effect from the decontamination solution spill scenario for Alternatives 2, 3, and 4 in 1990. (See Appendix B, Tables B-32, B-33, B-34, B-35, and B-36.)

A.1.8.1.3.3 Extraction Solvent Fire

Actinide separation involves a solvent extraction step to separate the actinides from the longer-lived fission products. The use of a flammable organic solvent could lead to a fire in the processing cell if a leak should develop. It is assumed that high-level waste is spilled on the cell floor concurrently with a leak of solvent. The solvent is assumed to ignite. If such an event were to occur, the airborne radionuclides would enter the cell ventilation system and be released to the atmosphere through the plant stack.



EXTRACTION SOLVENT FIRE

Inhalation, ingestion, and direct radiation are the pathways by which the general public would be exposed to radiation from an extraction solvent fire. The calculations show that the most significant pathways are inhalation and ingestion as shown in the illustration on the preceding page. Workers would not be affected because operations occur in isolated cells where the air pressure is negative. The scenario is illustrated in Subsection 4.5.1.2.2. The extraction solvent fire scenario applies only to Alternative 4.

The scenario is based on the following assumptions:

- The amount of high-level waste spilled is 400 ℓ (105 gal) (1 hr of operation).
- The fire in the cell causes 10% of the fission products and 1% of the actinides in the spilled liquid waste to become airborne.
- The decontamination factor is 10^9.
- The probability of occurrence is 1×10^{-2} event per year.
- A population of 71,000 is exposed to radiation in 1990.

The following sample calculation gives the maximum individual whole-body dose commitment for Alternative 4 from the significant radionuclide, ruthenium-106 (Ru-106), in 1990.

Calculation of Inhalation Pathway Dose

The contribution of a single isotope (Ru-106) to the maximum individual dose commitment from the inhalation pathway is given by the equations:

$$D_i = C_i \times V \times DF_i \qquad \text{(A-1)}$$

where

$$V = B \times T \qquad \text{(A-2)}$$

$$C_i = Q_i \times \frac{\chi}{Q} \qquad \text{(A-3)}$$

where

$$Q_i = Q_s \times F_i \times C_{ci} \times \frac{1}{3600T} \qquad \text{(A-4a)}$$

The parameters applied to the extraction solvent fire appear in Table A-36.

TABLE A-36

DATA FOR EXTRACTION SOLVENT FIRE SCENARIO
(Ru-106)

Variable	Quantity	Unit	Reference
Q_s	80	kg	Scenario
C_{ci}	9.7×10^{5}	μCi/kg	Table A-2
F_i	6.0×10^{-9}	none	Scenario
χ/Q	2.0×10^{-6}	sec/m^3	Scenario
R	2.0	m^3/hr	Working rate.
DF_i (lung)	3.80	rem/μCi	Table A-3
DF_i (liver)	1.15×10^{-2}	rem/μCi	Table A-3
DF_i (bone surface)	1.00×10^{-2}	rem/μCi	Table A-3
DF_i (total body)	6.18×10^{-2}	rem/μCi	Table A-3

Step 1

Substitution of the numerical values in Table A-36 into Equations A-1, A-2, A-3, and A-4a gives the maximum individual organ doses from inhalation of Ru-106:

D_i (lung) = 1.97×10^{-9} rem
D_i (liver) = 5.96×10^{-12} rem
D_i (bone surface) = 5.17×10^{-12} rem
D_i (total body) = 3.20×10^{-11} rem.

Step 2

The inhalation organ dose commitments from all radionuclides are determined by using the values of isotope concentrations in Table A-2 and appropriate DF_i values from NUREG/CR-0150. These total dose commitments are

D_t (lung) $= 3.24 \times 10^{-9}$ rem
D_t (liver) $= 7.25 \times 10^{-11}$ rem
D_t (bone surface) $= 2.66 \times 10^{-10}$ rem
D_t (total body) $= 6.81 \times 10^{-11}$ rem.

Calculation of Ingestion Pathway Dose

The ingestion pathway has three contributing subpathways: ingestion of fruits and vegetables, ingestion of milk, and ingestion of meat from animals grazed on contaminated forage. Basic to all three subpathways is the radionuclide concentration in vegetation which is calculated from Equation A-5.

$$C_{iv} = D_{pi}\left(R\,\frac{[1 - e^{-(\lambda_e + \lambda_i)t_e}]}{Y(\lambda_e + \lambda_i)} + B_{iv}\,\frac{[1 - e^{-\lambda_i t_s}]}{P\lambda_i}\right)e^{-\lambda_i t_c} \qquad \text{(A-5)}$$

where

$$D_{pi} = \frac{X}{Q} \times V_d \times Q_i \qquad \text{(A-6)}$$

where

$$Q_i = Q_s \times F_i \times C_{ci} \times \frac{1}{T} \quad . \qquad \text{(A-4b)}$$

The data for the calculation of C_{iv} appear in Tables A-36 and A-37. Dose commitments for the three ingestion subpathways are calculated separately as follows.

Calculation of Ingestion Dose Commitment from Fruits and Vegetables Consumption

Calculate the radionuclide concentration in fruits and vegetables using Equation A-5 and the data in Tables A-36 and A-37. The result is

$$C_{iv} = 1.01 \times 10^{-9} \ \mu Ci/kg \quad .$$

The dose from ingestion of fruits and vegetables is determined by the equations:

TABLE A-37

DATA FOR RADIONUCLIDE CONCENTRATION IN VEGETATION
EXTRACTION SOLVENT FIRE SCENARIO
(Ru-106)

Variable	Quantity	Unit	Reference
R	2.0×10^{-1}	none	RG 1.109
χ/Q	3.0×10^{-6}	sec/m^3	Table A-8
λ_e	0	hr^{-1}	Assumes no loss.
t_e	1.44×10^{3}	hr	RG 1.109
V_d	0.01	m/sec	Engineering judgment.
Y	2^a 0.7^b	kg/m^2	RG 1.109
B_{iv}	5.0×10^{-2}	none	RG 1.109
λ_i	7.85×10^{-5}	hr^{-1}	Ru-106
t_s	8.77×10^{3}	hr	1 yr
P	240	kg/m^2	RG 1.109
t_c	0	hr	Maximizes concentration.
T	8.77×10^{3}	hr	Scenario

a. For fruits and vegetables consumed directly by man.

b. For vegetation consumed by meat- or milk-producing animals.

$$D_{fi} = Q_{fi} \times DF_i \qquad \text{(A-7)}$$

where

$$Q_{fi} = U_f \times C_{iv} \quad . \qquad \text{(A-8)}$$

The data for calculation of the dose from consumption of fruits and vegetables appear in Table A-38.

TABLE A-38

DATA FOR FRUITS AND VEGETABLES CONSUMPTION
EXTRACTION SOLVENT FIRE SCENARIO
(Ru-106)

Variable	Quantity	Unit	Reference
U_f	584	kg/yr	RG 1.109
DF_i (bone surface)	9.57×10^{-3}	rem/μCi	Table A-4
DF_i (liver)	8.27×10^{-3}	rem/μCi	Table A-4
DF_i (lung)	2.17×10^{-4}	rem/μCi	Table A-4
DF_i (total body)	5.94×10^{-3}	rem/μCi	Table A-4
C_{iv}	1.01×10^{-9}	μCi/kg	Equation A-5

Step 1

Substitution of the numerical values from Table A-38 into Equations A-7 and A-8 gives the organ doses of Ru-106 from consumption of fruits and vegetables:

D_i (lung) $= 1.28 \times 10^{-10}$ rem
D_i (liver) $= 4.87 \times 10^{-9}$ rem
D_i (bone surface) $= 5.63 \times 10^{-9}$ rem
D_i (total body) $= 3.50 \times 10^{-9}$ rem.

Step 2

The organ doses from all radionuclides are determined by using the values of isotope concentrations in Table A-2 and the appropriate DF_i from NUREG/CR-0150.

D_t (lung) $= 5.55 \times 10^{-9}$ rem
D_t (liver) $= 2.42 \times 10^{-8}$ rem
D_t (bone surface) $= 1.79 \times 10^{-7}$ rem
D_t (total body) $= 3.23 \times 10^{-8}$ rem.

Calculation of Ingestion Dose Commitment from Meat Consumption

The dose resulting from consumption of meat produced from animals grazed on contaminated forage is obtained using the following equations. Calculate the radionuclide concentration in meat produced from animals grazed on contaminated forage using Equation A-5 and the data in Tables A-36 and A-37 where Y = 0.7 kg/m^2. The result is

$$C_{iv} = 2.88 \times 10^{-9} \ \mu Ci/kg \ .$$

The dose from ingestion of meat produced by animals grazed on contaminated forage is given by the equations:

$$D_{mfi} = Q_{mfi} \times DF_i \qquad (A\text{-}9)$$

where

$$Q_{mfi} = U_{mf} \times A_m \times S_{bi} \times C_{iv} \ . \qquad (A\text{-}10)$$

The data for calcuation of the dose from ingestion of meat produced by animals grazed on contaminated forage appear in Table A-39.

TABLE A-39

DATA FOR MEAT CONSUMPTION
EXTRACTION SOLVENT FIRE SCENARIO
(Ru-106)

Variable	Quantity	Unit	Reference
U_{mf}	110	kg/yr	RG 1.109
A_m	50	kg/day	RG 1.109
S_{bi}	4.0×10^{-1}	day/kg	RG 1.109
C_{iv}	2.88×10^{-9}	µCi/kg	Equation A-5
DF_i	Use applicable organ dose conversion factors.	rem/µCi	Table A-4

Step 1

Substitution of the numerical values from Table A-39 into Equations A-9 and A-10 gives the organ doses of Ru-106 from consumption of meat produced from animals grazed on contaminated forage:

D_i (lung) $= 1.38 \times 10^{-9}$ rem
D_i (liver) $= 5.26 \times 10^{-8}$ rem
D_i (bone surface) $= 6.08 \times 10^{-8}$ rem
D_i (total body) $= 3.77 \times 10^{-8}$ rem.

Step 2

The organ doses from all radionuclides are determined by using the values of isotope concentrations in Table A-2 and the appropriate DF_i values from NUREG/CR-0150:

D_t (lung) $= 1.96 \times 10^{-9}$ rem
D_t (liver) $= 5.45 \times 10^{-8}$ rem
D_t (bone surface) $= 6.52 \times 10^{-8}$ rem
D_t (total body) $= 3.92 \times 10^{-8}$ rem.

Calculation of the Ingestion Dose Commitment from Milk Consumption

The contribution of the significant nuclide, Ru-106, to the maximum individual dose commitment through ingestion of milk from animals grazed on contaminated forage is given by the equations:

$$D_{cfi} = Q_{cfi} \times DF_i \qquad \text{(A-11)}$$

where

$$Q_{cfi} = U_{cf} \times A_m \times S_{ci} \times C_{iv} \quad . \qquad \text{(A-12)}$$

The data for calculation of the dose from ingestion of milk produced from consumption of contaminated forage appear in Table A-40.

Step 1

Substitution of the numerical values from Table A-40 into Equations A-11 and A-12 gives the organ doses for isotope i, Ru-106, from milk produced by animals grazed on contaminated forage:

TABLE A-40

DATA FOR MILK CONSUMPTION
EXTRACTION SOLVENT FIRE SCENARIO
(Ru-106)

Variable	Quantity	Unit	Reference
U_{cf}	310	ℓ/yr	RG 1.109
A_m	50	kg/day	RG 1.109
S_{ci}	1.0×10^{-6}	day/ℓ	RG 1.109
C_{iv}	2.88×10^{-9}	μCi/kg	Table A-39
DF_i	Use applicable organ dose conversion factors.	rem/μCi	Table A-34

D_i (lung) $= 9.71 \times 10^{-15}$ rem
D_i (liver) $= 3.57 \times 10^{-13}$ rem
D_i (bone surface) $= 4.28 \times 10^{-13}$ rem
D_i (total body) $= 2.66 \times 10^{-13}$ rem.

Step 2

The organ doses from all radionuclides are determined by using the values of isotope concentrations in Table A-2 and the appropriate DF_i values from NUREG/CR-0150:

D_t (lung) $= 4.94 \times 10^{-8}$ rem
D_t (liver) $= 1.65 \times 10^{-8}$ rem
D_t (bone surface) $= 2.57 \times 10^{-8}$ rem
D_t (total body) $= 1.15 \times 10^{-8}$ rem.

Calculation of Direct Radiation Pathway Dose

The direct radiation dose results from material deposited on the ground as the result of an extraction solvent fire. The dose commitment from ground-plane deposition for 1 yr is given by the equations:

$$D_{gi} = t_x \times S_f \times C_{gi} \times DF_{gi} \quad \text{(A-13)}$$

where

$$C_{gi} = D_{pi} \frac{(1 - e^{-\lambda_i t_s})}{\lambda_i PL} \quad . \tag{A-14}$$

Substituting the numerical values from Table A-41 into Equations A-13 and A-14 gives the organ doses for ground-plane direct radiation.

TABLE A-41

DATA FOR GROUND-PLANE DIRECT RADIATION
EXTRACTION SOLVENT FIRE SCENARIO
(Ru-106)

Variable	Quantity	Unit	Reference
DF_{gi}	0	$\frac{rem/hr}{\mu Ci/cc}$	ISOSHLD
t_x	1	hr	Scenario
S_f	0.7	none	RG 1.109
λ_i	7.85×10^{-5}	1/hr	Ru-106
t_s	8.77×10^{3}	hr	1 yr

Step 1

Since Ru-106 is a beta emitter, the dose factor for the ground-plane dose is zero. Thus the contribution of Ru-106 is zero.

Step 2

The ground-plane doses from all isotopes are determined by using the isotope concentrations in Table A-2 and the dose conversion factors from the ISOSHLD code.

The total whole-body ground-plane deposition dose from the extraction solvent fire scenario is 4.18×10^{-10} rem.

Calculation of Whole-Body Equivalent Doses and Health Effects

Step 3

Step 3 consists of summing the dose commitments from all pathways, for all isotopes, and for all organs at risk. The total doses for each pathway are given in Table A-42.

TABLE A-42

INDIVIDUAL PATHWAY ORGAN DOSE COMMITMENTS (rem)
EXTRACTION SOLVENT FIRE SCENARIO

Organ	Inhalation	Fruits and Vegetables	Meat	Milk	Total
Bone surface	2.66×10^{-10}	1.79×10^{-7}	6.52×10^{-8}	2.57×10^{-8}	2.70×10^{-7}
Liver	7.25×10^{-11}	2.42×10^{-8}	5.45×10^{-8}	1.65×10^{-8}	9.53×10^{-8}
Lung	3.24×10^{-9}	5.55×10^{-9}	1.96×10^{-9}	4.94×10^{-9}	1.57×10^{-8}
Total body	6.81×10^{-11}	3.23×10^{-8}	3.92×10^{-8}	1.15×10^{-8}	8.31×10^{-8}

Step 4

Organ dose commitments calculated in Step 3 are multiplied by the appropriate weighting factor (W_T) from Table A-6 to calculate the whole-body equivalent (WBE) dose:

$$WBE_j = D_j \times W_{Tj}$$

where

WBE_j (bone surface) $= 2.70 \times 10^{-8}$ (0.03) $= 8.10 \times 10^{-9}$ rem
WBE_j (liver) $= 9.53 \times 10^{-8}$ (0.06) $= 5.72 \times 10^{-9}$ rem
WBE_j (lung) $= 1.57 \times 10^{-8}$ (0.12) $= 1.88 \times 10^{-9}$ rem
WBE_j (total body) $= 8.31 \times 10^{-8}$ (0.06) $= 4.99 \times 10^{-9}$ rem.

Using these calculated WBE doses and the procedures outlined in Subsection A.1.3.1 and the weighting factors from Table A-6, the maximum individual whole-body equivalent dose from the solvent extraction fire scenario is

$$WBE = 2.41 \times 10^{-7} \text{ rem.}$$

The WBE is sufficiently large that the ground-plane dose of 4.18×10^{-10} rem in 1 yr does not contribute significantly to the total dose.

Step 5

The population dose commitment is calculated from the maximum individual dose as follows.

$$\text{Population WBE dose} = (2.41 \times 10^{-7})\ (0.04)\ (71{,}000)$$
$$= 6.84 \times 10^{-4} \text{ man-rem.}$$

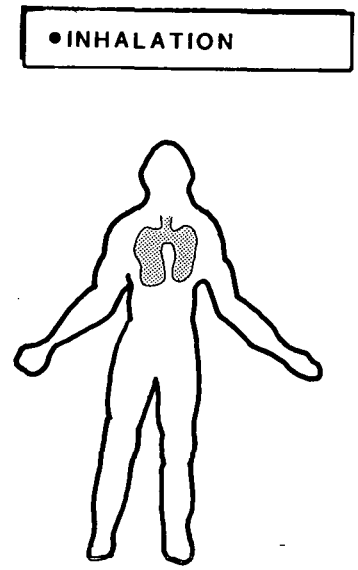
Step 6

The health effects associated with the population dose are based on the BEIR III Report in which it is estimated that 1 million man-rem cause between 75 and 230 excess cancer fatalities. Multiplying the WBE dose by 7.5×10^{-5} and 2.3×10^{-4} gives a range of 5.13×10^{-8} to 1.57×10^{-7} health effect from the extraction solvent fire scenario for Alternative 4 in 1990. (See Appendix B, Table B-40.)

A.1.8.1.3.4 Waste Shipment Accident

Offsite disposal of all or part of the waste inventory requires shipping the waste to a federal geologic repository. The risk associated with the waste shipment depends on many factors: the solidified waste form, shipment method (truck or train), travel distance, and the population distribution along the route. The waste would be packaged in containers and placed in shipping casks that meet Department of Transportation specifications for radiation and container integrity. A Type B cask must survive certain severe hypothetical accident conditions during which resistance to impact, puncture, fire, and submersion in water is demonstrated (49 CFR 173.398). Under these conditions, the Type B package must not release any of its contents. However, to evaluate the effects of a radionuclide release, a shipping cask is assumed to break open as shown in the illustration in Subsection 4.5.1.2.2.

Inhalation is the significant exposure pathway as shown in the illustration. Both individuals and the general population would be exposed to radiation.



WASTE SHIPMENT ACCIDENT

The waste shipment accident scenario applies to Alternatives 3, 4, and 5 and is based on the following assumptions:

- The accident occurs at an intersection.
- No special shipment procedures are followed and accident statistics for normal freight operations are used.
- Shipment accidents occur with equal probability in urban and rural areas.
- Five hundred people per accident are exposed to radiation at and near the scene of the accident.
- There are three canisters per shipment for Alternatives 3 and 5, and one canister per shipment for Alternative 4.
- The shipping distance is 2400 km (1,500 mi).
- The release fraction for stabilized calcine is 1×10^{-3}; the release fraction for the more stable glass form is 2.5×10^{-5}.
- Three canisters of stabilized calcine contain 4800 kg of calcine. Three canisters of vitrified calcine contain 2800 kg of calcine. The single canister of actinide glass contains the actinide fraction from 4.22×10^{5} kg of calcine.

- The probability of occurrence (event/year) is

Alternative 3: (stabilize calcine)	2.0×10^{-5}	in 1990-2000
	3.0×10^{-6}	in 2010-2020
Alternative 3: (glass)	3.0×10^{-5}	in 1990-2000
	5.0×10^{-6}	in 2010-2020
Alternative 4:	7.0×10^{-8}	in 1990-2000
	2.0×10^{-8}	in 2010-2020
Alternative 5:	3.0×10^{-5}	.

The following sample calculation gives the maximum individual whole-body dose commitment for Alternative 4 from plutonium-238 (Pu-238) in the period 1990 to 2020.

The contribution of the significant isotope, Pu-238, to the maximum individual dose commitment from the inhalation pathway is given by the equations

$$D_i = C_i \times V \times DF_i \qquad \text{(A-1)}$$

where

$$V = B \times T \qquad \text{(A-2)}$$

$$C_i = Q_i \times \frac{X}{Q} \qquad \text{(A-3)}$$

where

$$Q_i = Q_s \times F_i \times C_{ci} \times \frac{1}{3600T} \quad . \qquad \text{(A-4a)}$$

Data and parameters applied to a waste shipment accident are presented in Table A-43.

Step 1

Substitution of the numerical values from Table A-43 into Equations A-1, A-2, A-3, and A-4a gives the organ doses from inhalation of Pu-238:

D_i (lung) $= 1.99 \times 10^{1}$ rem
D_i (liver) $= 2.29 \times 10^{1}$ rem
D_i (bone surface) $= 1.07 \times 10^{2}$ rem
D_i (total body) $= 4.57$ rem.

TABLE A-43

DATA FOR INHALATION PATHWAY
WASTE SHIPMENT ACCIDENT SCENARIO
(Pu-238)

Variable	Quantity	Unit	Reference
Q_s	4.22×10^5	kg	Scenario
C_{ci}	7.0×10^4	μCi/kg	Figure A-2
χ/Q	1.0×10^{-4}	sec/m^3	Scenario
F_i	2×10^{-5}	none	Scenario
T	1.0	hr	Scenario
B	2.0	m^3/hr	RG 1.109
DF_i	Use applicable organ dose conversion factors.	rem/μCi	Table A-3

Step 2 and Step 3

The inhalation organ dose commitments from all radionuclides are determined by using the values of isotope concentrations in Figure A-2 and appropriate DF_i values from NUREG/CR-0150:

D_t (lung) $= 2.14 \times 10^1$ rem
D_t (liver) $= 2.51 \times 10^1$ rem
D_t (bone surface) $= 1.18 \times 10^2$ rem
D_t (total body) $= 5.05$ rem.

Step 4

Organ dose commitments calculated in Step 3 are multiplied by the appropriate weighting factors (W_T) from Table A-6 to calculate the whole-body equivalent (WBE) dose:

$WBE = 1.00 \times 10^1$ rem.

Step 5

The population dose commitment is calculated from the maximum individual dose for 500 people as follows.

Population WBE dose = (500) × (1.00×10^{1} rem) = 5.0×10^{3} man-rem.

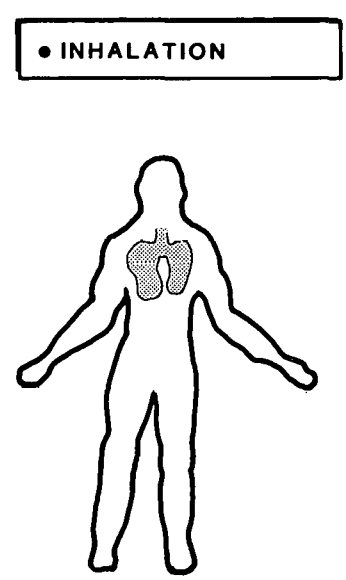
Step 6

The health effects associated with the population dose are based on the BEIR III Report in which it is estimated that each 1 million man-rem cause between 75 and 230 excess cancer fatalities. Multiplying the WBE dose by 7.5×10^{-5} and 2.3×10^{-4} gives a range of 0.375 to 1.15 health effects for Alternative 4 in 1990 to 2020. (See Appendix B, Table B-43.)

A.1.8.1.4 Migrational Modes

A.1.8.1.4.1 Living Over the Waste

To evaluate the effects of living over the waste it is postulated that houses are built directly over the calcine bins without the inhabitants being aware of the radioactive waste. Radon gas is assumed to enter the houses through a concrete slab floor. Inhalation is the pathway by which the inhabitants are exposed to radiation as shown in the accompanying illustration.



LIVING OVER THE WASTE

Should significant cracks develop in the bins, radon gas (a daughter product of radium-226) would diffuse from the bins through the soil and escape into the atmosphere. If a house is built on soil where radon concentrations are elevated, the gas can remain in a confined area long enough to allow the formation of daughter products that contribute to the lung dose of individuals inside the building.

The scenario is illustrated in Subsection 4.5.2.1.2. The living-over-the-waste scenario applies to Alternatives 1, 2, and 4 in which all or part of the waste inventory is disposed at the INEL site.

The relationship between radon emissions from the soil and radon daughter product concentrations depends, among other things, on the way the building is constructed. The construction technique assumed in this analysis is slab-on-grade. This technique results in close coupling of the ground and building so that potential indoor radon daughter concentrations are high relative to other methods of construction.

In this scenario, it is assumed that:

- There is a 7.6-m (25-ft) layer of clean soil between the waste and the house.
- The quantity of radon gas is reduced by diffusion through the soil to the surface.
- The probability of occurrence is 0.01 event per year.
- A population of 5 is exposed to radiation.

The following sample calculation gives the maximum individual whole-body dose commitment for Alternative 1 from radon-222 (Rn-222) in 202,000. Radon continues to increase in concentration in the waste calcine for the first 200,000 yr. Thus, the greatest 1-yr effect from living over the waste occurs in 202,000.

The maximum individual lung dose from inhalation of radon and radon daughters is obtained by the use of the equation:

$$D_{rn} = \bar{C}_{WL} \times DF_{rn} \quad . \tag{A-31}$$

The average radon flux from the soil surface and the radon progeny concentration in a house of slab-on-grade construction is related by an empirically derived formula:

$$\bar{C}_{WL} = 0.0087\ J^{0.46} \quad . \tag{A-32}$$

The radon flux, J, at the surface of the clean layer of soil is calculated from the radon flux, J_o, at the bin surface to account for the diffusion time through the clean soil. The radon flux, J_o, from the surface of a porous, homogeneous medium is given by:

$$J_o = 10^4 D C_{rn} \left(\lambda \frac{P}{D}\right)^{\frac{1}{2}} \quad . \tag{A-33}$$

The concentration of radon, C_{rn}, in the void space in a homogeneous, porous medium is given by:

$$C_{rn} = C_{ra} \left(\frac{E\rho}{P}\right) \quad .$$

Substituting the relation for C_{rn} in Equation A-33 gives:

$$J_o = 10^4 C_{ra} \times E\rho \left(\frac{\lambda D}{P}\right)^{\frac{1}{2}} \quad . \tag{A-34}$$

Shielding Layer

A layer of clean porous soil on top of a radium-bearing porous soil can be expected to attenuate the diffusing radon. At the surface of clean soil, the radon flux is described approximately by the simple attenuation equation:

$$J = J_o \exp\left[-Y\left(\lambda \frac{P}{D}\right)^{\frac{1}{2}}\right] \quad . \tag{A-35}$$

Substituting the values from Table A-44 into Equation A-35 gives

$$J = 1.08 \times 10^{-1} C_{ra} \quad .$$

The potential lung (tracheobronchial) dose equivalent rate is estimated from

$$D_{rn} = \bar{C}_{WL} \times DF_{rn} \tag{A-31}$$

where

$$\bar{C}_{WL} = 0.0087 \, J^{0.46} \tag{A-32}$$

TABLE A-44

DATA FOR INHALATION PATHWAY
LIVING OVER THE WASTE SCENARIO
(Rn-222)

Variable	Quantity	Unit	Reference
ρ	1.3	g/cc	Density of calcine.
E	1	none	Assumes total release.
C_{ra}	1.5×10^{4}	pCi/g	Figure A-2
Y	760	cm	Depth of soil layer.
λ	2.1×10^{-6}	sec^{-1}	Rn-222
P	0.3	none	Scenario
D	0.024	cm^2/sec	Scenario
T	7000	hr	Approximately 1-yr residence time.

and

$$DF_{rn} = \frac{100T}{5840} \quad . \tag{A-37}$$

Calculation of Inhalation Pathway Dose

Step 1

The radon daughter dose commitment to the lungs is calculated by substituting the values from Equations A-37 and A-32 into Equation A-31. The lung is the only organ affected by radon daughters. In the year 202,000, the Ra-226 concentration in soil is 1.5×10^{4} pCi/g. The dose commitment to the lungs is D_{rn} = 31.0 rem.

Step 2

Since radon daughters are the only source of exposure in this scenario, the organ dose for all isotopes is also D_{rn} = 31.0 rem.

Step 3

Since only one pathway contributes to the maximum individual dose commitment, the total organ dose commitment is 31.0 rem.

Step 4

The organ dose commitment calculated in Step 3 is multiplied by the weighting factor (W_T) from Table A-6 to calculate the whole-body equivalent (WBE) dose.

$$WBE = (31.0 \text{ rem}) \times (0.12) = 3.7 \text{ rem}.$$

Step 5

The population dose commitment is calculated from the maximum individual dose as follows.

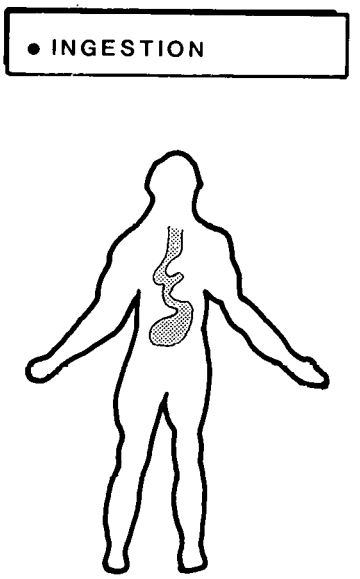
$$\text{Population WBE dose} = 3.7 \text{ rem} \times 5 \text{ people}$$
$$= 18.5 \text{ man-rem}.$$

Step 6

The health effects associated with the population dose are based on the BEIR III Report in which it is estimated that 1 million man-rem cause between 75 and 230 excess cancer fatalities. Multiplying the population WBE dose by 7.5×10^{-5} and 2.3×10^{-4} gives a range of 1.39×10^{-3} to 4.25×10^{-3} health effect from the living-over-the-waste scenario for Alternative 1 in the year 202,000. (See Appendix B, Table B-47.)

A.1.8.1.4.2 Waste Migration into Groundwater

Because the containment integrity of the calcine bins cannot be guaranteed in perpetuity, it is postulated that radionuclides in the bins are leached by water and eventually migrate to the aquifer. Ingestion is the pathway by which a small population would be exposed to radiation as shown in the accompanying illustration. The scenario applies to Alternatives 1, 2, and 4 in which the waste is disposed at the INEL.



WASTE MIGRATION INTO GROUNDWATER

In the waste-migration-into-groundwater scenario, four hypothetical wells are evaluated. The wells are located at distances of 0, 3, 10, and 120 mi downgradient from the point of injection into the aquifer. The scenario is illustrated in Subsection 4.5.2.1.

The amount of water required to leach the waste is equivalent to about 30 years' average precipitation at the INEL. Average annual precipitation is assumed to drive contaminated water by hydrostatic pressure from the bin bottom. The contaminated water then seeps through the soil layer, traverses a layer of lava, and reaches the aquifer where the radionuclides are transported downgradient to the hypothetical wells.

The annual precipitation is 22 cm (8.5 in.). Very little of this moisture actually reaches the aquifer; most is lost to the atmosphere by evaporation and transpiration. If current weather patterns continue, eventual radionuclide migration to the aquifer would be unlikely.

This scenario is evaluated to determine the potential consequences of aquifer contimination. In reality, the underlying Snake River Plain Aquifer is vast, and a very large amount of dilution would occur both initially and during the 120-mi underground movement of the water before it surfaces near

Hagerman in the Snake River Canyon. Ion-exchange processes in the soil and in the sediments underlying the waste disposal area would further diminish the quantity of radionuclides reaching the aquifer.

The scenario is based on the following assumptions:

- After the containment life of the stainless steel bins (500 yr), the surrounding concrete and reinforced concrete vault are assumed to deteriorate. The bin set covers an area of about 190 m^2 (2,000 ft^2) and is assumed to contain the entire radionuclide inventory.

- Half of the annual precipitation, 22 cm (8.5 in.), contacts and covers 1% of the waste.

- Thirty years' average precipitation fills the bin after which additional precipitation drives contaminated water by hydrostatic pressure from the bin bottom.

- The leached radionuclides seep through a soil layer 15 m (50 ft) thick, which has an effective ion-exchange capacity.

- The vertical flow rate is 1 cm/day.

- The probability of occurrence is 1×10^{-6} event per year.

- The populations exposed to radiation in 2600 when effects would be maximum are 5 at the 0- and 3-mi wells, 100 at the 10-mi well, 5000 at the 120-mi well.

- The radionuclides that reach the aquifer are assumed to be diluted by the volume of water under one vault. This dilution flow is about 110 m^3/day/m (1200 ft^3/day/ft) of vault width. The estimated vault width is 15 m (50 ft) which gives an annual dilution volume of 6.2×10^5 m^3/yr (2.2×10^7 ft^3/yr).

The following sample calculation is for a hypothetical well located at the point of discharge to the aquifer. The maximum individual whole-body dose commitment is calculated for Alternative 1 from cesium-135 (Cs-135) in 13,500.

Calculation of Ingestion Pathway Dose

The ingestion pathway dose is based on the radionuclide concentration in the aquifer. The radionuclide concentration in the aquifer is a function of the time required for radionuclides to migrate to the aquifer. The time interval required for the leached material to reach the aquifer is a function of soil retardation factors calculated from the distribution coefficients (K_d) listed in Table A-9.

The time required for a specific isotope to migrate through the 15-m soil layer is given by Equation A-16.

$$T_i = L \frac{(K_{di} \times R_p + 1)}{365\ W_g} \quad . \tag{A-16}$$

When the elapsed leach time from the bins is greater than the travel time, the concentration entering the aquifer is given by either Equation A-17 or Equation A-18 depending upon the pulse width of the migrating material. The pulse width of an instantaneous release from the bins is given by Equation A-19.

$$PW = 2.428\ K_{di} \quad . \tag{A-19}$$

If the time over which the isotope is released from the bins (100 yr in this scenario) is greater than the pulse width, the concentration reaching the aquifer is represented by a square wave equation:

$$Z_i = \frac{I_{ti} \times 10^6}{t_r \times W_a} \quad . \tag{A-17}$$

If, however, the pulse width is greater than the 100-yr release time, the concentration reaching the aquifer is more appropriately represented by:

$$Z_i = \frac{I_{ti} \times 365 \times 10^6}{T \left(\frac{2\pi L}{W_g T_e}\right)^{\frac{1}{2}} (K_{di} \times R_p + 1) W_a} \quad . \tag{A-18}$$

For K_{di} values of 0, 5, and 10, Equation 17 applies. For all other K_{di} values listed in Table A-9, Equation 18 applies. The data required to evaluate the aquifer concentration using Equation 18 are given in Table A-45, and $Z_i = 3.48 \times 10^{-6}$ μCi/cc.

TABLE A-45

DATA FOR WASTE MIGRATION INTO GROUNDWATER SCENARIO
(Cs-135)

Variable	Quantity	Unit	Reference
I_{ti}	1.53×10^3	Ci	Figure A-2
T_e	1	day	Scenario
K_{di}	500	$\frac{\text{meq/g solid}}{\text{meq/cc liquid}}$	Table A-9
R_p	5.33	g/cc	INEL soil.
L	1500	cm	Soil depth under bins.
W_g	1	cm/day	INEL data.
W_a	6.2×10^{11}	cc/yr	Scenario
T	1	day	Related to T_e.
DF_i (lung)	0	rem/μCi	NUREG/CR-0150
DF_i (liver)	1.12×10^{-2}	rem/μCi	NUREG/CR-0150
DF_i (bone surface)	1.30×10^{-2}	rem/μCi	NUREG/CR-0150
DF_i (total body)	6.61×10^{-3}	rem/μCi	NUREG/CR-0150
W	730	ℓ/yr	RG 1.109
Z_i	3.48×10^{-6}	μCi/cc	Equation A-18

Calculation of Food Subpathway Dose from Water Consumption

Three ingestion subpathways contribute to radiation exposure from consumption of contaminated water. The subpathways that result from radionuclide migration into water and subsequent ingestion by humans and animals are (1) direct consumption of drinking water, (2) consumption of meat from animals watered at a contaminated source, and (3) consumption of milk from animals watered at a contaminated source.

(1) Calculation of Ingestion Dose Commitment from Drinking Water

The contribution of Cs-135 to the maximum individual dose commitment from ingestion of contaminated water is given by the equation:

$$D_{pw} = W \times Z_i \times DF_i \times 10^3 \quad . \qquad \text{(A-15)}$$

Step 1

Substitution of the numerical values from Table A-45 into Equation A-15 gives the organ doses from ingestion of water containing Cs-135:

D_i (lung) = 0 rem
D_i^i (liver) = 2.84×10^{-2} rem
D_i^i (bone surface) = 3.29×10^{-2} rem
D_i^i (total body) = 1.67×10^{-2} rem.
D_i

Step 2

Since Cs-135 dominates the dose at 13,500, the total organ doses are essentially the same as in Step 1. The organ doses from all isotopes entering the aquifer in 13,500 are given below for rubidium-88 (Rb-88) and Cs-135.

D_t (lung) = 0 rem
D_t^t (liver) = 2.85×10^{-2} rem
D_t^t (bone surface) = 3.30×10^{-2} rem
D_t^t (total body) = 1.68×10^{-2} rem.
D_t

(2) Calculation of Ingestion Dose Commitment from Meat Consumption (Water)

The contribution of a single isotope, Cs-135, to the maximum individual dose commitment through ingestion of meat from animals watered at a contaminated source is given by the equations:

$$D_{mw} = Q_{mwi} \times DF_i \qquad \text{(A-22)}$$

where

$$Q_{mwi} = U_{mw} \times A_w \times S_{wi} \times Z_i \times 10^3 \quad . \qquad \text{(A-23)}$$

The data for calculation of the dose from ingestion of meat produced from animals watered at a contaminated source appear in Table A-46.

TABLE A-46

DATA FOR MEAT CONSUMPTION (WATER)
WASTE MIGRATION INTO GROUNDWATER SCENARIO
(Cs-135)

Variable	Quantity	Unit	Reference
U_{mw}	110	kg/yr	RG 1.109
A_w	50	ℓ/day	RG 1.109
S_{wi}	4.0×10^{-3}	day/kg	RG 1.109
Z_i	3.48×10^{-6}	μCi/cc	Equation A-18
DF_i	Use applicable organ dose conversion factors.	rem/μCi	NUREG/CR-0150

Step 1

Substitution of the numerical values from Table A-46 into Equations A-22 and A-23 gives the organ doses for Cs-135 from meat produced by animals watered at a contaminated source.

D_i (lung) = 0.0 rem
D_i (liver) = 8.55×10^{-4} rem
D_i (bone surface) = 9.92×10^{-4} rem
D_i (total body) = 5.05×10^{-4} rem.

Step 2

Since Cs-135 dominates the dose at 13,500, the total organ doses are the same as in Step 1.

(3) Calculation of Ingestion Dose Commitment from Milk Consumption (Water)

The contribution of a single nuclide, isotope i, to the maximum individual dose commitment from consumption of milk produced by animals watered at a contaminated source is given by the equations:

$$D_{cwi} = Q_{cwi} \times DF_i \quad \text{(A-24)}$$

where

$$Q_{cwi} = U_{cw} \times A_w \times S_{wi} \times Z_i \times 10^3 \quad . \quad \text{(A-25)}$$

The data needed for calculation of the dose from milk produced by animals watered at a contaminated source are presented in Table A-47.

TABLE A-47

DATA FOR MILK CONSUMPTION (WATER)
WASTE MIGRATION INTO GROUNDWATER SCENARIO
(Cs-135)

Variable	Quantity	Unit	Reference
U_{cw}	310	ℓ/yr	RG 1.109
A_w	60	ℓ/day	RG 1.109
S_{wi}	1.2×10^{-2}	day/ℓ	RG 1.109
Z_i	3.48×10^{-6}	μCi/cc	Equation A-18
DF_i	Use applicable organ dose conversion factors.	rem/μCi	NUREG/CR-0150

Substitution of the above values into Equations A-24 and A-25 gives the organ doses for Cs-135 in milk produced by animals watered at a contaminated source.

D_i (lung) = 0.0 rem
D_i (liver) = 8.67×10^{-3} rem
D_i (bone surface) = 1.01×10^{-2} rem
D_i (total body) = 5.12×10^{-3} rem.

Step 2

Since Cs-135 dominates the dose at 13,500, the total organ doses are the same as in Step 1.

Calculation of Food Subpathway Dose from Vegetation Consumption

Three ingestion subpathways contribute to radiation exposure from consumption of contaminated vegetation. The subpathways that result from growing crops and animal feed with contaminated irrigation water are (1) ingestion of fruits and vegetables, (2) ingestion of milk from animals grazed on contaminated forage, (3) ingestion of meat from animals grazed on contaminated forage. Basic to the subpathways is the isotope concentration in irrigation water used to grow the products consumed by man. The isotope concentration in vegetation is calculated as follows:

$$C_{iv} = D_{pi}\left(R\,\frac{[1 - e^{-(\lambda_e + \lambda_i)t_e}]}{Y(\lambda_e + \lambda_i)} + B_{iv}\,\frac{[1 - e^{-\lambda_i t_s}]}{P\lambda_i}\right)e^{-\lambda_i t_c} \qquad \text{(A-5)}$$

and

$$D_{pi} = Z_i \times I \times 10^3 \quad . \qquad \text{(A-6d)}$$

Substitution of the numerical values from Table A-48 gives the value for C_{iv}:

$$C_{iv} = 2.3 \times 10^{-2}\ \mu Ci/kg \quad .$$

Dose commitments for the three food ingestion subpathways are calculated separately in the following paragraphs.

TABLE A-48

DATA FOR FRUITS AND VEGETABLES CONSUMPTION
WASTE MIGRATION INTO GROUNDWATER SCENARIO
(Cs-135)

Variable	Quantity	Unit	Reference
Z_i	3.48×10^{-6}	μCi/cc	Equation A-18
I	8.8×10^{-2}	ℓ/m^2-hr	RG 1.109
D_{pi}	3.06×10^{-4}	$\mu Ci/m^2$-hr	Equation A-6d
R	2.5×10^{-1}	none	RG 1.109
λ_e	2.1×10^{-3}	hr^{-1}	RG 1.109
t_e	1.44×10^{3}[a] 7.20×10^{2}[b]	hr	RG 1.109
Y	2[a] 0.7[b]	kg/m^2	RG 1.109
B_{iv}	1.0×10^{-2}	none	RG 1.109
λ_i	3.4×10^{-11}	hr^{-1}	Cs-135
t_s	4.38×10^{5}	hr	50 year
P	240	kg/m^2	RG 1.109
t_c	0	hr	Maximum concentration.
U_f	584	kg/yr	RG 1.109
DF_i	Use applicable organ dose conversion factors.	rem/μCi	NUREG/CR-0150

a. For fruits and vegetables consumed directly by man.

b. For vegetation consumed by meat- or milk-producing amimals.

(1) Calculation of Ingestion Dose Commitment from Fruits and Vegetables Consumption

The dose from contaminated fruits and vetetables is determined by the equations:

$$D_{fi} = Q_{fi} \times DF_i \qquad \text{(A-7)}$$

where

$$Q_{fi} = U_f \times C_{iv} \quad . \qquad \text{(A-8)}$$

Step 1

Substitution of the numerical values from Table A-48 into Equations A-7 and A-8 gives the organ doses for Cs-135 from fruits and vegetables consumption:

D_i (lung) = 0.0 rem
D_i (liver) = 1.51×10^{-1} rem
D_i (bone surface) = 1.76×10^{-1} rem
D_i (total body) = 8.93×10^{-2} rem.

Step 2

Since Cs-135 dominates the dose at 13,500, the total organ doses are the same as in Step 1.

(2) Calculation of Ingestion Dose Commitment from Meat Consumption (Forage)

The dose resulting from consumption of meat produced by animals grazed on contaminated forage is obtained as follows. For meat produced by ingestion of contaminated forage, calculate the isotope concentrations in vegetation using Equation A-5 and the data in Table A-48 where t_e = 720 hours and Y = 0.7 kg/m^2. The result is

$$C_{iv} = 4.64 \times 10^2 \ \mu Ci/kg \quad .$$

The dose from consumption of meat produced by animals grazed on contaminated forage is given by the equations:

$$D_{mfi} = Q_{mfi} \times DF_i \qquad \text{(A-9)}$$

where

$$Q_{mfi} = U_{mf} \times A_m \times S_{bi} \times C_{iv} \quad . \qquad \text{(A-10)}$$

The data for calculation of the dose from ingestion of meat produced by animals grazed on contaminated forage appear in Table A-49.

TABLE A-49

DATA FOR MEAT CONSUMPTION (FORAGE)
WASTE MIGRATION INTO GROUNDWATER SCENARIO
(Cs-135)

Variable	Quantity	Unit	Reference
U_{mf}	110	kg/yr	RG 1.109
A_m	50	kg/day	RG 1.109
S_{bi}	4.0×10^{-3}	day/kg	RG 1.109
C_{iv}	4.64×10^{-2}	μCi/kg	Equation A-5
DF_i	Use applicable organ dose conversion factors.	rem/μCi	NUREG/CR-0150

Step 1

Substitution of the numerical values from Table A-49 into Equations A-9 and A-10 gives the organ doses for Cs-135 from meat produced by animals grazed on contaminated forage.

D_i (lung) = 0.0 rem
D_i (liver) = 1.14×10^{-2} rem
D_i (bone surface) = 1.33×10^{-2} rem
D_i (total body) = 6.76×10^{-3} rem.

Step 2

Since Cs-135 dominates the dose at 13,500, the total organ doses are the same as in Step 1.

(3) Calculation of Ingestion Dose Commitment from Milk Consumption (Forage)

The contribution of Cs-135 to the maximum individual dose commitment through ingestion of milk from animals grazed on contaminated forage is given by the equations:

$$D_{cfi} = Q_{cfi} \times DF_i \quad \text{(A-11)}$$

where

$$Q_{cfi} = U_{cf} \times A_m \times S_{ci} \times C_{iv} \quad . \quad \text{(A-12)}$$

The data for calculation of the dose from ingestion of milk produced by animals grazed on contaminated forage appear in Table A-50.

TABLE A-50

DATA FOR MILK CONSUMPTION (FORAGE)
WASTE MIGRATION INTO GROUNDWATER SCENARIO
(Cs-135)

Variable	Quantity	Unit	Reference
U_{cf}	310	ℓ/yr	RG 1.109
A_m	50	kg/day	RG 1.109
S_{ci}	1.2×10^{-2}	day/ℓ	RG 1.109
C_{iv}	4.64×10^{-2}	μCi/kg	Equation A-5
DF_i	Use applicable organ dose conversion factors.	rem/μCi	NUREG/CR-0150

Step 1

Substitution of the numerical values from Table A-50 into Equations A-11 and A-12 gives the organ doses for Cs-135 from milk produced by animals grazed on contaminated forage:

D_i (lung) = 0.0 rem
D_i (liver) = 9.68×10^{-2} rem
D_i (bone surface) = 1.12×10^{-1} rem
D_i (total body) = 5.71×10^{-2} rem.

Step 2

Since Cs-135 dominates the dose at 13,500, the total organ doses are the same as in Step 1.

Step 3

Step 3 consists of summing the dose commitments from all pathways, for all isotopes, and for all organs at risk. The total doses for each pathway are given in Table A-51.

TABLE A-51

INDIVIDUAL PATHWAY ORGAN DOSE COMMITMENTS (rem)
WASTE MIGRATION INTO GROUNDWATER SCENARIO

	Bone Surface	Liver	Lung	Total Body
Drinking Water	3.3×10^{-2}	2.8×10^{-2}	0	1.68×10^{-2}
Fruits and Vegetables	1.76×10^{-1}	1.5×10^{-1}	0	8.8×10^{-2}
Meat from Contaminated Forage	1.33×10^{-3}	1.14×10^{-2}	0	6.67×10^{-3}
Milk from Contaminated Forage	1.12×10^{-1}	9.68×10^{-2}	0	5.71×10^{-2}
Meat from Contaminated Water	9.92×10^{-4}	8.55×10^{-4}	0	5.12×10^{-3}
Milk from Contaminated Water	1.01×10^{-2}	8.67×10^{-3}	0	5.12×10^{-3}
TOTAL	3.45×10^{-1}	2.97×10^{-1}	0	1.76×10^{-1}

Step 4

Organ dose commitments calculated in Step 3 are multiplied by the appropriate weighting factor (W_T) from Table A-6 to calculate the whole-body equivalent (WBE) dose.

$$WBE_j = D_j \times W_{Tj}$$

where

WBE_j (bone surface) $= 3.45 \times 10^{-1}$ (0.03) $= 1.04 \times 10^{-2}$ rem
WBE_j (liver) $= 2.97 \times 10^{-1}$ (0.06) $= 1.78 \times 10^{-2}$ rem
WBE_j (lung) $= 0$ (0.12) $= 0$ rem
WBE_j (total body) $= 1.76 \times 10^{-1}$ (0.06) $= 1.06 \times 10^{-2}$ rem.

Using these calculated WBE doses and the procedures outlined in Subsection A.1.3.1 and weighting factors from Table A-6, the maximum individual dose from the waste migration into groundwater scenario is

$$WBE = 2.45 \times 10^{-1} \text{ rem.}$$

Step 5

The population dose commitment is calculated from the maximum individual dose as follows.

$$\text{Population WBE dose} = (2.45 \times 10^{-1})\ (1)\ (5)$$
$$= 1.22 \text{ man-rem.}$$

Step 6

The health effects associated with the population dose are based on the BEIR III Report in which it is estimated that 1 million man-rem cause between 75 and 230 excess cancer fatalities. Multiplying the WBE dose by 7.5×10^{-5} and 2.3×10^{-4}, gives a range of 9.19×10^{-5} to 2.82×10^{-4} excess cancer fatality from the waste-migration-into-groundwater scenario in the year 13,500 at the point of discharge to the aquifer. (See Appendix B, Table B-51.)

A.1.8.1.5 Intrusional Releases

A.1.8.1.5.1 Volcanism

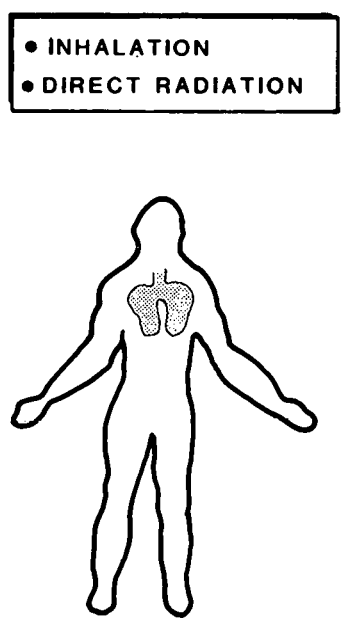
Since the INEL is located on part of a volcanic rift zone, the effects of future volcanic occurrences in the area must be considered. The mean occurrence interval for all types of activity in the Arco-Big Southern Butte

area (see Figure 3-3) is suggested to be 3000 yr. The probability for volcanic eruption in the calcine disposal area is estimated to be about 1×10^{-8} event per year.

No dose commitments resulting from air contamination caused by volcanic eruption are calculated because the effects would be less than the effects of a severe geologic disruption described in Subsection A.1.8.1.5.5. In the event of an eruption outside the calcine disposal area, any lava flow covering the bins would mitigate rather than enhance radiological effects by entombing the waste.

A.1.8.1.5.2 Intrusion into the Waste

After the cessation of institutional control at the INEL, it would be possible for an individual to dig into the waste since it is in a near-surface disposal complex. This individual could be a well driller, an archaeologist, a prospector, or simply someone who is curious. Once the intruder encounters the waste, he is exposed to radiation from the two significant pathways shown in the accompanying illustration. The intruder is exposed to direct penetrating radiation and can inhale dust containing radionuclides. The event is illustrated in Subsection 4.5.2.1.2. The intrusion-into-the-waste scenario applies to Alternatives 1, 2, and 4 which involve near-surface disposal at the INEL.



INTRUSION INTO THE WASTE

Contaminated soil which has been removed from around breached canisters and spread over the surface of the site is also a potential exposure pathway. The effects of living at the contaminated site and farming in contaminated soil are evaluated in Subsection A.1.8.1.5.3.

The intrusion-into-the-waste scenario is based on the following assumptions:

- The probability of occurrence is 0.01 event per year.
- A population of 10 individuals is exposed to radiation.

The following sample calculation gives the estimated maximum individual whole-body dose commitment for Alternative 1 from plutonium-239 (Pu-239) in the year 3000.

Calculation of Inhalation Pathway Dose

The contribution of the significant radionuclide, Pu-239, to the maximum individual dose commitment from the inhalation pathway is given by the equations:

$$D_i = C_i \times V \times DF_i \qquad \text{(A-1)}$$

where

$$V = B \times T \qquad \text{(A-2)}$$

$$C_i = C_w \times C_{ci} \times F_i \quad . \qquad \text{(A-3b)}$$

The data for calculation of the inhalation dose from individual intrusion into the waste appear in Table A-52.

Step 1

Substitution of the numerical values from Table A-52 into Equations A-1, A-2, and A-3b gives the maximum individual organ doses from inhalation of Pu-239:

D_i (lung) = 7.89 rem
D_i (liver) = 1.08×10^{1} rem
D_i (bone surface) = 5.66×10^{1} rem
D_i (total body) = 2.30 rem.

TABLE A-52

DATA FOR INHALATION PATHWAY
INTRUSION INTO THE WASTE SCENARIO
(Pu-239)

Variable	Quantity	Unit	Reference
C_w	1.0×10^{-4}	g/m^3	Scenario
C_{ci}	6.8×10^{-1}	μCi/g	Figure A-2
F_i	1	fraction	Maximizes dose.
B	2	m^3/hr	Working rate.
T	100	hr	Scenario
DF_i (bone surface)	4.16×10^3	rem/μCi	Table A-3
DF_i (lung)	5.80×10^2	rem/μCi	Table A-3
DF_i (liver)	7.97×10^2	rem/μCi	Table A-3
DF_i (total body)	1.69×10^2	rem/μCi	Table A-3

Step 2

The inhalation organ dose commitments from all radionuclides are determined by using the values of isotope concentrations from Figure A-2. The appropriate DF_i values are from NUREG/CR-0150. The organ dose commitments are

D_t (lung) $= 3.1 \times 10^1$ rem
D_t (liver) $= 4.2 \times 10^1$ rem
D_t (bone surface) $= 2.1 \times 10^2$ rem
D_t (total body) $= 8.9$ rem.

Calculation of Direct Radiation Pathway Dose

The direct radiation dose to an individual intruder into the waste is determined by the following equation:

$$D_i = Q_i \times DF_{gi} \qquad \text{(A-28)}$$

where

$$Q_i = C_{ci} \times F_c \times T \times \rho_c \times 10^{-6} \quad . \qquad \text{(A-29)}$$

The data for calculation of the dose from direct radiation appear in Table A-53.

TABLE A-53

DATA FOR DIRECT RADIATION PATHWAY
INTRUSION INTO THE WASTE SCENARIO*
(Sb-126)

Variable	Quantity	Unit	Reference
C_{ci}	3.2×10^{-2}	μCi/g	Figure A-2
F_c	1.0	fraction	Pure calcine.
T	100	hr	Scenario
ρ_c	1.3	g/cc	Scenario
DF_{gi} (Nb-93m)	1.03×10^4	$\frac{\text{rem/hr}}{\text{Ci/cc}}$	ISOSHLD
DF_{gi} (Sn-126)	1.15×10^4	$\frac{\text{rem/hr}}{\text{Ci/cc}}$	ISOSHLD
DF_{gi} (Sb-126)	7.69×10^5	$\frac{\text{rem/hr}}{\text{Ci/cc}}$	ISOSHLD
DF_{gi} (Am-241)	2.66×10^3	$\frac{\text{rem/hr}}{\text{Ci/cc}}$	ISOSHLD

* These dose factors were taken from data supplied using the shielding code ISOSHLD. The four values given here are representative of the major gamma ray emitters existing in the year 3000.

Step 1 and Step 2

Substitution of the numerical values from Table A-53 into Equations A-28 and A-29 gives the whole-body direct radiation dose from the significant nuclide in the year 3000.

D_i = 3.2 rem.

Calculation of Whole-Body Equivalent Doses and Health Effects

Step 3

Step 3 consists of summing the dose commitments from all pathways, isotopes, and organs at risk. In this scenario, the total maximum individual doses are calculated separately since exposure to external direct radiation occurs only at the time of exposure, while the inhaled material contributes to the 50-yr dose commitment.

The inhalation dose commitments from all pathways for all isotopes and all organs are

D_t (lung) = 3.10×10^1 rem
D_t (liver) = 4.20×10^1 rem
D_t (bone surface) = 2.10×10^2 rem
D_t (total body) = 8.90 rem.

The radiation dose from the direct radiation pathway for all isotopes is

D_t = 3.2 rem.

Step 4

Organ dose commitments calculated in Step 3 are multiplied by the appropriate weighting factors (W_T) from Table A-6, and the direct radiation dose is multiplied by its weighting factor, 1, to calculate the whole-body equivalent (WBE) dose.

WBE = 4.4 rem, direct radiation, and
WBE = 17 rem, inhalation.

For a 1-yr period, the maximum individual receives a total dose commitment of 21.4 rem from these two sources.

Step 5

The population dose commitment is calculated from the maximum individual dose as follows.

Population WBE dose = (10) (21.4)

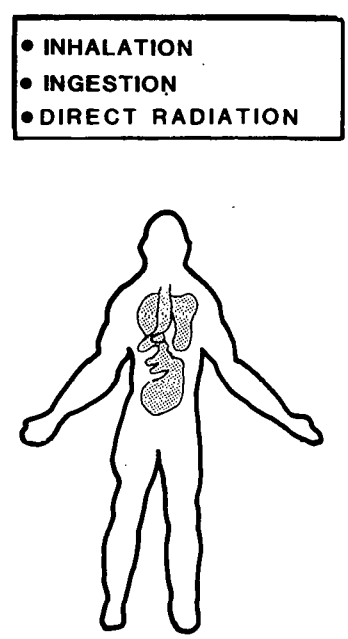
= 214 man-rem.

Step 6

The health effects associated with the population dose are based on the BEIR III Report in which it is estimated that each 1 million man-rem cause between 75 and 230 excess cancer fatalities. Multiplying the WBE dose by 7.5×10^{-5} and 2.3×10^{-4} gives a range of 1.60×10^{-2} to 4.92×10^{-2} health effect from the intrusion into the waste scenario for Alternative 1 in 3000. (See Appendix B, Table B-67.)

A.1.8.1.5.3 Living at Contaminated Site

Houses might be built at the disposal site after an individual intruder has deposited contaminated soil on the surface above the bins. Residents of these houses could be exposed to radiation from the three pathways shown in the accompanying illustration. These three pathways are consumption of food grown in the contaminated soil, direct exposure to penetrating radiation from surface contamination, and exposure to radon daughters in a house built on the contaminated land. The scenario is illustrated in Subsection 4.5.2.1.2. The effects of living at the contaminated site are evaluated for Alternatives 1, 2, and 4 which involve waste disposal at the INEL.



LIVING AT CONTAMINATED SITE

The scenario is based on the following assumptions:

- The probability of occurrence is 0.01 event per year.
- A population of 5 individuals is exposed to radiation.
- There is a 1% calcine concentration in the top 1-m (3.3-ft) layer of soil.
- The house is built on the surface of a 1-m layer of soil contaminated with radium.

The following sample calculation gives the maximum individual whole-body dose commitment for Alternative 1 from technetium-99 (Tc-99) in 3000.

Calculation of Ingestion Pathway Dose

The ingestion pathway has three contributing subpathways: ingestion of fruits and vegetables, ingestion of milk from animals grazed on contaminated forage, and ingestion of meat from animals grazed on contaminated forage. The maximum individual dose commitment from the ingestion pathway is calculated as follows.

The radionuclide concentration in vegetation is calculated from Equation A-5.

$$C_{iv} = D_{pi}\left(R\,\frac{[1 - e^{-(\lambda_e + \lambda_i)t_e}]}{Y(\lambda_e + \lambda_i)} + B_{iv}\,\frac{[1 - e^{-\lambda_i t_s}]}{P\lambda_i}\right)e^{-\lambda_i t_c} \qquad \text{(A-5)}$$

where

$$D_{pi} = \rho_s \times f \times PL \times C_{ci} \times \frac{1}{t_s} \quad . \qquad \text{(A-6a)}$$

The data for the calculation of C_{iv} appear in Table A-54. Substitution of the numerical values from Table A-54 in Equations A-5 and A-6a gives the value for C_{iv}:

$$C_{iv} = 5.25 \times 10^{-1}\ \mu Ci/kg \quad .$$

TABLE A-54

DATA FOR RADIONUCLIDE CONCENTRATION IN VEGETATION
LIVING AT CONTAMINATED SITE SCENARIO
(Tc-99)

Variable	Quantity	Unit	Reference
R	0	none	RG 1.109
λ_e	2.1×10^{-3}	hr^{-1}	RG 1.109
t_e	1.44×10^{3}[a] 7.20×10^{2}[b]	hr	RG 1.109
Y	2[a] 0.7[b]	kg/m^2	RG 1.109
B_{iv}	0.25	none	RG 1.109
λ_i	3.70×10^{-10}	hr^{-1}	Tc-99
t_s	1	hr	RG 1.109
P	240	kg/m^2	RG 1.109
t_c	0	hr	RG 1.109
ρ_s	1.6	g/cm^3	Idaho soil.
f	0.01	none	Scenario
PL	0.15	m	RG 1.109
C_{ci}	2.1×10^{-3}	μCi/g	Figure A-2

a. For fruits and vegetables consumed directly by man.

b. For vegetation consumed by meat- or milk-producing animals.

Dose commitments for the three ingestion subpathways are calculated separately as follows.

Calculation of Ingestion Dose Commitment from Fruits and Vegetables Consumption

The dose from ingestion of fruits and vegetables is determined by the equations:

$$D_{fi} = Q_{fi} \times DF_i \qquad \text{(A-7)}$$

where

$$Q_{fi} = U_f \times C_{iv} \quad . \qquad \text{(A-8)}$$

The dose resulting from consumption of fruits and vegetables raised in contaminated soil is obtained by substituting the data from Table A-55 in Equations A-7 and A-8.

TABLE A-55

DATA FOR FRUITS AND VEGETABLES CONSUMPTION
LIVING AT CONTAMINATED SITE SCENARIO
(Tc-99)

Variable	Quantity	Unit	Reference
U_f	584	kg/yr	RG 1.109
DF_i (lung)	0	rem/μCi	Table A-4
DF_i (liver)	6.28×10^{-4}	rem/μCi	Table A-4
DF_i (bone surface)	4.10×10^{-4}	rem/μCi	Table A-4
DF_i (total body)	2.14×10^{-4}	rem/μCi	Table A-4
C_{iv}	5.25	μCi/kg	Equation A-5

Step 1

Substitution of the numerical values from Table A-55 into Equations A-7 and A-8 gives the organ doses for Tc-99 from consumption of fruits and vegetables.

D_i (lung) = 0.0 rem
D_i (liver) = 1.93 rem
D_i (bone surface) = 1.26 rem
D_i (total body) = 6.56×10^{-1} rem.

Calculation of Ingestion Dose Commitment from Meat Consumption

The dose from consumption of meat produced from animals grazed on contaminated forage is given by using the following equations:

$$D_{mfi} = Q_{mfi} \times DF_i \qquad \text{(A-9)}$$

where

$$Q_{mfi} = U_{mf} \times A_m \times S_{bi} \times C_{iv} \quad . \qquad \text{(A-10)}$$

The data for calculation of the dose from consumption of meat produced by animals grazed on contaminated forage appear in Table A-56.

TABLE A-56

DATA FOR MEAT CONSUMPTION
LIVING AT CONTAMINATED SITE SCENARIO
(Tc-99)

Variable	Quantity	Unit	Reference
U_{mf}	110	kg/yr	RG 1.109
A_m	50	kg/day	RG 1.109
S_{bi}	4.0×10^{-1}	day/kg	RG 1.109
C_{iv}	5.25	μCi/kg	Equation A-5
DF_i	Use applicable organ dose conversion factors.	rem/μCi	Table A-4

Step 1

Substitution of the numerical values from Table A-56 into Equations A-9 and A-10 gives the organ doses for Tc-99 from consumption of meat produced from animals grazed on contaminated forage:

D_i (lung) = 0.0 rem
D_i (liver) = 7.25 rem
D_i (bone surface) = 4.75 rem
D_i (total body) = 2.48 rem.

Calculation of Ingestion Dose Commitment from Milk Consumption

The contribution of Tc-99 to the maximum individual dose commitment through ingestion of milk from animals grazed on contaminated forage is given by the equations:

$$D_{cfi} = Q_{cfi} \times DF_i \quad (A\text{-}11)$$

where

$$Q_{cfi} = U_{cf} \times A_m \times S_{ci} \times C_{iv} \quad . \quad (A\text{-}12)$$

The data for calculation of the dose from ingestion of milk produced by animals grazed on contaminated forage appear in Table A-57.

TABLE A-57

DATA FOR MILK CONSUMPTION
LIVING AT CONTAMINATED SITE SCENARIO
(Tc-99)

Variable	Quantity	Unit	Reference
U_{cf}	310	ℓ/yr	RG 1.109
A_m	50	kg/day	RG 1.109
S_{ci}	2.5×10^{-2}	day/ℓ	RG 1.109
C_{iv}	5.25	μCi/kg	Equation A-5
DF_i	Use applicable organ dose conversion factors.	rem/μCi	Table A-4

Step 1

Substitution of the numerical values from Table A-57 into Equations A-11 and A-12 gives the organ doses from Tc-99 in milk produced by animals grazed on contaminated forage.

D_i (lung) = 0.0 rem
D_i (liver) = 1.28 rem
D_i (bone surface) = 8.34×10^{-1} rem
D_i (total body) = 4.35×10^{-1} rem.

Calculation of Direct Radiation Pathway Dose

The dose resulting from direct radiation is calculated by using the following equations:

$$D_i = Q_i \times DF_{gi} \qquad \text{(A-28)}$$

where

$$Q_i = C_{ci} \times F_c \times T \times \rho_c \times 10^{-6} \quad . \qquad \text{(A-29)}$$

The data for calculation of the dose from direct radiation appear in Table A-58.

Step 1

Substitution of the numerical values from Table A-58 into Equations A-28 and A-29 gives the organ doses for antimony-126 (Sb-126) from direct radiation:

$$D_i = 3.23 \text{ rem.}$$

Step 2

The whole-body direct radiation doses from all radionuclides are determined by using the values of isotope concentrations in Figure A-2:

$$D_t = 4.40 \text{ rem.}$$

Calculation of Radon Inhalation Pathway Dose

The lung dose from radon inhalation is given by the equations:

$$D_{rn} = \bar{C}_{WL} \times DF_{rn} \qquad \text{(A-31)}$$

TABLE A-58

DATA FOR DIRECT RADIATION PATHWAY
LIVING AT CONTAMINATED SITE SCENARIO
(Sb-126)

Variable	Quantity	Unit	Reference
C_{ci}	3.2×10^{-2}	μCi/kg	Figure A-2
F_c	0.01	fraction	Scenario
T	7.0×10^{3}	hr	Approximately 1 yr
DF_{gi} (Nb-93m)	5.47×10^{3}	$\frac{\text{rem/hr}}{\text{Ci/cc}}$	ISOSHLD
DF_{gi} (Sn-126)	1.99×10^{4}	$\frac{\text{rem/hr}}{\text{Ci/cc}}$	ISOSHLD
DF_{gi} (Sb-126)	1.38×10^{6}	$\frac{\text{rem/hr}}{\text{Ci/cc}}$	ISOSHLD
DF_{gi} (Am-241)	5.50×10^{3}	$\frac{\text{rem/hr}}{\text{Ci/cc}}$	ISOSHLD

* These dose factors were taken from data supplied using the shielding code ISOSHLD for soil slab geometry. The four values given here are representative of the major gamma ray emitters existing in the year 3000.

where

$$DF_{rn} = \frac{100T}{5840} \qquad \text{(A-37)}$$

and

$$\bar{C}_{WL} = 0.0087\ J^{0.46} \qquad \text{(A-32)}$$

and

$$J = 10^{4}\ C_{ra}\ \rho E(\lambda\tfrac{D}{P})^{\frac{1}{2}}\ \tanh(Y(\lambda(\tfrac{P}{D})^{\frac{1}{2}}) \quad . \qquad \text{(A-36)}$$

The data for calculation of the lung dose from radon daughter products appear in Table A-59.

TABLE A-59

DATA FOR RADON INHALATION PATHWAY
LIVING AT CONTAMINATED SITE SCENARIO
(Rn-222)

Variable	Quantity	Unit	Reference
C_{ci}	3.35×10^{1}	pCi/g	Figure A-2
F_c	0.01	none	Fraction of soil that is calcine.
C_{ra}	0.33	pCi/g	$F_c \times C_{ci}$
λ	2.1×10^{-6}	sec^{-1}	Radon
ρ	1.3	g/cc	Calcine density.
E	1	none	Assumes total release.
Y	100	cm	Depth of soil layer.
P	0.3	none	Scenario
D	0.024	cm^2/sec	Scenario
tanh(x)	$\frac{e^{x} - e^{-x}}{e^{x} + e^{-x}}$	none	Mathematical identity.

Step 1 and Step 2

Substitution of the numerical values from Table A-59 into Equations A-31, A-37, A-32, and A-36 gives the lung dose for Rn-222 from living in a house built on contaminated soil.

$$D_i = 0.95 \text{ rem.}$$

Calculation of Whole-Body Equivalent Doses and Health Effects

Step 3

Step 3 consists of summing the doses from all pathways, all isotopes, and all organs at risk. In this scenario, the total maximum individual doses are calculated separately because exposure to direct radiation and radon occur only at the time of exposure, while the ingestion dose contributes to the 50-yr dose commitment.

The 50-yr dose commitments for the ingestion pathway are

D_i (lung) = 2.7×10^{-3} rem
D_i (liver) = 4.6×10^{1} rem
D_i (bone surface) = 1.7×10^{2} rem
D_i (total body) = 1.5×10^{1} rem.

The direct radiation pathway dose is

D_t = 4.40 rem.

The lung dose equivalent from radon exposure is

D_i = 0.95 rem.

Step 4

In order to evaluate the effects of living on the contaminated site, the data are summed as follows. The whole-body equivalent (WBE) lung dose includes the 1-yr radon exposure plus the 50-yr dose commitment from the ingestion pathway. Weighting factors used are from Table A-6.

WBE_j (lung) = (2.7×10^{-3} rem + 0.95 rem) (0.12) = 0.11 rem
WBE_j (liver) = (46 rem) (0.06) = 2.76 rem
WBE_j (bone surface) = (170 rem) (0.03) = 5.10 rem
WBE_j (total body) = (15 rem) (0.06) = 0.90 rem.

The total whole-body equivalent (WBE) dose via the ingestion pathway for all isotopes and all organs can be obtained by using the procedure outlined in

Subsection A.1.3.1, isotope data from Figure A.2, and weighting factors from Table A-6. The total WBE dose for ingestion (excluding the lung dose) is calculated to be 28 rem. The maximum individual whole-body equivalent dose is summarized:

lung (radon)	= 0.11	rem
direct radiation	= 4.40	rem
ingestion	= 28	rem
Total WBE	= 33	rem.

Step 5

The population dose commitment is calculated from the maximum individual dose as follows.

Population WBE dose = 5 × 33

= 165 man-rem.

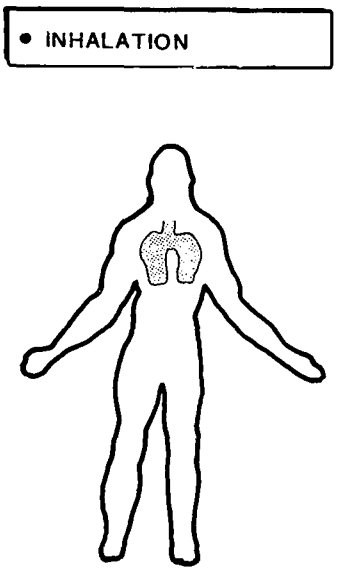
Step 6

The health effects associated with the population dose are based on the BEIR III Report in which it is estimated that 1 million man-rem cause between 75 and 230 cancer fatalities. Multiplying the WBE dose by 7.5×10^{-5} and 2.3×10^{-4} gives a range of 1.24×10^{-2} to 3.79×10^{-2} health effect from the living-at-contaminated-site scenario for Alternative 1 in 3000 (See Appendix B, Table B-71.)

A.1.8.1.5.4 Aircraft Impact

Because the calcine waste is in near-surface concrete vaults awaiting a decision on long-term management, the effects of an aircraft striking the vaults and dispersing some of the waste have been evaluated. Inhalation is the significant pathway by which the public would be exposed to radiation as shown in the illustration on the next page.

The aircraft impact scenario is evaluated for Alternatives 1, 2, 3, 4, and 5 during the processing period when calcine is in storage at the INEL. Beginning about 2060, after sufficient heat has been dissipated, the spaces between the bins and vaults will be filled with a concrete-like material. This type of decommissioning will be completed about 2100 and should preclude the possibility of a radionuclide release from an aircraft impact after the year 2100.



AIRCRAFT IMPACT

In this scenario, it is postulated that an aircraft loses altitude, falls on the calcine bin-vault complex, and ruptures some of the bins. Should the jet fuel ignite, the waste would become airborne in the smoke from the fire. The population would be affected by inhalation of the dispersed radionuclides regardless of the waste form. The event is illustrated in Subsection 4.5.1.2.2.

The aircraft impact scenario is based on the following assumptions:

- The impact penetrates a vault and ruptures two bins.
- The volume of waste penetrated is 32 m^3 (42,000 kg), and 0.1% (42 kg) becomes airborne;
- The probability of occurrence is 2×10^{-7} event per year (ERDA, 1977a).
- A population of 107,000 is exposed to radiation in 2020.

The following sample calculation gives the maximum individual whole-body dose commitment for Alternatives 1, 2, 3, and 4 from plutonium-238 (Pu-238) in the year 2020.

Calculation of Inhalation Pathway Dose

The contribution of the significant istope, Pu-238, to the maximum individual dose commitment from the inhalation pathway is given by the equations:

$$D_i = C_i \times V \times DF_i \qquad \text{(A-1)}$$

where

$$V = B \times T \qquad \text{(A-2)}$$

$$C_i = Q_i \times \frac{\chi}{Q} \qquad \text{(A-3)}$$

where

$$Q_i = Q_s \times F_i \times C_{ci} \times \frac{1}{3600T} \quad . \qquad \text{(A-4a)}$$

The data for calculation of the inhalation dose from an aircraft impact are given in Table A-60.

TABLE A-60

DATA FOR AIRCRAFT IMPACT SCENARIO
(Pu-238)

Variable	Quantity	Unit	Reference
Q_s	42	kg	Scenario
C_{ci}	5.8×10^4	μCi/kg	Fig. A-2
F_i	1	none	Scenario
χ/Q	7×10^{-6}	sec/m^3	Table A-7
B	2	m^3/hr	Working rate.
DF_i (bone surface)	3.27×10^3	rem/μCi	Table A-3
DF_i (liver)	7.00×10^2	rem/μCi	Table A-3
DF_i (lung)	6.08×10^2	rem/μCi	Table A-3
DF_i (total body)	1.40×10^2	rem/μCi	Table A-3

Step 1

Substitution of the numerical values from Table A-60 into Equations A-1, A-2, A-3, and A-4a gives the maximum individual organ doses from Pu-238 inhalation:

D_i^i (lung) = 5.74 rem
D_i^i (liver) = 6.63 rem
D_i^i (bone surface) = 3.09×10^1 rem
D_i^i (total body) = 1.32 rem.

Step 2

The inhalation organ dose commitments from all radionuclides are determined by using the values of isotope concentrations in Figure A-2 and the dose conversion factors from NUREG/CR-0150.

These total dose commitments are

D_t^t (lung) = 1.70×10^1 rem
D_t^t (liver) = 7.62 rem
D_t^t (bone surface) = 3.57×10^1 rem
D_t^t (total body) = 1.75 rem.

Step 3

Step 3 consists of summing the doses from all pathways for all isotopes and for all organs at risk. Since there is only one significant pathway for the aircraft impact scenario, the total organ dose commitments are those given in Step 2.

Step 4

Organ doses calculated in Step 3 are multiplied by the appropriate weighting factor (W_T) from Table A-6 to calculate the maximum individual whole-body equivalent (WBE) dose given below.

WBE = 4.48 rem.

Step 5

The population dose commitment is calculated from the maximum individual dose for the 107,000 persons projected to reside in Sector 7 in 2020 as follows.

Population WBE = (107,000) (4.48) (0.2)

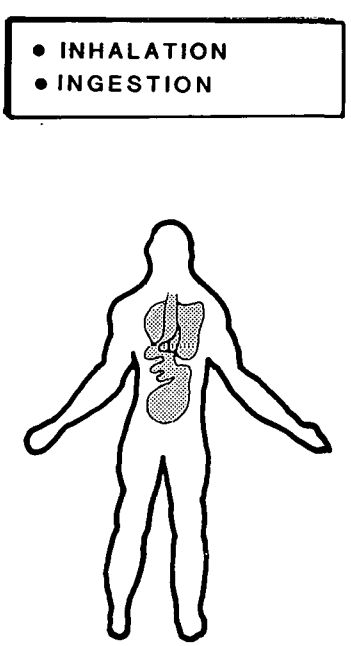
= 9.59×10^{4} man-rem.

Step 6

The health effects associated with the population dose are based on the BEIR III Report in which it is estimated that each 1 million person-rem cause between 75 and 230 excess cancer fatalities. Multiplying the WBE dose by 7.5×10^{-5} and 2.3×10^{-4} gives a range of 7.19 to 22.1 health effects from the aircraft impact scenario for Alternatives 1, 2, 3, and 4 in 2020. (See Appendix B, Tables B-75, B-76, B-77, B-78, B-79, B-80, B-81.)

A.1.8.1.5.5 Severe Geologic Disruption

A severe geologic disruption could disperse waste disposed at the INEL. However, it is impossible to predict what significant changes will occur to the earth over the time period evaluated in this report. The purpose of evaluating a severe geologic disruption is to determine the worst conceivable effects of waste dispersion. Consequently, the event is postulated so that its effects are more severe than would be the effects of other natural phenomena (earthquakes, tornadoes, floods, etc.). The general public would be exposed to radiation by the inhalation and ingestion pathways as shown in the accompanying illustration. The scenario applies to Alternatives 1, 2, and 4 and is illustrated in Subsection 4.5.2.2.



SEVERE GEOLOGIC DISRUPTION

The severe geologic disruption scenario is modeled as if a meteorite were to strike the waste disposal area. The event probability used is that of an explosive volcano that disperses the waste. The scenario is based on the following assumptions:

- The probability of occurrence is 1×10^{-8} event per year.

- A population of 107,000 is exposed to radiation in 2020.

- A meteorite of approximately 25 m in diameter strikes the waste disposal site at a speed of 35 km/sec, pulverizing the surrounding rock.

- One percent of the waste is dispersed.

- Fifty percent of the suspended material is uniformly distributed in a cylindrical base cloud the dimensions of which are 8000 m in diameter by 1200 m high.

- The maximum individual is exposed to the base cloud concentration for 2 hr (wind speed of approximately 1 m/sec) at 7000 m from the point of impact.

- The radionuclide source term is reduced by 50% to account for the distribution of material between the central and base clouds.

- Ten percent of the initial release of suspended material is in the respirable range.

The following sample calculation gives the maximum individual whole-body dose commitment for Alternatives 1 and 2 from plutonium-239 (Pu-239) in the year 2020.

Calculation of Inhalation Pathway Dose

The contribution of the significant isotope, Pu-239, to the maximum individual dose commitment from the inhalation pathway is given by the equations:

$$D_i = C_i \times V \times DF_i \qquad \text{(A-1)}$$

where

$$V = B \times T \qquad \text{(A-2)}$$

$$C_i = \frac{Q_w \times C_{ci} \times F_c \times f_s}{V_c} \quad . \qquad \text{(A-3a)}$$

The data for calculation of the inhalation dose appear in Table A-61.

TABLE A-61

DATA FOR SEVERE GEOLOGIC DISRUPTION SCENARIO
(Pu-239)

Variable	Quantity	Unit	Reference
Q_w	2.04×10^7	kg	Scenario
T	2.0	hr	Time for clouds to pass.
V_c	6.03×10^{10}	m^3	Calculated from scenario.
f_s	0.5	none	Scenario
C_{ci}	7.0×10^{-4}	Ci/kg	Table A-2
F_c	0.001	none	Scenario
B	1.25	m^3/hr	Normal breathing rate.
DF_i (lung)	5.80×10^2	rem/μCi	Table A-3
DF_i (liver)	7.79×10^2	rem/μCi	Table A-3
DF_i (bone surface)	4.16×10^3	rem/μCi	Table A-3
DF_i (total body)	1.69×10^2	rem/μCi	Table A-3

Step 1

Substitution of the numerical values from Table A-61 into Equations A-1, A-2, and A-3a gives the organ doses from inhalation of Pu-239.

D_i (lung) $= 1.72 \times 10^{-1}$ rem
D_i (liver) $= 2.36 \times 10^{-1}$ rem
D_i (bone surface) $= 1.23$ rem
D_i (total body) $= 5.0 \times 10^{-2}$ rem.

Step 2

The organ doses from all radionuclides are determined by using the values of isotope concentrations in Figure A-2 and the appropriate DF_i values:

D_t (lung) $= 4.4 \times 10^{1}$ rem
D_t (liver) $= 2.0 \times 10^{1}$ rem
D_t (bone surface) $= 9.2 \times 10^{1}$ rem
D_t (total body) $= 4.5$ rem.

Calculation of Ingestion Pathway Dose

The ingestion pathway has three contributing subpathways: ingestion of fruits and vegetables, ingestion of milk from animals grazed on contaminated forage, and ingestion of meat from animals grazed on contaminated forage. The maximum individual dose commitment from the ingestion pathway is calculated by first calculating the radionuclide concentration in vegetation using Equation A-5.

$$C_{iv} = D_{pi}\left(R\,\frac{[1 - e^{-(\lambda_e + \lambda_i)t_e}]}{Y(\lambda_e + \lambda_i)} + B_{iv}\,\frac{[1 - e^{-\lambda_i t_s}]}{P\lambda_i}\right)e^{-\lambda_i t_c} \qquad \text{(A-5)}$$

For a severe geologic disruption, it is assumed that $t_e = 0$, $t_c = 0$, and $\lambda_i t_s \ll 1$. Equation A-5 thus then reduces to

$$C_{iv} = \frac{D_{pi} \times B_{iv} \times t_s}{P}$$

where

$$D_{pi} = C_i \times V_d \times T \times \frac{3600}{t_s} \qquad \text{(A-6b)}$$

and C_i is calculated using Equation A-3a from the inhalation pathway.

Substituting the numerical values from Tables A-61 and A-62 into Equation A-5 gives $C_{iv} = 9.83 \times 10^{-8}$ μCi/kg.

The ingestion dose commitment from the three contributing subpathways can be calculated separately as described in Subsection A.1.8. The dose from each subpathway is calculated and the separate doses are summed to arrive at the total ingestion dose. In this scenario, an alternative method is used to

TABLE A-62

DATA FOR RADIONUCLIDE CONCENTRATION IN VEGETATION
SEVERE GEOLOGIC DISRUPTION SCENARIO
(Pu-239)

Variable	Quantity	Unit	Reference
T	2	hr	Cloud passage time.
C_{ci}	7.0×10^{-4}	Ci/kg	Table A-2
R	0	none	No surface deposition.
f_s	0.5	none	Scenario
λ_e	2.0×10^{-3}	hr^{-1}	RG 1.109
F_c	0.01	fraction	Scenario
t_e	0	hr	No airborne exposure.
Y	2	kg/m^2	RG 1.109
B_{iv}	2.5×10^{-4}	none	RG 1.109
λ_i	9.11×10^{-13}	sec^{-1}	Pu-239
t_s	1.0	hr	RG 1.109
V_d	0.01	m/sec	Maximum deposition.
P	240	kg/m^2	RG 1.109
t_c	0	hr	RG 1.109

obtain the total ingestion dose. The dose conversion factors are multiplied directly by the total quantity of isotope ingested from the three contributing subpathways.

Calculation of Quantity of Isotope i Ingested in Fruits and Vegetables

The quantity of isotope i ingested by consuming contaminated fruits and vegetables is determined by the following equation:

$$Q_{fi} = U_f \times C_{iv} \quad . \tag{A-8}$$

Substitution of the numerical values from Table A-63 into Equation A-8 gives the quantity of isotope i ingested from contaminated fruits and vegetables.

$$Q_{fi} = 5.11 \times 10^{-5} \ \mu Ci \quad .$$

TABLE A-63

DATA FOR FRUITS AND VEGETABLES CONSUMPTION
SEVERE GEOLOGIC DISRUPTION SCENARIO
(Pu-239)

Variable	Quantity	Unit	Reference
U_f	520	kg/yr	RG 1.109
C_{iv}	9.83×10^{-8}	μCi/kg	Equation A-5

Calculation of Quantity of Isotope i Ingested in Meat

The quantity of isotope i ingested from meat produced by animals grazed on contaminated forage is obtained using the following equation:

$$Q_{mfi} = U_{mf} \times A_m \times S_{bi} \times C_{iv} \quad . \tag{A-10}$$

The data for calculation of the dose from consumption of meat produced by animals grazed on contaminated forage appear in Table A-64.

TABLE A-64

DATA FOR MEAT CONSUMPTION
SEVERE GEOLOGIC DISRUPTION SCENARIO
(Pu-239)

Variable	Quantity	Unit	Reference
U_{mf}	110	kg/yr	RG 1.109
A_m	50	kg/day	RG 1.109
S_{bi}	1.45×10^{-4}	day/kg	RG 1.109
C_{iv}	9.83×10^{-8}	μCi/kg	Equation A-5

Substitution of the numerical values from Table A-64 into Equation A-10 gives the quantity of isotope i ingested from consumption of meat produced from contaminated forage:

$$Q_{mfi} = 7.84 \times 10^{-9} \text{ μCi} \quad .$$

Calculation of Quantity of Isotope i Ingested in Milk

The quantity of isotope i ingested from milk produced by animals grazed on contaminated forage is given by the equation:

$$Q_{cfi} = U_{cf} \times A_m \times S_{ci} \times C_{iv} \quad . \qquad \text{(A-12)}$$

The data for calculation of the dose from consumption of milk produced by animals grazed on contaminated forage appear in Table A-65.

Substitution of the numerical values from Table A-65 into Equation A-12 gives the quantity of isotope i from consumption of milk produced by animals grazed on contaminated forage.

$$Q_{cfi} = 3.05 \times 10^{-9} \text{ μCi} \quad .$$

TABLE A-65

DATA FOR MILK CONSUMPTION
SEVERE GEOLOGIC DISRUPTION SCENARIO
(Pu-239)

Variable	Quantity	Unit	Reference
U_{cf}	310	ℓ/yr	RG 1.109
A_m	50	kg/day	RG 1.109
S_{ci}	2.00×10^{-6}	day/ℓ	RG 1.109
C_{iv}	9.83×10^{-8}	μCi/kg	Equation A-5

Total Quantity of Isotope i Ingested

The total quantity of isotope i ingested from the three subpathways is summarized in Table A-66.

TABLE A-66

QUANTITY OF Pu-239 FROM INGESTION PATHWAYS

Pathway	Quantity (μCi)
Fruits and vegetables	5.11×10^{-5}
Meat	7.84×10^{-9}
Milk	3.05×10^{-9}
Total Pu-239 (Q_{ii})	5.11×10^{-5}

The ingestion dose commitment for isotope i, Pu-239, is calculated from the following equation

$$D_i = Q_{ii} \times DF_i$$

where DF_i are the dose conversion factors from Table A-4. The ingestion dose commitment values are

DF_i (lung) $= 9.35 \times 10^{-8}$ rem/μCi
DF_i (liver) $= 4.90 \times 10^{-1}$ rem/μCi
DF_i (bone surface) $= 2.60$ rem/μCi
DF_i (total body) $= 9.51 \times 10^{-2}$ rem/μCi.

Step 1

Substituting these DF_i values and the total quantity ingested (Table A-66) in the above equation gives the organ doses from all ingestion subpathways.

D_i (lung) $= 4.78 \times 10^{-12}$ rem
D_i (liver) $= 2.50 \times 10^{-5}$ rem
D_i (bone surface) $= 1.33 \times 10^{-4}$ rem
D_i (total body) $= 4.86 \times 10^{-6}$ rem.

Step 2

The organ doses from all ingestion subpathways and all isotopes are obtained by summation. They are

D_t (lung) $= 7.2 \times 10^{-1}$ rem
D_t (liver) $= 3.1$ rem
D_t (bone surface) $= 4.0 \times 10^{1}$ rem
D_t (total body) $= 5.8$ rem.

Calculation of Direct Radiation Pathway Dose

The direct radiation dose results from material deposited on the ground during passage of the contaminated cloud. Since Pu-239 is primarily an alpha emitter, it contributes very little to the direct radiation dose. Therefore, the sample calculation does not include a direct radiation dose. The direct radiation dose is included in Step 4. It is significant only during the first 500 yr.

Calculation of Whole-Body Equivalent Doses and Health Effects

Step 3

Step 3 consists of summing the dose commitments from all pathways, for all isotopes, and for all organs at risk. The total doses for each pathway are given in Table A-67.

Step 4

Organ dose commitments calculated in Step 3 are multiplied by the appropriate weighting factor (W_T) from Table A-6 to calculate the whole-body equivalent (WBE) dose.

TABLE A-67

INDIVIDUAL PATHWAY ORGAN DOSE COMMITMENTS (rem)
SEVERE GEOLOGIC DISRUPTION SCENARIO
(Pu-239)

Pathway	Lung	Liver	Bone Surface	Total Body
Ingestion	7.2×10^{-1}	3.1	4.0×10^{1}	5.8
Inhalation	4.4×10^{1}	2.0×10^{1}	9.2×10^{1}	4.5
TOTAL	4.47×10^{1}	2.31×10^{1}	1.32×10^{2}	1.03×10^{1}

The direct radiation dose from the ground-plane deposition of all isotopes is

direct radiation = 66.0 rem.

The maximum individual whole-body equivalent dose from ingestion and inhalation is

WBE = 18.5 rem.

Combining the direct radiation dose and the whole-body equivalent dose gives a total radiation dose commitment from 1 yr of exposure:

WBE = 84.5 rem.

Step 5

The population dose commitment is calculated from the maximum individual dose as follows.

Population WBE dose = (84.5)(0.6)(107,000).

$= 5.42 \times 10^{6}$ man-rem.

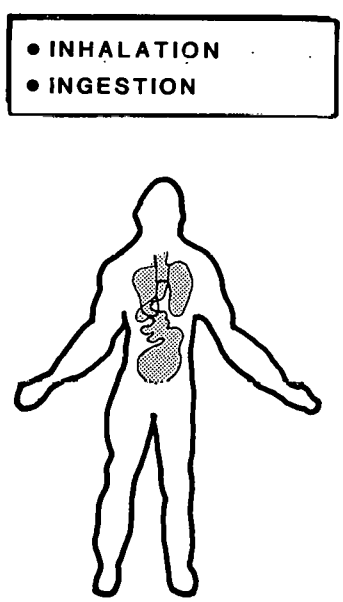
Step 6

The health effects associated with the population dose are based on the BEIR III Report in which it is estimated that each 1 million man-rem cause between 75 and 230 excess cancer fatalities. Multiplying the WBE dose by 7.5×10^{-5} and 2.3×10^{-4} gives a range of 407 to 1,250 health effects from the severe geologic disruption scenario for Alternatives 1, 2, and 4 in 2020. (See Appendix B, Tables B-82 through B-86.)

A.1.8.2 Repository Releases

A.1.8.2.1 Canister Drop

Waste canisters shipped to an offsite geologic repository could be dropped and damaged while being lowered into the repository. Canisters would be designed to preclude a release of radioactive waste from such an accident. However, it was assumed that a canister ruptures and releases radionuclides. The significant exposure pathways, inhalation and ingestion, are shown in the accompanying illustration. The scenario is applicable to Alternatives 3, 4, and 5 in which radioactive waste is shipped to a federal geological repository.



WASTE CANISTER DROP

The inhalation pathway occurs at the beginning of the incident. Ingestion and direct radiation contribute to the total dose over a longer period of time following the incident. The inhalation pathway dominates the total dose. The dose from direct radiation is negligible compared to the doses from the two significant

exposure pathways. This scenario applies to the period of repository operation (1990-2020) and is illustrated in Subsection 4.5.1.2.2. The canister drop produces the same effects as the calcine spill at the INEL.

The effects of a canister drop at a repository are evaluated for INEL waste by using the calculational methodology presented in the GEIS. The data have been modified for this report so that the dose commitments represent only the effects of INEL high-level waste. The scenario is based on the following assumptions:

- A waste canister is dropped to the bottom of the mine shaft, breaking and releasing part of its contents to the mine ventilation system.

- The mine ventilation system is protected by two HEPA filter systems which give an overall decontamination factor of 10^{7}.

- The following quantities of waste are released from the stack:

  - Alternative 3 (stabilize calcine): 31 kg released to the filter for a stack release of 31×10^{-7} kg calcine equivalent,

  - Alternatives 3 (glass) and 5: 13 kg released to the filter for a stack release of 13×10^{-7} kg calcine equivalent, and

  - Alternative 4: The waste contains highly concentrated actinides. Because of its high actinide concentration, a stack release of 1.9×10^{-4} kg calcine equivalent is estimated.

- The probability of occurrence is 7×10^{-7} event per year.

- A population of 2,000,000 is exposed to radiation.

The following sample calculation gives the estimated maximum individual whole-body dose commitment for Alternative 3 (stabilize calcine) for strontium-90 (Sr-90), the most significant radionuclide, for the year 1990.

Calculation of Inhalation Pathway Dose

The contribution of a single radionuclide, Sr-90, to the maximum individual dose commitment from inhalation is given by the following equations:

$$D_i = C_i \times V \times DF_i \qquad \text{(A-1)}$$

where

$$V = B \times T \qquad \text{(A-2)}$$

$$C_i = Q_i \times \frac{\chi}{Q} \qquad \text{(A-3)}$$

where

$$Q_i = Q_s \times F_i \times C_{ci} \times \frac{1}{3600T} \quad . \qquad \text{(A-4a)}$$

The data for calculation of the dose from inhalation appear in Table A-68.

TABLE A-68

DATA FOR INHALATION PATHWAY
CANISTER DROP SCENARIO
(Sr-90)

Variable	Quantity	Unit	Reference
Q_s	31	kg	Scenario
T	1	hr	Scenario
C_{ci}	13×10^6	μCi/kg	Figure A-2
F_i	1×10^{-7}	none	Scenario
χ/Q	1.3×10^{-5}	sec/m^3	Scenario
B	1.25	m^3/hr	Scenario
DF_i	Use appropriate organ dose conversion factors.	rem/μCi	Table A-3

Step 1

Substitution of the numerical values from Table A-68 into Equations A-1, A-2, A-3, and A-4a gives the organ doses from inhalation of Sr-90:

D_i (lung) $= 1.55 \times 10^{-6}$ rem
D_i (liver) $= 3.46 \times 10^{-9}$ rem
D_i (bone surface) $= 4.18 \times 10^{-8}$ rem
D_i (total body) $= 1.69 \times 10^{-8}$ rem.

Step 2

The organ doses from all radionuclides are determined by using the values of isotope concentrations in Figure A-2 and appropriate DF_i values. The total dose commitments are

D_t (lung) $= 2.61 \times 10^{-6}$ rem
D_t (liver) $= 7.82 \times 10^{-7}$ rem
D_t (bone surface) $= 3.59 \times 10^{-6}$ rem
D_t (total body) $= 1.94 \times 10^{-7}$ rem.

Calculation of Ingestion Pathway Dose

The ingestion pathway has three contributing subpathways: ingestion of contaminated fruits and vegetables, ingestion of milk from animals grazed on contaminated forage, and ingestion of meat from animals grazed on contaminated forage. The maximum individual dose commitment from the ingestion pathway is calculated as follows.

The radionuclide concentration in vegetation is calculated from Equation A-5.

$$C_{iv} = D_{pi}\left(R\,\frac{[1 - e^{-(\lambda_e + \lambda_i)t_e}]}{Y(\lambda_e + \lambda_i)} + B_{iv}\,\frac{[1 - e^{-\lambda_i t_s}]}{P\lambda_i}\right)e^{-\lambda_i t_c} \qquad \text{(A-5)}$$

where

$$D_{pi} = \frac{X}{Q} \times V_d \times Q_i \qquad \text{(A-6)}$$

where

$$Q_i = Q_s \times F_i \times C_{ci} \times \frac{1}{T} \quad . \tag{A-4b}$$

The data for the calculation of C_{iv} appear in Table A-69.

TABLE A-69

DATA FOR RADIONUCLIDE CONCENTRATION IN VEGETATION
CANISTER DROP SCENARIO
(Sr-90)

Variable	Quantity	Unit	Reference
$\frac{X}{Q}$	1.30×10^{-5}	sec/m^3	Scenario
D_{pi}	1.7×10^{-4}	$\mu Ci/m^2$-hr	Equation A-6
V_d	0.01	m/sec	Engineering judgment.
R	2.0×10^{-1}	none	RG 1.109
λ_e	0	hr^{-1}	RG 1.109
t_e	8.77×10^{3}[a] 7.20×10^{2}[b]	hr	RG 1.109
Y	2[a] 0.7[b]	kg/m^2	RG 1.109
B_{iv}	1.7×10^{-2}	none	RG 1.109
λ_i	2.73×10^{-6}	hr^{-1}	Sr-90
t_s	8.76×10^{-3}	hr	RG 1.109
P	240	kg/m^2	RG 1.109
Q_s	31	kg	Scenario
t_c	0	hr	RG 1.109
T	1	hr	Scenario

a. For fruits and vegetables consumed directly by man.

b. For vegetation consumed by meat- or milk-producing animals.

Substitution of the numerical values from Table A-69 into Equation A-5 gives the radionuclide concentration in vegetation:

$$C_{iv} = 5.18 \times 10^{-7} \text{ μCi/kg} .$$

Calculation of Ingestion Dose Commitment from Fruits and Vegetables Consumption

The dose from ingestion of fruits and vegetables is determined by the equations:

$$D_{fi} = Q_{fi} \times DF_i \qquad \text{(A-7)}$$

where

$$Q_{fi} = U_f \times C_{iv} . \qquad \text{(A-8)}$$

The data for calculation of the dose from consumption of fruits and vegetables appear in Table A-70.

TABLE A-70

DATA FOR FRUITS AND VEGETABLES CONSUMPTION
CANISTER DROP SCENARIO
(Sr-90)

Variable	Quantity	Unit	Reference
U_f	584	kg/yr	RG 1.109
DF_i	Use appropriate organ dose conversion factors.	rem/μCi	Table A-4
C_{iv}	5.18×10^{-7}	μCi/kg	Equation A-5

Step 1

Substitution of the numerical values from Table A-70 into Equations A-7 and A-8 gives the organ doses for Sr-90 from fruits and vegetables consumption:

D_i (lung) $= 1.80 \times 10^{-12}$ rem
D_i (liver) $= 1.76 \times 10^{-6}$ rem
D_i (bone surface) $= 2.60 \times 10^{-4}$ rem
D_i (total body) $= 2.86 \times 10^{-5}$ rem.

Step 2

The organ doses from all radionuclides are determined by using the values of isotope concentrations in Figure A-2 and appropriate DF_i values from NUREG/CR-0150. The dose commitments are

D_t (lung) $= 9.11 \times 10^{-6}$ rem
D_t (liver) $= 3.37 \times 10^{-5}$ rem
D_t (bone surface) $= 2.97 \times 10^{-4}$ rem
D_t (total body) $= 4.86 \times 10^{-5}$ rem.

Calculation of Ingestion Dose Commitment from Meat Consumption

The dose resulting from consumption of meat produced by animals grazed on contaminated forage is obtained as follows.

Calculate the radionuclide concentration in meat produced by animals grazed on contaminated forage using Equation A-5 and the data in Table A-69 where $Y = 0.7$ kg/m^2. The result is

$$C_{iv} = 1.48 \times 10^{-6} \ \mu Ci/kg \quad .$$

The dose from meat consumption is given by the equations:

$$D_{mfi} = Q_{mfi} \times DF_i \qquad (A\text{-}9)$$

where

$$Q_{mfi} = U_{mf} \times A_m \times S_{bi} \times C_{iv} \quad . \qquad (A\text{-}10)$$

The data for calculation of the dose from meat consumption appear in Table A-71.

Step 1

Substitution of the numerical values from Table A-71 into Equations A-9 and A-10 gives the organ doses for Sr-90 from meat consumption.

D_i (lung) $= 2.90 \times 10^{-14}$ rem
D_i (liver) $= 2.79 \times 10^{-8}$ rem
D_i (bone surface) $= 4.26 \times 10^{-6}$ rem
D_i (total body) $= 4.61 \times 10^{-7}$ rem.

TABLE A-71

DATA FOR MEAT CONSUMPTION
CANISTER DROP SCENARIO
(Sr-90)

Variable	Quantity	Unit	Reference
U_{mf}	110	kg/yr	RG 1.109
A_m	50	kg/day	RG 1.109
S_{bi}	6×10^{-4}	day/kg	RG 1.109
C_{iv}	1.48×10^{-6}	μCi/kg	Equation A-5
DF_i	Use applicable organ dose conversion factors.	rem/μCi	Table A-4

Step 2

The organ doses from all radionuclides are determined by using the values of isotope concentrations in Figure A-2 and the appropriate DF_i values from NUREG/CR-0150. The total dose commitments are

D_t (lung) $= 1.02 \times 10^{-6}$ rem
D_t (liver) $= 4.78 \times 10^{-6}$ rem
D_t (bone surface) $= 9.15 \times 10^{-6}$ rem
D_t (total body) $= 3.63 \times 10^{-6}$ rem.

Calculation of Ingestion Dose Commitment from Milk Consumption

The contribution of isotope i to the maximum individual dose commitment as a result of ingesting milk produced by animals grazed on contaminated forage is given by the following equations:

$$D_{cfi} = Q_{cfi} \times DF_i \qquad \text{(A-11)}$$

where

$$Q_{cfi} = U_{cf} \times A_m \times S_{ci} \times C_{iv} \quad . \qquad \text{(A-12)}$$

The data for calculation of the dose from consumption of contaminated milk appear in Table A-72.

TABLE A-72

DATA FOR MILK CONSUMPTION
CANISTER DROP SCENARIO
(Sr-90)

Variable	Quantity	Unit	Reference
U_{cfi}	310	ℓ/yr	RG 1.109
A_m	50	kg/day	RG 1.109
S_{ci}	8×10^{-4}	day/ℓ	RG 1.109
C_{iv}	1.48×10^{-6}	μCi/kg	Equation A-5
DF_i	Use applicable organ dose conversion factors.	rem/μCi	Table A-4

Step 1

Substituting the numerical values from Table A-72 into Equations A-11 and A-12 gives the organ doses from Sr-90 in milk:

D_i (lung) $= 1.09 \times 10^{-13}$ rem
D_i (liver) $= 1.05 \times 10^{-7}$ rem
D_i (bone surface) $= 1.58 \times 10^{-5}$ rem
D_i (total body) $= 1.73 \times 10^{-6}$ rem.

Step 2

The organ doses from all radionuclides are determined by using the values of isotope concentrations in Figure A-2 and appropriate dose conversion factors from NUREG/CR-0150. The total dose commitments are

D_t (lung) $= 8.29 \times 10^{-6}$ rem
D_t (liver) $= 2.78 \times 10^{-5}$ rem
D_t (bone surface) $= 4.31 \times 10^{-5}$ rem
D_t (total body) $= 1.94 \times 10^{-5}$ rem.

Calculation of Direct Radiation Pathway Dose

The direct radiation dose results from material deposited on the ground. The dose commitment from ground-plane deposition is given by Equation A-13.

$$D_{gi} = t_x \times S_f \times C_{gi} \times DF_{gi} \quad . \qquad \text{(A-13)}$$

The doses resulting from ground-plane deposition are negligible and therefore are not presented.

Calculation of Whole-Body Equivalent Doses and Health Effects

Step 3

The doses from all pathways for each organ are obtained by summation as shown in Table A-73.

TABLE A-73

INDIVIDUAL PATHWAY ORGAN DOSE COMMITMENTS (rem)
CANISTER DROP SCENARIO

Pathway	Lung	Liver	Bone Surface	Total Body
Inhalation	2.61×10^{-6}	7.82×10^{-7}	3.59×10^{-6}	1.94×10^{-7}
Fruits and Vegetable	9.11×10^{-6}	3.37×10^{-5}	2.97×10^{-4}	4.86×10^{-5}
Meat	1.02×10^{-6}	4.87×10^{-6}	9.15×10^{-6}	3.63×10^{-6}
Milk	8.29×10^{-6}	2.78×10^{-5}	4.31×10^{-5}	1.94×10^{-5}
TOTAL	2.10×10^{-5}	6.70×10^{-5}	3.52×10^{-4}	7.18×10^{-5}

Step 4

The whole-body equivalent dose (WBE) for the maximum individual is calculated by summing the product of all organ doses and appropriate weighting factors.

$$WBE = 9.40 \times 10^{-5} \text{ rem.}$$

Step 5

The population whole-body equivalent dose is calculated for 2 million people.

$$\text{Population WBE} = (2 \times 10^{6})\ (9.40 \times 10^{-5})\ (0.01)$$

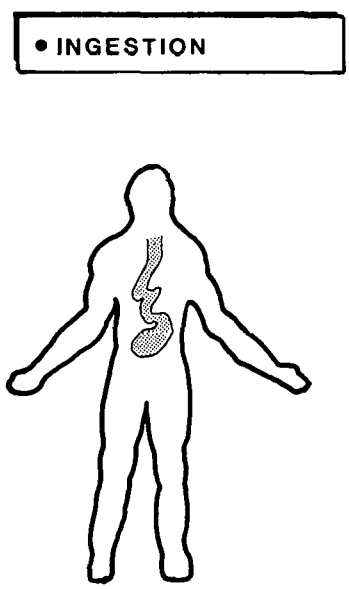
$$= 1.88 \text{ man-rem.}$$

Step 6

The health effects associated with the population dose are based on the BEIR III Report in which it is estimated that each 1 million man-rem cause between 75 and 230 excess cancer fatalities. Multiplying the WBE dose by 7.5×10^{-5} and 2.3×10^{-4} gives a range of 1.41×10^{-4} to 4.32×10^{-4} health effect for Alternative 3 (stabilize calcine) in 1990 for the canister drop scenario. (See Appendix B, Tables B-89, B-90.)

A.1.8.2.2 Fault and Flooding

Waste shipped to an offsite geologic repository could eventually expose the public to radiation if water were to enter the repository after containment failure of the canisters and transport radionuclides to drinking water sources. This scenario is illustrated in Subsection 4.5.2.2. The significant exposure pathway is ingestion as shown in the accompanying illustration. The ingestion pathway includes several subpathways. They are consumption of contaminated drinking water, fruits, vegetables, milk, meat, and fish. Direct radiation exposure while swimming and boating was evaluated and found to be an insignificant dose.



FAULT AND FLOODING

The effects of fault and flooding at a repository are evaluated for INEL waste by using the calculational methodology presented in the GEIS. The data have been modified for this report so that the dose commitments represent only the effects of the INEL high-level waste. This scenario is based on the following assumptions:

- A fracture or series of fractures, either from the surface or from near an aquifer, disrupts the repository, causing waste canisters to break open.
- The fractures connect and permit water to reach the waste.
- The water leaches and transports radionuclides into surface waters that are used for recreation and drinking.
- The rate of flow is 27 cm/day through 1000 m of soil. At this rate, it would take water a little over 10 yr to reach the river.
- Ion-exchange capacity of the soil is considered in the calculations. The K_d values used in this study are tabulated in Table A-9.
- The radionuclides that reach the river are assumed to be diluted by the river volume.
- The probability of occurrence is 2×10^{-13} event per year.
- The repository is leached in 2500.
- Two million people are exposed to radiation.

The following sample calculation gives the estimated maximum individual whole-body dose commitment for Alternative 3 (stabilize calcine) for technetium-99 (Tc-99) in 2600 when the radionuclides reach the river. Prior to 2600, all doses would be zero.

Calculation of Ingestion Pathway Dose

Before the ingestion doses can be calculated, the radionuclide concentration in river water must be determined (Equations A-17 and A-18). Contamination is dependent on the travel time required for leached radionuclides to reach the river (Equation A-16). These values are calculated below.

The time required for a specific radioisotope to migrate through 1000 m of soil is given by Equation A-16.

$$T_i = L \frac{(K_{di} \times R_p + 1)}{365\ W_g} \quad . \tag{A-16}$$

When the elapsed leach time from the repository is greater than the travel time to the river, the radionuclide concentration in the river is given either by Equation A-17 or Equation A-19, depending upon the pulse width of the migrating material. The pulse width of an instantaneous release from the repository is given by Equation A-19:

$$PW = 2.428\ K_{di} \quad . \tag{A-19}$$

If the time over which the isotope is released from the repository (1 yr in this scenario) is greater than the pulse width, the concentration reaching the river is represented by a square wave equation:

$$Z_i = \frac{T_{ti} \times 10^6}{t_r \times W_a} \quad . \tag{A-17}$$

If, however, the pulse width is greater than the 1-yr release time, the concentration reaching the river is more appropriately represented by:

$$Z_{ti} = \frac{I_{ti} \times 365 \times 10^6}{T \left(\frac{2\pi L}{W_g T_e}\right)^{\frac{1}{2}} (K_{di} \times R_p + 1)\ W_a} \quad . \tag{A-18}$$

For K_{di} values of 0, 5, and 10, Equation A-17 applies. For all other K_{di} values listed in Table A-9, Equation A-18 applies.

Calculation of Ingestion Dose Commitment from Water Consumption

The contribution of Tc-99 to the maximum individual dose commitment from ingestion of contaminated water is given by the equation:

$$D_{pw} = W \times Z_i \times DF_i \times 10^3 \qquad \text{(A-15)}$$

where

$$Z_i = \frac{I_{ti} \times 10^6}{t_r \times W_a} \; . \qquad \text{(A-17)}$$

The data for calculation of organ doses for Tc-99 appear in Table A-74.

Step 1

Substitution of the data from Table A-74 into Equation A-15 gives the organ doses for Tc-99 in drinking water:

D_i (lung) = 0.0 rem
D_i (liver) = 5.16×10^{-3} rem
D_i (bone surface) = 3.37×10^{-3} rem
D_i (total body) = 1.76×10^{-3} rem.

Step 2

Since Tc-99 is the only contributing isotope in 2600, Step 2 is identical to Step 1.

Calculation of Ingestion Dose Commitment from Freshwater Fish Consumption

The dose resulting from consumption of contaminated freshwater fish is obtained by use of the following equations:

$$D_{fw} = Q_{fwi} \times DF_i \qquad \text{(A-20)}$$

TABLE A-74

DATA FOR WATER CONSUMPTION
FAULT AND FLOODING SCENARIO
(Tc-99)

Variable	Quantity	Unit	Reference
I_{ti}	4.3×10^{4}	Ci	Figure A-2
T_e	1	day	Scenario
K_{di}	0	$\frac{\text{meq/g solid}}{\text{meq/cc liquid}}$	Table A-9
R	5.33	g/cc	INEL soil
D	1.0×10^{5}	cm	Soil depth
W_g	27	cm/day	Parameter from GEIS.
W_a	3.8×10^{15}	cc/yr	Scenario
T	1	day	Related to T_e.
t_r	1	yr	Scenario
DF_i (lung)	0	rem/μCi	NUREG/CR-0150
DF_i (liver)	6.28×10^{-4}	rem/μCi	NUREG/CR-0150
DF_i (bone surface)	4.10×10^{-4}	rem/μCi	NUREG/CR-0150
DF_i (total body)	2.14×10^{-4}	rem/μCi	NUREG/CR-0150
W	730	ℓ/yr	RG 1.109
Z_i	1.13×10^{-5}	μCi/cc	Equation A-17

where

$$Q_{fwi} = U_{fw} \times B_{fi} \times Z_i \times 10^{3} \quad . \tag{A-21}$$

The data for calculation of the dose from consumption of contaminated fish are given in Table A-75.

TABLE A-75

DATA FOR FRESHWATER FISH CONSUMPTION
FAULT AND FLOODING SCENARIO
(Tc-99)

Variable	Quantity	Unit	Reference
U_{fw}	2.1×10^{1}	kg/yr	RG 1.109
B_{fi}	1.5×10^{1}	$\frac{\mu Ci/kg}{\mu Ci/\ell}$	RG 1.109
Z_i	1.13×10^{-5}	μCi/cc	Equation A-17
DF_i	Use appropriate organ dose conversion factors.	rem/μCi	Table A-4

Substitution of the numerical values from Table A-75 into Equations A-20 and A-21 gives the maximum individual dose commitment from fish consumption:

Step 1

D_i^i (lung) = 0.0 rem
D_i^i (liver) = 2.23×10^{-3} rem
D_i^i (bone surface) = 1.45×10^{-3} rem
D_i^i (total body) = 7.59×10^{-4} rem.

Step 2

Since only one isotope contributes to the dose, Step 2 is identical to Step 1.

Calculation of Ingestion Dose Commitment from Shellfish Consumption

The dose resulting from consumption of Tc-99 in shellfish is obtained by the use of Equations A-20 and A-21 where U_{fw} is the quantity of shellfish consumed. The data for calculation of the dose from shellfish consumption are given in Table A-76.

TABLE A-76

DATA FOR SHELLFISH CONSUMPTION
FAULT AND FLOODING SCENARIO
(Tc-99)

Variable	Quantity	Unit	Reference
U_{fw}	5	kg/yr	RG 1.109
B_{fi}	5.0	$\frac{\mu Ci/kg}{\mu Ci/\ell}$	RG 1.109
Z_i	1.13×10^{-5}	μCi/cc	Equation A-17
DF_i	Use applicable organ dose conversion factors.	rem/μCi	Table A-4

Step 1

Substitution of the numerical values from Table A-76 into Equations A-20 and A-21 gives the organ dose commitment from shellfish consumption:

D_i (lung) = 0.0 rem
D_i (liver) = 1.77×10^{-4} rem
D_i (bone surface) = 1.15×10^{-4} rem
D_i (total body) = 6.02×10^{-5} rem.

Step 2

Since only one isotope contributes to the dose, Step 2 is identical to Step 1.

Calculation of Ingestion Dose Commitment from Meat Consumption (Water)

The contribution of a single nuclide, Tc-99, to the maximum individual dose commitment from ingestion of meat from animals watered at a contaminated source is given by the equation:

$$D_{mw} = Q_{mwi} \times DF_i \qquad \text{(A-22)}$$

where

$$Q_{mwi} = U_{mw} \times A_w \times S_{wi} \times Z_i \times 10^3 \quad . \qquad \text{(A-23)}$$

The data for calculation of the dose from consumption of contaminated meat from animals watered at a contaminated source appear in Table A-77.

TABLE A-77

DATA FOR MEAT CONSUMPTION (WATER)
FAULT AND FLOODING SCENARIO
(Tc-99)

Variable	Quantity	Unit	Reference
U_{mw}	1.1×10^2	kg/yr	RG 1.109
A_w	5.0×10^1	ℓ/day	RG 1.109
S_{wi}	4.0×10^{-1}	day/kg	RG 1.109
Z_i	1.13×10^{-5}	μCi/cc	Equation A-17
DF_i	Use applicable organ dose conversion factors.	rem/μCi	Table A-4

Step 1

Substitution of the numerical values from Table A-77 into Equations A-22 and A-23 gives the organ doses for isotope i, Tc-99:

D_i (lung) = 0.0 rem
D_i (liver) = 1.55×10^{-2} rem
D_i (bone surface) = 1.02×10^{-2} rem
D_i (total body) = 5.30×10^{-3} rem.

Step 2

Since Tc-99 is the only isotope that contributes to the dose, the total doses are the same as calculated in Step 1.

Calculation of Ingestion Dose Commitment from Milk Consumption (Water)

The contribution of a single nuclide, isotope i, to the maximum individual dose commitment from ingestion of milk produced by animals watered at a contaminated source is given by the equation:

$$D_{cwi} = Q_{cwi} \times DF_i \qquad \text{(A-24)}$$

where

$$Q_{cwi} = U_{cw} \times A_w \times S_{wi} \times Z_i \times 10^3 \ . \qquad \text{(A-25)}$$

The data for calculation of the dose from consumption of milk produced by animals watered at a contaminated source appear in Table A-78.

TABLE A-78

DATA FOR MILK CONSUMPTION (WATER)
FAULT AND FLOODING SCENARIO
(Tc-99)

Variable	Quantity	Unit	Reference
U_{cw}	3.1×10^2	ℓ/yr	RG 1.109
A_w	6.0×10^1	ℓ/day	RG 1.109
S_{wi}	2.5×10^{-2}	day/ℓ	RG 1.109
Z_i	1.13×10^{-5}	μCi/cc	Equation A-17
DF_i	Use applicable organ dose conversion factors.	rem/μCi	Table A-4

Step 1

Substitution of the numerical values from Table A-78 into Equations A-24 and A-25 gives the organ doses from ingestion of Tc-99:

D_i (lung) = 0.0 rem
D_i (liver) = 3.29×10^{-3} rem
D_i (bone surface) = 2.15×10^{-3} rem
D_i (total body) = 1.12×10^{-3} rem.

Step 2

Since Tc-99 is the only isotope that contributes to the dose, the total doses are the same as those calculated in Step 1.

Calculation of Food Subpathway Dose from Vegetation Consumption

The dose resulting from consumption of food produced by using contaminated irrigation water is obtained from the following equations:

$$C_{iv} = D_{pi}\left(R\,\frac{[1 - e^{-(\lambda_e + \lambda_i)t_e}]}{Y(\lambda_e + \lambda_i)} + B_{iv}\,\frac{[1 - e^{-\lambda_i t_s}]}{P\lambda_i}\right)e^{-\lambda_i t_c} \qquad \text{(A-5)}$$

where

$$D_{pi} = Z_i \times I \times 10^3 \quad . \qquad \text{(A-6d)}$$

The data for the calculation of C_{iv} appear in Table A-79. Substitution of the numerical values from Table A-79 into Equation A-5 gives the radionuclide concentration in vegetation:

$$C_{iv} = 5.1 \times 10^{-1}\ \mu Ci/kg \quad .$$

Calculation of Ingestion Dose Commitment from Fruits and Vegetables Consumption

The dose from ingestion of fruits and vegetables is determined by equations:

$$D_{fi} = Q_{fi} \times DF_i \qquad \text{(A-7)}$$

where

$$Q_{fi} = U_f \times C_{iv} \quad . \qquad \text{(A-8)}$$

The data for calculation of the dose from consumption of fruits and vegetables appear in Table A-80.

TABLE A-79

DATA FOR RADIONUCLIDE CONCENTRATION IN VEGETATION
FAULT AND FLOODING SCENARIO
(Tc-99)

Variable	Quantity	Unit	Reference
D_{pi}	9.94×10^{-4}	$\mu Ci/m^2$-hr	Equation A-6d
R	2.5×10^{-1}	none	RG 1.109
Z_i	1.13×10^{-5}	$\mu Ci/cc$	Equation A-17
λ_e	2.1×10^{-3}	hr^{-1}	RG 1.109
t_e	1.44×10^{3} [a] 7.20×10^{2} [b]	hr	RG 1.109
Y	2 [a] 0.7 [b]	kg/m^2	RG 1.109
I	8.8×10^{-2}	ℓ/m^2-hr	RG 1.109
B_{iv}	2.5×10^{-1}		RG 1.109
λ_i	3.7×10^{-10}	hr^{-1}	Tc-99
t_s	4.38×10^{5}	hr	RG 1.109
P	2.4×10^{2}	kg/m^2	RG 1.109
t_c	0	hr	Assumes no hold-up time.

a. For fruits and vegetables consumed directly by man.

b. For vegetation consumed by meat- or milk-producing animals.

Step 1

Substitution of the numerical values from Table A-80 into Equations A-7 and A-8 gives the organ doses from Tc-99 in fruits and vegetables:

D_i^1 (lung) = 0.0 rem
D_i^1 (liver) = 1.87×10^{-1} rem
D_i^1 (bone surface) = 1.22×10^{-1} rem
D_i^1 (total body) = 6.36×10^{-2} rem.

TABLE A-80

DATA FOR FRUITS AND VEGETABLES CONSUMPTION
FAULT AND FLOODING SCENARIO
(Tc-99)

Variable	Quantity	Unit	Reference
U_f	584	kg/yr	RG 1.109
DF_i	Use applicable organ dose conversion factors.	rem/μCi	Table A-4
C_{iv}	5.1×10^{-1}	μCi/kg	Equation A-5

Step 2

Since Tc-99 is the only isotope that contributes to the dose, the total doses are the same as calculated in Step 1.

Calculation of Ingestion Dose Commitment from Meat Consumption (Forage)

The dose resulting from consumption of meat produced from forage grown with contaminated irrigation water is obtained from two separate calculations.

Calculate C_{iv} for meat consumption using Equation A-5 and the data in Table A-79 where t_e = 720 hr and Y = 0.70 kg/m^2.

$$C_{iv} = 0.585 \ \mu Ci/kg \quad .$$

The dose from consumption of contaminated meat is given by the equations:

$$D_{mfi} = Q_{mfi} \times DF_i \qquad (A\text{-}9)$$

where

$$Q_{mfi} = U_{mf} \times A_m \times S_{bi} \times C_{iv} \quad . \qquad (A\text{-}10)$$

The data for calculation of the dose from consumption of meat produced from animals grazed on contaminated forage appear in Table A-81.

TABLE A-81

DATA FOR MEAT CONSUMPTION (FORAGE)
FAULT AND FLOODING SCENARIO
(Tc-99)

Variable	Quantity	Unit	Reference
U_{mf}	1.1×10^{2}	kg/yr	RG 1.109
A_m	5.0×10^{1}	kg/day	RG 1.109
S_{bi}	4.0×10^{-1}	day/kg	RG 1.109
C_{iv}	5.85×10^{-1}	μCi/kg	Equation A-5
DF_i	Use applicable organ dose conversion factors.	rem/μCi	Table A-4

Step 1

Substitution of the numerical values from Table A-81 and the value for C_{iv} into Equations A-9 and A-10 gives the organ doses from Tc-99:

D_i (lung) = 0.00 rem
D_i (liver) = 8.07×10^{-1} rem
D_i (bone surface) = 5.27×10^{-1} rem
D_i (total body) = 2.75×10^{-1} rem.

Step 2

Since Tc-99 is the only isotope that contributes to the dose, the total doses are the same as calculated in Step 1.

Calculation of Ingestion Dose Commitment from Milk Consumption (Forage)

The contribution of isotope i to the maximum individual dose commitment from ingestion of milk produced by animals grazed on contaminated forage is given by the equations:

$$D_{cfi} = Q_{cfi} \times DF_i \qquad \text{(A-11)}$$

where

$$Q_{cfi} = U_{cf} \times A_m \times S_{ci} \times C_{iv} \quad . \tag{A-12}$$

The data for calculation of the dose from consumption of milk produced by animals grazed on contaminated forage appear in Table A-82.

TABLE A-82

DATA FOR MILK CONSUMPTION (FORAGE)
FAULT AND FLOODING SCENARIO
(Tc-99)

Variable	Quantity	Unit	Reference
U_{cf}	3.1×10^{2}	ℓ/yr	RG 1.109
A_m	5.0×10^{1}	kg/day	RG 1.109
S_{ci}	2.5×10^{-2}	day/ℓ	RG 1.109
C_{iv}	5.85×10^{-1}	μCi/kg	Equation A-5
DF_i	Use applicable organ dose conversion factors.	rem/μCi	Table A-4

Step 1

Substitution of the numerical values from Table A-82 into Equations A-11 and A-12 gives the organ doses from ingestion of Tc-99:

D_i (lung) = 0.00 rem
D_i (liver) = 1.42×10^{-1} rem
D_i (bone surface) = 9.29×10^{-2} rem
D_i (total body) = 4.85×10^{-2} rem.

Step 2

Since Tc-99 is the only isotope that contributes to the dose, the total doses are the same as calculated in Step 1.

Calculation of Direct Radiation Pathway Dose

The direct radiation doses from swimming and boating in contaminated water have been calculated and are negligible compared to the ingestion dose.

Calculation of Whole-Body Equivalent Doses and Health Effects

Step 3

The total maximum individual organ doses for all pathways and all radionuclides is the sum of all doses calculated above. The selected organ doses are summarized in Table A-83.

TABLE A-83

INDIVIDUAL PATHWAY ORGAN DOSE COMMITMENTS (rem)
FAULT AND FLOODING SCENARIO
(Tc-99)

Pathway	Lung	Liver	Bone Surface	Total Body
Drinking Water	0.0	5.16×10^{-3}	3.37×10^{-3}	1.76×10^{-3}
Freshwater Fish	0.0	2.23×10^{-3}	1.45×10^{-3}	7.59×10^{-4}
Shellfish	0.0	1.77×10^{-4}	1.15×10^{-4}	6.02×10^{-5}
Fruits and Vegetables	0.0	1.87×10^{-1}	1.22×10^{-1}	6.36×10^{-2}
Meat from Forage	0.0	8.07×10^{-1}	5.27×10^{-1}	2.75×10^{-1}
Meat from Water	0.0	1.15×10^{-2}	1.02×10^{-2}	5.30×10^{-3}
Milk from Forage	0.0	1.42×10^{-1}	9.29×10^{-2}	4.85×10^{-2}
Milk from Water	0.0	3.29×10^{-3}	2.15×10^{-3}	1.12×10^{-3}
TOTAL	0.0	1.16	7.59×10^{-1}	3.96×10^{-1}

Step 4

The whole-body equivalent dose (WBE) for the maximum individual is calculated by summing the product of all organ doses and appropriate weighting factors.

WBE = 1.78 rem.

Step 5

The population whole-body equivalent dose is calculated for 2 million people as follows.

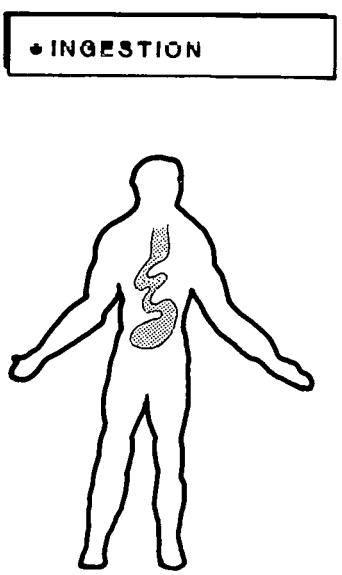
$$\text{Population WBE} = (2 \times 10^6)\ (1.78)\ (0.01)$$
$$= 3.56 \times 10^4 \text{ man-rem.}$$

Step 6

The health effects associated with the population dose are based on the BEIR III Report in which it is estimated that each 1 million man-rem cause between 75 and 230 excess cancer fatalities. Multiplying the population WBE by 7.5×10^{-5} and 2.3×10^{-4} gives a range of 2.67 to 8.19 health effects for Alternative 3 (stabilize calcine) in 2600 for the fault and flooding scenario (see Appendix B, Table B-80).

A.1.8.2.3 Solution Mining

Because bedded and domed salt formations are being seriously considered for a federal repository, solution mining to recover table salt is a potential source of radiation exposure to populations after institutional control has ceased. The scenario is illustrated in Subsection 4.5.2.2. Ingestion is the only significant pathway by which the population would be exposed to radiation as shown in the accompanying illustration. The scenario applies to Alternatives 3, 4, and 5 in which waste is shipped to a federal geologic repository. The waste canisters in a repository of bedded or domed salt are assumed to rupture



SOLUTION MINING

or disintegrate, thereby exposing the waste. During the mining process, radionuclides would be leached and enter the food chain in table salt.

The effects of solution mining at a repository are evaluated for INEL waste by using the calculational methodology presented in the GEIS. The data have been modified for this report so that the dose commitments represent only the effects of the INEL high-level waste. This scenario is based on the following assumptions:

- A population of 40,000,000 is exposed to radiation.
- Institutional control has ceased.
- The probability of occurrence is 1×10^{-6} event per year.

Based on studies for commerically generated waste, it is estimated that 4700 kg of waste would be leached from one of six repositories during a single year of solution mining. The 4700-kg release is assumed to be INEL high-level waste and is considered to be a conservative estimate. Although this quantity would increase with each year of solution mining, it is reasonable to anticipate that the contamination would be discovered and the mining operation would be terminated within the 1-yr period. Also, the decontamination of table salt that occurs during processing (which would be significant) is not factored into the calculation.

The following sample calculation gives the estimated maximum individual whole-body dose commitment for Alternatives 3, 4, and 5 for strontium-90 (Sr-90), the most significant radionuclide, for the year 2500.

Calculation of Ingestion Pathway Dose

The contribution of a single radionuclide, Sr-90, to the 50-yr dose commitment of an individual consuming contaminated salt is given by Equations A-26 and A-27:

$$D_i = C_i \times Q_c \times DF_i \qquad \text{(A-26)}$$

where

$$C_i = \frac{Q_i \times F_i}{Q_p} \qquad \text{(A-27)}$$

The data for calculation of ingestion dose appear in Table A-84.

TABLE A-84

DATA FOR SALT CONSUMPTION
SOLUTION MINING SCENARIO
(Sr-90)

Variable	Quantity	Unit	Reference
Q_t	1.8	kg/yr	Scenario
Q_i	2.0×10^{10}	μCi	Figure A-2
F_i	7.5×10^{-5}	none	Scenario (4.7×10^{3}/ 6.3×10^{7})
Q_p	2.4×10^{9}	kg/yr	Scenario
DF_i	Use applicable organ dose conversion factors.	rem/μCi	Table A-4

Step 1

Substituting the numerical values from Table A-84 into Equations A-26 and A-27 gives the organ doses from ingestion of Sr-90.

D_i (lung) $= 6.72 \times 10^{-12}$ rem
D_i (liver) $= 5.84 \times 10^{-6}$ rem
D_i (bone surface) $= 9.73 \times 10^{-4}$ rem
D_i (total body) $= 1.07 \times 10^{-4}$ rem.

Step 2 and Step 3

The total organ dose commitment from all radionuclides is the sum of all doses for each organ.

D_t (lung) $= 3.45 \times 10^{-6}$ rem
D_t (liver) $= 5.70 \times 10^{-2}$ rem
D_t (bone surface) $= 2.69 \times 10^{-1}$ rem
D_t (whole body) $= 1.11 \times 10^{-4}$ rem.

Step 4

The whole-body equivalent (WBE) dose for the maximum individual is calculated by summing the product of all organ doses and appropriate weighting factors.

$WBE = 1.71 \times 10^{-2}$ rem.

Step 5

The population whole-body equivalent dose commitment is calculated for 40 million people.

Population WBE $= (4 \times 10^7) \times (1.71 \times 10^{-2}$ rem$) = 6.84 \times 10^5$ man-rem.

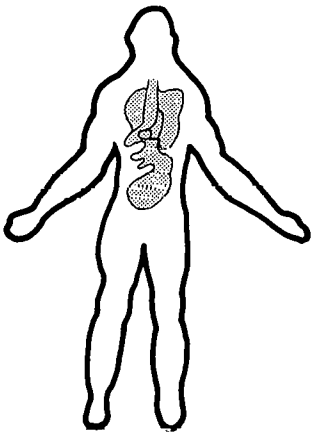
Step 6

The health effects associated with the population dose are based on the BEIR III Report in which it is estimated that each 1 million person-rem cause between 75 and 230 excess cancer fatalities. Multiplying the population WBE dose by 7.5×10^{-5} and 2.3×10^{-4} gives a range of 51.3 to 157 health effects for Alternatives 3, 4, and 5 in 2200 for the solution mining scenario. (See Appendix B, Tables B-101, B-102, B-103, B-104, B-105, B-106.)

A.1.8.2.4 Exploratory Drilling

Even though the wastes disposed in an offsite repository would be buried at substantial depth, it is possible that future drilling operations might breach the repository and bring radioactive material to the surface. The scenario is illustrated in Subsection 4.5.2.2. Ingestion, inhalation, and direct radiation are the pathways by which a few individuals would be exposed to radiation as shown in the accompanying illustration. This scenario applies to Alternatives 3, 4, and 5 in which radioactive waste is shipped to a federal geologic repository.

- INHALATION
- INGESTION
- DIRECT RADIATION



EXPLORATORY DRILLING

Since it is assumed that the drilling crew is unaware that its activities are spreading radioactive material around the drilling site, it is possible that the contaminated land could be used for a housing project after drilling activities have ceased. In addition to the initial inhalation dose received by drilling crew members, residents of the housing project would be exposed to direct radiation, ingestion of food grown on contaminated land, and inhalation of radon gas.

The effects of exploratory drilling at a repository are evaluated for INEL waste by using the calculational methodology presented in the GEIS. The data have been modified for this report so that the dose commitments represent only effects of the INEL high-level waste. The scenario is based on the following assumptions:

- Twenty-five individuals are exposed to radiation.
- Institutional control has ceased.
- The probability of occurrence is 5×10^{-7} event per year.
- The housing project is located on 0.5 ha of contaminated land.
- Five families (25 individuals) occupy 0.1-ha lots.

The following sample calculation gives the estimated maximum dose commitment for Alternative 3 (stabilize calcine) for plutonium-238 (Pu-238), the most significant radionuclide, in the year 2100.

Calculation of Inhalation Pathway Dose

The contribution of a single radionuclide, Pu-238, to the maximum individual dose commitment from inhalation of radionuclides brought to the surface by exploratory drilling is given by the following equations:

$$D_i = C_i \times V \times DF_i \qquad \text{(A-1)}$$

where

$$V = B \times T \qquad \text{(A-2)}$$

$$C_i = C_w \times C_{ci} \times F_i \qquad \text{(A-3b)}$$

where

$$C_w = Q_c \times F_r \times \frac{R_f}{3.15 \times 10^7} \times \frac{\chi}{Q} \quad . \qquad \text{(A-3c)}$$

The data for calculation of the inhalation dose appear in Table A-85.

Step 1

Substitution of the numerical values from Table A-85 into Equations A-1, A-2, A-3b, and A-3c gives the organ doses due to inhalation of Pu-238:

D_i (lung) $= 6.81 \times 10^{-1}$ rem
D_i (liver) $= 7.84 \times 10^{-1}$ rem
D_i (bone surface) $= 3.66$ rem
D_i (total body) $= 1.57 \times 10^{1}$ rem.

Step 2

The organ doses from all radionuclides were determined by using the values of isotope concentrations in Figure A-2. The total dose commitments are

TABLE A-85

DATA FOR INHALATION PATHWAY
EXPLORATORY DRILLING SCENARIO
(Pu-238)

Variable	Quantity	Unit	Reference
C_{ci}	3.1×10^{4}	μCi/kg	Figure A-2
F_r	0.25	none	RG 1.109
R_f	0.011	yr^{-1}	RG 1.109
$\frac{\chi}{Q}$	1.3×10^{-4}	sec/m^3	Scenario
Q_c	3.64×10^{5}	g	25% of the contents of one can of waste.
B	1	m^3/hr	Working rate.
T	8760	hr	1 yr
F_i	1	none	All airborne.
DF_i (lung)	6.08×10^{2}	rem/μCi	Table A-3
DF_i (liver)	7.00×10^{2}	rem/μCi	Table A-3
DF_i (bone surface)	3.27×10^{2}	rem/μCi	Table A-3
DF_i (total body)	1.40×10^{2}	rem/μCi	Table A-3

D_t (lung) = 1.2 rem
D_t (liver) = 9.7×10^{-1} rem
D_t (bone surface) = 4.6 rem
D_t (total body) = 2.0×10^{-1} rem.

Calculation of Ingestion Pathway Dose

The ingestion pathway has three contributing subpathways: ingestion of fruits and vegetables, ingestion of milk produced by animals grazed on contaminated forage, and ingestion of meat produced from animals grazed on contaminated forage. The maximum individual dose commitment from the ingestion pathway is calculated by first calculating the radionuclide concentration in vegetation using Equation A-5.

$$C_{iv} = D_{pi}\left(R\,\frac{[1 - e^{-(\lambda_e + \lambda_i)t_e}]}{Y(\lambda_e + \lambda_i)} + B_{iv}\,\frac{[1 - e^{-\lambda_i t_s}]}{P\lambda_i}\right)e^{-\lambda_i t_c} \qquad \text{(A-5)}$$

For drilling into the repository, it is assumed that R = 0, $t_c = 0$ and $\lambda_i t_s \ll 1$. Equation A-5 then reduces to

$$C_{iv} = \frac{D_{pi} \times B_{iv} \times t_s}{P}$$

where

$$D_{pi} = \frac{Q_c \times F_i \times C_{ci}}{t_s \times A} \quad . \qquad \text{(A-6c)}$$

The data for the calculation of C_{iv} appear in Table A-86.

TABLE A-86

DATA FOR RADIONUCLIDE CONCENTRATION IN VEGETATION
EXPLORATORY DRILLING SCENARIO
(Sr-90)

Variable	Quantity	Unit	Reference
C_{ci}	1.1×10^{6}	μCi/kg	Figure A-2
Q_c	364	kg	Scenario (1/4 can)
R	0	none	Scenario
B_{iv}	1.7×10^{-2}	none	RG 1.109
λ_i	2.75×10^{-6}	hr^{-1}	Sr-90
t_s	8.76×10^{3}	hr	1 yr
P	240	kg/m^2	RG 1.109
F_i	1.0	none	Alternative 3, Scenario
A	5.0×10^{3}	m^2	Scenario
t_c	0	hr	Scenario

Substitution of the numerical values from Table A-86 into Equations A-5 and A-6c gives

$$C_{iv} = 5.67 \ \mu Ci/kg \quad .$$

The ingestion dose commitment from the three contributing subpathways can be calculated separately as described in Subsection A.1.8. The dose from each subpathway is calculated and the separate doses are summed to arrive at the total ingestion dose. In this scenario, an alternative method is used to obtain the total ingestion dose. The dose conversion factors are multiplied directly by the total quantity of isotopes ingested from the three contributing subpathways.

Calculation of Quantity of Isotope i Ingested in Fruits and Vegetables

The quantity of isotope i ingested by consuming contaminated fruits and vegetables is determined by the following equation:

$$Q_{fi} = U_f \times C_{iv} \quad . \qquad \text{(A-8)}$$

The data for calculating the quantity of isotope i from consuming contaminated fruits and vegetables appear in Table A-87.

TABLE A-87

DATA FOR FRUITS AND VEGETABLES CONSUMPTION
EXPLORATORY DRILLING SCENARIO
(Sr-90)

Variable	Quantity	Unit	Reference
U_f	584	kg/yr	RG 1.109
C_{iv}	5.67	μCi/kg	Figure A-2

Substitution of the numerical values from Table A-87 into Equation A-8 gives the quantity of Sr-90 ingested from contaminated fruits and vegetables:

$$Q_{fi} = 3.31 \times 10^3 \ \mu Ci \quad .$$

Calculation of Quantity of Isotope i Ingested in Meat

The quantity of istope i ingested by consuming meat produced by animals grazed on contaminated forage is obtained from Equation A-10.

$$Q_{mfi} = U_{mf} \times A_m \times S_{bi} \times C_{iv} \quad . \qquad \text{(A-10)}$$

The data for calculating the quantity of istope i from consuming contaminated meat appear in Table A-88.

TABLE A-88

DATA FOR MEAT CONSUMPTION
EXPLORATORY DRILLING SCENARIO
(Sr-90)

Variable	Quantity	Unit
U_{mf}	110	kg/yr
A_m	50	kg/day
S_{bi}	6.04×10^{-4}	day/kg
C_{iv}	5.67	μCi/kg

Substitution of the numerical values from Table A-88 into Equation A-10 gives the quantity of Sr-90 ingested from contaminated meat.

$$Q_{mfi} = 18.7 \text{ μCi} \quad .$$

Calculation of Quantity of Isotope i Ingested in Milk

The quantity of isotope i ingested by consuming milk produced by animals grazed on contaminated forage is given by Equation A-12.

$$Q_{cfi} = U_{cf} \times A_m \times S_{ci} \times C_{iv} \quad . \qquad \text{(A-12)}$$

The data for calculating the quantity of isotope i from consuming milk appear in Table A-89.

TABLE A-89

DATA FOR MILK CONSUMPTION
EXPLORATORY DRILLING SCENARIO
(Sr-90)

Variable	Quantity	Unit	Reference
U_{cfi}	310	ℓ/yr	RG 1.109
A_m	50	kg/day	RG 1.109
S_{ci}	8.0×10^{-4}	day/ℓ	RG 1.109
C_{iv}	5.67	μCi/kg	Equation A-5

Substitution of the numerical values from Table A-89 into Equation A-12 gives the quantity of Sr-90 ingested from milk:

$$Q_{cfi} = 70.3 \ \mu Ci \quad .$$

The total quantity of Sr-90 ingested from all three subpathways is summed and given in Table A-90.

TABLE A-90

QUANTITY OF SR-90 FROM INGESTION PATHWAYS

Pathway	Quantity (μCi)
Fruits and Vegetables	3310
Meat	18.7
Milk	70.3
TOTAL	3399

Step 1

Using the values from Table A-90 and the appropriate dose conversion factors from Table A-4, the following ingestion dose commitments are obtained for Sr-90.

D_i (lung) $= 2.2 \times 10^{-5}$ rem
D_i (liver) $= 1.9 \times 10^{1}$ rem
D_i (bone surface) $= 2.9 \times 10^{3}$ rem
D_i (total body) $= 3.2 \times 10^{2}$ rem.

Step 2

The total organ doses from all ingestion subpathways and isotopes are obtained by summation. They are

D_t (lung) $= 5.8 \times 10^{1}$ rem
D_t (liver) $= 2.5 \times 10^{2}$ rem
D_t (bone surface) $= 3.2 \times 10^{3}$ rem
D_t (total body) $= 4.6 \times 10^{2}$ rem.

Calculation of Direct Radiation Pathway Dose

The dose resulting from direct radiation from exploratory drilling is determined by the following equations:

$$D_i = Q_i \times DF_{gi} \tag{A-28}$$

where

$$Q_i = C_{ci} \times F_c \times T \times \rho_c \times 10^{-6} \tag{A-29}$$

where

$$F_c = \frac{Q_c}{A \times PL \times \rho_s} \quad . \tag{A-30}$$

The fraction of soil that is calcine waste, F_c, is calculated by dividing the calcine volume by the soil volume as shown in Equation A-30.

The data for calculation of the whole-body equivalent dose from direct radiation appear in Table A-91. Since Sr-90, the isotope used in the sample calculation for ingestion and inhalation, is a beta emitter, its contribution to direct radiation is zero. Therefore, Ba-137m is used in the direct radiation calculation.

TABLE A-91

DATA FOR DIRECT RADIATION PATHWAY
EXPLORATORY DRILLING SCENARIO
(Ba-137m)

Variable	Quantity	Unit	Reference
C_{ci}	1.2×10^3	μCi/g	Figure A-2
T	7×10^3	hr	Scenario
DF_{gi}	5.22×10^5	$\frac{\text{rem/hr}}{\text{Ci/cc}}$	ISOSHLD
ρ_c	1.3	g/cc	Scenario
ρ_s	1600	kg/m^3	Scenario
Q_c	364	kg	1/4 canister
A	5000	m^2	Scenario
PL	0.05	m	Contamination depth.

Step 1

Substitution of the numerical values from Table A-91 into Equations A-28, A-29, and A-30 gives the direct radiation whole-body dose from isotope i.

$$D_i = 5.1 \times 10^3 \text{ rem} \quad .$$

Step 2

The whole-body dose from all radionuclides is determined by using the values of isotope concentrations in Figure A-2:

$$D_t = 5.2 \times 10^3 \text{ rem.}$$

Calculation of Whole-Body Equivalent Doses and Health Effects

Step 3

The total maximum individual organ dose for all pathways and all radionuclides is the sum of the doses for each organ as given in Table A-92.

TABLE A-92

INDIVIDUAL PATHWAY ORGAN DOSE COMMITMENTS (rem)
EXPLORATORY DRILLING SCENARIO

Pathway	Lung	Liver	Bone Surface	Total Body
Inhalation	1.2	9.7×10^{-1}	4.6	2.0×10^{-1}
Ingestion	5.8×10^{1}	2.5×10^{2}	3.2×10^{3}	4.6×10^{2}
TOTAL	5.92×10^{1}	2.51×10^{2}	3.21×10^{3}	4.60×10^{2}

Step 4

The procedures outlined in Subsection A.1.8 are used to determine the maximum individual whole-body equivalent dose, population dose, and health effects.

The whole-body equivalent dose (WBE) for the maximum individual is calculated by summing the WBE doses for inhalation, ingestion, and direct radiation. In this special case where the effects of 1 year's exposure are evaluated, the dose from direct radiation and the 50-yr dose commitment from internal exposure are added. The individual pathway WBE doses are given in Table A-93.

Step 5

The population whole-body equivalent dose is calculated from the values given in Table A-93 for 25 persons.

Population WBE = $25 \times (5.7 \times 10^{3}) = 1.43 \times 10^{5}$ man-rem.

TABLE A-93

INDIVIDUAL PATHWAY WBE DOSE COMMITMENTS (rem)
EXPLORATORY DRILLING SCENARIO

Pathway	WBE Dose
Inhalation	4.3×10^{-1}
Ingestion	5.2×10^{2}
Direct Radiation	5.2×10^{3}
Total	5.7×10^{3}

Step 6

The health effects associated with the population dose are based on the BEIR III Report in which it is estimated that each 1 million man rem cause between 75 and 230 excess cancer fatalities. Multiplying the population WBE dose by 7.5×10^{-5} and 2.3×10^{-4} gives a range of 10.7 to 32.9 health effects for Alternative 3 (stabilize calcine) in 2100 for the exploratory drilling scenario. (See Appendix B, Tables B-107, B-108.)

A.1.9 Mathematical Models

Mathematical equations used in Subsection A.1.8 are presented in this subsection to provide the reader with clarifying information about the terms used in the equations and the specific equations used to calculate the doses from a given pathway and scenario. The equations used in Subsection A.1.8 are referenced in this subsection by equation number. The term "dose" is often used in this subsection and means 50-yr dose commitment unless otherwise stated. The equations used to calculate the doses are generally grouped by exposure pathway. Equations used to calculate inhalation pathway doses are presented first followed by the equations used to calculate ingestion and direct radiation pathway doses. Since there is a series of equations used to calculate the dose from radon gas exposure, the equations are grouped separately and presented at the end of this subsection.

A.1.9.1 Calculation of Inhalation Doses

The contribution of a single radionuclide, isotope i, to the maximum individual dose from inhalation is given by the equations:

$$D_i = C_i \times V \times DF_i \quad \text{(A-1)}$$

where

D_i = dose commitment from inhalation of isotope i (rem)

DF_i = dose-conversion factor for inhalation of isotope i (rem/μCi)

$$V = B \times T \quad \text{(A-2)}$$

where

V = volume breathed (m^3)

B = breathing rate (m^3/hr)

T = exposure time (hr).

Calculation of Radionuclide Concentration for Operational Release Scenarios

$$C_i = Q_i \times \frac{\chi}{Q} \quad \text{(A-3)}$$

where

C_i = concentration of isotope i at receptor (μCi/m^3)

$\frac{\chi}{Q}$ = atmospheric dispersion factor (sec/m^3) .

For routine release:

$$Q_i = (Q_r[F_{ri} + F_{pi}] + Q_p \times F_{pi})\, C_{ci} \times 10^6 \quad \text{(A-4)}$$

where

Q_i = release rate of isotope i (μCi/sec)

Q_r = quantity of calcine retrieved (kg/yr)

F_{ri} = fraction of calcine retrieved that is released

F_{pi} = fraction of isotope i processed that is released

Q_p = quantity of fresh calcine produced (kg/yr)

C_{ci} = concentration of isotope i in calcine (μCi/kg)

10^6 = conversion factor (μCi/Ci).

For accidental release:

$$Q_i = Q_s \times F_i \times C_{ci} \times \frac{1}{3600T} \qquad \text{(A-4a)}$$

where

Q_i = release rate of isotope i (μCi/sec)

Q_s = quantity of calcine released in an accident (kg)

F_i = fraction of waste which is calcine

C_{ci} = concentration of isotope i in calcine (μCi/kg)

3600 = conversion factor (sec/hr)

T = release time or time of operation (hr).

Calculation of Radionuclide Concentration for Severe Geologic Disruption Scenario

$$C_i = \frac{Q_w \times C_{ci} \times F_r \times f_s}{V_c} \qquad \text{(A-3a)}$$

where

C_i = concentration of isotope i at receptor (μCi/m^3)

Q_w = quantity of waste released (kg)

V_c = volume of cloud (m^3)
= $[(4000m)^2 \times \pi \times 1200m] = 6.03 \times 10^{10}$ m^3

f_s = radionuclide fraction that stays in base cloud

F_r = respirable fraction of released inventory

C_{ci} = concentration of isotope i in calcine (μCi/kg).

Calculation of Radionuclide Concentration for Exploratory Drilling Scenario

$$C_i = C_w \times C_{ci} \times F_i \qquad \text{(A-3b)}$$

where

C_{ci} = concentration of isotope i in calcine (μCi/kg)

F_i = fraction of waste that is calcine

$$C_w = Q_c \times F_r \times \frac{R_f}{3.15 \times 10^7} \times \frac{\chi}{Q} \qquad \text{(A-3c)}$$

where

C_w = concentration of waste in air (kg/m^3)

Q_c = quantity of waste dispersed (kg)

F_r = fraction of waste available for resuspension

R_f = resuspension factor (yr^{-1})

3.15×10^7 = conversion factor from year to second (sec/yr)

$\frac{\chi}{Q}$ = atmospheric dispersion factor (sec/m^3).

A.1.9.2 Calculation of Ingestion Doses

A.1.9.2.1 Calculation of Ingestion Doses from Consumption of Food Produced from Contaminated Vegetation

Three ingestion pathways contribute to radiation exposure from consumption of food produced from contaminated vegetation. The pathways that result from radionuclide uptake by vegetation through plant roots and foliage are (1) ingestion of contaminated fruits and vegetables, (2) ingestion of meat from animals grazed on contaminated vegetation, and (3) ingestion of milk from animals grazed on contaminated vegetation. The maximum 50-yr dose commitment from these ingestion pathways is calculated by using equations appropriate to the scenario being evaluated. The equations required to calculate the ingestion dose from food consumption for the scenarios evaluated in this report are included in Equations A-5 through A-12.

The radionuclide concentration from uptake by vegetation is calculated using Equation A-5:

$$C_{iv} = D_{pi}\left(R\,\frac{[1 - e^{-(\lambda_e + \lambda_i)t_e}]}{Y(\lambda_e + \lambda_i)} + B_{iv}\,\frac{[1 - e^{-\lambda_i t_s}]}{P\lambda_i}\right)e^{-\lambda_i t_c} \qquad \text{(A-5)}$$

where

C_{iv} = concentration of isotope i in vegetation (μCi/kg)

R = fraction retained on leafy portion of the vegetation

λ_e = environmental decay constant (hr^{-1})

t_e = crop exposure time (hr)

Y = crop yield (kg/m^2)

B_{iv} = stable element transfer factor (vegetation/soil)

λ_i = radiological decay constant (hr^{-1})

t_s = soil accumulation time (hr)

t_c = time to consumption (hr)

P = effective plow layer (kg/m^2)

D_{pi} = deposition rate ($\mu Ci/m^2$-hr).

Calculation of ground-plane deposition rate for airborne releases:

$$D_{pi} = \frac{\chi}{Q} \times V_d \times Q_i \qquad \text{(A-6)}$$

where

χ/Q = atmospheric dispersion factor (sec/m^3)

V_d = deposition velocity (m/sec)

$$Q_i = Q_s \times F_i \times C_{ci} \times \frac{1}{T} \qquad \text{(A-4b)}$$

where

Q_i = release rate of isotope i (μCi/sec)

Q_s = quantity of waste released (kg)

F_i = fraction of waste which is calcine

C_{ci} = concentration of isotope i in calcine (μCi/kg)

T = time of release (hr).

Soil contamination from intrusion:

$$D_{pi} = \rho_s \times f \times PL \times C_{ci} \times \frac{1}{t_s} \qquad \text{(A-6a)}$$

where

ρ_s = soil density (kg/m^3)

f = fraction of soil that is waste calcine

PL = plow layer depth (m)

C_{ci} = concentration of isotope i in calcine ($\mu Ci/kg$)

t_s = soil accumulation time (hr).

Soil contamination from severe geologic disruption:

$$D_{pi} = C_i \times V_d \times T \times \frac{3600}{t_s} \qquad \text{(A-6b)}$$

where

C_i = concentration of isotope i at receptor ($\mu Ci/m^3$)

V_d = deposition velocity (m/sec)

T = time of release (hr)

t_s = soil accumulation time (hr)

3600 = conversion factor (sec/hr).

Soil contamination from exploratory drilling into a repository:

$$D_{pi} = \frac{Q_c \times F_i \times C_{ci}}{t_s \times A} \qquad \text{(A-6c)}$$

where

Q_c = quantity of waste dispersed (kg)

F_i = fraction of waste which is calcine

C_{ci} = concentration of isotope i in calcine ($\mu Ci/kg$)

t_s = soil accumulation time (hr)

A = area over which waste is dispersed (m^2).

Waste migration into groundwater:

$$D_{pi} = Z_i \times I \times 10^3 \qquad \text{(A-6d)}$$

where

Z_i = concentration in aquifer (μCi/cc)

I = irrigation rate (ℓ/m^2-hr)

10^3 = conversion factor (cc/ℓ).

(1) Calculation of Ingestion Dose from Consumption of Fruits and Vegetables

The dose from ingestion of contaminated fruits and vegetables is calculated by using Equations A-7 and A-8:

$$D_{fi} = Q_{fi} \times DF_i \qquad \text{(A-7)}$$

where

D_{fi} = dose from ingestion of isotope i in fruits and vegetables (rem)

DF_i = dose conversion factor for ingestion of isotope i (rem/μCi)

$$Q_{fi} = U_f \times C_{iv} \qquad \text{(A-8)}$$

where

Q_{fi} = quantity of isotope i from ingestion of contaminated fruits and vegetables

U_f = consumption rate (kg/yr)

C_{iv} = concentration of isotope i in vegetation (μCi/kg).

(2) Calculation of Ingestion Dose from Consumption of Meat

The dose from ingestion of meat from animals grazed on contaminated vegetation is calculated by using Equations A-9 and A-10:

$$D_{mfi} = Q_{mfi} \times DF_i \qquad \text{(A-9)}$$

where

D_{mfi} = dose from ingestion of isotope i in contaminated meat (rem)

DF_i = dose conversion factor for ingestion of isotope i (rem/μCi)

$$Q_{mfi} = U_{mf} \times A_m \times S_{bi} \times C_{iv} \quad \text{(A-10)}$$

where

Q_{mfi} = amount of isotope i from ingestion of contaminated meat (μCi/yr)

U_{mf} = meat consumption rate (kg/yr)

A_m = rate at which cows eat contaminated forage (kg/day)

S_{bi} = stable element transfer factor for isotope i from vegetation into meat (day/kg)

C_{iv} = concentration of isotope i in vegetation (μCi/kg).

(3) Calculation of Ingestion Dose from Consumption of Milk

The dose from ingestion of milk from animals grazed on contaminated vegetation is calculated by using Equations A-11 and A-12:

$$D_{cfi} = Q_{cfi} \times DF_i \quad \text{(A-11)}$$

where

D_{cfi} = dose from ingestion of isotope i in contaminated milk (rem)

DF_i = dose conversion factor for ingestion of isotope i (rem/μCi)

$$Q_{cfi} = U_{cf} \times A_m \times S_{ci} \times C_{iv} \quad \text{(A-12)}$$

where

Q_{cfi} = amount of isotope i from ingestion of contaminated milk (μCi/yr)

U_{cf} = consumption rate of milk (ℓ/yr)

A_m = rate at which animals consume contaminated forage (kg/day)

S_{ci} = stable element transfer factor for isotope i from vegetation into milk (day/ℓ)

C_{iv} = concentration of isotope i in vegetation (μCi/kg).

A.1.9.2.2 Calculation of Ingestion Doses from Consumption of Food Produced from Contaminated Water

Four ingestion pathways contribute to radiation exposure from contaminated water. The pathways that result from radionuclide migration into water

and ingestion by humans and animals are (1) direct potable water consumption, (2) freshwater fish consumption, (3) consumption of meat from animals watered at a contaminated source, and (4) consumption of milk from animals watered at contaminated sources.

(1) Calculation of Ingestion Dose from Water Consumption

The dose contributions from the drinking water pathways are estimated using the following equation:

$$D_{pw} = W \times Z_i \times DF_i \times 10^3 \qquad \text{(A-15)}$$

where

D_{pw} = dose from isotope i from ingestion of contaminated water (rem)

Z_i = concentration of isotope i in the water (μCi/cc)

W = water consumed (ℓ/yr)

10^3 = conversion factor (cm^3/ℓ)

DF_i = dose conversion factor (rem/μCi).

The potential dose associated with groundwater leaching of radioactive material from the INEL disposal site and transport to a source of drinking water is derived as follows:

$$T_i = L \frac{(K_{di} \times R_p + 1)}{365\ W_g} \qquad \text{(A-16)}$$

where

T_i = travel time from bin to aquifer for isotope i (yr)

L = distance from bin to aquifer (cm)

K_{di} = isotope ion-exchange constant (meq/g solids)/(meq/cc liquids)

R_p = ratio of soil density to soil porosity (g/cc)

W_g = groundwater migration rate (cm/day).

The following equations are used to determine radionuclide concentration in the aquifer resulting from groundwater migration.

When the elapsed time is less than the travel time, the concentration of the i-th nuclide in the aquifer is zero. When the travel time, T_i, is less than the time elapsed since leaching began, the concentration in the aquifer is given by:

$$Z_i = \frac{I_{ti} \times 10^6}{t_r \times W_a} \quad . \tag{A-17}$$

When the the travel time, T_i, is greater than the time elapsed since leaching began, the concentration in the aquifer is given by:

$$Z_i = \frac{I_{ti} \times 365 \times 10^6}{T \left(\frac{2\pi L}{W_g T_e}\right)^{\frac{1}{2}} (K_{di} \times R_p + 1) W_a} \tag{A-18}$$

where

Z_i = nuclide concentration in aquifer (μCi/cc)

I_{ti} = total inventory of isotope i (Ci)

L = distance through soil to aquifer (cm)

W_g = flow rate through soil to aquifer (cm/day)

W_a = aquifer dilution flow (cc/yr)

10^6 = conversion factor (μCi/Ci)

T = release time related to T_e (day)

K_{di} = isotope ion-exchange constant (meq/g solids)/(meq/cc liquids)

R_p = ratio of soil density to soil porosity (g/cc)

t_r = time over which inventory is released (yr)

T_e = time required to reach ion-exchange equilibrium between soil and water (day).

The pulse width is defined by Equation A-19:

$$PW = 2.428\ K_{di} \tag{A-19}$$

where

PW = the pulse width of an instantaneous release from the bins (yr)

K_{di} = distribution coefficient for isotope i (cc/g).

(2) Calculation of Ingestion Dose from Freshwater Fish Consumption

The dose resulting from consumption of freshwater fish is obtained by use of the following equations:

$$D_{fw} = Q_{fwi} \times DF_i \tag{A-20}$$

where

D_{fw} = dose commitment from ingestion of isotope i in freshwater fish (rem)

DF_i = dose conversion factor for ingestion of isotope i (rem/μCi)

$$Q_{fwi} = U_{fw} \times B_{fi} \times Z_i \times 10^3 \tag{A-21}$$

where

Q_{fwi} = quantity of isotope i ingested by an individual (μCi/yr)

U_{fw} = quantity of fish consumed (kg/yr)

B_{fi} = bioaccumulation factor (cc/g)

Z_i = nuclide concentration in water (μCi/cc)

10^3 = conversion factor (g/kg).

(3) Calculation of Ingestion Dose from Meat Consumption

The contribution of a single radionuclide, isotope i, to the 50-yr dose commitment from ingestion of meat produced from animals watered at a contaminated source is given by the equations:

$$D_{mw} = Q_{mwi} \times DF_i \tag{A-22}$$

where

D_{mw} = dose commitment from ingestion of isotope i in meat (rem)

DF_i = dose conversion factor for ingestion of isotope i (rem/μCi)

$$Q_{mwi} = U_{mw} \times A_w \times S_{wi} \times Z_i \times 10^3 \quad \text{(A-23)}$$

where

Q_{mwi} = quantity of radionuclide consumed in meat (μCi/yr)

U_{mw} = consumption rate (kg/yr)

A_w = rate at which milk-producing animals drink water (ℓ/day)

S_{wi} = stable element transfer factor for isotope i from water into meat (day/kg)

Z_i = nuclide concentration in aquifer (μCi/cc)

10^6 = conversion factor (cc/ℓ).

(4) Calculation of Ingestion Dose from Milk Consumption

The contribution of a single radionuclide, isotope i, to the 50-yr dose commitment from ingestion of milk produced by animals watered at a contaminated source is given by the equations:

$$D_{cwi} = Q_{cwi} \times DF_i \quad \text{(A-24)}$$

where

D_{cwi} = dose commitment from ingestion of isotope i in milk (μCi)

DF_i = dose conversion factor for ingestion of isotope i (rem/μCi)

$$Q_{cwi} = U_{cw} \times A_w \times S_{wi} \times Z_i \times 10^3 \quad \text{(A-25)}$$

where

Q_{cwi} = quantity of radionuclide consumed in milk (μCi/yr)

U_{cw} = consumption rate (ℓ/yr)

S_{wi} = stable element transfer factor for isotope i from water into milk (day/ℓ)

A_w = rate at which milk-producing animals drink water (ℓ/day)

Z_i = nuclide concentration in aquifer (μCi/cc)

10^3 = conversion factor (cc/ℓ).

A.1.9.2.3 Calculation of Ingestion Dose from Consuming Contaminated Salt

The contribution of a single radionuclide, isotope i, to the 50-yr dose commitment from ingesting contaminated salt is given by the equations:

$$D_i = C_i \times Q_c \times DF_i \qquad \text{(A-26)}$$

where

D_i = dose commitment from ingestion of isotope i in contaminated salt (rem)

Q_c = annual consumption of table salt (kg/yr)

DF_i = dose conversion factor for ingestion of isotope i (rem/μCi)

$$C_i = \frac{Q_i \times F_i}{Q_p} \qquad \text{(A-27)}$$

where

C_i = concentration of isotope i in salt (μCi-yr/kg)

Q_i = total inventory of isotope i at the time of interest (μCi)

F_i = fraction of total inventory leached during a year of solution mining operations

Q_p = annual production of salt from solution mining in the repository (kg/yr).

A.1.9.3 Calculation of Direct Radiation Dose

The dose from direct radiation is given by the equations:

$$D_{gi} = t_x \times S_f \times C_{gi} \times DF_{gi} \qquad \text{(A-13)}$$

where

D_{gi} = the annual whole-body dose from isotope i (rem)

S_f = the shielding factor that accounts for the dose reduction due to shielding provided by residential structures during occupancy

DF_{gi} = the open-field ground-plane whole-body dose conversion factor for isotope i [(rem/hr)/(μCi/cc)]

$$C_{gi} = D_{pi} \frac{(1 - e^{-\lambda_i t_s})}{\lambda_i PL} \quad \text{(A-14)}$$

where

C_{gi} = the ground-plane concentration of isotope i ($\mu Ci/cm^3$)

λ_i = radioactive decay constant (hr^{-1})

t_x = the exposure time (hr)

t_s = soil accumulation time (hr)

PL = soil mixing depth (cm)

D_{pi} = calculated from Equation A-6.

Individual Dose from Intrusion and Exploratory Drilling

The dose from direct radiation as the result of individual intrusion or exploratory drilling is determined by the following equations:

$$D_i = Q_i \times DF_{gi} \quad \text{(A-28)}$$

where

D_i = annual dose from direct radiation by isotope i (rem)

DF_{gi} = dose conversion factor generated from ISOSHLD code [(rem/hr)/(Ci/cc)]

$$Q_i = C_{ci} \times F_c \times T \times \rho_c \times 10^{-6} \quad \text{(A-29)}$$

where

C_{ci} = concentration of isotope i in calcine (μCi/g)

F_c = fraction of waste which is calcine

T = exposure time (hr)

ρ_c = calcine density (g/cc)

10^{-6} = conversion factor (Ci/μCi)

$$F_c = \frac{Q_c}{A \times PL \times \rho_s} \quad \text{(A-30)}$$

PL = depth to which the soil is mixed (m) (0.05 m for direct radiation)

ρ_s = soil density (kg/m^3)

Q_c = quantity of waste dispersed (kg)

A = area over which waste is uniformly dispersed (m^2).

A.1.9.4 Calculation of Dose from Radon Daughter Exposure

The methodology used to calculate radon exposure is derived from two studies: "Radioactivity of Lands and Associated Structures" (Roessler, 1978) and "Radon Migration in the Ground: A Review" (Tanner, 1964).

$$D_{rn} = \bar{C}_{WL} \times DF_{rn} \quad \text{(A-31)}$$

where

D_{rn} = dose equivalent to lung resulting from inhalation of radon and its daughters (rem/yr)

$\bar{C}_{WL}$ = concentration of radon and daughters in working levels (WL)

DF_{rn} = radon daughter dose conversion factor (rem/WL-yr).

Equation A-32 is an empirical equation for concrete slab floor construction and can be expressed as:

$$\bar{C}_{WL} = 0.0087\ J^{0.46} \quad \text{(A-32)}$$

where

J = average radon flux from the ground upon which a house is constructed (ground is a homogeneous medium of limited depth) (pCi/m^2-s).

A.1.9.4.1 Calculation of Radon Flux from a Homogeneous Medium

The radon flux, J_o, from the surface of a porous, homogeneous medium can be described by

$$J_o = 10^4 \, DC_{rn} \, (\lambda \frac{P}{D})^{\frac{1}{2}} \qquad \text{(A-33)}$$

where

J_o = radon flux from the surface (pCi/m^2-s)

λ = radioactive decay constant of radon (s^{-1})

D = diffusion coefficient for radon diffusing through the fluid (air, water, etc.) in the void spaces between the solid particles (cm^2/sec).

The concentration of radon, C_{rn}, in the void space in a homogeneous, porous medium is given by the relation:

$$C_{rn} = C_{ra} \times \frac{E\rho}{P}$$

where

C_{ra} = concentration of radium in medium (pCi/g)

E = emanation coefficient (fraction of radon released to void space from material)

ρ = bulk density of medium (g/cm^3)

P = porosity of medium (void fraction).

Substitution of the equation for C_{rn} gives

$$J_o = 10^4 C_{ra} \, E\rho \, (\frac{\lambda D}{P})^{\frac{1}{2}} \, . \qquad \text{(A-34)}$$

Shielding Layer

A layer of "clean" porous material on top of a radium-bearing porous material can be expected to attenuate the diffusing radon. At the surface of

clean material, the radon flux can be described approximately by the simple attenuation equation:

$$J = J_o \exp(-Y(\lambda\frac{P}{D})^{\frac{1}{2}} \quad \text{(A-35)}$$

where

Y = thickness of clean material layer (cm).

Finite Surface Layer

The radon flux from the surface of a porous, homogeneous medium of limited depth, bounded above by air and below by an impervious medium, can be described by the equation:

$$J = 10^4 \, C_{ra} \, \rho E(\lambda\frac{D}{P})^{\frac{1}{2}} \tanh(Y(\lambda\frac{P}{D})^{\frac{1}{2}}) \quad \text{(A-36)}$$

where

Y = depth of radium-bearing layer (cm).

A.1.9.4.2 Radon Daughter Concentration in a House on Radium-Bearing Soil

In an average residential dwelling, the relationship between the average indoor radon daughter concentration and the annual lung dose equivalent is about 100 mrem/yr per 0.001 working level (WL) average in the dwelling. This relation was obtained by reducing the occupational lung exposure data by a factor of 0.5 to reflect the lower respiration rate of individuals in a residence. This gives an estimated tracheobronchial dose equivalent of 2.9 rem per working-level month (WLM) in a house with ventilation equivalent to 1 air change/hr. Assuming a resident spends as much as 16 hr/day in a radon-contaminated house, his tracheobronchial dose equivalent per 0.001 WL is estimated to be increased by:

$$DF_{rn} = 0.001 \text{ WL} \frac{1\text{WLM}}{1\text{WL} \times 170 \text{ hr}} \times \frac{16 \text{ hr}}{\text{day}} \times \frac{365 \text{ days}}{\text{yr.}} \times \frac{2.9 \text{ rem}}{\text{WLM}}$$

$$= 0.1 \text{ rem}/.001 \text{ WL} .$$

One additional correction factor is required to calculate the concentration of radon in a residence. The exposure time for the WL is 16 hr/day × 365 day/yr = 5,840 hr/yr. To adjust for the actual exposure time, a factor of $\frac{T}{5840}$ must be included where T is in hours. For the scenarios evaluated in this report, an exposure time of 7000 hr was used. Therefore,

$$DF_{rn} = \frac{100T}{5840} . \qquad \text{(A-37)}$$

Assuming a house is built on radium-bearing soil that is uniform and semi-infinite in extent, the typical dose equivalent rate can be estimated in the following way. Over a limited range, $0.005 < D < 0.05$, the media diffusion coefficient, D, can be approximately determined from the function of soil moisture content:

$$D \propto \exp(-0.063 \times \% \text{ moisture}).$$

The radon flux from the surface of the sand, J_o ($\mu Ci/m^2$-s) can be calculated using the relation:

$$J_o = 10^4 C_{ra} E\rho \left(\frac{\lambda D}{P}\right)^{\frac{1}{2}} \qquad \text{(A-38)}$$

where

$E = 1.0$

$\rho = 1.3$ g/cm^3

$\lambda = 2.1 \times 10^{-6}$/sec

$D = 0.024$ cm^2/sec

$P = 0.3$

10^4 = conversion factor (cm^2/m^2)

and then

$$J_o = 5.33\ C_{ra} .$$

There are two radon daughter cases considered in this appendix: (1) a house built on a 1-m-deep layer of radium-bearing soil and (2) a house built on a 25-ft-deep layer of soil covering radium-bearing soil.

(1) House on 1-Meter Deep Layer of Radium-Bearing Soil

The dose equivalence rate associated with residence in a house built on a 1-m (3.3-ft) layer of radium-bearing soil is estimated as follows. The radon flux from the surface of a 1-m-deep layer of radium-bearing soil on top of an impervious layer is approximately

$$J = J_o \tanh\left(Y\left(\lambda\frac{P}{D}\right)^{\frac{1}{2}}\right)$$

where

$$J_o = 5.33\ C_{ra}$$

$$Y = 100\ \text{cm}$$

$$\lambda = 2.1 \times 10^{-6}/\text{sec}$$

$$P = 0.3$$

$$D = 0.24\ \text{cm}^2/\text{sec}$$

$$\tanh(x) = \frac{e^x - e^{-x}}{e^x + e^{-x}} .$$

Therefore,

$$J = 3.09\ C_{ra} .$$

(2) House on 25-Foot-Deep Layer of Soil Covering Radium-Bearing Soil

The dose equivalence rate associated with residence in a house on a 7.6-m layer (25 ft) of soil covering radium-bearing soil, semi-infinite in extent, is estimated as follows. The radon flux from the surface is estimated by the attenuation method. The appropriate equation is

$$J = J_o \exp\left(-Y\left(\lambda\frac{P}{D}\right)^{\frac{1}{2}}\right) .$$

After substituting all parameters, the following equation is obtained:

$$J = 1.08 \times 10^{-1}\ C_{ra} .$$

A.2 Nonradiological Effects

The assessment of nonradiological effects for this report consists of two types of evaluations: the emission of air pollutants during the construction and operations phases of alternative implementation and the evaluation of potential water contaminants during the disposal phase. Water quality effects at the INEL are evaluated in the waste-migration-into-groundwater scenario. Water quality effects at the federal geologic repository are evaluated in the fault-and-flooding and solution-mining scenarios.

The methodology used to evaluate the effects of nonradiological air and water pollutants consists of five components: (1) determination of potential air and water pollution sources, (2) estimation of emission and migration rates, (3) evaluation of offgas treatment systems and pollution control technology, (4) calculation of ambient air and water pollutant pollutant concentration increases, and (5) evaluation of effects of ambient air and water pollutant concentration increases. The analyses are based on the chemical compositions of present and future calcine waste shown in Table A-94.

A.2.1 Air Quality

The evaluation of potential air pollutants is based on a review of the processes required to implement the alternatives. To calculate emission rates of air pollutants it was assumed that:

- all nitrogen pentoxide, mercury, and cadmium contained in the calcine would be volatilized and released to the atmosphere during processing;

- nitrogen oxides produced during thermal decomposition of nitric acid used in waste form modification would be directly proportional to the consumption of nitric acid; and

- an offgas treatment system would be used to control air pollutant emissions and the process equipment evaporator would be equipped with a high efficiency scrubber for 90% or better removal of nitrogen oxide.

TABLE A-94

CHEMICAL COMPOSITION OF CALCINE

Composition	Alumina Waste	Zirconia Waste	Future Waste
Physical			
Mass median particle diameter (mm)	0.56 - 0.70	0.6 - 0.8	0.6 - 0.8
Bulk density (g/cm^3)	1.0 - 1.2	1.7	1.3
Chemical (wt.%):			
Zirconium (ZrO_2)	---	21.4	*
Calcium	---	54.2	*
Aluminum	88.2 - 89.1	21.9	*
Sodium	1.3 - 2.0	---	*
Nitrogen	3.9 - 4.1	1.9	*
Mercury	2.9	---	*
Water	2.0	0.6	*
Gross fission products as oxides	0.6	---	*

* The chemical composition of future calcine will be similar to the composition of zirconia waste. In addition, future waste will contain approximately 9% cadmium.

EPA-recommended long-term and short-term atmospheric dispersion models and site meteorological data (see Subsection A.1.5) were used to estimate ambient air concentrations of the pollutants emitted to the atmosphere. Concentrations were calculated for the point on the INEL boundary where concentrations would be a maximum. The annual average dispersion factor data presented in Subsection A.1.5 for the southern portion of the INEL boundary [approximately 10 mi (16 km) southeast of ICPP] were used to calculate long-term (annual) ambient air concentration increases of all potential emissions during the construction and operational phases. Short-term (1-hr) ambient air concentration increases were calculated using 1-hr average site meteorological data.

To evaluate the impact of the air pollutant concentration increases on the general public, INEL workers, and local flora and fauna, calculated concentration increases were compared to applicable EPA ambient air quality

standards and engineering guidelines. Where the calculated increases were below detection limits of the monitoring equipment, it was considered that effects of pollutants would be insignificant and would not affect the health and welfare of the general public, INEL workers, or the bioenvironment.

To evaluate the toxic chemical effects postulated to occur during the disposal phase, water pollutant concentrations in hypothetical wells were compared with applicable EPA drinking water standards and toxic ingestion levels for cadmium and mercury as oxides.

A.2.1.2 Construction Phase

A.2.1.2.1 Source Terms

Source terms for air pollutant emissions during the construction phase were determined by first estimating the amount of equipment and diesel fuel required for each alternative. These estimates were based on analyses and comparisons of equipment requirements for construction projects of similar magnitude. The estimated construction activities and fuel requirements for each alternative are presented in Table A-95.

The estimated total emissions for construction activities include dust generated during construction and construction equipment exhaust emissions. Exhaust emissions are directly proportional to diesel fuel usage. Approved emission factors for particulates, nitrogen oxides (NO_x), carbon monoxide (CO), sulfur dioxide (SO_2), and hydrocarbons were used to calculate emission rates (EPA, 1977). The particulate emissions from dust generation were calculated from the land area used for construction, the duration of the construction period, and the appropriate emission factor. The estimated total emissions (tons) during the construction phase for each alternative are presented in Table A-96.

The estimated total emissions were converted to annual emission rates (g/sec) to provide the source terms used to calculate increased pollutant concentrations. The annual emission rates were calculated by normalizing the

TABLE A-95

ESTIMATED CONSTRUCTION ACTIVITIES AND FUEL REQUIREMENTS

Alternative	Duration (mo)	Heavy Equipment (average)	Diesel Fuel (10^3 gal)
1. Leave-in-Place	18	25	375
2. Retrieve, Modify Calcine, Dispose at the INEL			
Pelletize Calcine	21	30	275
Convert Calcine to Glass	36	50	575
3. Retrieve, Modify Calcine, Dispose Offsite			
Stabilize Calcine	21	35	325
Convert Calcine to Glass	24	35	390
4. Retrieve, Separate Actinides, Dispose of Actinides Offsite, Dispose of Depleted Calcine at the INEL	40	50	1,110
5. Delay Retrieval, Modify Calcine, Dispose Offsite			
100 yr	24	35	390
300 yr	24	35	390
500 yr	24	35	390

total emissions to a 230-day/yr and 8-hr/day construction schedule. Emission rates for each alternative are presented in Table A-97.

A.2.1.2.2 Dispersion Factors

The atmospheric dispersion factor (χ/Q) used to determine the maximum long-term (annual) average pollutant concentrations at an INEL boundary during the construction phase was obtained from calculations based on the dispersion equation for continuously emitting point sources (Turner, 1970). An effective release height of ground level was used. The vertical dispersion function for this calculation was obtained using the McMullen equation for rural application.

TABLE A-96

ESTIMATED TOTAL EMISSIONS DURING THE CONSTRUCTION PHASE (tons)

Alternative	Particulates	NO_x	CO	SO_2	Hydrocarbons	Construction Time (yr)
1. Leave-in-Place	26.50	76.20	17.70	5.70	5.40	1.50
2. Retrieve, Modify Calcine, Dispose at the INEL						
Pelletize Calcine	54.00	56.00	13.10	4.28	4.00	1.75
Convert Calcine to Glass	93.42	109.40	25.60	8.36	7.80	3.00
3. Retrieve, Modify Calcine, Dispose Offsite						
Stabilize Calcine	29.44	66.16	15.50	5.06	4.72	1.75
Convert Calcine to Glass	33.86	78.88	18.46	6.02	5.64	2.00
4. Retrieve, Separate Actinides, Dispose of Actinides Offsite, Dispose of Depleted Calcine at the INEL	209.44	178.10	41.60	13.60	12.72	2.75
5. Delay Retrieval, Modify Calcine, Dispose Offsite						
100 yr	33.86	78.88	18.46	6.02	5.64	2.00
300 yr	33.86	78.88	18.46	6.02	5.64	2.00
500 yr	33.86	78.88	18.46	6.02	5.64	2.00

TABLE A-97

ESTIMATED EMISSION RATES FOR AIR POLLUTANTS
GENERATED DURING THE CONSTRUCTION PHASE (g/sec)

Alternative	Particulates	NO_x	CO	SO_2	Hydrocarbons
1. Leave-in-Place	2.4	7.0	1.6	0.52	0.49
2. Retrieve, Modify Calcine, Dispose at the INEL					
Pelletize Calcine	4.2	4.4	1.0	0.34	0.31
Convert Calcine to Glass	4.3	5.0	1.2	0.38	0.36
3. Retrieve, Modify Calcine, Dispose Offsite					
Stabilize Calcine	2.3	5.2	1.2	0.40	0.37
Convert Calcine to Glass	2.3	5.4	1.3	0.41	0.39
4. Retrieve, Separate Actinides, Dispose of Actinides Offsite, Dispose of Depleted Calcine at the INEL	10.0	8.9	2.1	0.68	0.63
5. Delay Retrieval, Modify Calcine, Dispose Offsite					
100 yr	2.3	5.4	1.3	0.41	0.39
300 yr	2.3	5.4	1.3	0.41	0.39
500 yr	2.3	5.4	1.3	0.41	0.39

Stability frequency data were not available for the ICPP site; however, a first order approximation was made of annual average concentrations by using the appropriate wind rose data and assuming the neutral stability Class D. This is considered to be a conservative assumption because construction would take place only during daylight hours when stability Class D conditions would most likely occur. The value of the dispersion factor for long-term concentrations using the neutral stability class was calculated to be 1.7×10^{-8} sec/m^3.

The dispersion factor used to determine the maximum short-term (1-hr) average pollutant concentration increases at an INEL boundary was obtained from calculations based on the Pasquill-Gifford diffusion equation for a single ground-level source (Turner, 1970). The maximum concentrations were calculated by assuming a stability Class F and effective release height at ground level. The worst-case dispersion factor for short-term construction activities was calculated to be 6.9×10^{-6} sec/m^3.

A.2.1.2.3 Calculation of Maximum Air Pollutant Concentration Increases During Construction

The maximum long-term and short-term air pollutant concentration increases at an INEL boundary during construction were calculated for each alternative by multiplying the emission rates in Table A-98 by the appropriate dispersion factor presented in Subsection A.2.2.2. The short-term dispersion factor is used to calculate concentrations controlled by 1- and 3-hr standards. The long-term dispersion factor is used to calculate concentrations controlled by annual standards. The resultant concentration of each pollutant for each alternative was compared with the strictest ambient air quality standard for that pollutant. Calculated increases in ambient air concentrations for pollutants emitted during construction are presented in Table A-98.

The following sample calculation is provided for determination of the NO_x concentration during construction activities in Alternative 4.

$$Q = 8.9 \text{ g/sec (from Table A-97)}$$

$$\chi/Q = 1.7 \times 10^{-8} \text{ sec/m}^3 \text{ (from Subsection A.2.2.2)}$$

TABLE A-98

CALCULATED CONCENTRATION INCREASES
OF AIR POLLUTANTS FROM CONSTRUCTION ACTIVITY ($\mu g/m^3$)[a,b]

Alternative	Particulates (annual geometric mean)	NO_x (annual arithmetic mean)	CO (1-hr average)	SO_2 (annual arithmetic mean)	Hydrocarbons (3-hr average)
1. Leave-In-Place	0.04	0.12	11.0	0.009	3.4
2. Retrieve, Modify Calcine, Dispose at the INEL					
Pelletize Calcine	0.07	0.07	6.9	0.006	2.2
Convert Calcine to Glass	0.07	0.09	8.3	0.007	2.5
3. Retrieve, Modify Calcine, Dispose Offsite					
Stabilize Calcine	0.04	0.09	8.3	0.007	2.6
Convert Calcine to Glass	0.04	0.09	9.0	0.007	2.7
4. Retrieve, Separate Actinides, Dispose of Actinides Offsite, Dispose of Depleted Calcine at the INEL	0.20	0.15	15.0	0.010	4.4
5. Delay Retrieval, Modify Calcine, Dispose Offsite					
100 yr	0.04	0.09	9.0	0.007	2.7
300 yr	0.04	0.09	9.0	0.007	2.7
500 yr	0.04	0.09	9.0	0.007	2.7
Federal standard[c]	60.00	100.00	40,000.0	80.00	160.00

a. At southern INEL boundary.

b. All calculated concentrations are below instrument detection limits. Detection limit: sulfur dioxide, 7.2 $\mu g/m^3$; nitrogen oxides, 4.3 $\mu g/m^3$; particulates, 1 $\mu g/m^3$; hydrocarbons, 16 $\mu g/m^3$.

c. 40 CFR 50. This is the most restrictive standard. It is the primary standard for sulfur dioxide and the secondary standard for particulates, nitrogen oxides, carbon monoxide, and hydrocarbons.

$$NO_x \text{ concentration} = Q \times \chi/Q$$
$$= 8.9 \times 1.7 \times 10^{-8}$$
$$= 0.15\ \mu g/m^3.$$

A.2.1.3 Operations Phase

A.2.1.3.1 Source Terms

Source terms for primary air pollutant emissions during the operations phase at the ICPP were determined for particulates, NO_x, CO, cadmium (Cd), and mercury (Hg). The major pollutant emission during the routine operations phase is NO_x. Nitrogen oxides are produced during processing by the thermal decomposition of nitric acid in the evaporator system and by volatilization of the nitric acid contained in the calcine. Cd and Hg also volatilize during processing. It is assumed that 95% of the Cd and 90% of the Hg are removed by the offgas treatment system before release to the atmosphere. The estimated emission rates (lb/day) for each alternative are presented in Table A-99.

The estimated emission rates in lb/day were converted to emission rates in g/sec to provide the source term used to calculate increased pollutant concentrations. The estimated emission rates (g/sec) for each alternative are presented in Table A-100.

A.2.1.3.2 Dispersion Factors

The atmospheric dispersion factor (χ/Q) used to determine the maximum long-term (annual) average pollutant concentrations at an INEL boundary during the operations phase is the dispersion factor used for elevated releases presented in Subsection A.1.5. The maximum annual dispersion factor at an INEL boundary is 4×10^{-8} sec/m^3.

The dispersion factor used to calculate the short-term (1-hr) average pollutant concentrations of elevated releases at the southern INEL boundary was obtained from calculations based on the Pasquill-Gifford diffusion equation for a single elevated source (Turner, 1970). The maximum concentrations were calculated by assuming a Class F stability and effective release

TABLE A-99

ESTIMATED EMISSION RATES FOR AIR POLLUTANTS GENERATED DURING THE OPERATIONS PHASE (lb/day)[a]

Alternative	Particulates	NO_x	CO	Cd	Hg
1. Leave-in-Place[b]	Negligible	0	0	0	0.0
2. Retrieve, Modify Calcine, Dispose at the INEL					
Pelletize Calcine	Negligible	4,895	0	40	3.8
Convert Calcine to Glass	Negligible	2,000	0	40	3.8
3. Retrieve, Modify Calcine, Dispose Offsite					
Stabilize Calcine	Negligible	1,987	0	40	3.8
Convert Calcine to Glass	Negligible	2,000	0	40	3.8
4. Retrieve, Separate Actinides, Dispose of Actinides Offsite, Dispose of Depleted Calcine at the INEL	Negligible	11,000	4,453	40	0.0[c]
5. Delay Retrieval, Modify Calcine, Dispose Offsite					
100 yr	Negligible	2,000	0	4	3.8
300 yr	Negligible	2,000	0	4	3.8
500 yr	Negligible	2,000	0	4	3.8

a. To calculate annual emissions, multiply emission rates by 230 days/yr of operation.

b. No nitrogen oxides, cadmium, mercury, or carbon monoxide result from the leave-in-place alternative.

c. No mercury emissions result from Alternative 4.

TABLE A-100

ESTIMATED EMISSION RATES FOR AIR POLLUTANTS
GENERATED DURING THE OPERATIONS PHASE (g/sec)

Alternative	Particulates	NO_x	CO	Cd	Hg
1. Leave-in-Place	Negligible	0	0	0	0
2. Retrieve, Modify Calcine, Dispose at the INEL					
Pelletize Calcine	Negligible	26	0	0.2	0.02
Convert Calcine to Glass	Negligible	11	0	0.2	0.02
3. Retrieve, Modify Calcine, Dispose Offsite					
Stabilize Calcine	Negligible	10	0	0.2	0.02
Convert Calcine to Glass	Negligible	11	0	0.2	0.02
4. Retrieve, Separate Actinides, Dispose of Actinides Offsite, Dispose of Depleted Calcine at the INEL	Negligible	58	23	0.2	0.00
5. Delay Retrieval, Modify Calcine, Dispose Offsite					
100 yr	Negligible	11	0	0.2	0.02
300 yr	Negligible	11	0	0.2	0.02
500 yr	Negligible	11	0	0.2	0.02

height of 76 m considering plume buoyancy. The calculated dispersion factor for short-term operational releases is 2.8×10^{-7} sec/m^3.

A.2.1.3.3 Calculation of Maximum Air Pollutant Concentration Increases During Operations

The long-term and short-term air pollutant concentration increases at the southern INEL boundary during operations were calculated by multiplying the emission rates in Table A-100 by the dispersion factors presented in Subsection A.2.3.2. The resultant concentrations of each pollutant were compared with applicable ambient air quality standards. The calculated concentration increases are presented in Table A-101.

None of the calculated pollutant concentrations is above the applicable ambient air quality standard. The calculated concentration for Cd is well below the background level of 0.03 $\mu g/m^3$. The calculated Hg concentration is below the threshold detection limit of 0.01 mg/m^3.

The following sample calculation is provided for determination of the NO_x concentration during operations in Alternative 4.

$$Q = 58 \text{ g/sec (from Table A-6)}$$

$$\chi/Q = 4 \times 10^{-8} \text{ sec/m}^3 \text{ (from Subsection A.2.3.2)}$$

$$NO_x \text{ concentration} = Q \times \chi/Q$$

$$= 58 \times 4 \times 10^{-8}$$

$$= 2.3 \ \mu g/m^3 \ .$$

A.2.2 Water Quality

A.2.2.1 Releases at the ICPP

A.2.2.1.1 Waste Migration into Groundwater

Cadmium (Cd) and mercury (Hg) contamination of the groundwater is postulated to occur in the waste-migration-into-groundwater scenario described initially in Subsection A.1.8.1.4.2.

TABLE A-101

CALCULATED CONCENTRATION INCREASES OF AIR POLLUTANTS DURING THE OPERATIONS PHASE ($\mu g/m^3$)

Alternative	Particulates	NO_x (Annual Average)	CO (1-hr Average)	Cd (Annual Average)	Hg (Annual Average)
1. Leave-In-Place	Negligible	0	0	0	0
2. Retrieve, Modify Calcine, Dispose at the INEL					
Pelletize Calcine	Negligible	1.00	0	0.008	0.0008
Convert Calcine to Glass	Negligible	0.44	0	0.008	0.0008
3. Retrieve, Modify Calcine, Dispose Offsite					
Stabilize Calcine	Negligible	0.40	0	0.008	0.0008
Convert Calcine to Glass	Negligible	0.44	0	0.008	0.0008
4. Retrieve, Separate Actinides, Dispose of Actinides Offsite, Dispose of Depleted Calcine at the INEL	Negligible	2.3	6.4	0.008	0
5. Delay Retrieval, Modify Calcine, Dispose Offsite					
100 yr	Negligible	0.44	0	0.008	0.0008
300 yr	Negligible	0.44	0	0.008	0.0008
500 yr	Negligible	0.44	0	0.008	0.0008
Federal Standard*	60	100	40,000	None	None

* 40 CFR 50

Since the containment integrity of the calcine storage bins cannot be guaranteed in perpetuity, it is assumed that the waste is leached by water into the aquifer. The amount of water required to leach the waste is equivalent to about 30 years' average rainfall. Average annual rainfall is assumed to drive contaminated water by hydrostatic pressure from the bin bottom.

The contaminated water then seeps through a sediment layer, traverses a layer of lava, and reaches the aquifer which transports cadmium and mercury downgradient to four hypothetical wells. The first well is assumed to be adjacent to the point of injection into the aquifer; the second, 3 mi downgradient from the injection point; the third, 10 mi downgradient from the injection point; and the fourth, 120 mi downgradient from the injection point.

The annual precipitation is 22 cm (8.5 in). Very little of this moisture actually reaches the aquifer; most is lost to the atmosphere by evaporation and transpiration. If current weather patterns continue, eventual toxic chemical migration to the aquifer would be unlikely. Flooding of the waste bins by the Big Lost River is precluded by current geologic-hydrologic conditions at the site (see Subsection 4.5).

This scenario is evaluated to determine the potential consequences of aquifer contamination. In reality, the underlying Snake River Plain Aquifer is vast, and a very large amount of dilution would occur both initially and during the 120-mi underground movement of the water before it surfaces near Hagerman in the Snake River Canyon. Ion-exchange processes in the soil layer underlying the bins would further diminish the quantity of Cd and Hg reaching the aquifer.

The scenario affects Alternatives 1, 2, and 4 and is based on the following assumptions. Mercury is removed during actinide separation so is not a potential pollutant in Alternative 4. The stainless steel bins, surrounding concrete, and reinforced concrete vaults deteriorate to where incident rainwater can enter the bins and contact the stored calcine. A bin set contains about 1400 m^3 (50,000 ft^3) of waste and covers an area of about 190 m^2 (2,000 ft^2). However, the total estimated quantity of Cd and Hg are assumed

to be contained in one bin set. The total weight of Cd and Hg is very conservatively assumed to be diluted by the volume of water under one bin-vault complex. The total calcine volume will be 545,000 ft^3 in 2020. With an average density of 1.31 gm/cm^3, the total weight would be 2.04×10^7 kg, of which 0.3% is estimated to be Hg and 9% is estimated to be Cd. If about half of the annual incident precipitation, 11 cm (4.25 in.), contacts the waste, there would be enough water during the course of a year to cover about 1% of the waste. Although much of the waste is not very leachable, 10% of the Cd and Hg in 1% of calcine is assumed to leach from the waste in 1 yr. This leachate then would leave the disposal area and percolate downward to the aquifer. The vertical distance to the aquifer is about 140 m (450 ft). Approximately 105 to 120 m (350 to 400 ft) of this is lava. Therefore, the effective ion-exchange capacity is based on 15 m (50 ft) of soil cover.

The pathways considered for human exposure are water from the hypothetical well and the food chain as a result of crop irrigation with contaminated well water.

A.2.2.1.1.1 Calculation of Aquifer Concentration

The method used to determine toxic chemical concentrations in the aquifer depends on the relationship between the period of release and the pulse width of the aquifer at the point of release.

The rate of flow through the soil layer above the aquifer is assumed to be 1 cm/day. The actual rate of travel for most metallic contaminants is considerably slower than this flow rate due to the natural ion-exchange capacity of the soil. The ion-exchange distribution coefficient (K_d) for the soil layer determines the rate of migration from the bins to the aquifer. The K_d value for both Cd and Hg is 100 (Burkholder, 1976). The cadmium and mercury reaching the aquifer are assumed to be diluted only by the flow of the water under one bin-vault complex. This dilution flow is about 110 m^3/day/m (1200 ft^3/day/ft) of width. For Alternatives 1, 2 (pellets), and 4, the width of the calcine vault is taken as 15 m (50 ft), leading to an annual dilution volume of 6.02×10^5 m^3/yr (2.2×10^7 ft^3/yr). For Alternative 2 (glass), the

width of the calcine disposal area is 870 m (2,850 ft) with an annual dilution volume of 3.5×10^7 m^3/yr (1.2×10^9 ft^3/yr).

The release time, 100 years (1 ÷ fraction of waste released per year), is assumed to be instantaneous because of the restrictive influence of the percolation rate and ion-exchange distribution coefficients. Calculated release times for the alternatives are

Alternative	Release Time (years)
1, 4	100
2 (Pellets)	10,000
2 (Glass)	1,000,000

Therefore, for Alternatives 1 and 4, the maximum fraction (F) of the instantaneous release entering the aquifer is given by:

$$F = \frac{1}{\left(\frac{2\pi D}{Wt}\right)^{1/2}\left(\frac{K_d \rho}{p} + 1\right)}$$

where

D = distance to aquifer, 1500 cm

W = leachwater flow rate, 1 cm/day

t = ion-exchange equilibrium time, 1 day

K_d = ion-exchange distribution coefficient, 100 $\frac{\text{meq/g solid}}{\text{meq/m}\ell \text{ liquid}}$

ρ = soil density, 1.6 g/mℓ

p = soil porosity, 0.3 mℓ/liquid/cm^3.

Thus,

$$F = \frac{1}{\left(\frac{2\pi 1500}{1 \times 1}\right)^{1/2}\left(\frac{100 \times 1.6}{0.3} + 1\right)} = 1.9 \times 10^{-5} .$$

Since F is the fraction of the release in an "equilibrium stage" of ion exchange, and the equilibrium time is 1 day, the release rate is given in kg/day. Therefore, 2.04×10^{6} kg of calcine is leached and the maximum amount entering the aquifer is

$$1.9 \times 10^{-5} \times 2.04 \times 10^{6} = 39 \text{ kg/day.}$$

The aquifer concentration, C, is

$$C = \frac{39 \text{ kg/day} \times 365 \text{ days/yr}}{\text{aquifer flow}} .$$

Therefore, with an aquifer flow of 6.02×10^{11} mℓ/yr, the final concentration in Alternatives 1 and 4 would be

$$C = \frac{39 \text{ kg/day} \times 365 \text{ days/yr}}{6.02 \times 10^{11} \text{ mℓ/yr}} = 2.3 \times 10^{-8} \text{ kg calcine/mℓ.}$$

For Alternative 2, the calcine is assumed to enter the aquifer at the same rate as it leaves the bins.

In Alternative 2 (pellets), the fraction of calcine leaving the bin is 1.0×10^{-4} and the maximum amount entering the aquifer is 2.04×10^{3} kg/yr. The aquifer concentration, C, is

$$C = \frac{2.04 \times 10^{3}}{6.02 \times 10^{11}} = 3.4 \times 10^{-9} \text{ kg calcine/mℓ.}$$

In Alternative 2 (glass), the fraction leaving the bin is 1.0×10^{-6} and the maximum amount entering the aquifer is 2.04×10^{1} kg/yr. The aquifer concentration, C, is

$$C = \frac{2.04 \times 10^{1}}{3.5 \times 10^{13}} = 5.8 \times 10^{-13} \text{ kg calcine/mℓ.}$$

It is assumed, conservatively, that the calcine concentration (C) in the aquifer, will be further diluted by a 30°-dispersion plume as it is transported downgradient to the 3-mi and 10-mi wells. The 120-mi well is assumed to have the same dilution as the 10-mi well.

The dilution factor for each well is calculated as follows:

$$D_f = \text{distance (mi)} \times 1609.34 \text{ m/mi} \times \frac{2(\tan 30/2 + 15/2)}{15 \text{ m}}$$

$$= \text{distance (mi)} \times 57.5 + 1 \ .$$

Therefore, the dilution factors for the 3-, 10-, and 120-mi wells are approximately 175, 575, and 575, respectively.

The diluted calcine concentrations are then found by the equation

$$C_{mi} = C/D_f \quad \text{(kg calcine/mℓ)}.$$

The concentrations in the 0-, 3-, 10-, and 120-mi wells are

Alternatives 1 and 4	Alternative 2 (Pellets)	Alternative 2 (Glass)
$C_0 = 2.3 \times 10^{-8}$	$C_0 = 3.4 \times 10^{-9}$	$C_0 = 5.8 \times 10^{-13}$
$C_3 = 1.3 \times 10^{-10}$	$C_3 = 1.9 \times 10^{-11}$	$C_3 = 3.3 \times 10^{-15}$
$C_{10} = 4.0 \times 10^{-11}$	$C_{10} = 5.9 \times 10^{-12}$	$C_{10} = 1.0 \times 10^{-15}$
$C_{120} = 4.0 \times 10^{-11}$	$C_{120} = 5.9 \times 10^{-12}$	$C_{120} = 1.0 \times 10^{-15}$

The calcine is assumed to contain approximately 9% cadmium and 0.3% mercury by weight. The values for cadmium and mercury concentrations in the four hypothetical wells are given in Table A-102.

A.2.2.1.1.2 Ingestion Concentrations

This section presents the models and equations required to estimate ingested quantities of cadmium and mercury from drinking water, vegetation, and animal products. Typical daily consumption values are given in Table A-103 (NRC, 1977).

TABLE A-102

WELL CONCENTRATIONS OF CADMIUM AND MERCURY

Alternative	Toxic Chemical	Concentration, (mg/ℓ) Discharge Point, 0 mi	3 mi	10 mi	120 mi	Federal Standard[a]
1	Cadmium	2.1	1.2×10^{-2}	3.6×10^{-3}	3.6×10^{-3}	0.010
	Mercury	6.9×10^{-2}	3.9×10^{-4}	1.2×10^{-4}	1.2×10^{-4}	0.002
4[b]	Cadmium	2.1	1.2×10^{-2}	3.6×10^{-3}	3.6×10^{-3}	0.010
2	(Pellets)					
	Cadmium	3.1×10^{-1}	1.7×10^{-3}	5.3×10^{-4}	5.3×10^{-4}	0.010
	Mercury	1.0×10^{-2}	5.7×10^{-5}	1.8×10^{-5}	1.8×10^{-5}	0.002
2	(Glass)					
	Cadmium	5.2×10^{-5}	3.0×10^{-7}	9.0×10^{-8}	9.0×10^{-8}	0.010
	Mercury	1.7×10^{-6}	9.9×10^{-9}	3.0×10^{-9}	3.0×10^{-9}	0.002

a. National Interim Primary Drinking Water Standards (40 CFR 141).

b. Mercury is removed before disposal in Alternative 4.

TABLE A-103

STANDARD MAXIMUM DAILY CONSUMPTION VALUES

Consumption		Value (ℓ/day or kg/day)
Man		
Drinking water	(Q_w)	2.00
Fruit, vegtables, and grain	(Q_v)	1.50
Leafy vegetables	(Q_{lv})	0.20
Milk (cow)	(Q_m)	0.90
Meat (cattle)	(Q_{mt})	0.30
Fish (freshwater)	(Q_f)	0.06
Animal		
Milk (cow)		
Water	(Q_{mw})	60.0
Forage or feed	(Q_{mf})	50.0
Meat (cattle)		
Water	(Q_{mtw})	50.0
Forage or feed	(Q_{mf})	50.0

The daily ingestion of cadmium and mercury from drinking water is calculated from the equation

$$I_w = c_{Cd,\ Hg} \times Q_w$$

where

I_w = intake of Cd or Hg from drinking water by well (mg/day)

c = concentration of Cd or Hg in drinking water by well (mg/ℓ)

Q_w = amount value of drinking water consumed (ℓ/day) assumed to be 2.0.

The vegetation concentrations for fruits, vegetables and grain, leafy vegetables, and forage or feed are calculated by

$$V_{v,lv,mf} = c \times d \left(\frac{r\ t_e}{Y} + \frac{B_1 t_b}{P} \right)$$

where

$V_{v,lv,mf}$ = concentration of Cd or Hg in vegetation by well (mg/kg)

c = concentration of Cd or Hg in irrigation water by well (mg/ℓ), $C \times 1.0 \times 10^9 \times .09$ Cd and $C \times 1.0 \times 10^9 \times .003$ Hg

d = spray irrigation rate on vegetation (ℓ/m^2-sec) 2.42×10^{-3} (30 in./yr)

r = fraction of Cd or Hg remaining on vegetation from irrigation (dimensionless), 0.25

$t_e = \frac{1}{\lambda}(1 - e^{-\lambda\tau})$, accumulation time for Cd or Hg deposited on vegetation: vegetables, 1.7×10^6; forage, 1.4×10^6

λ = environmental removal constant (ℓ/sec), 5.7×10^{-7}

τ = vegetation growing season (sec), vegetables, 5.2×10^6, forage, 2.6×10^6

Y = agricultural productivity, vegetation yield (kg/m^2): vegetables, 2.0; forage 0.75

B_1 = stable element transfer factor for vegetation (kg soil/kg vegetation), Cd = 0.30, Hg = 0.38

t_b = time duration of irrigation (s), 1.58×10^9 (50 yr)

P = effective soil surface density (kg/m^2), 240.

The ingestion of cadmium and mercury from fruits, vegetables, grain, and leafy vegetables, and forage or feed is found by

$$I_{v,lv,mf} = V_{v,lv,mf} \times Q_{v,lv,mf}$$

where

$I_{v,lv,mf}$ = intake of Cd or Hg from fruit, vegetables and grain (v), leafy vegetables (lv), and forage or feed (mf) by well (mg/day)

$Q_{v,lv,mf}$ = consumption value of vegetables (v), leafy vegetables (lv), and forage or feed (mf) by well (kg/day); 1.50, 0.20, and 50.0.

The ingestion value for milk consumption is

$$I_m = Q_m(c\ Q_{mw} + I_{mf})\ B_2$$

where

c = concentration of Cd or Hg in water by well (mg/ℓ)

Q_m = milk consumption (ℓ/day), 0.90

Q_{mw} = water consumed by cow (ℓ/day), 60.0

B_2 = stable element transfer factor for milk [(kg forage or ℓ water/ℓ milk)/(kg forage or ℓ water/day)] Cd = 1.2×10^{-4}, Hg = 3.8×10^{-2}.

The ingestion value for meat (cattle) consumption is given by the equation

$$I_{mt} = Q_{mt}(c\ Q_{mtw} + I_{mf})\ B_3$$

where

I_{mt} = intake of Cd or Hg from meat by well (mg/day)

Q_{mt} = meat consumption (kg/day), 0.30

Q_{mtw} = water consumed by cattle (ℓ/day), 50.0

B_3 = stable element transfer factor for meat [(kg forage or ℓ water/kg meat)/(kg forage or ℓ water/day)] Cd = 5.3×10^{-4}, Hg = 2.6×10^{-1}.

The ingestion value for fish (freshwater) consumption at the 120-mi well is given by the equation

$$I_f = Q_f(c_{120}\ B_4)$$

where

I_f = intake of Cd or Hg from fish at the 120-mi well (mg/day)

Q_f = fish consumption (kg/day), 0.06

c_{120} = concentration in water at the 120-mi well (mg/ℓ); Cd = 3.6×10^{-3}, Hg = 1.2×10^{-4}

B_4 = bioconcentration factor (ℓ/kg); Cd = 3.0, Hg = 10,000.

The values for I_w, I_v, I_{lv}, I_{mf}, I_m, I_{mt}, I_f, and V_v, V_{lv}, and V_{mf} are given in Table A-104.

The total ingestion or intake value for the 0-, 3-, and 10-mi wells is expressed as:

$$I_T = I_w + I_v + I_{lv} + I_m + I_{mt}$$

The 120-mi well adds the I_f (fish) term

$$I_T = I_w + I_v + I_{lv} + I_m + I_{mt} + I_f \quad .$$

The human body will absorb and retain only a fraction of the total amount of cadmium and mercury ingested. Calculated ingestion values would be reduced by about 6% for cadmium and 15% for mercury if retention were accounted for in the ingestion calculations. Estimated ingestion values are given in Table A-105 for cadmium and in Table A-106 for mercury.

In Alternative 1, the groundwater concentrations at the discharge point, 2.1 Cd mg/ℓ and 0.069 Hg mg/ℓ (Tables A-105 and A-106), convert to an estimated ingestion from water and food of 198 mg/day Cd and 34 mg/day Hg. EPA drinking water standards for cadmium and mercury are exceeded at the discharge-point well and cadmium standards are exceeded at the 3-mi well. In Alternative 4, the mercury is removed before disposal; the cadmium concentrations are the same as in Alternative 1.

TABLE A-104

VEGETATION AND INGESTION VALUES
FOR CADMIUM AND MERCURY BY WELL FOR ALTERNATIVES 1 and 4

Well Location (mi)	Concentration							
	Cadium				Mercury			
	0	3	10	120	0	3	10	120
Vegetation (mg/kg)								
$V_{v,lv}$	1.1×10^{2}	6.4×10^{-1}	1.9×10^{-1}	1.9×10^{-1}	4.5	2.6×10^{-2}	7.9×10^{-3}	7.9×10^{-3}
V_{mf}	1.2×10^{2}	7.1×10^{-1}	2.1×10^{-1}	2.1×10^{-1}	5.0	2.8×10^{-2}	8.6×10^{-3}	8.6×10^{-3}
Ingestion (mg/day)								
I_w	4.2	2.4×10^{-2}	7.2×10^{-3}	7.2×10^{-3}	1.4×10^{-1}	7.8×10^{-4}	2.4×10^{-4}	2.4×10^{-4}
I_v	1.7×10^{2}	9.6×10^{-1}	2.9×10^{-1}	2.9×10^{-1}	6.8	3.9×10^{-2}	1.2×10^{-2}	1.2×10^{-2}
I_{lv}	2.2×10^{1}	1.3×10^{-1}	3.8×10^{-2}	3.8×10^{-2}	9.0×10^{-1}	5.2×10^{-3}	1.6×10^{-3}	1.6×10^{-3}
I_{mf}	5.5×10^{3}	3.2×10^{1}	9.5	9.5	2.3×10^{2}	1.3	4.0×10^{-1}	4.0×10^{-1}
I_m	6.1×10^{-1}	3.5×10^{-3}	1.1×10^{-3}	1.1×10^{-3}	8.0	4.5×10^{-2}	1.4×10^{-2}	1.4×10^{-2}
I_{mt}	8.9×10^{-1}	5.2×10^{-3}	1.6×10^{-3}	1.6×10^{-3}	1.8×10^{1}	1.0×10^{-1}	3.2×10^{-2}	3.2×10^{-2}
I_f	NA*	NA	NA	6.5×10^{-4}	NA	NA	NA	7.2×10^{-2}

* Not applicable because fish are not typically raised in water pumped from wells. The parameter is evaluated at the 120-mi well because springs currently discharge at this location.

TABLE A-105

ESTIMATED INGESTION OF CADMIUM FROM HYPOTHETICAL WELLS (mg/day)

Alternative	Discharge Point, 0 mi	3 mi	10 mi	120 mi	Toxic Level[a]
1 and 4					
Food	193.50	1.099	0.331	0.331	
Fish	NA[b]	NA	NA	0.001	
Water	4.14	0.024	0.007	0.007	
Total	197.64[c]	1.120[d]	0.34	0.34	0.50
2 (Pellets)					
Food	25.445	0.145	0.044	0.044	
Fish	NA	NA	NA	0	
Water	0.620	0.003	0.001	0.001	
Total	26.07[c]	0.15	0.05	0.05	0.50
2 (Glass)					
Food	0.006	0	0	0	
Fish	NA	NA	NA	0	
Water	0	0	0	0	
Total	0.01	0.00	0.00	0	0.50

a. Approximate value for cadmium as an oxide (Kjellstrom, 1977; WHO, 1977).

b. Not applicable.

c. Levels not toxic due to human emetic response above 15 mg.

d. Toxic level exceeded.

TABLE A-106

ESTIMATED INGESTION OF MERCURY FROM HYPOTHETICAL WELLS (mg/day)

Alternative	Discharge Point, 0 mi	3 mi	10 mi	120 mi	Toxic Level[a]
1					
Food	33.700	0.189	0.06	0.060	
Fish	NA[b]	NA	NA	0.072	
Water	0.138	0.001	0	0	
Total	33.84	0.19	0.06	0.13	0.30
2 (Pellets)					
Food	5.241	0.030	0.001	0.001	
Fish	NA	NA	NA	0.011	
Water	0.020	0	0	0	
Total	5.26	0.03	0.00	0.01	0.30
2 (Glass)					
Food	0.001	0	0	0	
Fish	NA	NA	NA	0	
Water	0	0	0	0	
Total	0.001	0	0	0	0.30

a. Approximate value for mercury as an oxide (Nordberg and Strangert, 1976; SEG, 1971).

b. NA, not applicable.

Conservative estimates for total intake of Cd and Hg indicate that toxic levels are reached for the discharge-point well and the 3-mi well. The amount of cadmium ingested at the discharge-point well would exceed 15 mg, the level at which emesis occurs. Consequently, the well would not be used as a drinking water supply. Aquifer contamination would persist for a distance of about 5 mi downgradient of the discharge point in an area about 5 mi wide until chemical reactions and dispersion in the aquifer reduced the toxic chemical concentrations to harmless levels.

In Alternative 2 (pellets), the groundwater concentrations at the discharge point, 0.3 Cd mg/ℓ and 0.005 Hg mg/ℓ (Tables A-105 and A-106), also exceed EPA drinking water standards. Total ingestion estimates, 26.1 Cd mg/day and 5.3 Hg mg/day, indicate that lethal levels are reached only at the 0-mi well.

In Alternative 2 (glass), maximum groundwater concentrations, 5.2×10^{-5} Cd mg/ℓ and 1.7×10^{-6} Hg mg/ℓ (Tables A-105 and A-106), do not exceed EPA drinking water standards. Total ingestion does not produce adverse health effects.

A.2.2.2 Repository Releases

A.2.2.2.1 Fault and Flooding

The fault-and-flooding scenario is described in detail for the radiological case in Subsection A.1.8.2.2. The scenario is the same for evaluating the effects of toxic chemicals in the waste. The computations for Cd and Hg are similar to those in the groundwater migration scenario. In the fault-and-flooding scenario, the river is analogous to the aquifer in the waste-migration-into-groundwater scenario. The fault-and-flooding scenario affects Alternatives 3 and 5 which involve waste disposal in a federal geologic repository. This scenario does not affect Alternative 4 because the actinide waste disposed in a repository would not contain nonradiologically toxic chemicals.

The release times for Alternatives 3 and 5 are

Alternative	Release Time (Yr)
3 (Stabilize Calcine)	1
3 (Glass), 5	10,000

Therefore, Alternative 3 (stabilize calcine) is treated as an instantaneous release, and Alternative 3 (glass) and Alternative 5 are treated as long-term releases.

For Alternative 3 (stablize calcine), the fraction of calcine released from the repository is 1.2×10^{-5} with the following variable changes.

Variable	Value
D	100,000 cm
W	27 cm/day

The amount of stabilized calcine entering the river is 2.4×10^{1} kg/day and the resultant concentration is 2.3×10^{-2} mg/ℓ.

For Alternative 3 (glass) and Alternative 5, the fraction leaving the repository is 2.04×10^{7} kg over 10,000 yr. With a river flow of 3.8×10^{12} ℓ/yr for all the alternatives, the river calcine concentration is 5.4×10^{-4} mg/ℓ.

The concentrations of Cd and Hg in the river are given in Table A-107.

The total ingestion values for cadmium and mercury from the fault-and-flooding scenario are given in Table A-108. These values do not exceed the toxic levels for Cd and Hg.

A.2.2.2.2 Solution Mining

The solution mining scenario is described in detail in Subsection A.1.8.2.3 for the radiological case. The scenario is the same for evaluating the effects of toxic chemicals in the waste. The solution mining scenario affects Alternatives 3 and 5 which involve waste disposal in a salt formation at a federal geologic repository. This scenario does not affect Alternative 4 because the actinide waste disposed in a repository would not contain

TABLE A-107

CADMIUM AND MERCURY CONCENTRATIONS IN A RIVER
FAULT AND FLOODING SCENARIO (mg/ℓ)

Alternative	Cadmium	Mercury
3 (Stabilize Calcine)	2.0×10^{-3}	7.0×10^{-5}
3 (Glass) and 5	4.9×10^{-5}	1.6×10^{-6}
Federal Standard*	0.010	0.002

* National Interim Primary Drinking Water Standards (40 CFR 141).

TABLE A-108

ESTIMATED INGESTION OF CADMIUM AND MERCURY
FAULT AND FLOODING SCENARIO (mg/day)

Alternative	Cadmium	Mercury
3 (Stabilize Calcine)		
Food	1.8×10^{-1}	3.7×10^{-2}
Water	4.1×10^{-3}	1.4×10^{-4}
Total	1.8×10^{-1}	3.7×10^{-2}
3 (Glass) and 5		
Food	1.5×10^{-3}	3.7×10^{-4}
Water	9.7×10^{-5}	3.3×10^{-2}
Total	1.6×10^{-3}	8.8×10^{-4}
Toxic Level[a]	0.50	0.30[b]

a. Approximate value for cadmium as an oxide (Kjellstrom, 1977; WHO, 1977).

b. Approximate value for mercury as an oxide (Nordberg and Strangert, 1976; SEG, 1971).

nonradiologically toxic chemicals. Effects would be the same for all waste forms.

The quantity of Cd or Hg ingested as salt is given by the equation

$$I_s = c\ Q_s\ F_s$$

where,

c = concentration of Cd or Hg in calcine (mg/kg), Cd = 0.09, Hg = 0.003

Q_s = consumption rate of salt (kg/day), 4.9×10^{-3}

and

F_s = calcine concentration in salt (kg calcine/kg salt)

$$= \frac{Q_l}{Q_p} = 1.96 \times 10^{-6}$$

where

Q_l = calcine leached by solution mining (kg/yr), 4.7×10^{3}

Q_p = salt produced from solution mining (kg/yr), 2.4×10^{9}.

The daily estimated ingestion rates of Cd and Hg from consumption of table salt are given in Table A-109. Also shown are the values of salt and water consumption combined. This assumes consumption of 2 ℓ of water per day, 1.4×10^{-4} mg/ℓ Cd, and 4.7×10^{-6} mg/ℓ Hg. The values do not exceed toxic levels.

TABLE A-109

ESTIMATED INGESTION OF CADMIUM AND MERCURY
SOLUTION MINING SCENARIO (mg/day)

Alternative	Cadmium	Mercury
3 and 5	2.8×10^{-4}	9.4×10^{-6}
Toxic Level*	0.50[a]	0.30

a. Approximate value for cadmium as an oxide (Kjellstrom, 1977; WHO, 1977).

b. Approximate value for mercury as an oxide (Nordberg and Strangert, 1976; SEG, 1971).

REFERENCES FOR APPENDIX A

Burkholder, H., "Nuclear Waste Partitioning Incentives," in Proceedings of the NRC Workshop on Management of Radioactive Waste: Waste Partitioning as an Alternative, NF-CONF-00, p. 465, 1976.

49 CFR 173.393 (Code of Federal Regulations, Transportation), "General Packaging and Shipping Requirements," 1981.

40 CFR 140 (Code of Federal Regulations, Protection of Environment), "National Interim Primary Drinking Water Standards," 1979.

40 CFR 50 (Code of Federal Regulations, Protection of Environment), "National Secondary Ambient Air Quality Standards," 1978.

49 CFR 173.398 (Code of Federal Regulations, Transportation), "Special Tests," 1977.

DOE (U.S. Department of Energy), "Final Environmental Impact Statement, Management of Commercially Generated Radioactive Waste," DOE/EIS-0046F, 1980.

Dunning, D. E., et al., "Estimates of Internal Dose Equivalent to 22 Target Organs for Radionuclides Occurring in Routine Releases from Nuclear Fuel-Cycle Facilities," Vol. II, NUREG/CR-0150-2, Nuclear Regulatory Commission, 1979.

Engle, R. L., et al., "ISOSHLD, a Computer Code for General Purpose Isotope Shielding Analysis," BNWL-236, Battelle Northwest Laboratories, June, 1966.

EPA (U.S. Environmental Protection Agency), "Ambient Water Quality Criteria: Mercury," Washington, D.C., PB-297 925, 1978.

EPA (U.S. Environmental Protection Agency), "Compilation of Air Pollutant Emission Factors," Third Edition, August, 1977.

ERDA (U.S. Energy Research and Development Administration), "Alternatives for the Long-Term Management of Defense High-Level Radioactive Waste, Idaho Chemical Processing Plant, Idaho Falls, Idaho," ERDA 77-43, September, 1977a.

ERDA (U.S. Energy Research and Development Administration), "Alternatives for the Long-Term Management of Defense High-Level Radioactive Waste, Savannah River Plant, Aiken, South Carolina," ERDA 77-42, 1977b.

ICRP (International Commission on Radiological Protection), Publication 26, "Recommendations of the International Commission on Radiological Protection, Annals of the ICRP," Vol. 1, No. 3, Pergamon Press, Oxford, New York, Frankfort, 1977.

Kjellstrom, T., "Accumulation and Renal Effects of Cadmium in Man," Ph.D. Thesis, Karolinska Inst., Dep. Environ. Hyg., Stockholm, Sweden, 1977.

NASNRC (National Academy of Sciences/National Research Council), "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation," The BEIR III Report, Washington, D.C., 1980.

Nordberg, G. F. and P. Strangert, pp. 18-23, in Effects and Dose-Response of Toxic Metals, Rep. International Meet., arranged by the Sub-Comm. on Tox. Metals, Tokyo, 1976.

NRC (U.S. Nuclear Regulatory Commission), "Calculation of Annual Dose to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I," Regulatory Guide 1.109, October 1977.

NRC (U.S. Nuclear Regulatory Commission), "Methods for Estimating Atmospheric Transport and Dispersion of Gaseous Effluents in Routine Releases from Light-Water-Cooled Reactors," Regulatory Guide 1.111, July, 1977.

Roessler, C. E., et al., "Radioactivity of Lands and Associated Structures," Fourth Semi-Annual Technical Report, University of Florida, Figure 7, 1978.

SEG (Swedish Expert Group), "Methyl Mercury in Fish--Toxicological-Epidemiological Evaluation of Risks, Report from an Expert Group," Nordisk. Hyg Tidsknift. Suppl. 4, 1971.

Start, G. E., Deputy Chief, ARL FRO, "Six-Year Average of Calculated Annual Total Integrated Concentration for ICPP Chimney," May 12, 1978.

Start, G. E. and L. L. Wendell, "Regional Effluent Dispersion Calculations Considering Spatial and Temporal Meteorological Variations," Technical Memorandem ERL ARL-44, National Oceanic and Atmospheric Administration, 1974.

Tanner, A., "Radon Migration in the Ground: A Review," The Natural Radiation Environment, 161-190, 1964.

Turner, D. B., "Workbook of Atmospheric Dispersion Estimates," U.S. Environmental Protection Agency, Revised 1970.

WHO Task Group, "Environmental Health Aspects of Cadmium," World Health Organization, Geneva, 1977.

Yanskey, George R., et al., "Climatography of the National Reactor Testing Station," 100-12048, January, 1966.

APPENDIX B

DETAILED RESULTS OF RADIOLOGICAL CALCULATIONS

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B.0 DETAILED RESULTS OF DOSE CALCULATIONS AND CALCULATION OF NONRADIOLOGICAL EMISSIONS

Appendix B presents the results of the maximum individual and population dose commitment calculations discussed in Appendix A. Data are given for each of the release scenarios evaluated in this report. Scenarios include routine and abnormal events postulated to occur during all waste management implementation phases. Implementation phases include construction, operations and waste shipment, decontamination and decommissioning, and disposal. The scenarios evaluate routine operations, accidents, and abnormal events postulated to occur at both the ICPP site and a federal geologic repository.

B.1 Radiological Effects

Dose commitments and associated health effects for each scenario have been listed in tables which are identified by the scenario title and by the alternative evaluated. Data are presented for the 50-year dose commitment to an individual receiving the maximum possible dose and for the resulting population effects. Radiological effects are found in Section B.1. Nonradiological effects of construction and routine operations and of disposal are presented in Section B.2. The following is a list of the scenarios that have radiological effects.

Operations Phase Releases:

- routine operations,
- routine waste shipment exposure,
- waste shipment accident,
- calcine spill,
- decontamination solution spill, and
- extraction solvent fire during actinide removal.

Disposal Phase Releases at the INEL:

- waste migration into groundwater after bin disintegration,

- aircraft impact that strikes the bins,
- intrusion into the bins by an archaeologist or prospector,
- living at the site and consuming food grown in soil that has been contaminated by prior intrusions,
- living over the bins after containment failure, and
- severe geologic disruption that disperses the waste.

Disposal Phase Releases at the Repository:

- waste canister drop down a mine shaft which ruptures the canister and disperses radioactive waste,
- fault and flooding of the repository which leaches and disperses radioactive waste,
- exploratory drilling which penetrates a waste canister, and
- solution mining at a repository in salt.

The following is a brief explanation of how the data are presented in the tables. Detailed discussion of the calculation procedure is found in Subsection A.1.3. A sample table heading is presented below on which each column is identified by number reading from left to right.

1	2	3	4	5	6	7	8	9	10	11
	50-Year Dose Commitment to Maximum Individual					Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)

Column 1 is the year of exposure evaluated for both the maximum individual and the population effects. Columns 2, 3, 4, and 5 must be multiplied individually by the appropriate weighting factors (see Subsection A.1.3.2). The sum of Columns 2, 3, 4, and 5 multiplied by the appropriate weighting factors equals Column 6. Column 7 multiplied by its weighting factor (see Subsection A.1.3.2) and then multiplied by Column 6 equals Column 8, the whole-body equivalent dose in man-rem. Column 8 multiplied by the cancer risk factors (see in Subsection A.1.4) equals Column 9,

the range of health effects. The two products for each year in this column indicate a range of results, not two separate health effects. Finally, Column 11, population risk, is the product of Column 8 multiplied by Column 10.

B.1.1 Releases at the ICPP

B.1.1.1 Routine Stack Releases

Data for routine stack releases at the ICPP include effects for the implementation of Alternative 2 (pelletization and vitrification), Alternative 3 (stabilization and vitrification), Alternative 4, and Alternative 5 (retrieval delayed 100 years, 300 years, and 500 years).

TABLE B-1

ROUTINE STACK RELEASES AT THE ICPP
ALTERNATIVE 2 - PELLETIZE CALCINE

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
1990.	6.29E-07	2.92E-07	1.01E-06	8.70E-07	3.00E-06	1.990E 05	2.39E-02	1.79E-06 5.49E-06	1.00	2.39E-02
2000.	6.29E-07	2.92E-07	1.01E-06	8.70E-07	3.00E-06	2.340E 05	2.81E-02	2.11E-06 6.46E-06	1.00	2.81E-02
2010.	2.22E-07	1.03E-07	3.56E-07	3.07E-07	1.06E-06	2.690E 05	1.14E-02	8.55E-07 2.62E-06	1.00	1.14E-02
2020.	2.22E-07	1.03E-07	3.56E-07	3.07E-07	1.06E-06	3.030E 05	1.28E-02	9.63E-07 2.95E-06	1.00	1.28E-02

TABLE B-2

ROUTINE STACK RELEASES AT THE ICPP
ALTERNATIVE 2 - VITRIFY CALCINE

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
1990.	6.29E-07	2.92E-07	1.01E-06	8.70E-07	3.00E-06	1.990E 05	2.39E-02	1.79E-06 5.49E-06	1.00	2.39E-02
2000.	6.29E-07	2.92E-07	1.01E-06	8.70E-07	3.00E-06	2.340E 05	2.81E-02	2.11E-06 6.46E-06	1.00	2.81E-02
2010.	2.22E-07	1.03E-07	3.56E-07	3.07E-07	1.06E-06	2.690E 05	1.14E-02	8.55E-07 2.62E-06	1.00	1.14E-02
2020.	2.22E-07	1.03E-07	3.56E-07	3.07E-07	1.06E-06	3.030E 05	1.28E-02	9.63E-07 2.95E-06	1.00	1.28E-02

TABLE B-3

ROUTINE STACK RELEASES AT THE ICPP
ALTERNATIVE 3 - STABILIZE CALCINE

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
1990.	1.83E-09	9.69E-10	5.97E-09	2.20E-09	6.54E-09	1.990E 05	5.21E-05	3.90E-09 1.20E-08	1.00	5.21E-05
2000.	1.83E-09	9.69E-10	5.97E-09	2.20E-09	6.54E-09	2.340E 05	6.12E-05	4.59E-09 1.41E-08	1.00	6.12E-05
2010.	6.12E-10	3.04E-10	1.98E-09	7.29E-10	2.52E-09	2.690E 05	2.71E-05	2.03E-09 6.24E-09	1.00	2.71E-05
2020.	6.12E-10	3.04E-10	1.98E-09	7.29E-10	2.52E-09	3.030E 05	3.05E-05	2.29E-09 7.02E-09	1.00	3.05E-05

TABLE B-4

ROUTINE STACK RELEASES AT THE ICPP
ALTERNATIVE 3 - VITRIFY CALCINE

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
1990.	6.29E-07	2.92E-07	1.01E-06	8.70E-07	3.00E-06	1.990E 05	2.39E-02	1.79E-06 5.49E-06	1.00	2.39E-02
2000.	6.29E-07	2.92E-07	1.01E-06	8.70E-07	3.00E-06	2.340E 05	2.81E-02	2.11E-06 6.46E-06	1.00	2.81E-02
2010.	2.22E-07	1.03E-07	3.56E-07	3.07E-07	1.06E-06	2.690E 05	1.14E-02	8.55E-07 2.62E-06	1.00	1.14E-02
2020.	2.22E-07	1.03E-07	3.56E-07	3.07E-07	1.06E-06	3.030E 05	1.28E-02	9.63E-07 2.95E-06	1.00	1.28E-02

TABLE B-5

ROUTINE STACK RELEASES AT THE ICPP
ALTERNATIVE 4

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
1990.	2.24E-09	1.22E-09	8.25E-09	2.66E-09	7.35E-09	1.990E 05	5.85E-05	4.39E-09 1.35E-08	1.00	5.85E-05
2000.	2.24E-09	1.22E-09	8.25E-09	2.66E-09	7.35E-09	2.340E 05	6.88E-05	5.16E-09 1.58E-08	1.00	6.88E-05
2010.	7.82E-10	3.98E-10	2.95E-09	8.83E-10	3.04E-09	2.690E 05	3.27E-05	2.45E-09 7.52E-09	1.00	3.27E-05
2020.	7.82E-10	3.98E-10	2.95E-09	8.83E-10	3.04E-09	3.030E 05	3.68E-05	2.76E-09 8.47E-09	1.00	3.68E-05

TABLE B-6

ROUTINE STACK RELEASES AT THE ICPP
ALTERNATIVE 5 - RETRIEVAL DELAYED 100 YEARS

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2090.	6.23E-11	4.75E-11	5.17E-10	8.80E-11	1.63E-10	5.460E 05	3.56E-06	2.67E-10 8.19E-10	1.00	3.56E-06
2100.	6.23E-11	4.75E-11	5.17E-10	8.80E-11	1.63E-10	5.810E 05	3.79E-06	2.84E-10 8.71E-10	1.00	3.79E-06
2110.	6.23E-11	4.75E-11	5.17E-10	8.80E-11	1.63E-10	6.150E 05	4.01E-06	3.01E-10 9.22E-10	1.00	4.01E-06
2120.	6.23E-11	4.75E-11	5.17E-10	8.80E-11	1.63E-10	6.500E 05	4.24E-06	3.18E-10 9.75E-10	1.00	4.24E-06

TABLE B-7

ROUTINE STACK RELEASES AT THE ICPP
ALTERNATIVE 5 - RETRIEVAL DELAYED 300 YEARS

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2290.	4.62E-12	7.86E-12	1.01E-10	2.12E-11	8.61E-12	6.500E 05	2.24E-07	1.68E-11 5.15E-11	1.00	2.24E-07
2300.	4.62E-12	7.86E-12	1.01E-10	2.12E-11	8.61E-12	6.500E 05	2.24E-07	1.68E-11 5.15E-11	1.00	2.24E-07
2310.	4.62E-12	7.86E-12	1.01E-10	2.12E-11	8.61E-12	6.500E 05	2.24E-07	1.68E-11 5.15E-11	1.00	2.24E-07
2320.	4.62E-12	7.86E-12	1.01E-10	2.12E-11	8.61E-12	6.500E 05	2.24E-07	1.68E-11 5.15E-11	1.00	2.24E-07

TABLE B-8

ROUTINE STACK RELEASES AT THE ICPP
ALTERNATIVE 5 - RETRIEVAL DELAYED 500 YEARS

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2490.	2.54E-12	3.54E-12	6.00E-11	1.26E-11	4.27E-12	6.500E 05	1.11E-07	8.33E-12 2.55E-11	1.00	1.11E-07
2500.	2.54E-12	3.54E-12	6.00E-11	1.26E-11	4.27E-12	6.500E 05	1.11E-07	8.33E-12 2.55E-11	1.00	1.11E-07
2510.	2.54E-12	3.54E-12	6.00E-11	1.26E-11	4.27E-12	6.500E 05	1.11E-07	8.33E-12 2.55E-11	1.00	1.11E-07
2520.	2.54E-12	3.54E-12	6.00E-11	1.26E-11	4.27E-12	6.500E 05	1.11E-07	8.33E-12 2.55E-11	1.00	1.11E-07

B.1.1.2 Routine Waste Shipment Exposure

Data for routine waste shipment exposure include effects for the implementation of Alternative 3 (stabilization and vitrification), Alternative 4, and Alternative 5 (retrieval delayed 100 years, 300 years, and 500 years).

TABLE B-9

ROUTINE WASTE SHIPMENT EXPOSURE
ALTERNATIVE 3 - STABILIZE CALCINE

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
1990.	NA	NA	NA	NA	1.900E-02	1.250E 05	2.37E 02	1.78E-02 5.46E-02	1.00	2.37E 02
2000.	NA	NA	NA	NA	1.900E-02	1.320E 05	2.51E 02	1.88E-02 5.77E-02	1.00	2.51E 02
2010.	NA	NA	NA	NA	1.900E-02	1.420E 05	2.70E 02	2.02E-02 6.21E-02	1.00	2.70E 02
2020.	NA	NA	NA	NA	1.900E-02	1.500E 05	2.85E 02	2.14E-02 6.55E-02	1.00	2.85E 02

TABLE B-10

ROUTINE WASTE SHIPMENT EXPOSURE
ALTERNATIVE 3 - VITRIFY CALCINE

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
1990.	NA	NA	NA	NA	2.900E-02	1.250E 05	3.62E 02	2.72E-02 8.34E-02	1.00	3.62E 02
2000.	NA	NA	NA	NA	2.900E-02	1.320E 05	3.83E 02	2.87E-02 8.80E-02	1.00	3.83E 02
2010.	NA	NA	NA	NA	2.900E-02	1.420E 05	4.12E 02	3.09E-02 9.47E-02	1.00	4.12E 02
2020.	NA	NA	NA	NA	2.900E-02	1.500E 05	4.35E 02	3.26E-02 1.00E-01	1.00	4.35E 02

TABLE B-11

ROUTINE WASTE SHIPMENT EXPOSURE
ALTERNATIVE 4

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
1990.	NA	NA	NA	NA	1.000E-03	1.250E 05	1.25E 01	9.37E-04 2.87E-03	1.00	1.25E 01
2000.	NA	NA	NA	NA	1.000E-03	1.320E 05	1.32E 01	9.90E-04 3.04E-03	1.00	1.32E 01
2010.	NA	NA	NA	NA	1.000E-03	1.420E 05	1.42E 01	1.06E-03 3.27E-03	1.00	1.42E 01
2020.	NA	NA	NA	NA	1.000E-03	1.500E 05	1.50E 01	1.12E-03 3.45E-03	1.00	1.50E 01

TABLE B-12

ROUTINE WASTE SHIPMENT EXPOSURE
ALTERNATIVE 5 - RETRIEVAL DELAYED 100 YEARS

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2090.	NA	NA	NA	NA	1.400E-02	2.090E 05	2.93E 02	2.19E-02 6.73E-02	1.00	2.93E 02
2100.	NA	NA	NA	NA	1.400E-02	2.170E 05	3.04E 02	2.28E-02 6.99E-02	1.00	3.04E 02
2110.	NA	NA	NA	NA	1.400E-02	2.250E 05	3.15E 02	2.36E-02 7.24E-02	1.00	3.15E 02
2120.	NA	NA	NA	NA	1.400E-02	2.340E 05	3.28E 02	2.46E-02 7.53E-02	1.00	3.28E 02

TABLE B-13

ROUTINE WASTE SHIPMENT EXPOSURE
ALTERNATIVE 5 - RETRIEVAL DELAYED 300 YEARS

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2290.	NA	NA	NA	NA	8.600E-03	2.500E 05	2.15E 02	1.61E-02 4.94E-02	1.00	2.15E 02
2300.	NA	NA	NA	NA	8.600E-03	2.500E 05	2.15E 02	1.61E-02 4.94E-02	1.00	2.15E 02
2310.	NA	NA	NA	NA	8.600E-03	2.500E 05	2.15E 02	1.61E-02 4.94E-02	1.00	2.15E 02
2320.	NA	NA	NA	NA	8.600E-03	2.500E 05	2.15E 02	1.61E-02 4.94E-02	1.00	2.15E 02

TABLE B-14

ROUTINE WASTE SHIPMENT EXPOSURE
ALTERNATIVE 5 - RETRIEVAL DELAYED 500 YEARS

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2490.	NA	NA	NA	NA	2.900E-03	2.500E 05	7.25E 01	5.44E-03 1.67E-02	1.00	7.25E 01
2500.	NA	NA	NA	NA	2.900E-03	2.500E 05	7.25E 01	5.44E-03 1.67E-02	1.00	7.25E 01
2510.	NA	NA	NA	NA	2.900E-03	2.500E 05	7.25E 01	5.44E-03 1.67E-02	1.00	7.25E 01
2520.	NA	NA	NA	NA	2.900E-03	2.500E 05	7.25E 01	5.44E-03 1.67E-02	1.00	7.25E 01

B.1.1.3 Occupational Exposure

Data for occupational exposure include effects for the implementation of Alternative 1, Alternative 2 (pelletization and vitrification), Alternative 3 (stabilization and vitrification), Alternative 4, and Alternative 5 (retrieval delayed 100 years, 300 years, and 500 years).

Occupational exposures are given for waste management workers at the ICPP for routine operations and for decontamination and decommissioning. For Alternatives 3, 4, and 5, data include train crew members who would be exposed to radiation from shipment of waste to a federal repository.

TABLE B-15

OCCUPATIONAL EXPOSURE
ALTERNATIVE 1

Project Phase	Number of Years of Exposure	Number of Workers Exposed	Average Dose/Worker (Rem/Yr)	Whole-Body Dose (Man-Rem)
Operations	0	0	0	0
Decontamination and Decommissioning	2	0	0	0

TABLE B-16

OCCUPATIONAL EXPOSURE
ALTERNATIVE 2 - PELLETIZE CALCINE

Project Phase	Number of Years of Exposure	Number of Workers Exposed	Average Dose/Worker (Rem/Yr)	Whole-Body Dose (Man-Rem)
Operations	10	40	1	400
	20	20	1	400
Decontamination and Decommissioning	2	13	1	25

TABLE B-17

OCCUPATIONAL EXPOSURE
ALTERNATIVE 2 - VITRIFY CALCINE

Project Phase	Number of Years of Exposure	Number of Workers Exposed	Average Dose/Worker (Rem/Yr)	Whole-Body Dose (Man-Rem)
Operations	10	55	1	500
	20	35	1	700
Decontamination and Decommissioning	2	25	1	50

TABLE B-18

OCCUPATIONAL EXPOSURE
ALTERNATIVE 3 - STABILIZE CALCINE

Project Phase	Number of Years of Exposure	Number of Workers Exposed	Average Dose/Worker (Rem/Yr)	Whole-Body Dose (Man-Rem)
Operations	10	45	1	450
	20	25	1	500
Decontamination and Decommissioning	2	25	1	50
Waste Shipment	30	90	0.1	270

TABLE B-19

OCCUPATIONAL EXPOSURE
ALTERNATIVE 3 - VITRIFY CALCINE

Project Phase	Number of Years of Exposure	Number of Workers Exposed	Average Dose/Worker (Rem/Yr)	Whole-Body Dose (Man-Rem)
Operations	10	50	1	500
	20	30	1	600
Decontamination and Decommissioning	2	25	1	50
Waste Shipment	30	90	0.1	270

TABLE B-20

OCCUPATIONAL EXPOSURE
ALTERNATIVE 4

Project Phase	Number of Years of Exposure	Number of Workers Exposed	Average Dose/Worker (Rem/Yr)	Whole-Body Dose (Man-Rem)
Operations	10	100	1	1,000
	20	35	1	700
Decontamination and Decommissioning	2	38	1	75
Waste Shipment	30	90	0.01	27

TABLE B-21

OCCUPATIONAL EXPOSURE
ALTERNATIVE 5 - RETRIEVAL DELAYED 100 YEARS

Project Phase	Number of Years of Exposure	Number of Workers Exposed	Average Dose/Worker (Rem/Yr)	Whole-Body Dose (Man-Rem)
Operations	30	50	0.5	750
Decontamination and Decommissioning	2	30	0.5	30
Waste Shipment	30	90	0.05	135

TABLE B-22

OCCUPATIONAL EXPOSURE
ALTERNATIVE 5 - RETRIEVAL DELAYED 300 YEARS

Project Phase	Number of Years of Exposure	Number of Workers Exposed	Average Dose/Worker (Rem/Yr)	Whole-Body Dose (Man-Rem)
Operations	30	50	0.3	450
Decontamination and Decommissioning	2	30	0.3	18
Waste Shipment	30	90	0.03	81

TABLE B-23

OCCUPATIONAL EXPOSURE
ALTERNATIVE 5 - RETRIEVAL DELAYED 500 YEARS

Project Phase	Number of Years of Exposure	Number of Workers Exposed	Average Dose/Worker (Rem/Yr)	Whole-Body Dose (Man-Rem)
Operations	30	50	0.1	150
Decontamination and Decommissioning	2	30	0.1	6
Waste Shipment	30	90	0.01	27

B.1.1.4 Accidental Releases

B.1.1.4.1 Calcine Spill

Data for accidental releases at the ICPP due to a calcine spill include effects for the implementation of Alternative 2 (pelletization and vitrification), Alternative 3 (stabilization and vitrification), Alternative 4, and Alternative 5 (retrieval delayed 100 years, 300 years, and 500 years).

TABLE B-24

ACCIDENTAL RELEASE AT THE ICPP DUE TO CALCINE SPILL
ALTERNATIVE 2 - PELLETIZE CALCINE

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
1990.	6.95E-10	2.05E-10	3.41E-09	6.49E-10	9.10E-10	7.100E 04	2.58E-06	1.94E-10 5.94E-10	0.200	5.17E-07
2000.	6.95E-10	2.05E-10	3.41E-09	6.49E-10	9.10E-10	8.300E 04	3.02E-06	2.27E-10 6.95E-10	0.200	6.04E-07
2010.	6.95E-10	2.05E-10	3.41E-09	6.49E-10	9.10E-10	9.500E 04	3.46E-06	2.59E-10 7.95E-10	0.200	6.92E-07
2020.	6.95E-10	2.05E-10	3.41E-09	6.49E-10	9.10E-10	1.070E 05	3.89E-06	2.92E-10 8.96E-10	0.200	7.79E-07

TABLE B-25

ACCIDENTAL RELEASE AT THE ICPP DUE TO CALCINE SPILL
ALTERNATIVE 2 - VITRIFY CALCINE

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
1990.	6.95E-10	2.05E-10	3.41E-09	6.49E-10	9.10E-10	7.100E 04	2.58E-06	1.94E-10 5.94E-10	0.200	5.17E-07
2000.	6.95E-10	2.05E-10	3.41E-09	6.49E-10	9.10E-10	8.300E 04	3.02E-06	2.27E-10 6.95E-10	0.200	6.04E-07
2010.	6.95E-10	2.05E-10	3.41E-09	6.49E-10	9.10E-10	9.500E 04	3.46E-06	2.59E-10 7.95E-10	0.200	6.92E-07
2020.	6.95E-10	2.05E-10	3.41E-09	6.49E-10	9.10E-10	1.070E 05	3.89E-06	2.92E-10 8.96E-10	0.200	7.79E-07

TABLE B-26

ACCIDENTAL RELEASE AT THE ICPP DUE TO CALCINE SPILL
ALTERNATIVE 3 - STABILIZE CALCINE

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
1990.	6.95E-10	2.05E-10	3.41E-09	6.49E-10	9.10E-10	7.100E 04	2.58E-06	1.94E-10 5.94E-10	0.200	5.17E-07
2000.	6.95E-10	2.05E-10	3.41E-09	6.49E-10	9.10E-10	8.300E 04	3.02E-06	2.27E-10 6.95E-10	0.200	6.04E-07
2010.	6.95E-10	2.05E-10	3.41E-09	6.49E-10	9.10E-10	9.500E 04	3.46E-06	2.59E-10 7.95E-10	0.200	6.92E-07
2020.	6.95E-10	2.05E-10	3.41E-09	6.49E-10	9.10E-10	1.070E 05	3.89E-06	2.92E-10 8.96E-10	0.200	7.79E-07

TABLE B-27

ACCIDENTAL RELEASE AT THE ICPP DUE TO CALCINE SPILL
ALTERNATIVE 3 - VITRIFY CALCINE

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
1990.	6.95E-10	2.05E-10	3.41E-09	6.49E-10	9.10E-10	7.100E 04	2.58E-06	1.94E-10 5.94E-10	0.200	5.17E-07
2000.	6.95E-10	2.05E-10	3.41E-09	6.49E-10	9.10E-10	8.300E 04	3.02E-06	2.27E-10 6.95E-10	0.200	6.04E-07
2010.	6.95E-10	2.05E-10	3.41E-09	6.49E-10	9.10E-10	9.500E 04	3.46E-06	2.59E-10 7.95E-10	0.200	6.92E-07
2020.	6.95E-10	2.05E-10	3.41E-09	6.49E-10	9.10E-10	1.070E 05	3.89E-06	2.92E-10 8.96E-10	0.200	7.79E-07

TABLE B-28

ACCIDENTAL RELEASE AT THE ICPP DUE TO CALCINE SPILL
ALTERNATIVE 4

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
1990.	6.95E-10	2.05E-10	3.41E-09	6.49E-10	9.10E-10	7.100E 04	2.58E-06	1.94E-10 5.94E-10	0.200	5.17E-07
2000.	6.95E-10	2.05E-10	3.41E-09	6.49E-10	9.10E-10	8.300E 04	3.02E-06	2.27E-10 6.95E-10	0.200	6.04E-07
2010.	6.95E-10	2.05E-10	3.41E-09	6.49E-10	9.10E-10	9.500E 04	3.46E-06	2.59E-10 7.95E-10	0.200	6.92E-07
2020.	6.95E-10	2.05E-10	3.41E-09	6.49E-10	9.10E-10	1.070E 05	3.89E-06	2.92E-10 8.96E-10	0.200	7.79E-07

TABLE B-29

ACCIDENTAL RELEASE AT THE ICPP DUE TO CALCINE SPILL
ALTERNATIVE 5 - RETRIEVAL DELAYED 100 YEARS

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2090.	7.24E-11	1.92E-11	4.85E-10	8.62E-11	8.87E-11	1.930E 05	6.85E-07	5.14E-11 1.57E-10	0.200	1.37E-07
2100.	5.83E-11	1.58E-11	4.07E-10	7.36E-11	7.18E-11	2.060E 05	5.92E-07	4.44E-11 1.36E-10	0.200	1.18E-07
2110.	4.71E-11	1.30E-11	3.45E-10	6.35E-11	5.83E-11	2.180E 05	5.08E-07	3.81E-11 1.17E-10	0.200	1.02E-07
2120.	3.82E-11	1.07E-11	2.96E-10	5.54E-11	4.77E-11	2.300E 05	4.39E-07	3.29E-11 1.01E-10	0.200	8.78E-08

TABLE B-30

ACCIDENTAL RELEASE AT THE ICPP DUE TO CALCINE SPILL
ALTERNATIVE 5 - RETRIEVAL DELAYED 300 YEARS

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2290.	4.06E-12	1.23E-12	8.67E-11	1.84E-11	6.19E-12	2.300E 05	5.69E-08	4.27E-12 1.31E-11	0.200	1.14E-08
2300.	3.86E-12	1.14E-12	8.44E-11	1.79E-11	5.93E-12	2.300E 05	5.46E-08	4.09E-12 1.25E-11	0.200	1.09E-08
2310.	3.69E-12	1.07E-12	8.23E-11	1.74E-11	5.70E-12	2.300E 05	5.24E-08	3.93E-12 1.21E-11	0.200	1.05E-08
2320.	3.55E-12	1.00E-12	8.03E-11	1.70E-11	5.49E-12	2.300E 05	5.05E-08	3.79E-12 1.16E-11	0.200	1.01E-08

TABLE B-31

ACCIDENTAL RELEASE AT THE ICPP DUE TO CALCINE SPILL
ALTERNATIVE 5 - RETRIEVAL DELAYED 500 YEARS

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2490.	2.41E-12	4.96E-13	5.80E-11	1.23E-11	3.74E-12	2.300E 05	3.46E-08	2.59E-12 7.96E-12	0.200	6.92E-09
2500.	2.37E-12	4.82E-13	5.70E-11	1.21E-11	3.69E-12	2.300E 05	3.39E-08	2.55E-12 7.81E-12	0.200	6.79E-09
2510.	2.33E-12	4.69E-13	5.60E-11	1.19E-11	3.63E-12	2.300E 05	3.34E-08	2.50E-12 7.68E-12	0.200	6.68E-09
2520.	2.29E-12	4.56E-13	5.51E-11	1.17E-11	3.57E-12	2.300E 05	3.28E-08	2.46E-12 7.55E-12	0.200	6.57E-09

B.1.1.4.2 Decontamination Solution Spill

Data for accidental releases at the ICPP due to a decontamination solution spill include effects for the implementation of Alternative 2 (pellctization and vitrification), Alternative 3 (stabilization and vitrification), Alternative 4, and Alternative 5 (retrieval delayed 100 years, 300 years, and 500 years).

TABLE B-32

ACCIDENTAL RELEASE AT THE ICPP DUE TO DECONTAMINATION SOLUTION SPILL
ALTERNATIVE 2 - PELLETIZE CALCINE

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
1990.	4.65E-02	1.40E-02	2.29E-01	4.35E-02	6.10E-02	7.100E 04	8.66E 02	6.50E-02 1.99E-01	0.100	8.66E 01
2000.	4.65E-02	1.40E-02	2.29E-01	4.35E-02	6.10E-02	8.300E 04	1.01E 03	7.59E-02 2.33E-01	0.100	1.01E 02
2010.	4.65E-02	1.40E-02	2.29E-01	4.35E-02	6.10E-02	9.500E 04	1.16E 03	8.69E-02 2.67E-01	0.100	1.16E 02
2020.	4.65E-02	1.40E-02	2.29E-01	4.35E-02	6.10E-02	1.070E 05	1.31E 03	9.79E-02 3.00E-01	0.100	1.31E 02

TABLE B-33

ACCIDENTAL RELEASE AT THE ICPP DUE TO DECONTAMINATION SOLUTION SPILL
ALTERNATIVE 2 - VITRIFY CALCINE

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
1990.	4.65E-02	1.40E-02	2.29E-01	4.35E-02	6.10E-02	7.100E 04	8.66E 02	6.50E-02 1.99E-01	0.100	8.66E 01
2000.	4.65E-02	1.40E-02	2.29E-01	4.35E-02	6.10E-02	8.300E 04	1.01E 03	7.59E-02 2.33E-01	0.100	1.01E 02
2010.	4.65E-02	1.40E-02	2.29E-01	4.35E-02	6.10E-02	9.500E 04	1.16E 03	8.69E-02 2.67E-01	0.100	1.16E 02
2020.	4.65E-02	1.40E-02	2.29E-01	4.35E-02	6.10E-02	1.070E 05	1.31E 03	9.79E-02 3.00E-01	0.100	1.31E 02

TABLE B-34

ACCIDENTAL RELEASE AT THE ICPP DUE TO DECONTAMINATION SOLUTION SPILL
ALTERNATIVE 3 - STABILIZE CALCINE

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
1990.	4.65E-02	1.40E-02	2.29E-01	4.35E-02	6.10E-02	7.100E 04	8.66E 02	6.50E-02 1.99E-01	0.100	8.66E 01
2000.	4.65E-02	1.40E-02	2.29E-01	4.35E-02	6.10E-02	8.300E 04	1.01E 03	7.59E-02 2.33E-01	0.100	1.01E 02
2010.	4.65E-02	1.40E-02	2.29E-01	4.35E-02	6.10E-02	9.500E 04	1.16E 03	8.69E-02 2.67E-01	0.100	1.16E 02
2020.	4.65E-02	1.40E-02	2.29E-01	4.35E-02	6.10E-02	1.070E 05	1.31E 03	9.79E-02 3.00E-01	0.100	1.31E 02

TABLE B-35

ACCIDENTAL RELEASE AT THE ICPP DUE TO DECONTAMINATION SOLUTION SPILL
ALTERNATIVE 3 - VITRIFY CALCINE

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
1990.	4.65E-02	1.40E-02	2.29E-01	4.35E-02	6.10E-02	7.100E 04	8.66E 02	6.50E-02 1.99E-01	0.100	8.66E 01
2000.	4.65E-02	1.40E-02	2.29E-01	4.35E-02	6.10E-02	8.300E 04	1.01E 03	7.59E-02 2.33E-01	0.100	1.01E 02
2010.	4.65E-02	1.40E-02	2.29E-01	4.35E-02	6.10E-02	9.500E 04	1.16E 03	8.69E-02 2.67E-01	0.100	1.16E 02
2020.	4.65E-02	1.40E-02	2.29E-01	4.35E-02	6.10E-02	1.070E 05	1.31E 03	9.79E-02 3.00E-01	0.100	1.31E 02

TABLE B-36

ACCIDENTAL RELEASE AT THE ICPP DUE TO DECONTAMINATION SOLUTION SPILL
ALTERNATIVE 4

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
1990.	4.65E-02	1.40E-02	2.29E-01	4.35E-02	6.10E-02	7.100E 04	8.66E 02	6.50E-02 1.99E-01	0.100	8.66E 01
2000.	4.65E-02	1.40E-02	2.29E-01	4.35E-02	6.10E-02	8.300E 04	1.01E 03	7.59E-02 2.33E-01	0.100	1.01E 02
2010.	4.65E-02	1.40E-02	2.29E-01	4.35E-02	6.10E-02	9.500E 04	1.16E 03	8.69E-02 2.67E-01	0.100	1.16E 02
2020.	4.65E-02	1.40E-02	2.29E-01	4.35E-02	6.10E-02	1.070E 05	1.31E 03	9.79E-02 3.00E-01	0.100	1.31E 02

TABLE B-37

ACCIDENTAL RELEASE AT THE ICPP DUE TO DECONTAMINATION SOLUTION SPILL
ALTERNATIVE 5 - RETRIEVAL DELAYED 100 YEARS

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2090.	4.85E-03	1.35E-03	3.26E-02	5.81E-03	5.95E-03	1.930E 05	2.30E 02	1.72E-02 5.28E-02	0.100	2.30E 01
2100.	3.91E-03	1.11E-03	2.74E-02	4.97E-03	4.82E-03	2.060E 05	1.99E 02	1.49E-02 4.57E-02	0.100	1.99E 01
2110.	3.16E-03	9.15E-04	2.33E-02	4.29E-03	3.92E-03	2.180E 05	1.71E 02	1.28E-02 3.93E-02	0.100	1.71E 01
2120.	2.56E-03	7.60E-04	2.00E-02	3.74E-03	3.21E-03	2.300E 05	1.48E 02	1.11E-02 3.40E-02	0.100	1.48E 01

TABLE B-38

ACCIDENTAL RELEASE AT THE ICPP DUE TO DECONTAMINATION SOLUTION SPILL
ALTERNATIVE 5 - RETRIEVAL DELAYED 300 YEARS

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2290.	2.74E-04	9.40E-05	5.67E-03	1.24E-03	4.20E-04	2.300E 05	1.93E 01	1.45E-03 4.44E-03	0.100	1.93E 00
2300.	2.61E-04	8.78E-05	5.71E-03	1.21E-03	4.02E-04	2.300E 05	1.85E 01	1.39E-03 4.25E-03	0.100	1.85E 00
2310.	2.50E-04	8.24E-05	5.57E-03	1.18E-03	3.86E-04	2.300E 05	1.78E 01	1.33E-03 4.08E-03	0.100	1.78E 00
2320.	2.40E-04	7.75E-05	5.43E-03	1.15E-03	3.73E-04	2.300E 05	1.72E 01	1.29E-03 3.95E-03	0.100	1.72E 00

TABLE B-39

ACCIDENTAL RELEASE AT THE ICPP DUE TO DECONTAMINATION SOLUTION SPILL
ALTERNATIVE 5 - RETRIEVAL DELAYED 500 YEARS

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2490.	1.63E-04	3.87E-05	3.91E-03	8.29E-04	2.54E-04	2.300E 05	1.17E 01	8.76E-04 2.69E-03	0.100	1.17E 00
2500.	1.60E-04	3.76E-05	3.85E-03	8.15E-04	2.50E-04	2.300E 05	1.15E 01	8.62E-04 2.64E-03	0.100	1.15E 00
2510.	1.57E-04	3.66E-05	3.78E-03	8.02E-04	2.45E-04	2.300E 05	1.13E 01	8.45E-04 2.59E-03	0.100	1.13E 00
2520.	1.55E-04	3.56E-05	3.72E-03	7.88E-04	2.41E-04	2.300E 05	1.11E 01	8.31E-04 2.55E-03	0.100	1.11E 00

B.1.1.4.3 Extraction Solvent Fire

Data for accidental releases at the ICPP due to an extraction solvent fire include only the effects from implementation of Alternative 4.

TABLE B-40

ACCIDENTAL RELEASE AT THE ICPP DUE TO EXTRACTION SOLVENT FIRE
ALTERNATIVE 4

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
1990.	8.31E-08	1.57E-08	2.70E-07	9.53E-08	2.41E-07	7.100E 04	6.84E-04	5.13E-08 1.57E-07	1.000E-02	6.84E-06
2000.	8.31E-08	1.57E-08	2.70E-07	9.53E-08	2.41E-07	8.300E 04	8.00E-04	6.00E-08 1.84E-07	1.000E-02	8.00E-06
2010.	8.31E-08	1.57E-08	2.70E-07	9.53E-08	2.41E-07	9.500E 04	9.16E-04	6.87E-08 2.11E-07	1.000E-02	9.16E-06
2020.	8.31E-08	1.57E-08	2.70E-07	9.53E-08	2.41E-07	1.070E 05	1.03E-03	7.74E-08 2.37E-07	1.000E-02	1.03E-05

B.1.1.4.4 Waste Shipment Accident

Data for releases due to a waste shipment accident include effects from the implementation of alternatives that involve offsite shipment to a federal repository. These alternatives are Alternative 3 (stabilization and vitrification), Alternative 4, and Alternative 5 (retrieval delayed 100 years, 300 years, and 500 years).

TABLE B-41

RELEASE DUE TO WASTE SHIPMENT ACCIDENT
ALTERNATIVE 3 - STABILIZE CALCINE

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
1990-2000	3.31E 00	4.46E 01	6.13E 01	1.34E 01	9.78E 00	500.	4.89E 03	3.67E-01 1.12E 00	2.000E-05	9.78E-02
2010-2020	3.31E 00	4.46E 01	6.13E 01	1.34E 01	9.78E 00	500.	4.89E 03	3.67E-01 1.12E 00	3.000E-06	1.47E-02

TABLE B-42

RELEASE DUE TO WASTE SHIPMENT ACCIDENT
ALTERNATIVE 3 - VITRIFY CALCINE

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
1990-2000	4.31E-02	5.81E-01	7.98E-01	1.74E-01	1.27E-01	500.	6.35E 01	4.76E-03 1.46E-02	3.000E-05	1.90E-03
2010-2020	4.31E-02	5.81E-01	7.98E-01	1.74E-01	1.27E-01	500.	6.35E 01	4.76E-03 1.46E-02	5.000E-06	3.17E-04

TABLE B-43

RELEASE DUE TO WASTE SHIPMENT ACCIDENT
ALTERNATIVE 4

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
1990-2000	5.05E 00	2.14E 01	1.18E 02	2.51E 01	1.00E 01	500.	5.00E 03	3.75E-01 1.15E 00	7.000E-08	3.50E-04
2010-2020	5.05E 00	2.14E 01	1.18E 02	2.51E 01	1.00E 01	500.	5.00E 03	3.75E-01 1.15E 00	2.000E-08	1.00E-04

TABLE B-44

RELEASE DUE TO WASTE SHIPMENT ACCIDENT
ALTERNATIVE 5 - RETRIEVAL DELAYED 100 YEARS

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2090.	1.90E-02	1.13E-01	4.24E-01	9.03E-02	4.11E-02	500.	2.05E 01	1.54E-03 4.73E-03	3.000E-05	6.16E-04
2100.	1.77E-02	1.00E-01	3.97E-01	8.45E-02	3.77E-02	500.	1.88E 01	1.41E-03 4.34E-03	3.000E-05	5.65E-04
2110.	1.65E-02	8.96E-02	3.72E-01	7.92E-02	3.47E-02	500.	1.73E 01	1.30E-03 3.99E-03	3.000E-05	5.20E-04
2120.	1.54E-02	8.04E-02	3.49E-01	7.42E-02	3.20E-02	500.	1.60E 01	1.20E-03 3.68E-03	3.000E-05	4.80E-04

TABLE B-45

RELEASE DUE TO WASTE SHIPMENT ACCIDENT
ALTERNATIVE 5 - RETRIEVAL DELAYED 300 YEARS

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2290.	5.88E-03	2.34E-02	1.36E-01	2.85E-02	1.14E-02	500.	5.70E 00	4.27E-04 1.31E-03	3.000E-05	1.71E-04
2300.	5.62E-03	2.22E-02	1.30E-01	2.72E-02	1.09E-02	500.	5.45E 00	4.09E-04 1.25E-03	3.000E-05	1.63E-04
2310.	5.37E-03	2.11E-02	1.24E-01	2.60E-02	1.04E-02	500.	5.20E 00	3.90E-04 1.20E-03	3.000E-05	1.56E-04
2320.	5.14E-03	2.01E-02	1.19E-01	2.49E-02	9.91E-03	500.	4.95E 00	3.72E-04 1.14E-03	3.000E-05	1.49E-04

TABLE B-46

RELEASE DUE TO WASTE SHIPMENT ACCIDENT
ALTERNATIVE 5 - RETRIEVAL DELAYED 500 YEARS

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2490.	2.90E-03	1.07E-02	6.68E-02	1.38E-02	5.47E-03	500.	2.73E 00	2.05E-04 6.29E-04	3.000E-05	8.20E-05
2500.	2.82E-03	1.04E-02	6.51E-02	1.35E-02	5.33E-03	500.	2.66E 00	2.00E-04 6.13E-04	3.000E-05	7.99E-05
2510.	2.76E-03	1.01E-02	6.35E-02	1.31E-02	5.20E-03	500.	2.60E 00	1.95E-04 5.98E-04	3.000E-05	7.80E-05
2520.	2.69E-03	9.84E-03	6.20E-02	1.28E-02	5.07E-03	500.	2.53E 00	1.90E-04 5.83E-04	3.000E-05	7.60E-05

B.1.1.5 Migrational Releases

B.1.1.5.1 Living Over the Waste

Data for effects resulting from migrational releases at the ICPP to future generations living over the waste include effects for the implementation of Alternative 1, Alternative 2 (pelletization and vitrification), and Alternative 4. The effects evaluated are from radon emanation and the buildup of radon daughter products should waste containment fail.

TABLE B-47

LIVING OVER THE WASTE
ALTERNATIVE

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2500.	0.0	9.20E-01	0.0	0.0	1.10E-01	5.00	5.50E-01	4.12E-05 1.26E-04	1.000E-02	5.50E-03
3000.	0.0	1.90E 00	0.0	0.0	2.20E-01	5.00	1.10E 00	8.25E-05 2.53E-04	1.000E-02	1.10E-02
4000.	0.0	3.50E 00	0.0	0.0	4.20E-01	5.00	2.10E 00	1.57E-04 4.83E-04	1.000E-02	2.10E-02
7000.	0.0	7.10E 00	0.0	0.0	8.50E-01	5.00	4.25E 00	3.19E-04 9.77E-04	1.000E-02	4.25E-02
12000.	0.0	1.10E 01	0.0	0.0	1.30E 00	5.00	6.50E 00	4.87E-04 1.49E-03	1.000E-02	6.50E-02
22000.	0.0	1.60E 01	0.0	0.0	1.90E 00	5.00	9.50E 00	7.12E-04 2.18E-03	1.000E-02	9.50E-02
52000.	0.0	2.30E 01	0.0	0.0	2.80E 00	5.00	1.40E 01	1.05E-03 3.22E-03	1.000E-02	1.40E-01
102000.	0.0	2.80E 01	0.0	0.0	3.40E 00	5.00	1.70E 01	1.27E-03 3.91E-03	1.000E-02	1.70E-01
202000.	0.0	3.10E 01	0.0	0.0	3.70E 00	5.00	1.85E 01	1.39E-03 4.25E-03	1.000E-02	1.85E-01
502000.	0.0	2.40E 01	0.0	0.0	2.90E 00	5.00	1.45E 01	1.09E-03 3.33E-03	1.000E-02	1.45E-01
1002000.	0.0	1.30E 01	0.0	0.0	1.50E 00	5.00	7.50E 00	5.62E-04 1.72E-03	1.000E-02	7.50E-02

TABLE B-48

LIVING OVER THE WASTE
ALTERNATIVE 2 - PELLETIZE CALCINE

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2500.	0.0	7.60E-01	0.0	0.0	9.20E-02	5.00	4.60E-01	3.45E-05 1.06E-04	1.000E-02	4.60E-03
3000.	0.0	1.50E 00	0.0	0.0	1.90E-01	5.00	9.50E-01	7.12E-05 2.18E-04	1.000E-02	9.50E-03
4000.	0.0	2.90E 00	0.0	0.0	3.50E-01	5.00	1.75E 00	1.31E-04 4.02E-04	1.000E-02	1.75E-02
7000.	0.0	5.90E 00	0.0	0.0	7.10E-01	5.00	3.55E 00	2.66E-04 8.16E-04	1.000E-02	3.55E-02
12000.	0.0	9.20E 00	0.0	0.0	1.10E 00	5.00	5.50E 00	4.12E-04 1.26E-03	1.000E-02	5.50E-02
22000.	0.0	1.30E 01	0.0	0.0	1.60E 00	5.00	8.00E 00	6.00E-04 1.84E-03	1.000E-02	8.00E-02
52000.	0.0	1.90E 01	0.0	0.0	2.30E 00	5.00	1.15E 01	8.62E-04 2.64E-03	1.000E-02	1.15E-01
102000.	0.0	2.40E 01	0.0	0.0	2.80E 00	5.00	1.40E 01	1.05E-03 3.22E-03	1.000E-02	1.40E-01
202000.	0.0	2.60E 01	0.0	0.0	3.10E 00	5.00	1.55E 01	1.16E-03 3.56E-03	1.000E-02	1.55E-01
502000.	0.0	2.00E 01	0.0	0.0	2.40E 00	5.00	1.20E 01	9.00E-04 2.76E-03	1.000E-02	1.20E-01
1002000.	0.0	1.10E 01	0.0	0.0	1.30E 00	5.00	6.50E 00	4.87E-04 1.49E-03	1.000E-02	6.50E-02

TABLE B-49

LIVING OVER THE WASTE
ALTERNATIVE 2 - VITRIFY CALCINE

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2500.	0.0	1.30E-01	0.0	0.0	1.50E-02	5.00	7.50E-02	5.62E-06 1.72E-05	1.000E-02	7.50E-04
3000.	0.0	2.60E-01	0.0	0.0	3.10E-02	5.00	1.55E-01	1.16E-05 3.56E-05	1.000E-02	1.55E-03
4000.	0.0	4.80E-01	0.0	0.0	5.70E-02	5.00	2.85E-01	2.14E-05 6.55E-05	1.000E-02	2.85E-03
7000.	0.0	9.80E-01	0.0	0.0	1.20E-01	5.00	6.00E-01	4.50E-05 1.38E-04	1.000E-02	6.00E-03
12000.	0.0	1.50E 00	0.0	0.0	1.80E-01	5.00	9.00E-01	6.75E-05 2.07E-04	1.000E-02	9.00E-03
22000.	0.0	2.20E 00	0.0	0.0	2.60E-01	5.00	1.30E 00	9.75E-05 2.99E-04	1.000E-02	1.30E-02
52000.	0.0	3.20E 00	0.0	0.0	3.80E-01	5.00	1.90E 00	1.42E-04 4.37E-04	1.000E-02	1.90E-02
102000.	0.0	3.90E 00	0.0	0.0	4.70E-01	5.00	2.35E 00	1.76E-04 5.40E-04	1.000E-02	2.35E-02
202000.	0.0	4.20E 00	0.0	0.0	5.10E-01	5.00	2.55E 00	1.91E-04 5.86E-04	1.000E-02	2.55E-02
502000.	0.0	3.30E 00	0.0	0.0	4.00E-01	5.00	2.00E 00	1.50E-04 4.60E-04	1.000E-02	2.00E-02
1002000.	0.0	1.80E 00	0.0	0.0	2.10E 00	5.00	1.05E 01	7.87E-04 2.41E-03	1.000E-02	1.05E-01

TABLE B-50

LIVING OVER THE WASTE
ALTERNATIVE 4

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2500.	0.0	1.80E-02	0.0	0.0	2.20E-03	5.00	1.10E-02	8.25E-07 2.53E-06	1.000E-02	1.10E-04
3000.	0.0	3.70E-02	0.0	0.0	4.40E-03	5.00	2.20E-02	1.65E-06 5.06E-06	1.000E-02	2.20E-04
4000.	0.0	6.90E-02	0.0	0.0	8.30E-03	5.00	4.15E-02	3.11E-06 9.54E-06	1.000E-02	4.15E-04
7000.	0.0	1.40E-01	0.0	0.0	1.70E-02	5.00	8.50E-02	6.37E-06 1.95E-05	1.000E-02	8.50E-04
12000.	0.0	2.20E-01	0.0	0.0	2.60E-02	5.00	1.30E-01	9.75E-06 2.99E-05	1.000E-02	1.30E-03
22000.	0.0	3.10E-01	0.0	0.0	3.80E-02	5.00	1.90E-01	1.42E-05 4.37E-05	1.000E-02	1.90E-03
52000.	0.0	4.60E-01	0.0	0.0	5.50E-02	5.00	2.75E-01	2.06E-05 6.32E-05	1.000E-02	2.75E-03
102000.	0.0	5.60E-01	0.0	0.0	6.80E-02	5.00	3.40E-01	2.55E-05 7.82E-05	1.000E-02	3.40E-03
202000.	0.0	6.10E-01	0.0	0.0	7.30E-02	5.00	3.65E-01	2.74E-05 8.39E-05	1.000E-02	3.65E-03
502000.	0.0	4.80E-01	0.0	0.0	5.80E-02	5.00	2.90E-01	2.17E-05 6.67E-05	1.000E-02	2.90E-03
1002000.	0.0	2.60E-01	0.0	0.0	3.10E-02	5.00	1.55E-01	1.16E-05 3.56E-05	1.000E-02	1.55E-03

B.1.1.5.2 Waste Migration Into Groundwater

Data for migrational releases at the ICPP as the result of waste migration into groundwater include effects for the implementation of Alternative 1 (0-, 3-, 10-, and 120-mile wells), Alternative 2 (pelletization, 0-, 3-, 10-, and 120-mile wells, and vitrification, 0-, 3-, 10-, and 120-mile wells), and Alternative 4 (0-, 3-, 10-, and 120-mile wells).

TABLE B-51

WASTE MIGRATION INTO GROUNDWATER
ALTERNATIVE 1
0-MILE WELL

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2500.	2.42E 01	0.00E-01	4.64E 01	7.11E 01	1.09E 02	5.00	5.45E 02	4.09E-02 1.25E-01	1.000E-06	5.45E-04
3600.	4.91E-11	7.42E-18	4.44E-10	2.95E-12	5.64E-11	5.00	2.82E-10	2.11E-14 6.49E-14	1.000E-06	2.82E-16
13500.	1.76E-01	0.00E-01	3.45E-01	2.97E-01	2.45E-01	5.00	1.22E 00	9.19E-05 2.82E-04	1.000E-06	1.22E-06
24500.	5.32E 01	1.60E-02	3.29E 02	4.12E 01	3.33E 01	5.00	1.66E 02	1.25E-02 3.83E-02	1.000E-06	1.66E-04

TABLE B-52

WASTE MIGRATION INTO GROUNDWATER
ALTERNATIVE 1
3-MILE WELL

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2500.	1.40E-01	0.00E-01	2.68E-01	4.11E-01	6.30E-01	5.00	3.15E 00	2.36E-04 7.24E-04	1.000E-06	3.15E-06
3600.	2.84E-13	4.29E-20	2.57E-12	1.71E-14	3.26E-13	5.00	1.63E-12	1.22E-16 3.75E-16	1.000E-06	1.63E-18
13500.	1.02E-03	0.00E-01	1.99E-03	1.72E-03	1.42E-03	5.00	7.10E-03	5.32E-07 1.63E-06	1.000E-06	7.10E-09
24500.	3.08E-01	9.25E-05	1.90E 00	2.38E-01	1.92E-01	5.00	9.60E-01	7.20E-05 2.21E-04	1.000E-06	9.60E-07

TABLE B-53

WASTE MIGRATION INTO GROUNDWATER
ALTERNATIVE 1
10-MILE WELL

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2500.	4.21E-02	0.00E-01	8.07E-02	1.24E-01	1.90E-01	100.	1.90E 01	1.42E-03 4.37E-03	1.000E-06	1.90E-05
3600.	8.54E-14	1.29E-20	7.72E-13	5.13E-15	9.81E-14	100.	9.81E-12	7.36E-16 2.26E-15	1.000E-06	9.81E-18
13500.	3.06E-04	0.00E-01	6.00E-04	5.17E-04	4.26E-04	100.	4.26E-02	3.19E-06 9.80E-06	1.000E-06	4.26E-08
24500.	9.25E-02	2.78E-05	5.72E-01	7.17E-02	5.79E-02	100.	5.79E 00	4.34E-04 1.33E-03	1.000E-06	5.79E-06

TABLE B-54

WASTE MIGRATION INTO GROUNDWATER
ALTERNATIVE 1
120-MILE WELL

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2500.	4.21E-02	0.00E-01	8.07E-02	1.24E-01	1.90E-01	5.000E 03	9.50E 02	7.12E-02 2.18E-01	1.000E-06	9.50E-04
3600.	8.54E-14	1.29E-20	7.72E-13	5.13E-13	9.81E-14	5.000E 03	4.90E-10	3.68E-14 1.13E-13	1.000E-06	4.90E-16
13500.	3.06E-04	0.00E-01	6.00E-04	5.17E-04	4.26E-04	5.000E 03	2.13E 00	1.60E-04 4.90E-04	1.000E-06	2.13E-06
24500.	9.25E-02	2.78E-05	5.72E-01	7.17E-02	5.79E-02	5.000E 03	2.89E 02	2.17E-02 6.66E-02	1.000E-06	2.89E-04

TABLE B-55

WASTE MIGRATION INTO GROUNDWATER
ALTERNATIVE 2 - PELLETIZE CALCINE
0-MILE WELL

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2500.	2.42E-01	0.00E-01	4.64E-01	7.11E-01	1.09E 00	5.00	5.45E 00	4.09E-04 1.25E-03	1.000E-06	5.45E-06
3000.	2.42E-01	0.00E-01	4.64E-01	7.10E-01	1.09E 00	5.00	5.45E 00	4.09E-04 1.25E-03	1.000E-06	5.45E-06
3600.	2.42E-01	5.28E-20	4.63E-01	7.09E-01	1.09E 00	5.00	5.45E 00	4.09E-04 1.25E-03	1.000E-06	5.45E-06
4000.	2.41E-01	3.48E-24	4.62E-01	7.08E-01	1.08E 00	5.00	5.40E 00	4.05E-04 1.24E-03	1.000E-06	5.40E-06
4700.	2.41E-01	1.68E-31	4.61E-01	7.06E-01	1.08E 00	5.00	5.40E 00	4.05E-04 1.24E-03	1.000E-06	5.40E-06
7000.	2.39E-01	0.00E-01	4.58E-01	7.01E-01	1.07E 00	5.00	5.35E 00	4.01E-04 1.23E-03	1.000E-06	5.35E-06
12000.	2.35E-01	0.00E-01	4.50E-01	6.90E-01	1.06E 00	5.00	5.30E 00	3.97E-04 1.22E-03	1.000E-06	5.30E-06
13500.	1.25E-02	0.00E-01	2.45E-02	2.11E-02	1.74E-02	5.00	8.70E-02	6.52E-06 2.00E-05	1.000E-06	8.70E-08
22000.	1.24E-02	0.00E-01	2.44E-02	2.11E-02	1.73E-02	5.00	8.65E-02	6.49E-06 1.99E-05	1.000E-06	8.65E-08
24500.	7.55E 00	2.26E-03	4.67E 01	5.85E 00	4.73E 00	5.00	2.36E 01	1.77E-03 5.44E-03	1.000E-06	2.36E-05

TABLE B-56

WASTE MIGRATION INTO GROUNDWATER
ALTERNATIVE 2 - PELLETIZE CALCINE
3-MILE WELL

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2500.	1.40E-03	0.00E-01	2.68E-03	4.11E-03	6.30E-03	5.00	3.15E-02	2.36E-06 7.24E-06	1.000E-06	3.15E-08
3000.	1.40E-03	0.00E-01	2.68E-03	4.10E-03	6.30E-03	5.00	3.15E-02	2.36E-06 7.24E-06	1.000E-06	3.15E-08
3600.	1.40E-03	3.05E-22	2.68E-03	4.10E-03	6.30E-03	5.00	3.15E-02	2.36E-06 7.24E-06	1.000E-06	3.15E-08
4000.	1.39E-03	2.01E-26	2.67E-03	4.09E-03	6.24E-03	5.00	3.12E-02	2.34E-06 7.18E-06	1.000E-06	3.12E-08
4700.	1.39E-03	9.71E-34	2.66E-03	4.08E-03	6.24E-03	5.00	3.12E-02	2.34E-06 7.18E-06	1.000E-06	3.12E-08
7000.	1.38E-03	0.00E-01	2.65E-03	4.05E-03	6.18E-03	5.00	3.09E-02	2.32E-06 7.11E-06	1.000E-06	3.09E-08
12000.	1.36E-03	0.00E-01	2.60E-03	3.99E-03	6.13E-03	5.00	3.06E-02	2.30E-06 7.05E-06	1.000E-06	3.06E-08
13500.	7.23E-05	0.00E-01	1.42E-04	1.22E-04	1.01E-04	5.00	5.05E-04	3.79E-08 1.16E-07	1.000E-06	5.05E-10
22000.	7.17E-05	0.00E-01	1.41E-04	1.22E-04	1.00E-04	5.00	5.00E-04	3.75E-08 1.15E-07	1.000E-06	5.00E-10
24500.	4.36E-02	1.31E-05	2.70E-01	3.38E-02	2.73E-02	5.00	1.36E-01	1.02E-05 3.14E-05	1.000E-06	1.36E-07

TABLE B-57

WASTE MIGRATION INTO GROUNDWATER
ALTERNATIVE 2 - PELLETIZE CALCINE
10-MILE WELL

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2500.	4.21E-04	0.00E-01	8.07E-04	1.24E-03	1.90E-03	100.	1.90E-01	1.42E-05 4.37E-05	1.000E-06	1.90E-07
3000.	4.21E-04	0.00E-01	8.07E-04	1.23E-03	1.90E-03	100.	1.90E-01	1.42E-05 4.37E-05	1.000E-06	1.90E-07
3600.	4.21E-04	9.18E-23	8.05E-04	1.23E-03	1.90E-03	100.	1.90E-01	1.42E-05 4.37E-05	1.000E-06	1.90E-07
4000.	4.19E-04	6.05E-27	8.03E-04	1.23E-03	1.88E-03	100.	1.88E-01	1.41E-05 4.32E-05	1.000E-06	1.88E-07
4700.	4.19E-04	2.92E-34	8.03E-04	1.23E-03	1.88E-03	100.	1.88E-01	1.41E-05 4.32E-05	1.000E-06	1.88E-07
7000.	4.16E-04	0.00E-01	7.97E-04	1.22E-03	1.86E-03	100.	1.86E-01	1.39E-05 4.28E-05	1.000E-06	1.86E-07
12000.	4.09E-04	0.00E-01	7.85E-04	1.20E-03	1.84E-03	100.	1.84E-01	1.38E-05 4.23E-05	1.000E-06	1.84E-07
13500.	2.17E-05	0.00E-01	4.25E-05	3.67E-05	3.03E-05	100.	3.03E-03	2.27E-07 6.97E-07	1.000E-06	3.03E-09
22000.	2.16E-05	0.00E-01	4.24E-05	3.67E-05	3.01E-05	100.	3.01E-03	2.26E-07 6.92E-07	1.000E-06	3.01E-09
24500.	1.31E-02	3.93E-06	8.12E-02	1.02E-02	8.23E-03	100.	8.23E-01	6.17E-05 1.89E-04	1.000E-06	8.23E-07

TABLE B-58

WASTE MIGRATION INTO GROUNDWATER
ALTERNATIVE 2 - PELLETIZE CALCINE
120-MILE WELL

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2500.	4.21E-04	0.00E-01	8.07E-04	1.24E-03	1.90E-03	5.000E 03	9.50E 00	7.12E-04 2.18E-03	1.000E-06	9.50E-06
3000.	4.21E-04	0.00E-01	8.07E-04	1.23E-03	1.90E-03	5.000E 03	9.50E 00	7.12E-04 2.18E-03	1.000E-06	9.50E-06
3600.	4.21E-04	9.18E-23	8.05E-04	1.23E-03	1.90E-03	5.000E 03	9.50E 00	7.12E-04 2.18E-03	1.000E-06	9.50E-06
4000.	4.19E-04	6.05E-27	8.03E-04	1.23E-03	1.88E-03	5.000E 03	9.40E 00	7.05E-04 2.16E-03	1.000E-06	9.40E-06
4700.	4.19E-04	2.92E-34	8.02E-04	1.23E-03	1.88E-03	5.000E 03	9.40E 00	7.05E-04 2.16E-03	1.000E-06	9.40E-06
7000.	4.16E-04	0.00E-01	7.97E-04	1.22E-03	1.86E-03	5.000E 03	9.30E 00	6.97E-04 2.14E-03	1.000E-06	9.30E-06
12000.	4.09E-04	0.00E-01	7.83E-04	1.20E-03	1.84E-03	5.000E 03	9.20E 00	6.90E-04 2.12E-03	1.000E-06	9.20E-06
13500.	2.17E-05	0.00E-01	4.26E-05	3.67E-05	3.03E-05	5.000E 03	1.51E-01	1.14E-05 3.48E-05	1.000E-06	1.51E-07
22000.	2.16E-05	0.00E-01	4.24E-05	3.67E-05	3.01E-05	5.000E 03	1.50E-01	1.13E-05 3.46E-05	1.000E-06	1.50E-07
24500.	1.31E-02	3.93E-06	8.12E-02	1.02E-02	8.23E-03	5.000E 03	4.11E 01	3.09E-03 9.46E-03	1.000E-06	4.11E-05

TABLE B-59

WASTE MIGRATION INTO GROUNDWATER
ALTERNATIVE 2 - VITRIFY CALCINE
0-MILE WELL

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2500.	5.37E-05	0.00E-01	1.03E-04	1.58E-04	2.41E-04	5.00	1.20E-03	9.04E-08 2.77E-07	1.000E-06	1.20E-09
3000.	5.36E-05	0.00E-01	1.03E-04	1.57E-04	2.41E-04	5.00	1.20E-03	9.04E-08 2.77E-07	1.000E-06	1.20E-09
3600.	5.35E-05	1.17E-23	1.02E-04	1.57E-04	2.41E-04	5.00	1.20E-03	9.04E-08 2.77E-07	1.000E-06	1.20E-09
4000.	5.34E-05	7.71E-28	1.02E-04	1.57E-04	2.40E-04	5.00	1.20E-03	9.00E-08 2.76E-07	1.000E-06	1.20E-09
4700.	5.33E-05	3.72E-35	1.02E-04	1.56E-04	2.40E-04	5.00	1.20E-03	9.00E-08 2.76E-07	1.000E-06	1.20E-09
7000.	5.29E-05	0.00E-01	1.01E-04	1.55E-04	2.38E-04	5.00	1.19E-03	8.92E-08 2.74E-07	1.000E-06	1.19E-09
12000.	5.21E-05	0.00E-01	9.97E-05	1.53E-04	2.34E-04	5.00	1.17E-03	8.77E-08 2.69E-07	1.000E-06	1.17E-09
13500.	5.46E-05	0.00E-01	1.05E-04	1.57E-04	2.36E-04	5.00	1.18E-03	8.85E-08 2.71E-07	1.000E-06	1.18E-09
22000.	5.31E-05	0.00E-01	1.02E-04	1.53E-04	2.30E-04	5.00	1.15E-03	8.62E-08 2.64E-07	1.000E-06	1.15E-09
24500.	1.72E-03	5.01E-07	1.04E-02	1.45E-03	1.25E-03	5.00	6.25E-03	4.69E-07 1.44E-06	1.000E-06	6.25E-09
52000.	2.15E-03	5.11E-07	1.42E-02	1.31E-03	1.50E-03	5.00	7.50E-03	5.62E-07 1.72E-06	1.000E-06	7.50E-09
102000.	2.63E-03	5.08E-07	1.96E-02	1.40E-03	1.83E-03	5.00	9.15E-03	6.86E-07 2.10E-06	1.000E-06	9.15E-09
202000.	2.76E-03	4.51E-07	2.26E-02	1.43E-03	1.95E-03	5.00	9.75E-03	7.31E-07 2.24E-06	1.000E-06	9.75E-09
502000.	1.58E-03	2.42E-07	1.37E-02	8.70E-04	1.13E-03	5.00	5.65E-03	4.24E-07 1.30E-06	1.000E-06	5.65E-09
1002000.	4.63E-04	8.58E-08	4.16E-03	3.23E-04	3.39E-04	5.00	1.69E-03	1.27E-07 3.90E-07	1.000E-06	1.69E-09

TABLE B-60

WASTE MIGRATION INTO GROUNDWATER
ALTERNATIVE 2 - VITRIFY CALCINE
3-MILE WELL

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2500.	3.10E-07	0.00E-01	5.95E-07	9.13E-07	1.39E-06	5.00	6.95E-06	5.21E-10 1.60E-09	1.000E-06	6.95E-12
3000.	3.10E-07	0.00E-01	5.95E-07	9.08E-07	1.39E-06	5.00	6.95E-06	5.21E-10 1.60E-09	1.000E-06	6.95E-12
3600.	3.09E-07	6.76E-26	5.90E-07	9.08E-07	1.39E-06	5.00	6.95E-06	5.21E-10 1.60E-09	1.000E-06	6.95E-12
4000.	3.09E-07	4.46E-30	5.90E-07	9.08E-07	1.39E-06	5.00	6.95E-06	5.21E-10 1.60E-09	1.000E-06	6.95E-12
4700.	3.08E-07	2.15E-37	5.90E-07	9.02E-07	1.39E-06	5.00	6.95E-06	5.21E-10 1.60E-09	1.000E-06	6.95E-12
7000.	3.06E-07	0.00E-01	5.84E-07	8.96E-07	1.38E-06	5.00	6.90E-06	5.17E-10 1.59E-09	1.000E-06	6.90E-12
12000.	3.01E-07	0.00E-01	5.76E-07	8.84E-07	1.35E-06	5.00	6.75E-06	5.06E-10 1.55E-09	1.000E-06	6.75E-12
13500.	3.15E-07	0.00E-01	6.07E-07	9.08E-07	1.36E-06	5.00	6.80E-06	5.10E-10 1.56E-09	1.000E-06	6.80E-12
22000.	3.07E-07	0.00E-01	5.90E-07	8.84E-07	1.33E-06	5.00	6.65E-06	4.99E-10 1.53E-09	1.000E-06	6.65E-12
24500.	9.94E-06	2.90E-09	6.01E-05	8.38E-06	7.23E-06	5.00	3.61E-05	2.71E-09 8.31E-09	1.000E-06	3.61E-11
52000.	1.24E-05	2.95E-09	8.21E-05	7.57E-06	8.67E-06	5.00	4.33E-05	3.25E-09 9.97E-09	1.000E-06	4.33E-11
102000.	1.52E-05	2.94E-09	1.13E-04	8.09E-06	1.06E-05	5.00	5.30E-05	3.97E-09 1.22E-08	1.000E-06	5.30E-11
202000.	1.60E-05	2.61E-09	1.31E-04	8.27E-06	1.13E-05	5.00	5.65E-05	4.24E-09 1.30E-08	1.000E-06	5.65E-11
502000.	9.13E-06	1.40E-09	7.92E-05	5.03E-06	6.53E-06	5.00	3.26E-05	2.45E-09 7.51E-09	1.000E-06	3.26E-11
1002000.	2.68E-06	4.96E-10	2.40E-05	1.87E-06	1.96E-06	5.00	9.80E-06	7.35E-10 2.25E-09	1.000E-06	9.80E-12

TABLE B-61

WASTE MIGRATION INTO GROUNDWATER
ALTERNATIVE 2 - VITRIFY CALCINE
10-MILE WELL

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2500.	9.34E-08	0.00E-01	1.79E-07	2.75E-07	4.19E-07	100.	4.19E-05	3.14E-09 9.64E-09	1.000E-06	4.19E-11
3000.	9.32E-08	0.00E-01	1.79E-07	2.73E-07	4.19E-07	100.	4.19E-05	3.14E-09 9.64E-09	1.000E-06	4.19E-11
3600.	9.30E-08	2.03E-26	1.77E-07	2.73E-07	4.19E-07	100.	4.19E-05	3.14E-09 9.64E-09	1.000E-06	4.19E-11
4000.	9.29E-08	1.34E-30	1.77E-07	2.73E-07	4.17E-07	100.	4.17E-05	3.13E-09 9.59E-09	1.000E-06	4.17E-11
4700.	9.27E-08	6.47E-38	1.77E-07	2.71E-07	4.17E-07	100.	4.17E-05	3.13E-09 9.59E-09	1.000E-06	4.17E-11
7000.	9.20E-08	0.00E-01	1.76E-07	2.70E-07	4.14E-07	100.	4.14E-05	3.10E-09 9.52E-09	1.000E-06	4.14E-11
12000.	9.06E-08	0.00E-01	1.73E-07	2.66E-07	4.07E-07	100.	4.07E-05	3.05E-09 9.36E-09	1.000E-06	4.07E-11
13500.	9.50E-08	0.00E-01	1.83E-07	2.73E-07	4.10E-07	100.	4.10E-05	3.07E-09 9.43E-09	1.000E-06	4.10E-11
22000.	9.23E-08	0.00E-01	1.77E-07	2.66E-07	4.00E-07	100.	4.00E-05	3.00E-09 9.20E-09	1.000E-06	4.00E-11
24500.	2.99E-06	8.71E-10	1.81E-05	2.52E-06	2.17E-06	100.	2.17E-04	1.63E-08 4.99E-08	1.000E-06	2.17E-10
52000.	3.74E-06	8.89E-10	2.47E-05	2.28E-06	2.61E-06	100.	2.61E-04	1.96E-08 6.00E-08	1.000E-06	2.61E-10
102000.	4.57E-06	8.83E-10	3.41E-05	2.43E-06	3.18E-06	100.	3.18E-04	2.38E-08 7.31E-08	1.000E-06	3.18E-10
202000.	4.80E-06	7.84E-10	3.93E-05	2.49E-06	3.39E-06	100.	3.39E-04	2.54E-08 7.80E-08	1.000E-06	3.39E-10
502000.	2.75E-06	4.21E-10	2.38E-05	1.51E-06	1.97E-06	100.	1.97E-04	1.48E-08 4.53E-08	1.000E-06	1.97E-10
1002000.	8.05E-07	1.49E-10	7.23E-06	5.62E-07	5.90E-07	100.	5.90E-05	4.42E-09 1.36E-08	1.000E-06	5.90E-11

TABLE B-62

WASTE MIGRATION INTO GROUNDWATER
ALTERNATIVE 2 - VITRIFY CALCINE
120-MILE WELL

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2500.	9.34E-08	0.00E-01	1.79E-07	2.75E-07	4.19E-07	5.000E 03	2.09E-03	1.57E-07 4.82E-07	1.000E-06	2.09E-09
3000.	9.32E-08	0.00E-01	1.79E-07	2.73E-07	4.19E-07	5.000E 03	2.09E-03	1.57E-07 4.82E-07	1.000E-06	2.09E-09
3600.	9.30E-08	2.03E-26	1.77E-07	2.73E-07	4.19E-07	5.000E 03	2.09E-03	1.57E-07 4.82E-07	1.000E-06	2.09E-09
4000.	9.29E-08	1.34E-30	1.77E-07	2.73E-07	4.17E-07	5.000E 03	2.08E-03	1.56E-07 4.80E-07	1.000E-06	2.08E-09
4700.	9.27E-08	6.47E-38	1.77E-07	2.71E-07	4.17E-07	5.000E 03	2.08E-03	1.56E-07 4.80E-07	1.000E-06	2.08E-09
7000.	9.20E-08	0.00E-01	1.76E-07	2.70E-07	4.14E-07	5.000E 03	2.07E-03	1.55E-07 4.76E-07	1.000E-06	2.07E-09
12000.	9.06E-08	0.00E-01	1.73E-07	2.66E-07	4.07E-07	5.000E 03	2.03E-03	1.53E-07 4.68E-07	1.000E-06	2.03E-09
13500.	9.50E-08	0.00E-01	1.83E-07	2.73E-07	4.10E-07	5.000E 03	2.05E-03	1.54E-07 4.71E-07	1.000E-06	2.05E-09
22000.	9.23E-08	0.00E-01	1.77E-07	2.66E-07	4.00E-07	5.000E 03	2.00E-03	1.50E-07 4.60E-07	1.000E-06	2.00E-09
24500.	2.99E-06	8.71E-10	1.81E-05	2.52E-06	2.17E-06	5.000E 03	1.08E-02	8.14E-07 2.50E-06	1.000E-06	1.08E-08
52000.	3.74E-06	8.89E-10	2.47E-05	2.28E-06	2.61E-06	5.000E 03	1.30E-02	9.79E-07 3.00E-06	1.000E-06	1.30E-08
102000.	4.57E-06	8.83E-10	3.41E-05	2.43E-06	3.18E-06	5.000E 03	1.59E-02	1.19E-06 3.66E-06	1.000E-06	1.59E-08
202000.	4.80E-06	7.84E-10	3.93E-05	2.49E-06	3.39E-06	5.000E 03	1.69E-02	1.27E-06 3.90E-06	1.000E-06	1.69E-08
502000.	2.75E-06	4.21E-10	2.38E-05	1.51E-06	1.97E-06	5.000E 03	9.85E-03	7.39E-07 2.27E-06	1.000E-06	9.85E-09
1002000.	8.05E-07	1.49E-10	7.23E-06	5.62E-07	5.90E-07	5.000E 03	2.95E-03	2.21E-07 6.78E-07	1.000E-06	2.95E-09

TABLE B-63

WASTE MIGRATION INTO GROUNDWATER
ALTERNATIVE 4
0-MILE WELL

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2500.	2.40E 01	0.00E-01	4.60E 01	7.04E 01	1.08E 02	5.00	5.40E 02	4.05E-02 1.24E-01	1.000E-06	5.40E-04
3600.	4.86E-11	7.35E-18	4.40E-10	2.92E-12	5.58E-11	5.00	2.79E-10	2.09E-14 6.42E-14	1.000E-06	2.79E-16
13500.	1.74E-01	0.00E-01	3.42E-01	2.94E-01	2.42E-01	5.00	1.21E 00	9.07E-05 2.78E-04	1.000E-06	1.21E-06
24500.	1.06E-02	3.19E-06	6.58E-02	8.24E-03	6.66E-03	5.00	3.33E-02	2.50E-06 7.66E-06	1.000E-06	3.33E-08

TABLE B-64

WASTE MIGRATION INTO GROUNDWATER
ALTERNATIVE 4
3-MILE WELL

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2500.	1.39E-01	0.00E-01	2.66E-01	4.07E-01	6.24E-01	5.00	3.12E 00	2.34E-04 7.18E-04	1.000E-06	3.12E-06
3600.	2.81E-13	4.25E-20	2.54E-12	1.69E-14	3.23E-13	5.00	1.61E-12	1.21E-16 3.71E-16	1.000E-06	1.61E-18
13500.	1.01E-03	0.00E-01	1.98E-03	1.70E-03	1.40E-03	5.00	7.00E-03	5.25E-07 1.61E-06	1.000E-06	7.00E-09
24500.	6.13E-05	1.84E-08	3.80E-04	4.76E-05	3.85E-05	5.00	1.92E-04	1.44E-08 4.43E-08	1.000E-06	1.92E-10

TABLE B-65

WASTE MIGRATION INTO GROUNDWATER
ALTERNATIVE 4
10-MILE WELL

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2500.	4.17E-02	0.00E-01	8.00E-02	1.22E-01	1.88E-01	100.	1.88E 01	1.41E-03 4.32E-03	1.000E-06	1.88E-05
3600.	8.45E-14	1.28E-20	7.65E-13	5.08E-15	9.70E-14	100.	9.70E-12	7.27E-16 2.23E-15	1.000E-06	9.70E-18
13500.	3.03E-04	0.00E-01	5.95E-04	5.11E-04	4.21E-04	100.	4.21E-02	3.16E-06 9.68E-06	1.000E-06	4.21E-08
24500.	1.84E-05	5.55E-09	1.14E-04	1.43E-05	1.16E-05	100.	1.16E-03	8.70E-08 2.67E-07	1.000E-06	1.16E-09

TABLE B-66

WASTE MIGRATION INTO GROUNDWATER
ALTERNATIVE 4
120-MILE WELL

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2500.	4.17E-02	0.00E-01	8.00E-02	1.22E-01	1.88E-01	5.000E 03	9.40E 02	7.05E-02 2.16E-01	1.000E-06	9.40E-04
3600.	8.45E-14	1.28E-20	7.65E-13	5.08E-15	9.70E-14	5.000E 03	4.85E-10	3.64E-14 1.12E-13	1.000E-06	4.85E-16
13500.	3.03E-04	0.00E-01	5.95E-04	5.11E-04	4.21E-04	5.000E 03	2.10E 00	1.58E-04 4.84E-04	1.000E-06	2.10E-06
24500.	1.84E-05	5.55E-09	1.14E-04	1.43E-05	1.16E-05	5.000E 03	5.80E-02	4.35E-06 1.33E-05	1.000E-06	5.80E-08

B.1.1.6 Intrusional Releases

B.1.1.6.1 Individual Intrusion

Data for releases at the ICPP as the result of individual intrusion into the disintegrated waste bins include effects for the implementation of Alternative 1, Alternative 2 (pelletization and vitrification), and Alternative 4.

TABLE B-67

RELEASE DUE TO INDIVIDUAL INTRUSION INTO BINS
ALTERNATIVE 1

	50-Year Dose Commitment to Maximum Individual					Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2500.	1.80E 01	6.70E 01	4.20E 02	8.60E 01	4.38E 01	10.0	4.38E 02	3.28E-02 1.01E-01	1.000E-02	4.38E 00
3000.	8.90E 00	3.10E 01	2.10E 02	4.20E 01	2.14E 01	10.0	2.14E 02	1.60E-02 4.92E-02	1.000E-02	2.14E 00
4000.	5.00E 00	1.70E 01	1.20E 02	2.30E 01	1.34E 01	10.0	1.34E 02	1.00E-02 3.08E-02	1.000E-02	1.34E 00
7000.	3.40E 00	1.20E 01	8.30E 01	1.60E 01	1.03E 01	10.0	1.03E 02	7.72E-03 2.37E-02	1.000E-02	1.03E 00
12000.	2.60E 00	9.10E 00	6.30E 01	1.20E 01	8.60E 00	10.0	8.60E 01	6.45E-03 1.98E-02	1.000E-02	8.60E-01
22000.	1.60E 00	5.90E 00	4.00E 01	7.70E 00	6.60E 00	10.0	6.60E 01	4.95E-03 1.52E-02	1.000E-02	6.60E-01
52000.	6.30E-01	2.40E 00	1.50E 01	2.90E 00	4.10E 00	10.0	4.10E 01	3.07E-03 9.43E-03	1.000E-02	4.10E-01
102000.	2.00E-01	8.70E-01	4.70E 00	8.70E-01	2.59E 00	10.0	2.59E 01	1.94E-03 5.96E-03	1.000E-02	2.59E-01
202000.	8.30E-02	4.20E-01	1.80E 00	3.10E-01	1.46E 00	10.0	1.46E 01	1.09E-03 3.36E-03	1.000E-02	1.46E-01
502000.	5.00E-02	2.40E-01	1.10E 00	1.80E-01	5.74E-01	10.0	5.74E 00	4.30E-04 1.32E-03	1.000E-02	5.74E-02
1002000.	2.20E-02	9.80E-02	4.80E-01	7.60E-02	3.10E-01	10.0	3.10E 00	2.32E-04 7.13E-04	1.000E-02	3.10E-02

TABLE B-68

RELEASE DUE TO INDIVIDUAL INTRUSION INTO BINS
ALTERNATIVE 2 - PELLETIZE CALCINE

	50-Year Dose Commitment to Maximum Individual					Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2500.	1.40E 00	5.30E 00	3.30E 01	6.90E 00	1.05E 01	10.0	1.05E 02	7.87E-03 2.41E-02	1.000E-02	1.05E 00
3000.	7.10E-01	2.50E 00	1.70E 01	3.30E 00	4.70E 00	10.0	4.70E 01	3.52E-03 1.08E-02	1.000E-02	4.70E-01
4000.	4.00E-01	1.40E 00	9.60E 00	1.90E 00	3.85E 00	10.0	3.85E 01	2.89E-03 8.85E-03	1.000E-02	3.85E-01
7000.	2.70E-01	9.50E-01	6.70E 00	1.30E 00	3.52E 00	10.0	3.52E 01	2.64E-03 8.10E-03	1.000E-02	3.52E-01
12000.	2.10E-01	7.30E-01	5.10E 00	9.70E-01	3.29E 00	10.0	3.29E 01	2.47E-03 7.57E-03	1.000E-02	3.29E-01
22000.	1.30E-01	4.70E-01	3.20E 00	6.10E-01	2.95E 00	10.0	2.95E 01	2.21E-03 6.78E-03	1.000E-02	2.95E-01
52000.	5.00E-02	1.90E-01	1.20E 00	2.30E-01	2.40E 00	10.0	2.40E 01	1.80E-03 5.52E-03	1.000E-02	2.40E-01
102000.	1.60E-02	7.00E-02	3.80E-01	7.00E-02	1.73E 00	10.0	1.73E 01	1.30E-03 3.98E-03	1.000E-02	1.73E-01
202000.	6.60E-03	3.40E-02	1.50E-01	2.50E-02	1.01E 00	10.0	1.01E 01	7.57E-04 2.32E-03	1.000E-02	1.01E-01
502000.	4.00E-03	1.90E-02	8.90E-02	1.40E-02	3.47E-01	10.0	3.47E 00	2.60E-04 7.98E-04	1.000E-02	3.47E-02
1002000.	1.70E-03	7.80E-03	3.80E-02	6.10E-03	1.83E-01	10.0	1.83E 00	1.37E-04 4.21E-04	1.000E-02	1.83E-02

TABLE B-69

RELEASE DUE TO INDIVIDUAL INTRUSION INTO BINS
ALTERNATIVE 2 - VITRIFY CALCINE

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2500.	6.00E-02	2.20E-01	1.40E 00	2.80E-01	6.80E-01	10.0	6.80E 00	5.10E-04 1.56E-03	1.000E-02	6.80E-02
3000.	2.90E-02	1.00E-01	6.90E-01	1.40E-01	3.05E-01	10.0	3.05E 00	2.29E-04 7.01E-04	1.000E-02	3.05E-02
4000.	1.60E-02	5.70E-02	4.00E-01	7.70E-02	2.51E-01	10.0	2.51E 00	1.88E-04 5.77E-04	1.000E-02	2.51E-02
7000.	1.10E-02	3.90E-02	2.80E-01	5.30E-02	2.31E-01	10.0	2.31E 00	1.73E-04 5.31E-04	1.000E-02	2.31E-02
12000.	8.50E-03	3.00E-02	2.10E-01	4.00E-02	2.26E-01	10.0	2.26E 00	1.69E-04 5.20E-04	1.000E-02	2.26E-02
22000.	5.40E-03	1.90E-02	1.30E-01	2.50E-02	2.00E-01	10.0	2.00E 00	1.50E-04 4.60E-04	1.000E-02	2.00E-02
52000.	2.10E-03	7.80E-03	5.00E-02	9.50E-03	1.64E-01	10.0	1.64E 00	1.23E-04 3.77E-04	1.000E-02	1.64E-02
102000.	6.60E-04	2.90E-03	1.60E-02	2.90E-03	1.21E-01	10.0	1.21E 00	9.07E-05 2.78E-04	1.000E-02	1.21E-02
202000.	2.70E-04	1.40E-03	6.10E-03	1.00E-03	6.85E-02	10.0	6.85E-01	5.14E-05 1.58E-04	1.000E-02	6.85E-03
502000.	1.60E-04	7.80E-04	3.70E-03	6.00E-04	2.13E-02	10.0	2.13E-01	1.60E-05 4.90E-05	1.000E-02	2.13E-03
1002000.	7.20E-05	3.20E-04	1.60E-03	2.50E-04	1.01E-02	10.0	1.01E-01	7.57E-06 2.32E-05	1.000E-02	1.01E-03

TABLE B-70

RELEASE DUE TO INDIVIDUAL INTRUSION INTO BINS
ALTERNATIVE 4

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2500.	4.00E-03	2.80E-02	8.40E-02	1.70E-02	8.51E 00	10.0	8.51E 01	6.38E-03 1.96E-02	1.000E-02	8.51E-01
3000.	1.80E-03	8.40E-03	4.20E-02	8.40E-03	3.90E 00	10.0	3.90E 01	2.92E-03 8.97E-03	1.000E-02	3.90E-01
4000.	1.00E-03	5.60E-03	2.40E-02	4.70E-03	3.80E 00	10.0	3.80E 01	2.85E-03 8.74E-03	1.000E-02	3.80E-01
7000.	7.20E-04	4.50E-03	1.70E-02	3.20E-03	3.80E 00	10.0	3.80E 01	2.85E-03 8.74E-03	1.000E-02	3.80E-01
12000.	5.60E-04	3.90E-03	1.30E-02	2.50E-03	3.70E 00	10.0	3.70E 01	2.77E-03 8.51E-03	1.000E-02	3.70E-01
22000.	3.70E-04	3.20E-03	8.10E-03	1.60E-03	3.40E 00	10.0	3.40E 01	2.55E-03 7.82E-03	1.000E-02	3.40E-01
52000.	1.60E-04	2.30E-03	3.10E-03	6.00E-04	2.90E 00	10.0	2.90E 01	2.17E-03 6.67E-03	1.000E-02	2.90E-01
102000.	7.30E-05	1.70E-03	9.70E-04	2.00E-04	2.20E 00	10.0	2.20E 01	1.65E-03 5.06E-03	1.000E-02	2.20E-01
202000.	4.20E-05	1.20E-03	3.90E-04	8.10E-05	1.30E 00	10.0	1.30E 01	9.75E-04 2.99E-03	1.000E-02	1.30E-01
502000.	2.30E-05	4.80E-04	2.40E-04	5.00E-05	4.60E-01	10.0	4.60E 00	3.45E-04 1.06E-03	1.000E-02	4.60E-02
1002000.	1.10E-05	1.10E-04	1.10E-04	2.50E-05	2.60E-01	10.0	2.60E 00	1.95E-04 5.98E-04	1.000E-02	2.60E-02

B.1.1.6.2 Exposure from Living at the Contaminated Site

Data for effects on future generations resulting from living at the contaminated site include effects for the implementation of Alternative 1, Alternative 2 (pelletization and vitrification), and Alternative 4. Contamination of the ICPP site is assumed to result from a previous intrusion by an individual, such as an archaeologist or prospector (see Subsection B.1.1.6.1).

TABLE B-71

EXPOSURE DUE TO LIVING AT CONTAMINATED SITE
ALTERNATIVE 1

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2500.	2.40E 01	6.70E-01	3.60E 02	8.60E 01	5.31E 01	5.00	2.65E 02	1.99E-02	1.000E-02	2.65E 00
3000.	1.50E 01	9.33E-01	1.70E 02	4.60E 01	3.30E 01	5.00	1.65E 02	6.11E-02 1.24E-02	1.000E-02	1.65E 00
4000.	1.10E 01	1.80E 00	5.10E 01	2.00E 01	2.46E 01	5.00	1.23E 02	3.79E-02 9.22E-03	1.000E-02	1.23E 00
7000.	1.10E 01	3.60E 00	2.30E 01	1.50E 01	2.36E 01	5.00	1.18E 02	2.83E-02 8.85E-03	1.000E-02	1.18E 00
12000.	1.50E 01	5.70E 00	2.80E 01	1.70E 01	2.67E 01	5.00	1.33E 02	2.71E-02 1.00E-02	1.000E-02	1.33E 00
22000.	2.10E 01	8.10E 00	4.00E 01	2.10E 01	3.08E 01	5.00	1.54E 02	3.07E-02 1.15E-02	1.000E-02	1.54E 00
52000.	3.70E 01	1.20E 01	6.80E 01	3.10E 01	4.15E 01	5.00	2.08E 02	3.54E-02 1.56E-02	1.000E-02	2.07E 00
102000.	5.20E 01	1.50E 01	9.70E 01	4.00E 01	5.10E 01	5.00	2.55E 02	4.77E-02 1.91E-02	1.000E-02	2.55E 00
202000.	5.90E 01	1.60E 01	1.10E 02	4.40E 01	5.31E 01	5.00	2.65E 02	5.86E-02 1.99E-02	1.000E-02	2.65E 00
502000.	3.40E 01	1.20E 01	6.80E 01	2.50E 01	2.98E 01	5.00	1.49E 02	6.11E-02 1.12E-02	1.000E-02	1.49E 00
1002000.	9.00E 00	6.60E 00	2.20E 01	7.00E 00	8.30E 00	5.00	4.15E 01	3.43E-02 3.11E-03 9.54E-03	1.000E-02	4.15E-01

TABLE B-72

EXPOSURE DUE TO LIVING AT CONTAMINATED SITE
ALTERNATIVE 2 - PELLETIZE CALCINE

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2500.	1.90E-01	3.92E-01	2.90E 00	6.90E-01	8.08E 00	5.00	4.04E 01	3.03E-03 9.29E-03	1.000E-02	4.04E-01
3000.	1.20E-01	7.90E-01	1.40E 00	3.60E-01	3.61E 00	5.00	1.80E 01	1.35E-03 4.15E-03	1.000E-02	1.80E-01
4000.	8.60E-02	1.50E 00	4.10E-01	1.60E-01	3.24E 00	5.00	1.62E 01	1.21E-03 3.73E-03	1.000E-02	1.62E-01
7000.	8.90E-02	3.00E 00	1.90E-01	1.20E-01	3.31E 00	5.00	1.65E 01	1.24E-03 3.81E-03	1.000E-02	1.65E-01
12000.	1.20E-01	4.70E 00	2.30E-01	1.40E-01	3.44E 00	5.00	1.72E 01	1.29E-03 3.96E-03	1.000E-02	1.72E-01
22000.	1.70E-01	6.70E 00	3.20E-01	1.70E-01	3.52E 00	5.00	1.76E 01	1.32E-03 4.05E-03	1.000E-02	1.76E-01
52000.	2.90E-01	9.90E 00	5.40E-01	2.50E-01	3.60E 00	5.00	1.80E 01	1.35E-03 4.14E-03	1.000E-02	1.80E-01
102000.	4.10E-01	1.20E 01	7.70E-01	3.20E-01	3.38E 00	5.00	1.69E 01	1.27E-03 3.89E-03	1.000E-02	1.69E-01
202000.	4.70E-01	1.30E 01	8.90E-01	3.50E-01	2.81E 00	5.00	1.40E 01	1.05E-03 3.23E-03	1.000E-02	1.40E-01
502000.	2.70E-01	1.00E 01	5.40E-01	2.00E-01	1.60E 00	5.00	8.00E 00	6.00E-04 1.84E-03	1.000E-02	8.00E-02
1002000.	7.20E-02	5.50E 00	1.70E-01	5.60E-02	7.93E-01	5.00	3.96E 00	2.97E-04 9.12E-04	1.000E-02	3.96E-02

TABLE B-73

EXPOSURE DUE TO LIVING AT CONTAMINATED SITE
ALTERNATIVE 2 - VITRIFY CALCINE

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Surface Bone Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2500.	7.80E-04	3.90E-01	1.20E-02	2.80E-03	7.75E 00	5.00	3.88E 01	2.91E-03 8.91E-03	1.000E-02	3.87E-01
3000.	5.00E-04	7.90E-01	5.60E-03	1.50E-03	3.40E 00	5.00	1.70E 01	1.27E-03 3.91E-03	1.000E-02	1.70E-01
4000.	3.50E-04	1.50E 00	1.70E-03	6.70E-04	3.08E 00	5.00	1.54E 01	1.15E-03 3.54E-03	1.000E-02	1.54E-01
7000.	3.70E-04	3.00E 00	7.70E-04	4.90E-04	3.16E 00	5.00	1.58E 01	1.18E-03 3.63E-03	1.000E-02	1.58E-01
12000.	4.80E-04	4.70E 00	9.40E-04	5.60E-04	3.27E 00	5.00	1.63E 01	1.23E-03 3.76E-03	1.000E-02	1.63E-01
22000.	7.00E-04	6.70E 00	1.30E-03	6.90E-04	3.31E 00	5.00	1.65E 01	1.24E-03 3.81E-03	1.000E-02	1.65E-01
52000.	1.20E-03	9.90E 00	2.20E-03	1.00E-03	3.30E 00	5.00	1.65E 01	1.24E-03 3.79E-03	1.000E-02	1.65E-01
102000.	1.70E-03	1.20E 01	3.20E-03	1.30E-03	3.00E 00	5.00	1.50E 01	1.12E-03 3.45E-03	1.000E-02	1.50E-01
202000.	1.90E-03	1.30E 01	3.70E-03	1.40E-03	2.41E 00	5.00	1.20E 01	9.04E-04 2.77E-03	1.000E-02	1.20E-01
502000.	1.10E-03	1.00E 01	2.20E-03	8.30E-04	1.38E 00	5.00	6.90E 00	5.17E-04 1.59E-03	1.000E-02	6.90E-02
1002000.	3.00E-04	5.50E 00	7.10E-04	2.30E-04	7.34E-01	5.00	3.67E 00	2.75E-04 8.44E-04	1.000E-02	3.67E-02

TABLE B-74

EXPOSURE DUE TO LIVING AT CONTAMINATED SITE
ALTERNATIVE 4

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2500.	4.70E 00	2.09E-01	1.40E 01	1.10E 01	2.70E 01	5.00	1.35E 02	1.01E-02 3.10E-02	1.000E-02	1.35E 00
3000.	3.60E 00	1.90E-02	6.80E 00	1.00E 01	2.02E 01	5.00	1.01E 02	7.57E-03 2.32E-02	1.000E-02	1.01E 00
4000.	3.50E 00	3.60E-02	6.80E 00	1.00E 01	2.02E 01	5.00	1.01E 02	7.57E-03 2.32E-02	1.000E-02	1.01E 00
7000.	3.50E 00	7.30E-02	6.70E 00	1.00E 01	2.01E 01	5.00	1.00E 02	7.54E-03 2.31E-02	1.000E-02	1.00E 00
12000.	3.50E 00	1.10E-01	6.60E 00	1.00E 01	1.90E 01	5.00	9.50E 01	7.12E-03 2.18E-02	1.000E-02	9.50E-01
22000.	3.30E 00	1.60E-01	6.40E 00	9.80E 00	1.87E 01	5.00	9.35E 01	7.01E-03 2.15E-02	1.000E-02	9.35E-01
52000.	3.00E 00	2.40E-01	5.80E 00	8.90E 00	1.71E 01	5.00	8.55E 01	6.41E-03 1.97E-02	1.000E-02	8.55E-01
102000.	2.60E 00	2.90E-01	5.00E 00	7.60E 00	1.42E 01	5.00	7.10E 01	5.32E-03 1.63E-02	1.000E-02	7.10E-01
202000.	1.90E 00	3.10E-01	3.60E 00	5.50E 00	9.54E 00	5.00	4.77E 01	3.58E-03 1.10E-02	1.000E-02	4.77E-01
502000.	7.40E-01	2.50E-01	1.40E 00	2.10E 00	3.49E 00	5.00	1.74E 01	1.31E-03 4.01E-03	1.000E-02	1.74E-01
1002000.	1.70E-01	1.30E-01	3.30E-01	4.60E-01	7.75E-01	5.00	3.87E 00	2.91E-04 8.91E-04	1.000E-02	3.87E-02

B.1.1.6.3 Aircraft Impact

Data for releases resulting from an aircraft impact at the ICPP include effects for the implementation of Alternative 1, Alternative 2, Alternative 3, Alternative 4, and Alternative 5 (retrieval delayed 100 years, 300 years, and 500 years). Effects are assumed to be independent of the waste form. Effects apply to Alternative 3 only during the period of operations.

TABLE B-75

ACCIDENTAL RELEASE AT THE ICPP DUE TO AIRCRAFT IMPACT
ALTERNATIVE 1

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
1990.	1.94E 00	2.09E 01	3.87E 01	8.29E 00	5.20E 00	7.100E 04	7.38E 04	5.54E 00 1.70E 01	2.000E-07	1.48E-02
2000.	1.88E 00	1.96E 01	3.77E 01	8.06E 00	4.95E 00	8.300E 04	8.22E 04	6.16E 00 1.89E 01	2.000E-07	1.64E-02
2010.	1.81E 00	1.82E 01	3.66E 01	7.83E 00	4.71E 00	9.500E 04	8.95E 04	6.71E 00 2.06E 01	2.000E-07	1.79E-02
2020.	1.75E 00	1.70E 01	3.57E 01	7.62E 00	4.48E 00	1.070E 05	9.59E 04	7.19E 00 2.21E 01	2.000E-07	1.92E-02
2060.	1.25E 00	8.91E 00	2.72E 01	5.80E 00	2.86E 00	1.560E 05	8.92E 04	6.69E 00 2.05E 01	2.000E-07	1.78E-02

TABLE B-76

ACCIDENTAL RELEASE AT THE ICPP DUE TO AIRCRAFT IMPACT
ALTERNATIVE 2

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
1990.	1.94E 00	2.09E 01	3.87E 01	8.29E 00	5.20E 00	7.100E 04	7.38E 04	5.54E 00 1.70E 01	2.000E-07	1.48E-02
2000.	1.88E 00	1.96E 01	3.77E 01	8.06E 00	4.95E 00	8.300E 04	8.22E 04	6.16E 00 1.89E 01	2.000E-07	1.64E-02
2010.	1.81E 00	1.82E 01	3.66E 01	7.83E 00	4.71E 00	9.500E 04	8.95E 04	6.71E 00 2.06E 01	2.000E-07	1.79E-02
2020.	1.75E 00	1.70E 01	3.57E 01	7.62E 00	4.48E 00	1.070E 05	9.59E 04	7.19E 00 2.21E 01	2.000E-07	1.92E-02
2060.	1.25E 00	8.91E 00	2.72E 01	5.80E 00	2.86E 00	1.560E 05	8.92E 04	6.69E 00 2.05E 01	2.000E-07	1.78E-02

TABLE B-77

ACCIDENTAL RELEASE AT THE ICPP DUE TO AIRCRAFT IMPACT
ALTERNATIVE 3

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
1990.	1.94E 00	2.09E 01	3.87E 01	8.29E 00	5.20E 00	7.100E 04	7.38E 04	5.54E 00 1.70E 01	2.000E-07	1.48E-02
2000.	1.88E 00	1.96E 01	3.77E 01	8.06E 00	4.95E 00	8.300E 04	8.22E 04	6.16E 00 1.89E 01	2.000E-07	1.64E-02
2010.	1.81E 00	1.82E 01	3.66E 01	7.83E 00	4.71E 00	9.500E 04	8.95E 04	6.71E 00 2.06E 01	2.000E-07	1.79E-02
2020.	1.75E 00	1.70E 01	3.57E 01	7.62E 00	4.48E 00	1.070E 05	9.59E 04	7.19E 00 2.21E 01	2.000E-07	1.92E-02

TABLE B-78

ACCIDENTAL RELEASE AT THE ICPP DUE TO AIRCRAFT IMPACT
ALTERNATIVE 4

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
1990.	1.94E 00	2.09E 01	3.87E 01	8.29E 00	5.20E 00	7.100E 04	7.38E 04	5.54E 00 1.70E 01	2.000E-07	1.48E-02
2000.	1.88E 00	1.96E 01	3.77E 01	8.06E 00	4.95E 00	8.300E 04	8.22E 04	6.16E 00 1.89E 01	2.000E-07	1.64E-02
2010.	1.81E 00	1.82E 01	3.66E 01	7.83E 00	4.71E 00	9.500E 04	8.95E 04	6.71E 00 2.06E 01	2.000E-07	1.79E-02
2020.	1.75E 00	1.70E 01	3.57E 01	7.62E 00	4.48E 00	1.070E 05	9.59E 04	7.19E 00 2.21E 01	2.000E-07	1.92E-02
2060.	1.25E 00	8.91E 00	2.72E 01	5.80E 00	2.86E 00	1.560E 05	8.92E 04	6.69E 00 2.05E 01	2.000E-07	1.78E-02

TABLE B-79

ACCIDENTAL RELEASE AT THE ICPP DUE TO AIRCRAFT IMPACT
ALTERNATIVE 5 - RETRIEVAL DELAYED 100 YEARS

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
1990.	1.94E 00	2.09E 01	3.87E 01	8.29E 00	5.20E 00	7.100E 04	7.38E 04	5.54E 00 1.70E 01	2.000E-07	1.48E-02
2000.	1.88E 00	1.96E 01	3.77E 01	8.06E 00	4.95E 00	8.300E 04	8.22E 04	6.16E 00 1.89E 01	2.000E-07	1.64E-02
2010.	1.81E 00	1.82E 01	3.66E 01	7.83E 00	4.71E 00	9.500E 04	8.95E 04	6.71E 00 2.06E 01	2.000E-07	1.79E-02
2020.	1.75E 00	1.70E 01	3.57E 01	7.62E 00	4.48E 00	1.070E 05	9.59E 04	7.19E 00 2.21E 01	2.000E-07	1.92E-02
2060.	1.25E 00	8.91E 00	2.72E 01	5.80E 00	2.86E 00	1.560E 05	8.92E 04	6.69E 00 2.05E 01	2.000E-07	1.78E-02
2090.	9.98E-01	5.94E 00	2.22E 01	4.73E 00	2.15E 00	1.930E 05	8.30E 04	6.22E 00 1.91E 01	2.000E-07	1.66E-02

TABLE B-80

ACCIDENTAL RELEASE AT THE ICPP DUE TO AIRCRAFT IMPACT
ALTERNATIVE 5 - RETRIEVAL DELAYED 300 YEARS

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
1990.	1.94E 00	2.09E 01	3.87E 01	8.29E 00	5.20E 00	7.100E 04	7.38E 04	5.54E 00 1.70E 01	2.000E-07	1.48E-02
2000.	1.88E 00	1.96E 01	3.77E 01	8.06E 00	4.95E 00	8.300E 04	8.22E 04	6.16E 00 1.89E 01	2.000E-07	1.64E-02
2010.	1.81E 00	1.82E 01	3.66E 01	7.83E 00	4.71E 00	9.500E 04	8.95E 04	6.71E 00 2.06E 01	2.000E-07	1.79E-02
2020.	1.75E 00	1.70E 01	3.57E 01	7.62E 00	4.48E 00	1.070E 05	9.59E 04	7.19E 00 2.21E 01	2.000E-07	1.92E-02
2060.	1.25E 00	8.91E 00	2.72E 01	5.80E 00	2.86E 00	1.560E 05	8.92E 04	6.69E 00 2.05E 01	2.000E-07	1.78E-02
2090.	9.98E-01	5.94E 00	2.22E 01	4.73E 00	2.15E 00	1.930E 05	8.30E 04	6.22E 00 1.91E 01	2.000E-07	1.66E-02
2100.	9.28E-01	5.26E 00	2.08E 01	4.43E 00	1.98E 00	2.060E 05	8.16E 04	6.12E 00 1.88E 01	2.000E-07	1.63E-02
2200.	4.91E-01	2.12E 00	1.13E 01	2.39E 00	9.71E-01	2.300E 05	4.47E 04	3.35E 00 1.03E 01	2.000E-07	8.93E-03
2290.	3.08E-01	1.23E 00	7.12E 00	1.50E 00	5.97E-01	2.300E 05	2.75E 04	2.06E 00 6.32E 00	2.000E-07	5.49E-03

TABLE B-81

ACCIDENTAL RELEASE AT THE ICPP DUE TO AIRCRAFT IMPACT
ALTERNATIVE 5 - RETRIEVAL DELAYED 500 YEARS

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
1990.	1.94E 00	2.09E 01	3.87E 01	8.29E 00	5.20E 00	7.100E 04	7.38E 04	5.54E 00 1.70E 01	2.000E-07	1.48E-02
2000.	1.88E 00	1.96E 01	3.77E 01	8.06E 00	4.95E 00	8.300E 04	8.22E 04	6.16E 00 1.89E 01	2.000E-07	1.64E-02
2010.	1.81E 00	1.82E 01	3.66E 01	7.83E 00	4.71E 00	9.500E 04	8.95E 04	6.71E 00 2.06E 01	2.000E-07	1.79E-02
2020.	1.75E 00	1.70E 01	3.57E 01	7.62E 00	4.48E 00	1.070E 05	9.59E 04	7.19E 00 2.21E 01	2.000E-07	1.92E-02
2060.	1.25E 00	8.91E 00	2.72E 01	5.80E 00	2.86E 00	1.560E 05	8.92E 04	6.69E 00 2.05E 01	2.000E-07	1.78E-02
2090.	9.98E-01	5.94E 00	2.22E 01	4.73E 00	2.15E 00	1.930E 05	8.30E 04	6.22E 00 1.91E 01	2.000E-07	1.66E-02
2100.	9.28E-01	5.26E 00	2.08E 01	4.43E 00	1.98E 00	2.060E 05	8.16E 04	6.12E 00 1.88E 01	2.000E-07	1.63E-02
2200.	4.91E-01	2.12E 00	1.13E 01	2.39E 00	9.71E-01	2.300E 05	4.47E 04	3.35E 00 1.03E 01	2.000E-07	8.93E-03
2290.	3.08E-01	1.23E 00	7.12E 00	1.50E 00	5.97E-01	2.300E 05	2.75E 04	2.06E 00 6.32E 00	2.000E-07	5.49E-03
2300.	2.95E-01	1.17E 00	6.80E 00	1.43E 00	5.69E-01	2.300E 05	2.62E 04	1.96E 00 6.02E 00	2.000E-07	5.23E-03
2400.	1.98E-01	7.51E-01	4.57E 00	9.53E-01	3.78E-01	2.300E 05	1.74E 04	1.30E 00 4.00E 00	2.000E-07	3.48E-03
2490.	1.52E-01	5.59E-01	3.50E 00	7.24E-01	2.87E-01	2.300E 05	1.32E 04	9.90E-01 3.04E 00	2.000E-07	2.64E-03

B.1.1.6.4 Severe Geologic Disruption

Data for releases resulting from a severe geologic disruption at the ICPP include effects for the implementation of Alternative 1, Alternative 2 (pelletization and vitrification), Alternative 4, and Alternative 5 (retrieval delayed 100 years, 300 years, and 500 years). No calculations were performed for the effects of volcanic activity, tornadoes, earthquakes, or floods, since the severe geologic disruption event would cause maximum effects on the public.

TABLE B-82

ACCIDENTAL RELEASE AT THE ICPP DUE TO SEVERE GEOLOGIC DISRUPTION
ALTERNATIVE 1

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
1990.	4.80E 00	2.14E 01	5.80E 01	9.70E 00	4.23E 01	7.100E 04	1.80E 06	1.35E 02 4.14E 02	1.000E-08	1.80E-02
2000.	7.10E 00	3.05E 01	8.60E 01	1.42E 01	6.03E 01	8.300E 04	3.00E 06	2.25E 02 6.91E 02	1.000E-08	3.00E-02
2010.	8.90E 00	3.76E 01	1.10E 02	1.87E 01	7.15E 01	9.500E 04	4.08E 06	3.06E 02 9.37E 02	1.000E-08	4.08E-02
2020.	1.03E 01	4.47E 01	1.32E 02	2.31E 01	8.45E 01	1.070E 05	5.42E 06	4.07E 02 1.25E 03	1.000E-08	5.42E-02
2060.	5.40E 00	2.33E 01	8.50E 01	1.62E 01	3.39E 01	1.560E 05	3.17E 06	2.38E 02 7.30E 02	1.000E-08	3.17E-02
2100.	3.27E 00	1.41E 01	5.99E 01	1.15E 01	1.58E 01	2.060E 05	1.95E 06	1.46E 02 4.49E 02	1.000E-08	1.95E-02
2200.	1.38E 00	5.51E 00	2.96E 01	6.25E 00	3.56E 00	2.300E 05	4.91E 05	3.68E 01 1.13E 02	1.000E-08	4.91E-03
2300.	7.69E-01	3.00E 00	1.81E 01	3.71E 00	1.61E 00	2.300E 05	2.22E 05	1.67E 01 5.11E 01	1.000E-08	2.22E-03
2400.	5.12E-01	1.90E 00	1.20E 01	2.51E 00	9.94E-01	2.300E 05	1.37E 05	1.03E 01 3.15E 01	1.000E-08	1.37E-03
2500.	3.81E-01	1.40E 00	8.82E 00	1.80E 00	7.24E-01	2.300E 05	9.99E 04	7.49E 00 2.30E 01	1.000E-08	9.99E-04
2600.	3.11E-01	1.10E 00	7.12E 00	1.50E 00	5.83E-01	2.300E 05	8.05E 04	6.03E 00 1.85E 01	1.000E-08	8.05E-04
2700.	2.61E-01	9.31E-01	6.11E 00	1.20E 00	4.93E-01	2.300E 05	6.80E 04	5.10E 00 1.56E 01	1.000E-08	6.80E-04
2800.	2.31E-01	8.11E-01	5.41E 00	1.10E 00	4.33E-01	2.300E 05	5.98E 04	4.48E 00 1.37E 01	1.000E-08	5.98E-04
2900.	2.11E-01	7.31E-01	4.81E 00	9.73E-01	3.93E-01	2.300E 05	5.42E 04	4.07E 00 1.25E 01	1.000E-08	5.42E-04
3000.	1.91E-01	6.61E-01	4.41E 00	8.83E-01	3.53E-01	2.300E 05	4.87E 04	3.65E 00 1.12E 01	1.000E-08	4.87E-04
4000.	1.01E-01	3.72E-01	2.50E 00	4.91E-01	2.02E-01	2.300E 05	2.79E 04	2.09E 00 6.41E 00	1.000E-08	2.79E-04
7000.	7.26E-02	2.55E-01	1.80E 00	3.41E-01	1.42E-01	2.300E 05	1.96E 04	1.47E 00 4.51E 00	1.000E-08	1.96E-04
12000.	5.58E-02	1.98E-01	1.30E 00	2.61E-01	1.03E-01	2.300E 05	1.42E 04	1.07E 00 3.27E 00	1.000E-08	1.42E-04
22000.	3.62E-02	1.31E-01	8.52E-01	1.61E-01	6.95E-02	2.300E 05	9.59E 03	7.19E-01 2.21E 00	1.000E-08	9.59E-05
52000.	1.51E-02	6.70E-02	3.24E-01	6.27E-02	2.96E-02	2.300E 05	4.08E 03	3.06E-01 9.40E-01	1.000E-08	4.08E-05
102000.	7.20E-03	3.80E-02	1.05E-01	2.03E-02	1.36E-02	2.300E 05	1.88E 03	1.41E-01 4.32E-01	1.000E-08	1.88E-05
202000.	5.00E-03	3.09E-02	4.52E-02	9.00E-03	9.01E-03	2.300E 05	1.24E 03	9.33E-02 2.86E-01	1.000E-08	1.24E-05
502000.	3.00E-03	2.20E-02	2.68E-02	5.20E-03	5.75E-03	2.300E 05	7.93E 02	5.95E-02 1.83E-01	1.000E-08	7.93E-06
1002000.	9.70E-04	1.14E-02	1.12E-02	1.99E-03	2.38E-03	2.300E 05	3.28E 02	2.46E-02 7.55E-02	1.000E-08	3.28E-06

TABLE B-83

ACCIDENTAL RELEASE AT THE ICPP DUE TO SEVERE GEOLOGIC DISRUPTION
ALTERNATIVE 2 - PELLETIZE CALCINE

	50-Year Dose Commitment to Maximum Individual					Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
1990.	4.80E 00	2.14E 01	5.80E 01	9.70E 00	4.23E 01	7.100E 04	1.80E 06	1.35E 02 4.14E 02	1.000E-08	1.80E-02
2000.	7.10E 00	3.05E 01	8.60E 01	1.42E 01	6.03E 01	8.300E 04	3.00E 06	2.25E 02 6.91E 02	1.000E-08	3.00E-02
2010.	8.90E 00	3.76E 01	1.10E 02	1.87E 01	7.15E 01	9.500E 04	4.08E 06	3.04E 02 9.37E 02	1.000E-08	4.08E-02
2020.	1.03E 01	4.47E 01	1.32E 02	2.31E 01	8.45E 01	1.070E 05	5.42E 06	4.07E 02 1.25E 03	1.000E-08	5.42E-02
2060.	5.40E 00	2.33E 01	8.50E 01	1.62E 01	3.39E 01	1.560E 05	3.17E 06	2.38E 02 7.30E 02	1.000E-08	3.17E-02
2100.	3.27E 00	1.41E 01	5.99E 01	1.15E 01	1.58E 01	2.060E 05	1.95E 06	1.46E 02 4.49E 02	1.000E-08	1.95E-02
2200.	1.38E 00	5.51E 00	2.96E 01	6.25E 00	3.56E 00	2.300E 05	4.91E 05	3.68E 01 1.13E 02	1.000E-08	4.91E-03
2300.	7.69E-01	3.00E 00	1.81E 01	3.71E 00	1.61E 00	2.300E 05	2.22E 05	1.67E 01 5.11E 01	1.000E-08	2.22E-03
2400.	5.12E-01	1.90E 00	1.20E 01	2.51E 00	9.94E-01	2.300E 05	1.37E 05	1.03E 01 3.15E 01	1.000E-08	1.37E-03
2500.	3.81E-01	1.40E 00	8.82E 00	1.80E 00	7.24E-01	2.300E 05	9.99E 04	7.49E 00 2.30E 01	1.000E-08	9.99E-04
2600.	3.11E-01	1.10E 00	7.12E 00	1.50E 00	5.83E-01	2.300E 05	8.05E 04	6.03E 00 1.85E 01	1.000E-08	8.05E-04
2700.	2.61E-01	9.31E-01	6.11E 00	1.20E 00	4.93E-01	2.300E 05	6.80E 04	5.10E 00 1.56E 01	1.000E-08	6.80E-04
2800.	2.31E-01	8.11E-01	5.41E 00	1.10E 00	4.33E-01	2.300E 05	5.98E 04	4.48E 00 1.37E 01	1.000E-08	5.98E-04
2900.	2.11E-01	7.31E-01	4.81E 00	9.73E-01	3.93E-01	2.300E 05	5.42E 04	4.07E 00 1.25E 01	1.000E-08	5.42E-04
3000.	1.91E-01	6.61E-01	4.41E 00	8.83E-01	3.53E-01	2.300E 05	4.87E 04	3.65E 00 1.12E 01	1.000E-08	4.87E-04
4000.	1.01E-01	3.72E-01	2.50E 00	4.91E-01	2.02E-01	2.300E 05	2.79E 04	2.09E 00 6.41E 00	1.000E-08	2.79E-04
7000.	7.26E-02	2.55E-01	1.80E 00	3.41E-01	1.42E-01	2.300E 05	1.96E 04	1.47E 00 4.51E 00	1.000E-08	1.96E-04
12000.	5.58E-02	1.98E-01	1.30E 00	2.61E-01	1.03E-01	2.300E 05	1.42E 04	1.07E 00 3.27E 00	1.000E-08	1.42E-04
22000.	3.62E-02	1.31E-01	8.52E-01	1.61E-01	6.95E-02	2.300E 05	9.59E 03	7.19E-01 2.21E 00	1.000E-08	9.59E-05
52000.	1.51E-02	6.70E-02	3.24E-01	6.27E-02	2.96E-02	2.300E 05	4.08E 03	3.06E-01 9.40E-01	1.000E-08	4.08E-05
102000.	7.20E-03	3.80E-02	1.05E-01	2.03E-02	1.36E-02	2.300E 05	1.88E 03	1.41E-01 4.32E-01	1.000E-08	1.88E-05
202000.	5.00E-03	3.09E-02	4.52E-02	9.00E-03	9.01E-03	2.300E 05	1.24E 03	9.33E-02 2.86E-01	1.000E-08	1.24E-05
502000.	3.00E-03	2.20E-02	2.68E-02	5.20E-03	5.75E-03	2.300E 05	7.93E 02	5.95E-02 1.83E-01	1.000E-08	7.93E-06
1002000.	9.70E-04	1.14E-02	1.12E-02	1.99E-03	2.38E-03	2.300E 05	3.28E 02	2.46E-02 7.55E-02	1.000E-08	3.28E-06

TABLE B-84

ACCIDENTAL RELEASE AT THE ICPP DUE TO SEVERE GEOLOGIC DISRUPTION
ALTERNATIVE 2 - VITRIFY CALCINE

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
1990.	4.80E 00	2.14E 01	5.80E 01	9.70E 00	4.23E 01	7.100E 04	1.80E 06	1.35E 02 4.14E 02	1.000E-08	1.80E-02
2000.	7.10E 00	3.05E 01	8.60E 01	1.42E 01	6.03E 01	8.300E 04	3.00E 06	2.25E 02 6.91E 02	1.000E-08	3.00E-02
2010.	8.90E 00	3.76E 01	1.10E 02	1.87E 01	7.15E 01	9.500E 04	4.08E 06	3.06E 02 9.37E 02	1.000E-08	4.08E-02
2020.	1.03E 01	4.47E 01	1.32E 02	2.31E 01	8.45E 01	1.070E 05	5.42E 06	4.07E 02 1.25E 03	1.000E-08	5.42E-02
2060.	5.40E 00	2.33E 01	8.50E 01	1.62E 01	3.39E 01	1.560E 05	3.17E 06	2.38E 02 7.30E 02	1.000E-08	3.17E-02
2100.	3.27E 00	1.41E 01	5.99E 01	1.15E 01	1.58E 01	2.060E 05	1.95E 06	1.46E 02 4.49E 02	1.000E-08	1.95E-02
2200.	1.38E 00	5.51E 00	2.96E 01	6.25E 00	3.56E 00	2.300E 05	4.91E 05	3.68E 01 1.13E 02	1.000E-08	4.91E-03
2300.	7.69E-01	3.00E 00	1.81E 01	3.71E 00	1.61E 00	2.300E 05	2.22E 05	1.67E 01 5.11E 01	1.000E-08	2.22E-03
2400.	5.12E-01	1.90E 00	1.20E 01	2.51E 00	9.94E-01	2.300E 05	1.37E 05	1.03E 01 3.15E 01	1.000E-08	1.37E-03
2500.	3.81E-01	1.40E 00	8.82E 00	1.80E 00	7.24E-01	2.300E 05	9.99E 04	7.49E 00 2.30E 01	1.000E-08	9.99E-04
2600.	3.11E-01	1.10E 00	7.12E 00	1.50E 00	5.83E-01	2.300E 05	8.05E 04	6.03E 00 1.85E 01	1.000E-08	8.05E-04
2700.	2.61E-01	9.31E-01	6.11E 00	1.20E 00	4.93E-01	2.300E 05	6.80E 04	5.10E 00 1.56E 01	1.000E-08	6.80E-04
2800.	2.31E-01	8.11E-01	5.41E 00	1.10E 00	4.33E-01	2.300E 05	5.98E 04	4.48E 00 1.37E 01	1.000E-08	5.98E-04
2900.	2.11E-01	7.31E-01	4.81E 00	9.73E-01	3.93E-01	2.300E 05	5.42E 04	4.07E 00 1.25E 01	1.000E-08	5.42E-04
3000.	1.91E-01	6.61E-01	4.41E 00	8.83E-01	3.53E-01	2.300E 05	4.87E 04	3.65E 00 1.12E 01	1.000E-08	4.87E-04
4000.	1.01E-01	3.72E-01	2.50E 00	4.91E-01	2.02E-01	2.300E 05	2.79E 04	2.09E 00 6.41E 00	1.000E-08	2.79E-04
7000.	7.26E-02	2.55E-01	1.80E 00	3.41E-01	1.42E-01	2.300E 05	1.96E 04	1.47E 00 4.51E 00	1.000E-08	1.96E-04
12000.	5.58E-02	1.98E-01	1.30E 00	2.61E-01	1.03E-01	2.300E 05	1.42E 04	1.07E 00 3.27E 00	1.000E-08	1.42E-04
22000.	3.62E-02	1.31E-01	8.52E-01	1.61E-01	6.95E-02	2.300E 05	9.59E 03	7.19E-01 2.21E 00	1.000E-08	9.59E-05
52000.	1.51E-02	6.70E-02	3.24E-01	6.27E-02	2.96E-02	2.300E 05	4.08E 03	3.06E-01 9.40E-01	1.000E-08	4.08E-05
102000.	7.20E-03	3.80E-02	1.05E-01	2.03E-02	1.36E-02	2.300E 05	1.88E 03	1.41E-01 4.32E-01	1.000E-08	1.88E-05
202000.	5.00E-03	3.09E-02	4.52E-02	9.00E-03	9.01E-03	2.300E 05	1.24E 03	9.33E-02 2.86E-01	1.000E-08	1.24E-05
502000.	3.00E-03	2.20E-02	2.68E-02	5.20E-03	5.75E-03	2.300E 05	7.93E 02	5.95E-02 1.83E-01	1.000E-08	7.93E-06
1002000.	9.70E-04	1.14E-02	1.12E-02	1.99E-03	2.38E-03	2.300E 05	3.28E 02	2.46E-02 7.55E-02	1.000E-08	3.28E-06

TABLE B-85

ACCIDENTAL RELEASE AT THE ICPP DUE TO SEVERE GEOLOGIC DISRUPTION
ALTERNATIVE 4

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
1990.	4.80E 00	2.14E 01	5.80E 01	9.70E 00	4.23E 01	7.100E 04	1.84E 06	1.35E 02 4.14E 02	1.000E-08	1.80E-02
2000.	4.52E 00	1.95E 01	2.86E 01	2.37E 00	5.43E 01	8.300E 04	2.74E 06	2.03E 02 6.22E 02	1.000E-08	2.70E-02
2010.	5.61E 00	2.46E 01	3.58E 01	2.91E 00	6.40E 01	9.500E 04	3.65E 06	2.74E 02 8.39E 02	1.000E-08	3.65E-02
2020.	6.39E 00	2.77E 01	4.09E 01	3.24E 00	7.53E 01	1.070E 05	4.85E 06	3.63E 02 1.11E 03	1.000E-08	4.83E-02
2060.	2.42E 00	1.03E 01	1.54E 01	1.29E 00	2.79E 01	1.560E 05	2.61E 06	1.96E 02 6.01E 02	1.000E-08	2.61E-02
2100.	9.37E-01	4.01E 00	5.94E 00	4.98E-01	1.11E 01	2.060E 05	1.37E 06	1.03E 02 3.16E 02	1.000E-08	1.37E-02
2200.	8.82E-02	3.71E-01	5.48E-01	5.17E-02	1.10E 00	2.300E 05	1.52E 05	1.14E 01 3.49E 01	1.000E-08	1.52E-03
2500.	3.54E-04	6.14E-04	2.58E-03	1.00E-03	2.85E-03	2.300E 05	3.93E 02	2.95E-02 9.05E-02	1.000E-08	3.93E-06
3000.	2.38E-04	2.06E-04	1.26E-03	7.60E-04	1.69E-03	2.300E 05	2.33E 02	1.75E-02 5.36E-02	1.000E-08	2.33E-06
4000.	2.22E-04	1.70E-04	8.90E-04	6.79E-04	1.65E-03	2.300E 05	2.23E 02	1.71E-02 5.24E-02	1.000E-08	2.28E-06
7000.	2.15E-04	1.95E-04	7.30E-04	6.38E-04	1.63E-03	2.300E 05	2.25E 02	1.69E-02 5.17E-02	1.000E-08	2.25E-06
12000.	2.02E-04	2.43E-04	6.40E-04	6.12E-04	1.59E-03	2.300E 05	2.19E 02	1.65E-02 5.05E-02	1.000E-08	2.19E-06
22000.	1.98E-04	2.98E-04	5.30E-04	5.83E-04	1.52E-03	2.300E 05	2.10E 02	1.57E-02 4.82E-02	1.000E-08	2.10E-06
52000.	1.73E-04	3.79E-04	3.95E-04	5.13E-04	1.33E-03	2.300E 05	1.84E 02	1.38E-02 4.22E-02	1.000E-08	1.84E-06
102000.	1.51E-04	4.47E-04	3.00E-04	4.24E-04	1.09E-03	2.300E 05	1.50E 02	1.13E-02 3.46E-02	1.000E-08	1.50E-06
202000.	1.11E-04	4.66E-04	2.08E-04	3.12E-04	7.27E-04	2.300E 05	1.00E 02	7.52E-03 2.31E-02	1.000E-08	1.00E-06
502000.	4.15E-05	3.50E-04	8.40E-05	1.21E-04	2.67E-04	2.300E 05	3.68E 01	2.76E-03 8.47E-03	1.000E-08	3.68E-07
1002000.	9.83E-06	1.82E-04	2.03E-05	2.65E-05	7.66E-05	2.300E 05	1.06E 01	7.93E-04 2.43E-03	1.000E-08	1.06E-07

TABLE B-86

ACCIDENTAL RELEASE AT THE ICPP DUE TO SEVERE GEOLOGIC DISRUPTION
ALTERNATIVE 5 - RETRIEVAL DELAYED 100 YEARS

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
1990.	4.80E 00	2.14E 01	5.80E 01	9.70E 00	4.23E 01	7.100E 04	1.80E 06	1.35E 02 4.14E 02	1.000E-08	1.80E-02
2000.	7.10E 00	3.05E 01	8.60E 01	1.42E 01	6.03E 01	8.300E 04	3.00E 06	2.25E 02 6.91E 02	1.000E-08	3.00E-02
2010.	8.90E 00	3.76E 01	1.10E 02	1.87E 01	7.15E 01	9.500E 04	4.08E 06	3.06E 02 9.37E 02	1.000E-08	4.08E-02
2020.	1.03E 01	4.47E 01	1.32E 02	2.31E 01	8.45E 01	1.070E 05	5.42E 06	4.07E 02 1.25E 03	1.000E-08	5.42E-02
2060.	5.40E 00	2.33E 01	8.50E 01	1.62E 01	3.39E 01	1.560E 05	3.17E 06	2.38E 02 7.30E 02	1.000E-08	3.17E-02
2100.	3.27E 00	1.41E 01	5.99E 01	1.15E 01	1.58E 01	2.060E 05	1.95E 06	1.46E 02 4.49E 02	1.000E-08	1.95E-02

TABLE B-87

ACCIDENTAL RELEASE AT THE ICPP DUE TO SEVERE GEOLOGIC DISRUPTION
ALTERNATIVE 5 - RETRIEVAL DELAYED 300 YEARS

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
1990.	4.80E 00	2.14E 01	5.80E 01	9.70E 00	4.23E 01	7.100E 04	1.80E 06	1.35E 02 4.14E 02	1.000E-08	1.80E-02
2000.	7.10E 00	3.05E 01	8.60E 01	1.42E 01	6.03E 01	8.300E 04	3.00E 06	2.25E 02 6.91E 02	1.000E-08	3.00E-02
2010.	8.90E 00	3.76E 01	1.10E 02	1.87E 01	7.15E 01	9.500E 04	4.08E 06	3.06E 02 9.37E 02	1.000E-08	4.08E-02
2020.	1.03E 01	4.47E 01	1.32E 02	2.31E 01	8.45E 01	1.070E 05	5.42E 06	4.07E 02 1.25E 03	1.000E-08	5.42E-02
2060.	5.40E 00	2.33E 01	8.50E 01	1.62E 01	3.39E 01	1.560E 05	3.17E 06	2.38E 02 7.30E 02	1.000E-08	3.17E-02
2100.	3.27E 00	1.41E 01	5.99E 01	1.15E 01	1.58E 01	2.060E 05	1.95E 06	1.46E 02 4.49E 02	1.000E-08	1.95E-02
2200.	1.38E 00	5.51E 00	2.96E 01	6.25E 00	3.56E 00	2.300E 05	4.91E 05	3.68E 01 1.13E 02	1.000E-08	4.91E-03
2300.	7.69E-01	3.00E 00	1.81E 01	3.71E 00	1.61E 00	2.300E 05	2.22E 05	1.67E 01 5.11E 01	1.000E-08	2.22E-03

TABLE B-88

ACCIDENTAL RELEASE AT THE ICPP DUE TO SEVERE GEOLOGIC DISRUPTION
ALTERNATIVE 5 - RETRIEVAL DELAYED 500 YEARS

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
1990.	4.80E 00	2.14E 01	5.80E 01	9.70E 00	4.23E 01	7.10E 04	1.80E 06	1.35E 02 4.14E 02	1.000E-08	1.80E-02
2000.	7.10E 00	3.05E 01	8.60E 01	1.42E 01	6.03E 01	8.30E 04	3.00E 06	2.25E 02 6.91E 02	1.000E-08	3.00E-02
2010.	8.90E 00	3.76E 01	1.10E 02	1.87E 01	7.15E 01	9.50E 04	4.08E 06	3.06E 02 9.37E 02	1.000E-08	4.08E-02
2020.	1.03E 01	4.47E 01	1.32E 02	2.31E 01	8.45E 01	1.07E 05	5.42E 06	4.07E 02 1.25E 03	1.000E-08	5.42E-02
2060.	5.40E 00	2.33E 01	8.50E 01	1.62E 01	3.39E 01	1.56E 05	3.17E 06	2.38E 02 7.30E 02	1.000E-08	3.17E-02
2100.	3.27E 00	1.41E 01	5.99E 01	1.15E 01	1.58E 01	2.06E 05	1.95E 06	1.46E 02 4.49E 02	1.000E-08	1.95E-02
2200.	1.38E 00	5.51E 00	2.96E 01	6.25E 00	3.56E 00	2.30E 05	4.91E 05	3.68E 01 1.13E 02	1.000E-08	4.91E-03
2300.	7.69E-01	3.00E 00	1.81E 01	3.71E 00	1.61E 00	2.30E 05	2.22E 05	1.67E 01 5.11E 01	1.000E-08	2.22E-03
2400.	5.12E-01	1.90E 00	1.20E 01	2.51E 00	9.94E-01	2.30E 05	1.37E 05	1.03E 01 3.15E 01	1.000E-08	1.37E-03
2500.	3.81E-01	1.40E 00	8.82E 00	1.80E 00	7.24E-01	2.30E 05	9.99E 04	7.49E 00 2.30E 01	1.000E-08	9.99E-04

B.1.2 Repository Releases

B.1.2.1 Waste Canister Drop

Data for operational releases resulting from a canister drop at the repository include effects for the implementation of Alternative 3 (stabilization and vitrification), Alternative 4, and Alternative 5 (retrieval delayed 100 years, 300 years, and 500 years).

TABLE B-89

OPERATIONAL RELEASE AT THE REPOSITORY DUE TO CANISTER DROP
ALTERNATIVE 3 - STABILIZE CALCINE

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
1990-2020	7.18E-05	2.10E-05	3.52E-04	6.70E-05	9.40E-05	2.000E 06	1.88E 00	1.41E-04 4.32E-04	7.000E-07	1.32E-06

TABLE B-90

OPERATIONAL RELEASE AT THE REPOSITORY DUE TO CANISTER DROP
ALTERNATIVE 3 - VITRIFY CALCINE

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
1990-2020	1.00E-05	2.94E-06	4.92E-05	9.36E-06	1.31E-05	2.000E 06	2.62E-01	1.96E-05 6.03E-05	7.000E-07	1.83E-07

TABLE B-91

OPERATIONAL RELEASE AT THE REPOSITORY DUE TO CANISTER DROP
ALTERNATIVE 4

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
1990-2020	6.90E-05	5.12E-05	8.12E-04	1.68E-04	1.02E-04	2.000E 06	2.04E 00	1.53E-04 4.69E-04	7.000E-07	1.43E-06

TABLE B-92

OPERATIONAL RELEASE AT THE REPOSITORY DUE TO CANISTER DROP
ALTERNATIVE 5 - RETRIEVAL DELAYED 100 YEARS

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2090.	1.04E-06	2.73E-07	6.98E-06	1.24E-06	1.28E-06	2.000E 06	2.56E-02	1.92E-06 5.89E-06	7.000E-07	1.79E-08
2100.	8.40E-07	2.23E-07	5.86E-06	1.06E-06	1.03E-06	2.000E 06	2.06E-02	1.54E-06 4.74E-06	7.000E-07	1.44E-08
2110.	6.78E-07	1.84E-07	4.96E-06	9.13E-07	8.40E-07	2.000E 06	1.68E-02	1.26E-06 3.86E-06	7.000E-07	1.18E-08
2120.	5.50E-07	1.52E-07	4.25E-06	7.95E-07	6.87E-07	2.000E 06	1.37E-02	1.03E-06 3.16E-06	7.000E-07	9.62E-09

TABLE B-93

OPERATIONAL RELEASE AT THE REPOSITORY DUE TO CANISTER DROP
ALTERNATIVE 5 - RETRIEVAL DELAYED 300 YEARS

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2290.	5.83E-08	1.67E-08	1.25E-06	2.63E-07	8.88E-08	2.000E 06	1.78E-03	1.33E-07 4.08E-07	7.000E-07	1.24E-09
2300.	5.54E-08	1.55E-08	1.21E-06	2.57E-07	8.50E-08	2.000E 06	1.70E-03	1.27E-07 3.91E-07	7.000E-07	1.19E-09
2310.	5.31E-08	1.45E-08	1.18E-06	2.50E-07	8.17E-08	2.000E 06	1.63E-03	1.23E-07 3.76E-07	7.000E-07	1.14E-09
2320.	5.10E-08	1.36E-08	1.15E-06	2.44E-07	7.88E-08	2.000E 06	1.58E-03	1.18E-07 3.62E-07	7.000E-07	1.10E-09

TABLE B-94

OPERATIONAL RELEASE AT THE REPOSITORY DUE TO CANISTER DROP
ALTERNATIVE 5 - RETRIEVAL DELAYED 500 YEARS

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2490.	3.47E-08	6.70E-09	8.33E-07	1.77E-07	5.40E-08	2.000E 06	1.08E-03	8.10E-08 2.48E-07	7.000E-07	7.56E-10
2500.	3.41E-08	6.52E-09	8.19E-07	1.74E-07	5.30E-08	2.000E 06	1.06E-03	7.95E-08 2.44E-07	7.000E-07	7.42E-10
2510.	3.35E-08	6.34E-09	8.06E-07	1.71E-07	5.21E-08	2.000E 06	1.04E-03	7.81E-08 2.40E-07	7.000E-07	7.29E-10
2520.	3.30E-08	6.17E-09	7.92E-07	1.68E-07	5.12E-08	2.000E 06	1.02E-03	7.68E-08 2.36E-07	7.000E-07	7.17E-10

B.1.2.2 Fault and Flooding

Data for migrational releases as the result of fault and flooding at the repository include effects for the implementation of Alternative 3 (stabilization and vitrification), Alternative 4, and Alternative 5 (retrieval delayed 100 years, 300 years, and 500 years).

TABLE B-95

MIGRATIONAL RELEASE AT THE REPOSITORY DUE TO FAULT AND FLOODING
ALTERNATIVE 3 - STABILIZE CALCINE

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed Number	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2500.	0.00	0.00	0.00	0.00	0.00	2.000E 06	0.00	0.00	2.000E-13	0.00
2600.	3.96E-01	0.00E-01	7.59E-01	1.16E 00	1.78E 00	2.000E 06	3.56E 04	2.67E 00 8.19E 00	2.000E-13	7.12E-09
269300.	3.91E-05	0.00E-01	7.69E-05	6.62E-05	5.45E-05	2.000E 06	1.09E 00	8.17E-05 2.51E-04	2.000E-13	2.18E-13
535900.	2.33E-03	2.82E-07	1.87E-02	2.30E-03	2.71E-03	2.000E 06	5.42E 01	4.06E-03 1.25E-02	2.000E-13	1.08E-11

TABLE B-96

MIGRATIONAL RELEASE AT THE REPOSITORY DUE TO FAULT AND FLOODING
ALTERNATIVE 3 - VITRIFY CALCINE

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2500.	0.00	0.00	0.00	0.00	0.00	2.000E 06	0.00	0.00	2.000E-13	0.00
2600.	3.96E-05	0.00E-01	7.59E-05	1.16E-04	1.78E-04	2.000E 06	3.56E 00	2.67E-04 8.19E-04	2.000E-13	7.12E-13
2700.	3.96E-05	0.00E-01	7.59E-05	1.16E-04	1.78E-04	2.000E 06	3.56E 00	2.67E-04 8.19E-04	2.000E-13	7.12E-13
2800.	3.96E-05	0.00E-01	7.59E-05	1.16E-04	1.78E-04	2.000E 06	3.56E 00	2.67E-04 8.19E-04	2.000E-13	7.12E-13
2900.	3.96E-05	0.00E-01	7.58E-05	1.16E-04	1.78E-04	2.000E 06	3.56E 00	2.67E-04 8.19E-04	2.000E-13	7.12E-13
3000.	3.96E-05	0.00E-01	7.58E-05	1.16E-04	1.78E-04	2.000E 06	3.56E 00	2.67E-04 8.19E-04	2.000E-13	7.12E-13
4000.	3.94E-05	0.00E-01	7.56E-05	1.16E-04	1.77E-04	2.000E 06	3.54E 00	2.65E-04 8.14E-04	2.000E-13	7.08E-13
7000.	3.91E-05	0.00E-01	7.48E-05	1.15E-04	1.76E-04	2.000E 06	3.52E 00	2.64E-04 8.10E-04	2.000E-13	7.04E-13
12000.	3.84E-05	0.00E-01	7.36E-05	1.13E-04	1.73E-04	2.000E 06	3.46E 00	2.59E-04 7.96E-04	2.000E-13	6.92E-13
269300.	1.37E-05	0.00E-01	2.69E-05	2.32E-05	1.91E-05	2.000E 06	3.82E-01	2.86E-05 8.79E-05	2.000E-13	7.64E-14
535900.	1.63E-03	1.98E-07	1.31E-02	1.61E-03	1.89E-03	2.000E 06	3.78E 01	2.83E-03 8.69E-03	2.000E-13	7.56E-12

TABLE B-97

MIGRATIONAL RELEASE AT THE REPOSITORY DUE TO FAULT AND FLOODING
ALTERNATIVE 4

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2500.	0.00	0.00	0.00	0.00	0.00	2.00CE 06	0.00	0.00	2.000E-13	0.00
2600.	3.96E-07	0.00E-01	7.59E-07	1.16E-06	1.78E-06	2.000E 06	3.56E-02	2.67E-06 8.19E-06	2.000E-13	7.12E-15
3000.	3.96E-07	0.00E-01	7.58E-07	1.16E-06	1.78E-06	2.000E 06	3.56E-02	2.67E-06 8.19E-06	2.000E-13	7.12E-15
4000.	3.94E-07	0.00E-01	7.56E-07	1.16E-06	1.77E-06	2.000E 06	3.54E-02	2.65E-06 8.14E-06	2.000E-13	7.08E-15
7000.	3.91E-07	0.00E-01	7.48E-07	1.15E-06	1.76E-06	2.000E 06	3.52E-02	2.64E-06 8.10E-06	2.000E-13	7.04E-15
12000.	3.84E-07	0.00E-01	7.36E-07	1.13E-06	1.73E-06	2.000E 06	3.46E-02	2.59E-06 7.96E-06	2.000E-13	6.92E-15
269300.	1.37E-07	0.00E-01	2.69E-07	2.32E-07	1.91E-07	2.000E 06	3.82E-03	2.86E-07 8.79E-07	2.000E-13	7.64E-16
535900.	1.63E-03	1.97E-07	1.31E-02	1.61E-03	1.89E-03	2.000E 06	3.78E 01	2.83E-03 8.69E-03	2.000E-13	7.56E-12

TABLE B-98

MIGRATIONAL RELEASE AT THE REPOSITORY DUE TO FAULT AND FLOODING
ALTERNATIVE 5 - RETRIEVAL DELAYED 100 YEARS

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2700.	3.96E-05	0.00E-01	7.59E-05	1.16E-04	1.78E-04	2.000E 06	3.56E 00	2.67E-04 8.19E-04	2.000E-13	7.12E-13
2800.	3.96E-05	0.00E-01	7.59E-05	1.16E-04	1.78E-04	2.000E 06	3.56E 00	2.67E-04 8.19E-04	2.000E-13	7.12E-13
2900.	3.96E-05	0.00E-01	7.58E-05	1.16E-04	1.78E-04	2.000E 06	3.56E 00	2.67E-04 8.19E-04	2.000E-13	7.12E-13
3000.	3.96E-05	0.00E-01	7.58E-05	1.16E-04	1.78E-04	2.000E 06	3.56E 00	2.67E-04 8.19E-04	2.000E-13	7.12E-13
4000.	3.94E-05	0.00E-01	7.56E-05	1.16E-04	1.77E-04	2.000E 06	3.54E 00	2.65E-04 8.14E-04	2.000E-13	7.08E-13
7000.	3.91E-05	0.00E-01	7.48E-05	1.15E-04	1.76E-04	2.000E 06	3.52E 00	2.64E-04 8.10E-04	2.000E-13	7.04E-13
12000.	3.84E-05	0.00E-01	7.36E-05	1.13E-04	1.73E-04	2.000E 06	3.46E 00	2.59E-04 7.96E-04	2.000E-13	6.92E-13
269400.	1.37E-05	0.00E-01	2.69E-05	2.32E-05	1.91E-05	2.000E 06	3.82E-01	2.86E-05 8.79E-05	2.000E-13	7.64E-14
536000.	1.63E-03	1.97E-07	1.31E-02	1.61E-03	1.89E-03	2.000E 06	3.78E 01	2.83E-03 8.69E-03	2.000E-13	7.56E-12

TABLE B-99

MIGRATIONAL RELEASE AT THE REPOSITORY DUE TO FAULT AND FLOODING
ALTERNATIVE 5 - RETRIEVAL DELAYED 300 YEARS

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2900.	3.96E-05	0.00E-01	7.58E-05	1.16E-04	1.78E-04	2.000E 06	3.56E 00	2.67E-04 8.19E-04	2.000E-13	7.12E-13
3000.	3.96E-05	0.00E-01	7.58E-05	1.16E-04	1.78E-04	2.000E 06	3.56E 00	2.67E-04 8.19E-04	2.000E-13	7.12E-13
4000.	3.94E-05	0.00E-01	7.56E-05	1.16E-04	1.77E-04	2.000E 06	3.54E 00	2.65E-04 8.14E-04	2.000E-13	7.08E-13
7000.	3.91E-05	0.00E-01	7.48E-05	1.15E-04	1.76E-04	2.000E 06	3.52E 00	2.64E-04 8.10E-04	2.000E-13	7.04E-13
12000.	3.84E-05	0.00E-01	7.36E-05	1.13E-04	1.73E-04	2.000E 06	3.46E 00	2.59E-04 7.96E-04	2.000E-13	6.92E-13
269600.	1.37E-05	0.00E-01	2.69E-05	2.32E-05	1.91E-05	2.000E 06	3.82E-01	2.86E-05 8.79E-05	2.000E-13	7.64E-14
536200.	1.63E-03	1.97E-07	1.31E-02	1.61E-03	1.89E-03	2.000E 06	3.78E 01	2.83E-03 8.69E-03	2.000E-13	7.56E-12

TABLE B-100

MIGRATIONAL RELEASE AT THE REPOSITORY DUE TO FAULT AND FLOODING
ALTERNATIVE 5 - RETRIEVAL DELAYED 500 YEARS

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
3100.	3.96E-05	0.00E-01	7.58E-05	1.16E-04	1.78E-04	2.000E 06	3.56E 00	2.67E-04 8.19E-04	2.000E-13	7.12E-13
4000.	3.94E-05	0.00E-01	7.56E-05	1.16E-04	1.77E-04	2.000E 06	3.54E 00	2.65E-04 8.14E-04	2.000E-13	7.08E-13
7000.	3.91E-05	0.00E-01	7.48E-05	1.15E-04	1.76E-04	2.000E 06	3.52E 00	2.64E-04 8.10E-04	2.000E-13	7.04E-13
12000.	3.84E-05	0.00E-01	7.36E-05	1.13E-04	1.73E-04	2.000E 06	3.46E 00	2.59E-04 7.96E-04	2.000E-13	6.92E-13
269800.	1.37E-05	0.00E-01	2.69E-05	2.32E-05	1.91E-05	2.000E 06	3.82E-01	2.86E-05 8.79E-05	2.000E-13	7.64E-14
536400.	1.63E-03	1.97E-07	1.31E-02	1.61E-03	1.89E-03	2.000E 06	3.78E 01	2.83E-03 8.69E-03	2.000E-13	7.56E-12

B.1.2.3 Solution Mining

Data for migrational releases as the result of solution mining at the repository include effects for the implementation of Alternative 3 (stabilization and vitrification), Alternative 4, and Alternative 5 (retrieval delayed 100 years, 300 years, and 500 years).

TABLE B-101

MIGRATIONAL RELEASE AT THE REPOSITORY DUE TO SOLUTION MINING
ALTERNATIVE 3 - STABILIZE CALCINE

	50-Year Dose Commitment to Maximum Individual					Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2500.	1.11E-02	3.45E-06	2.69E-01	5.70E-02	1.71E-02	4.000E 07	6.84E 05	5.13E 01 1.57E 02	1.000E-06	6.84E-01
2600.	9.50E-03	8.33E-07	2.28E-01	4.85E-02	1.45E-02	4.000E 07	5.80E 05	4.35E 01 1.33E 02	1.000E-06	5.80E-01
2700.	8.16E-03	5.24E-07	1.95E-01	4.13E-02	1.24E-02	4.000E 07	4.96E 05	3.72E 01 1.14E 02	1.000E-06	4.96E-01
2800.	7.02E-03	4.54E-07	1.66E-01	3.53E-02	1.06E-02	4.000E 07	4.24E 05	3.18E 01 9.75E 01	1.000E-06	4.24E-01
2900.	6.06E-03	4.13E-07	1.42E-01	3.02E-02	9.12E-03	4.000E 07	3.65E 05	2.74E 01 8.39E 01	1.000E-06	3.65E-01
3000.	5.25E-03	3.81E-07	1.22E-01	2.59E-02	7.83E-03	4.000E 07	3.13E 05	2.35E 01 7.20E 01	1.000E-06	3.13E-01
4000.	1.51E-03	2.31E-07	2.84E-02	5.97E-03	1.93E-03	4.000E 07	7.72E 04	5.79E 00 1.78E 01	1.000E-06	7.72E-02
7000.	5.55E-04	1.92E-07	4.41E-03	8.72E-04	4.18E-04	4.000E 07	1.67E 04	1.25E 00 3.85E 00	1.000E-06	1.67E-02
12000.	5.40E-04	1.89E-07	3.66E-03	6.80E-04	3.69E-04	4.000E 07	1.48E 04	1.11E 00 3.39E 00	1.000E-06	1.48E-02
22000.	5.51E-04	1.87E-07	3.27E-03	5.23E-04	3.44E-04	4.000E 07	1.38E 04	1.03E 00 3.16E 00	1.000E-06	1.38E-02
52000.	6.21E-04	1.83E-07	3.75E-03	4.17E-04	3.73E-04	4.000E 07	1.49E 04	1.12E 00 3.43E 00	1.000E-06	1.49E-02
102000.	6.99E-04	1.74E-07	4.84E-03	4.24E-04	4.32E-04	4.000E 07	1.73E 04	1.30E 00 3.97E 00	1.000E-06	1.73E-02
202000.	6.98E-04	1.48E-07	5.48E-03	4.34E-04	4.50E-04	4.000E 07	1.80E 04	1.35E 00 4.14E 00	1.000E-06	1.80E-02
502000.	3.93E-04	7.76E-08	3.38E-03	2.71E-04	2.65E-04	4.000E 07	1.06E 04	7.95E-01 2.44E 00	1.000E-06	1.06E-02
1002000.	1.23E-04	2.88E-08	1.10E-03	1.07E-04	8.66E-05	4.000E 07	3.46E 03	2.60E-01 7.97E-01	1.000E-06	3.46E-03

TABLE B-102

MIGRATIONAL RELEASE AT THE REPOSITORY DUE TO SOLUTION MINING
ALTERNATIVE 3 - VITRIFY CALCINE

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2500.	1.11E-02	3.45E-06	2.69E-01	5.70E-02	1.71E-02	4.00GE 07	6.84E 05	5.13E 01 1.57E 02	1.000E-06	6.84E-01
2600.	9.50E-03	8.33E-07	2.28E-01	4.85E-02	1.45E-02	4.000E 07	5.80E 05	4.35E 01 1.33E 02	1.000E-06	5.80E-01
2700.	8.16E-03	5.24E-07	1.95E-01	4.13E-02	1.24E-02	4.000E 07	4.96E 05	3.72E 01 1.14E 02	1.000E-06	4.96E-01
2800.	7.02E-03	4.54E-07	1.66E-01	3.53E-02	1.06E-02	4.000E 07	4.24E 05	3.18E 01 9.75E 01	1.000E-06	4.24E-01
2900.	6.06E-03	4.13E-07	1.42E-01	3.02E-02	9.12E-03	4.000E 07	3.65E 05	2.74E 01 8.39E 01	1.000E-06	3.65E-01
3000.	5.25E-03	3.81E-07	1.22E-01	2.59E-02	7.83E-03	4.000E 07	3.13E 05	2.35E 01 7.20E 01	1.000E-06	3.13E-01
4000.	1.51E-03	2.31E-07	2.84E-02	5.97E-03	1.93E-03	4.000E 07	7.72E 04	5.79E 00 1.78E 01	1.000E-06	7.72E-02
7000.	5.55E-04	1.92E-07	4.41E-03	8.72E-04	4.18E-04	4.000E 07	1.67E 04	1.25E 00 3.85E 00	1.000E-06	1.67E-02
12000.	5.40E-04	1.89E-07	3.66E-03	6.80E-04	3.69E-04	4.000E 07	1.48E 04	1.11E 00 3.39E 00	1.000E-06	1.48E-02
22000.	5.51E-04	1.87E-07	3.27E-03	5.23E-04	3.44E-04	4.000E 07	1.38E 04	1.03E 00 3.16E 00	1.000E-06	1.38E-02
52000.	6.21E-04	1.83E-07	3.75E-03	4.17E-04	3.73E-04	4.000E 07	1.49E 04	1.12E 00 3.43E 00	1.000E-06	1.49E-02
102000.	6.99E-04	1.74E-07	4.84E-03	4.24E-04	4.32E-04	4.000E 07	1.73E 04	1.30E 00 3.97E 00	1.000E-06	1.73E-02
202000.	6.98E-04	1.48E-07	5.48E-03	4.34E-04	4.50E-04	4.000E 07	1.80E 04	1.35E 00 4.14E 00	1.000E-06	1.80E-02
502000.	3.93E-04	7.76E-08	3.38E-03	2.71E-04	2.65E-04	4.000E 07	1.06E 04	7.95E-01 2.44E 00	1.000E-06	1.06E-02
1002000.	1.23E-04	2.88E-08	1.10E-03	1.07E-04	8.66E-05	4.000E 07	3.46E 03	2.60E-01 7.97E-01	1.000E-06	3.46E-03

TABLE B-103

MIGRATIONAL RELEASE AT THE REPOSITORY DUE TO SOLUTION MINING
ALTERNATIVE 4

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2500.	1.11E-02	6.35E-07	2.68E-01	5.70E-02	1.71E-02	4.000E 07	6.84E 05	5.13E 01 1.57E 02	1.000E-06	6.84E-01
2600.	9.50E-03	5.50E-07	2.28E-01	4.84E-02	1.45E-02	4.000E 07	5.80E 05	4.35E 01 1.33E 02	1.000E-06	5.80E-01
2700.	8.15E-03	4.96E-07	1.95E-01	4.13E-02	1.24E-02	4.000E 07	4.96E 05	3.72E 01 1.14E 02	1.000E-06	4.96E-01
2800.	7.02E-03	4.51E-07	1.66E-01	3.53E-02	1.06E-02	4.000E 07	4.24E 05	3.18E 01 9.75E 01	1.000E-06	4.24E-01
2900.	6.06E-03	4.13E-07	1.42E-01	3.02E-02	9.11E-03	4.000E 07	3.64E 05	2.73E 01 8.38E 01	1.000E-06	3.64E-01
3000.	5.25E-03	3.81E-07	1.22E-01	2.59E-02	7.83E-03	4.000E 07	3.13E 05	2.35E 01 7.20E 01	1.000E-06	3.13E-01
4000.	1.50E-03	2.31E-07	2.84E-02	5.97E-03	1.93E-03	4.000E 07	7.72E 04	5.79E 00 1.78E 01	1.000E-06	7.72E-02
7000.	5.54E-04	1.91E-07	4.41E-03	8.70E-04	4.15E-04	4.000E 07	1.66E 04	1.24E 00 3.82E 00	1.000E-06	1.66E-02
12000.	5.39E-04	1.89E-07	3.65E-03	6.78E-04	3.66E-04	4.000E 07	1.46E 04	1.10E 00 3.37E 00	1.000E-06	1.46E-02
22000.	5.50E-04	1.87E-07	3.27E-03	5.21E-04	3.41E-04	4.000E 07	1.36E 04	1.02E 00 3.14E 00	1.000E-06	1.36E-02
52000.	6.20E-04	1.83E-07	3.75E-03	4.15E-04	3.70E-04	4.000E 07	1.48E 04	1.11E 00 3.40E 00	1.000E-06	1.48E-02
102000.	6.98E-04	1.74E-07	4.83E-03	4.22E-04	4.30E-04	4.000E 07	1.72E 04	1.29E 00 3.96E 00	1.000E-06	1.72E-02
202000.	6.97E-04	1.48E-07	5.48E-03	4.32E-04	4.48E-04	4.000E 07	1.79E 04	1.34E 00 4.12E 00	1.000E-06	1.79E-02
502000.	3.92E-04	7.76E-08	3.37E-03	2.69E-04	2.63E-04	4.000E 07	1.05E 04	7.89E-01 2.42E 00	1.000E-06	1.05E-02
1002000.	1.22E-04	2.88E-08	1.10E-03	1.06E-04	8.59E-05	4.000E 07	3.44E 03	2.58E-01 7.90E-01	1.000E-06	3.44E-03

TABLE B-104

MIGRATIONAL RELEASE AT THE REPOSITORY DUE TO SOLUTION MINING
ALTERNATIVE 5 - RETRIEVAL DELAYED 100 YEARS

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2600.	9.50E-03	8.33E-07	2.28E-01	4.85E-02	1.45E-02	4.000E 07	5.80E 05	4.35E 01 1.33E 02	1.000E-06	5.80E-01
2700.	8.16E-03	5.24E-07	1.95E-01	4.13E-02	1.24E-02	4.000E 07	4.96E 05	3.72E 01 1.14E 02	1.000E-06	4.96E-01
2800.	7.02E-03	4.54E-07	1.66E-01	3.53E-02	1.06E-02	4.000E 07	4.24E 05	3.18E 01 9.75E 01	1.000E-06	4.24E-01
2900.	6.06E-03	4.13E-07	1.42E-01	3.02E-02	9.12E-03	4.000E 07	3.65E 05	2.74E 01 8.39E 01	1.000E-06	3.65E-01
3000.	5.25E-03	3.81E-07	1.22E-01	2.59E-02	7.83E-03	4.000E 07	3.13E 05	2.35E 01 7.20E 01	1.000E-06	3.13E-01
4000.	1.51E-03	2.31E-07	2.84E-02	5.97E-03	1.93E-03	4.000E 07	7.72E 04	5.79E 00 1.78E 01	1.000E-06	7.72E-02
7000.	5.55E-04	1.92E-07	4.41E-03	8.72E-04	4.18E-04	4.000E 07	1.67E 04	1.25E 00 3.85E 00	1.000E-06	1.67E-02
12000.	5.40E-04	1.89E-07	3.66E-03	6.80E-04	3.69E-04	4.000E 07	1.48E 04	1.11E 00 3.39E 00	1.000E-06	1.48E-02
22000.	5.51E-04	1.87E-07	3.27E-03	5.23E-04	3.44E-04	4.000E 07	1.38E 04	1.03E 00 3.16E 00	1.000E-06	1.38E-02
52000.	6.21E-04	1.83E-07	3.75E-03	4.17E-04	3.73E-04	4.000E 07	1.49E 04	1.12E 00 3.43E 00	1.000E-06	1.49E-02
102000.	6.99E-04	1.74E-07	4.84E-03	4.24E-04	4.32E-04	4.000E 07	1.73E 04	1.30E 00 3.97E 00	1.000E-06	1.73E-02
202000.	6.98E-04	1.48E-07	5.48E-03	4.34E-04	4.50E-04	4.000E 07	1.80E 04	1.35E 00 4.14E 00	1.000E-06	1.80E-02
502000.	3.93E-04	7.76E-08	3.38E-03	2.71E-04	2.65E-04	4.000E 07	1.06E 04	7.95E-01 2.44E 00	1.000E-06	1.06E-02
1002000.	1.23E-04	2.88E-08	1.10E-03	1.07E-04	8.66E-05	4.000E 07	3.46E 03	2.60E-01 7.97E-01	1.000E-06	3.46E-03

TABLE B-105

MIGRATIONAL RELEASE AT THE REPOSITORY DUE TO SOLUTION MINING
ALTERNATIVE 5 - RETRIEVAL DELAYED 300 YEARS

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2800.	7.02E-03	4.54E-07	1.66E-01	3.53E-02	1.06E-02	4.000E 07	4.24E 05	3.18E 01 9.75E 01	1.000E-06	4.24E-01
2900.	6.06E-03	4.13E-07	1.42E-01	3.02E-02	9.12E-03	4.000E 07	3.65E 05	2.74E 01 8.39E 01	1.000E-06	3.65E-01
3000.	5.25E-03	3.81E-07	1.22E-01	2.59E-02	7.83E-03	4.000E 07	3.13E 05	2.35E 01 7.20E 01	1.000E-06	3.13E-01
4000.	1.51E-03	2.31E-07	2.84E-02	5.97E-03	1.93E-03	4.000E 07	7.72E 04	5.79E 00 1.78E 01	1.000E-06	7.72E-02
7000.	5.55E-04	1.92E-07	4.41E-03	8.72E-04	4.18E-04	4.000E 07	1.67E 04	1.25E 00 3.85E 00	1.000E-06	1.67E-02
12000.	5.40E-04	1.89E-07	3.66E-03	6.80E-04	3.69E-04	4.000E 07	1.48E 04	1.11E 00 3.39E 00	1.000E-06	1.48E-02
22000.	5.51E-04	1.87E-07	3.27E-03	5.23E-04	3.44E-04	4.000E 07	1.38E 04	1.03E 00 3.16E 00	1.000E-06	1.38E-02
52000.	6.21E-04	1.83E-07	3.75E-03	4.17E-04	3.73E-04	4.000E 07	1.49E 04	1.12E 00 3.43E 00	1.000E-06	1.49E-02
102000.	6.99E-04	1.74E-07	4.84E-03	4.24E-04	4.32E-04	4.000E 07	1.73E 04	1.30E 00 3.97E 00	1.000E-06	1.73E-02
202000.	6.98E-04	1.48E-07	5.48E-03	4.34E-04	4.50E-04	4.000E 07	1.80E 04	1.35E 00 4.14E 00	1.000E-06	1.80E-02
502000.	3.93E-04	7.76E-08	3.38E-03	2.71E-04	2.65E-04	4.000E 07	1.06E 04	7.95E-01 2.44E 00	1.000E-06	1.06E-02
1002000.	1.23E-04	2.88E-08	1.10E-03	1.07E-04	8.66E-05	4.000E 07	3.46E 03	2.60E-01 7.97E-01	1.000E-06	3.46E-03

TABLE B-106

MIGRATIONAL RELEASE AT THE REPOSITORY DUE TO SOLUTION MINING
ALTERNATIVE 5 - RETRIEVAL DELAYED 500 YEARS

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
3000.	5.25E-03	3.81E-07	1.22E-01	2.59E-02	7.83E-03	4.000E 07	3.13E 05	2.35E 01 7.20E 01	1.000E-06	3.13E-01
4000.	1.51E-03	2.31E-07	2.84E-02	5.97E-03	1.93E-03	4.000E 07	7.72E 04	5.79E 00 1.78E 01	1.000E-06	7.72E-02
7000.	5.55E-04	1.92E-07	4.41E-03	8.72E-04	4.18E-04	4.000E 07	1.67E 04	1.25E 00 3.85E 00	1.000E-06	1.67E-02
12000.	5.40E-04	1.89E-07	3.66E-03	6.80E-04	3.69E-04	4.000E 07	1.48E 04	1.11E 00 3.39E 00	1.000E-06	1.48E-02
22000.	5.51E-04	1.87E-07	3.27E-03	5.23E-04	3.44E-04	4.000E 07	1.38E 04	1.03E 00 3.16E 00	1.000E-06	1.38E-02
52000.	6.21E-04	1.83E-07	3.75E-03	4.17E-04	3.73E-04	4.000E 07	1.49E 04	1.12E 00 3.43E 00	1.000E-06	1.49E-02
102000.	6.99E-04	1.74E-07	4.84E-03	4.24E-04	4.32E-04	4.000E 07	1.73E 04	1.30E 00 3.97E 00	1.000E-06	1.73E-02
202000.	6.98E-04	1.48E-07	5.48E-03	4.34E-04	4.50E-04	4.000E 07	1.80E 04	1.35E 00 4.14E 00	1.000E-06	1.80E-02
502000.	3.93E-04	7.76E-08	3.38E-03	2.71E-04	2.65E-04	4.000E 07	1.06E 04	7.95E-01 2.44E 00	1.000E-06	1.06E-02
1002000.	1.23E-04	2.88E-08	1.10E-03	1.07E-04	8.66E-05	4.000E 07	3.46E 03	2.60E-01 7.97E-01	1.000E-06	3.46E-03

B.1.2.4 Exploratory Drilling

Data for intrusional releases resulting from exploratory drilling at the repository include effects for the implementation of Alternative 3 (stabilization and vitrification), Alternative 4, and Alternative 5 (retrieval delayed 100 years, 300 years, and 500 years).

TABLE B-107

INTRUSIONAL RELEASE AT THE REPOSITORY DUE TO EXPLORATORY DRILLING
ALTERNATIVE 3 - STABILIZE CALCINE

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2100.	4.60E 02	5.92E 01	3.20E 03	2.51E 02	5.72E 03	25.0	1.43E 05	1.07E 01 3.29E 01	5.000E-07	7.15E-02
2200.	4.41E 01	6.27E 00	3.02E 02	2.95E 01	5.70E 02	25.0	1.43E 04	1.07E 00 3.28E 00	5.000E-07	7.12E-03
2500.	7.43E-01	1.26E-01	1.17E 01	2.76E 00	2.36E 00	25.0	5.90E 01	4.42E-03 1.36E-02	5.000E-07	2.95E-05
3000.	4.76E-01	5.61E-02	5.47E 00	1.47E 00	1.32E 00	25.0	3.30E 01	2.47E-03 7.59E-03	5.000E-07	1.65E-05
4000.	3.29E-01	3.11E-02	1.72E 00	6.52E-01	1.03E 00	25.0	2.57E 01	1.93E-03 5.92E-03	5.000E-07	1.29E-05
7000.	3.36E-01	2.11E-02	8.50E-01	4.79E-01	9.72E-01	25.0	2.43E 01	1.82E-03 5.59E-03	5.000E-07	1.21E-05
12000.	4.45E-01	1.61E-02	9.60E-01	5.32E-01	1.03E 00	25.0	2.57E 01	1.93E-03 5.92E-03	5.000E-07	1.29E-05
22000.	6.33E-01	1.11E-02	1.27E 00	6.44E-01	1.14E 00	25.0	2.85E 01	2.14E-03 6.55E-03	5.000E-07	1.42E-05
52000.	1.10E 00	4.27E-03	2.03E 00	9.35E-01	1.38E 00	25.0	3.45E 01	2.59E-03 7.93E-03	5.000E-07	1.72E-05
102000.	1.60E 00	1.67E-03	2.91E 00	1.20E 00	1.61E 00	25.0	4.02E 01	3.02E-03 9.26E-03	5.000E-07	2.01E-05
202000.	1.80E 00	8.25E-04	3.30E 00	1.30E 00	1.61E 00	25.0	4.02E 01	3.02E-03 9.26E-03	5.000E-07	2.01E-05
502000.	1.00E 00	4.65E-04	2.00E 00	7.50E-01	8.65E-01	25.0	2.16E 01	1.62E-03 4.97E-03	5.000E-07	1.08E-05
1002000.	2.70E-01	1.93E-04	6.51E-01	2.10E-01	2.30E-01	25.0	5.75E 00	4.31E-04 1.32E-03	5.000E-07	2.87E-06

TABLE B-108

INTRUSIONAL RELEASE AT THE REPOSITORY DUE TO EXPLORATORY DRILLING
ALTERNATIVE 3 - VITRIFY CALCINE

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2100.	3.10E 02	3.98E 01	2.10E 03	1.71E 02	3.75E 03	25.0	9.38E 04	7.03E 00 2.16E 01	5.000E-07	4.69E-02
2200.	2.91E 01	4.22E 00	2.02E 02	1.94E 01	3.73E 02	25.0	9.33E 03	6.99E-01 2.14E 00	5.000E-07	4.66E-03
2300.	3.24E 00	5.60E-01	2.80E 01	4.21E 00	3.91E 01	25.0	9.77E 02	7.33E-02 2.25E-01	5.000E-07	4.89E-04
2400.	7.80E-01	1.49E-01	1.07E 01	2.24E 00	4.96E 00	25.0	1.24E 02	9.30E-03 2.85E-02	5.000E-07	6.20E-05
2500.	4.92E-01	8.60E-02	7.81E 00	1.81E 00	1.55E 00	25.0	3.87E 01	2.91E-03 8.91E-03	5.000E-07	1.94E-05
2600.	4.28E-01	6.45E-02	6.51E 00	1.58E 00	1.13E 00	25.0	2.82E 01	2.12E-03 6.50E-03	5.000E-07	1.41E-05
2700.	3.95E-01	5.41E-02	5.65E 00	1.37E 00	1.02E 00	25.0	2.55E 01	1.91E-03 5.86E-03	5.000E-07	1.27E-05
2800.	3.63E-01	4.71E-02	4.81E 00	1.26E 00	9.65E-01	25.0	2.41E 01	1.81E-03 5.55E-03	5.000E-07	1.21E-05
2900.	3.32E-01	4.21E-02	4.18E 00	1.06E 00	9.12E-01	25.0	2.28E 01	1.71E-03 5.24E-03	5.000E-07	1.14E-05
3000.	3.11E-01	3.81E-02	3.65E 00	9.61E-01	8.80E-01	25.0	2.20E 01	1.65E-03 5.06E-03	5.000E-07	1.10E-05
4000.	2.16E-01	2.10E-02	1.15E 00	4.39E-01	6.82E-01	25.0	1.70E 01	1.28E-03 3.92E-03	5.000E-07	8.52E-06
7000.	2.24E-01	1.50E-02	5.70E-01	3.20E-01	6.48E-01	25.0	1.62E 01	1.21E-03 3.73E-03	5.000E-07	8.10E-06
12000.	2.93E-01	1.10E-02	6.48E-01	3.55E-01	6.76E-01	25.0	1.69E 01	1.27E-03 3.89E-03	5.000E-07	8.45E-06
22000.	4.22E-01	7.25E-03	8.39E-01	4.29E-01	7.54E-01	25.0	1.88E 01	1.41E-03 4.34E-03	5.000E-07	9.42E-06
52000.	7.31E-01	2.95E-03	1.42E 00	6.23E-01	9.31E-01	25.0	2.33E 01	1.75E-03 5.35E-03	5.000E-07	1.16E-05
102000.	1.00E 00	1.15E-03	1.91E 00	8.11E-01	1.08E 00	25.0	2.70E 01	2.02E-03 6.21E-03	5.000E-07	1.35E-05
202000.	1.20E 00	5.63E-04	2.20E 00	8.80E-01	1.07E 00	25.0	2.67E 01	2.01E-03 6.15E-03	5.000E-07	1.34E-05
502000.	6.80E-01	3.13E-04	1.40E 00	5.00E-01	5.77E-01	25.0	1.44E 01	1.08E-03 3.32E-03	5.000E-07	7.21E-06
1002000.	1.80E-01	1.29E-04	4.31E-01	1.40E-01	1.57E-01	25.0	3.92E 00	2.94E-04 9.03E-04	5.000E-07	1.96E-06

TABLE B-109

INTRUSIONAL RELEASE AT THE REPOSITORY DUE TO EXPLORATORY DRILLING
ALTERNATIVE 4

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2100.	1.66E 03	4.10E 02	1.73E 04	2.38E 03	1.80E 04	25.0	4.50E 05	3.37E 01	5.000E-07	2.25E-01
2200.	4.01E 02	1.47E 02	6.83E 03	1.35E 03	2.15E 03	25.0	5.38E 04	1.03E 02 4.03E 00	5.000E-07	2.69E-02
2500.	1.79E 02	3.50E 01	3.32E 03	7.05E 02	2.71E 02	25.0	6.78E 03	1.24E 01 5.08E-01	5.000E-07	3.39E-03
3000.	1.05E 02	1.60E 01	1.51E 03	3.32E 02	1.38E 02	25.0	3.45E 03	1.56E 00 2.59E-01	5.000E-07	1.72E-03
4000.	6.56E 01	9.12E 00	4.53E 02	1.00E 02	5.38E 01	25.0	1.34E 03	7.93E-01 1.01E-01	5.000E-07	6.72E-04
7000.	6.88E 01	6.32E 00	1.94E 02	4.94E 01	4.39E 01	25.0	1.10E 03	3.09E-01 8.23E-02	5.000E-07	5.49E-04
12000.	9.94E 01	4.82E 00	2.23E 02	6.64E 01	6.60E 01	25.0	1.65E 03	2.52E-01 1.24E-01	5.000E-07	8.25E-04
22000.	1.61E 02	3.12E 00	3.11E 02	1.03E 02	1.13E 02	25.0	2.83E 03	3.79E-01 2.12E-01	5.000E-07	1.41E-03
52000.	3.00E 02	1.22E 00	5.58E 02	1.91E 02	2.22E 02	25.0	5.55E 03	6.50E-01 4.16E-01	5.000E-07	2.77E-03
102000.	4.30E 02	4.82E-01	8.12E 02	2.90E 02	3.21E 02	25.0	8.03E 03	1.28E 00 6.02E-01	5.000E-07	4.01E-03
202000.	5.00E 02	2.39E-01	9.41E 02	3.40E 02	3.81E 02	25.0	9.53E 03	1.85E 00 7.14E-01	5.000E-07	4.76E-03
502000.	2.90E 02	1.30E-01	5.81E 02	2.00E 02	2.21E 02	25.0	5.53E 03	2.19E 00 4.14E-01	5.000E-07	2.76E-03
1002000.	7.80E 01	5.49E-02	1.90E 02	5.80E 01	6.03E 01	25.0	1.51E 03	1.27E 00 1.13E-01 3.47E-01	5.000E-07	7.54E-04

TABLE B-110

INTRUSIONAL RELEASE AT THE REPOSITORY DUE TC EXPLORATORY DRILLING
ALTERNATIVE 5 - RETRIEVAL DELAYED 100 YEARS

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2200.	2.91E 01	4.22E 00	2.02E 02	1.94E 01	3.73E 02	25.0	9.33E 03	6.99E-01 2.14E 00	5.000E-07	4.66E-03
2300.	3.24E 00	5.60E-01	2.80E 01	4.21E 00	3.91E 01	25.0	9.77E 02	7.33E-02 2.25E-01	5.000E-07	4.89E-04
2400.	7.80E-01	1.49E-01	1.07E 01	2.24E 00	4.96E 00	25.0	1.24E 02	9.30E-03 2.85E-02	5.000E-07	6.20E-05
2500.	4.92E-01	8.60E-02	7.81E 00	1.81E 00	1.55E 00	25.0	3.87E 01	2.91E-03 8.91E-03	5.000E-07	1.94E-05
2600.	4.28E-01	6.45E-02	6.51E 00	1.58E 00	1.13E 00	25.0	2.82E 01	2.12E-03 6.50E-03	5.000E-07	1.41E-05
2700.	3.95E-01	5.41E-02	5.65E 00	1.37E 00	1.02E 00	25.0	2.55E 01	1.91E-03 5.86E-03	5.000E-07	1.27E-05
2800.	3.63E-01	4.71E-02	4.81E 00	1.26E 00	9.65E-01	25.0	2.41E 01	1.81E-03 5.55E-03	5.000E-07	1.21E-05
2900.	3.32E-01	4.21E-02	4.18E 00	1.06E 00	9.12E-01	25.0	2.28E 01	1.71E-03 5.24E-03	5.000E-07	1.14E-05
3000.	3.11E-01	3.81E-02	3.65E 00	9.61E-01	8.80E-01	25.0	2.20E 01	1.65E-03 5.06E-03	5.000E-07	1.10E-05
4000.	2.16E-01	2.10E-02	1.15E 00	4.39E-01	6.82E-01	25.0	1.70E 01	1.28E-03 3.92E-03	5.000E-07	8.52E-06
7000.	2.24E-01	1.50E-02	5.70E-01	3.20E-01	6.48E-01	25.0	1.62E 01	1.21E-03 3.73E-03	5.000E-07	8.10E-06
12000.	2.93E-01	1.10E-02	6.48E-01	3.55E-01	6.76E-01	25.0	1.69E 01	1.27E-03 3.89E-03	5.000E-07	8.45E-06
22000.	4.22E-01	7.25E-03	8.39E-01	4.29E-01	7.54E-01	25.0	1.88E 01	1.41E-03 4.34E-03	5.000E-07	9.42E-06
52000.	7.31E-01	2.95E-03	1.42E 00	6.23E-01	9.31E-01	25.0	2.33E 01	1.75E-03 5.35E-03	5.000E-07	1.16E-05
102000.	1.00E 00	1.15E-03	1.91E 00	8.11E-01	1.08E 00	25.0	2.70E 01	2.02E-03 6.21E-03	5.000E-07	1.35E-05
202000.	1.20E 00	5.63E-04	2.20E 00	8.80E-01	1.07E 00	25.0	2.67E 01	2.01E-03 6.15E-03	5.000E-07	1.34E-05
502000.	6.80E-01	3.13E-04	1.40E 00	5.00E-01	5.77E-01	25.0	1.44E 01	1.08E-03 3.32E-03	5.000E-07	7.21E-06
1002000.	1.80E-01	1.29E-04	4.31E-01	1.40E-01	1.57E-01	25.0	3.92E 00	2.94E-04 9.03E-04	5.000E-07	1.96E-06

TABLE B-111

INTRUSIONAL RELEASE AT THE REPOSITORY DUE TO EXPLORATORY DRILLING
ALTERNATIVE 5 - RETRIEVAL DELAYED 300 YEARS

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2300.	3.24E 00	5.60E-01	2.80E 01	4.21E 00	3.91E 01	25.0	9.77E 02	7.33E-02 2.25E-01	5.000E-07	4.89E-04
2400.	7.80E-01	1.49E-01	1.07E 01	2.24E 00	4.96E 00	25.0	1.24E 02	9.30E-03 2.85E-02	5.000E-07	6.20E-05
2500.	4.92E-01	8.60E-02	7.81E 00	1.81E 00	1.55E 00	25.0	3.87E 01	2.91E-03 8.91E-03	5.000E-07	1.94E-05
2600.	4.28E-01	6.45E-02	6.51E 00	1.58E 00	1.13E 00	25.0	2.82E 01	2.12E-03 6.50E-03	5.000E-07	1.41E-05
2700.	3.95E-01	5.41E-02	5.65E 00	1.37E 00	1.02E 00	25.0	2.55E 01	1.91E-03 5.86E-03	5.000E-07	1.27E-05
2800.	3.63E-01	4.71E-02	4.81E 00	1.26E 00	9.65E-01	25.0	2.41E 01	1.81E-03 5.55E-03	5.000E-07	1.21E-05
2900.	3.32E-01	4.21E-02	4.18E 00	1.06E 00	9.12E-01	25.0	2.28E 01	1.71E-03 5.24E-03	5.000E-07	1.14E-05
3000.	3.11E-01	3.81E-02	3.65E 00	9.61E-01	8.80E-01	25.0	2.20E 01	1.65E-03 5.06E-03	5.000E-07	1.10E-05
4000.	2.16E-01	2.10E-02	1.15E 00	4.39E-01	6.82E-01	25.0	1.70E 01	1.28E-03 3.92E-03	5.000E-07	8.52E-06
7000.	2.24E-01	1.50E-02	5.70E-01	3.20E-01	6.48E-01	25.0	1.62E 01	1.21E-03 3.73E-03	5.000E-07	8.10E-06
12000.	2.93E-01	1.10E-02	6.48E-01	3.55E-01	6.76E-01	25.0	1.69E 01	1.27E-03 3.89E-03	5.000E-07	8.45E-06
22000.	4.22E-01	7.25E-03	8.39E-01	4.29E-01	7.54E-01	25.0	1.88E 01	1.41E-03 4.34E-03	5.000E-07	9.42E-06
52000.	7.31E-01	2.95E-03	1.42E 00	6.23E-01	9.31E-01	25.0	2.33E 01	1.75E-03 5.35E-03	5.000E-07	1.16E-05
102000.	1.00E 00	1.15E-03	1.91E 00	8.11E-01	1.08E 00	25.0	2.70E 01	2.02E-03 6.21E-03	5.000E-07	1.35E-05
202000.	1.20E 00	5.63E-04	2.20E 00	8.80E-01	1.07E 00	25.0	2.67E 01	2.01E-03 6.15E-03	5.000E-07	1.34E-05
502000.	6.80E-01	3.13E-04	1.40E 00	5.00E-01	5.77E-01	25.0	1.44E 01	1.08E-03 3.32E-03	5.000E-07	7.21E-06
1002000.	1.80E-01	1.29E-04	4.31E-01	1.40E-01	1.57E-01	25.0	3.92E 00	2.94E-04 9.03E-04	5.000E-07	1.96E-06

TABLE B-112

INTRUSIONAL RELEASE AT THE REPOSITORY DUE TO EXPLORATORY DRILLING
ALTERNATIVE 5 - RETRIEVAL DELAYED 500 YEARS

50-Year Dose Commitment to Maximum Individual						Population Effects				
Year of Exposure	Total Body Dose (Rem)	Lung Dose (Rem)	Bone Surface Dose (Rem)	Liver Dose (Rem)	Whole-Body Equivalent Dose (Rem)	Population Exposed (Number)	Whole-Body Equivalent Dose (Man-Rem)	Range Health Effects	Probability of Event (Events/Year)	Population Risk (Man-Rem/Year)
2600.	4.28E-01	6.45E-02	6.51E 00	1.58E 00	1.13E 00	25.0	2.82E 01	2.12E-03 6.50E-03	5.000E-07	1.41E-05
2700.	3.95E-01	5.41E-02	5.65E 00	1.37E 00	1.02E 00	25.0	2.55E 01	1.91E-03 5.86E-03	5.000E-07	1.27E-05
2800.	3.63E-01	4.71E-02	4.81E 00	1.26E 00	9.65E-01	25.0	2.41E 01	1.81E-03 5.55E-03	5.000E-07	1.21E-05
2900.	3.32E-01	4.21E-02	4.18E 00	1.06E 00	9.12E-01	25.0	2.28E 01	1.71E-03 5.24E-03	5.000E-07	1.14E-05
3000.	3.11E-01	3.81E-02	3.65E 00	9.61E-01	8.80E-01	25.0	2.20E 01	1.65E-03 5.06E-03	5.000E-07	1.10E-05
4000.	2.16E-01	2.10E-02	1.15E 00	4.39E-01	6.82E-01	25.0	1.70E 01	1.28E-03 3.92E-03	5.000E-07	8.52E-06
7000.	2.24E-01	1.50E-02	5.70E-01	3.20E-01	6.48E-01	25.0	1.62E 01	1.21E-03 3.73E-03	5.000E-07	8.10E-06
12000.	2.93E-01	1.10E-02	6.48E-01	3.55E-01	6.76E-01	25.0	1.69E 01	1.27E-03 3.89E-03	5.000E-07	8.45E-06
22000.	4.22E-01	7.25E-03	8.39E-01	4.29E-01	7.54E-01	25.0	1.88E 01	1.41E-03 4.34E-03	5.000E-07	9.42E-06
52000.	7.31E-01	2.95E-03	1.42E 00	6.23E-01	9.31E-01	25.0	2.33E 01	1.75E-03 5.35E-03	5.000E-07	1.16E-05
102000.	1.00E 00	1.15E-03	1.91E 00	8.11E-01	1.08E 00	25.0	2.70E 01	2.02E-03 6.21E-03	5.000E-07	1.35E-05
202000.	1.20E 00	5.63E-04	2.20E 00	8.80E-01	1.07E 00	25.0	2.67E 01	2.01E-03 6.15E-03	5.000E-07	1.34E-05
502000.	6.80E-01	3.13E-04	1.40E 00	5.00E-01	5.77E-01	25.0	1.44E 01	1.08E-03 3.32E-03	5.000E-07	7.21E-06
1002000.	1.80E-01	1.29E-04	4.31E-01	1.40E-01	1.57E-01	25.0	3.92E 00	2.94E-04 9.03E-04	5.000E-07	1.96E-06

B.2 Nonradiological Effects

The data for the nonradiological effects from the construction, operations, and disposal phases of alternative implementation are presented in tabular form in the nonradiological section of Appendix A. The following information lists the table number where the corresponding data can be reviewed.

TABLE TITLE	TABLE NUMBER
NONRADIOLOGICAL EFFECTS	
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Chemical Composition of Calcine	A-94
Construction Phase	
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Estimated Emission Rates for Air Pollutants Generated During the Construction Phase	A-97
Calculated Concentration Increases of Air Pollutants from Construction Activity	A-98
Operations Phase	
Estimated Emission Rates for Air Pollutants Generated During the Operations Phase	A-99
Estimated Emission Rates for Air Pollutants Generated During the Operations Phase	A-100
Calculated Concentration Increases of Air Pollutants During the Operations Phase	A-101

TABLE TITLE	TABLE NUMBER
Disposal Phase	
Well Concentrations of Cadmium and Mercury	A-102
Standard Maximum Daily Consumption Values	A-103
Vegetation and Ingestion Values for Cadmium and Mercury by Well for Alternatives 1 and 4	A-104
Estimated Ingestion of Cadmium from Hypothetical Wells	A-105
Estimated Ingestion of Mercury from Hypothetical Wells	A-106
Cadmium and Mercury Concentration in a River Fault and Flooding Scenario	A-107
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APPENDIX C

SUBSTANTIVE COMMENTS ON THE
IDAHO DEFENSE WASTE DOCUMENT

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APPENDIX C
SUBSTANTIVE COMMENTS ON THE IDAHO DEFENSE WASTE DOCUMENT (DWD)

This appendix is a summary of the substantive comments received from interested agencies, organizations, and individuals on the document "Alternatives for Long-Term Management of Defense High-Level Radioactive Waste -- Idaho Chemical Processing Plant" (ERDA, 1977a). The document is also known as the Defense Waste Document, or the Idaho DWD.

The DWD is a technical review document which provides preliminary data on alternatives for the long-term management of defense high-level radioactive waste (HLW) stored at the Idaho Chemical Processing Plant (ICPP). The document evaluates public risk and presents preliminary cost estimates for selected alternatives.

In September 1977, the Energy Research and Development Administration (ERDA) released the DWD for public comment. The consensus of those who commented was that the DWD met its limited objective of providing technical information. However, most members of the public suggested that the discussion from the DWD be expanded to address such issues as migration of waste into the aquifer, the priority of defense waste management versus commercial waste management, costs, and the ultimate disposition of HLW. Five of the 22 substantive responses indicated approval of the DWD.

The comments from the remaining 17 statements have been considered in the preparation of this report and a concerted effort has been made to incorporate these comments into discussions at appropriate points in the text. Many of the issues raised, such as the question of waste migration into the aquifer, are addressed directly in the text. Other issues, such as concern about assessment of health effects, have been accommodated by broadening the scope of the major evaluations and by addressing them in the text.

Most of the respondents expressed concern about the conclusion stated in the DWD that the migration of radionuclides to the aquifer is incredible.

Many suggested that an analysis of ion exchange and solution dissolution phenomena be evaluated. In response to this suggestion, radionuclide migration into the aquifer has been analyzed in Appendix A, Subsection A.1.8.1.4.2. A discussion of the use of the potentially contaminated water is also provided.

An additional environmental concern was air contamination. This, as well as soil erosion, is addressed in Appendix A.2. A discussion of these effects is presented in subsections of this report.

Another major comment was that the DWD did not sufficiently address long-term environmental impacts. Suggestions were made that an analysis of environmental impacts be performed over a time period that would reflect the extremely long half-lives of some of the radionuclides present in the waste. Maximum individual and population doses for this report have been calculated for incremental time periods from 1990 to one million years. An evaluation of health effects and risks is also provided in response to public comment on the need to discuss exposure-induced health effects. Health effects are discussed in Sections 2 and 4 of this report. The methodology used in calculating doses and health effects is given in Appendix A, and the results of the calculations are given in Appendix B.

Concern expressed about the assumed stability of the geologic and hydrologic environment has been recognized in the preparation of this report. However, the time span involved (one million years) makes any assumptions about geohydrologic conditions totally speculative. Therefore, release scenarios were postulated that assume extreme conditions not known to have existed at the ICPP in the past. Airborne dispersions of the waste by a severe geologic disruption and waterborne transport of the waste into groundwater have been evaluated.

The public expressed concern that the time schedule assumed in the DWD for processing the HLW was unacceptably long to ensure public safety. As currently managed, the HLW does not present a near-term environmental or

public safety threat. Therefore, there are no safety reasons to accelerate the current schedule. The integrity of the waste bins is described in Section 2, and the effects of current management procedures are documented in the Final Environmental Impact Statement on Waste Management Operations, Idaho National Engineering Laboratory, Idaho (ERDA, 1977b).

Another public concern was that the high priority assigned to the processing of defense waste should be shifted to the processing of commercial waste. An EIS for the management of commercial HLW has been published (DOE, 1980). Therefore, that concern is not considered in this report.

Another recommendation was that the DWD cost-risk assessment be developed as a tool for decisionmaking and that the relative benefits of each alternative be discussed. Risks associated with each alternative have been evaluated, and are discussed in Section 4 and summarized in Subsection 2.5 of this report. Costs have been estimated in evaluating resource commitments.

The use of the 50-year instead of a 70-year dose commitment received criticism. The Nuclear Regulatory Commission accepts the 50-year dose commitment method for all reactor licensing evaluations. It is based on a 50-year life expectancy for the working population which is very similar to a 70-year life expectancy for the entire population. The total population includes children and the elderly.

One reviewer suggested development of a scenario describing intrusion by man into the calcine after institutional controls have ceased. This scenario is considered in Appendixes A and B, Subsections A.1.8.1.5.2, A.1.8.1.5.3, A.1.8.2.3, A.1.8.2.4, B.1.1.1.6, B.1.1.2.3, B.1.1.2.4, and in Subsections 4.5.2.1.2 and 4.5.2.2.

Comments concerning a decision on ultimate disposition of the HLW are addressed in Sections 1 and 2 of this report.

REFERENCES FOR APPENDIX C

DOE (U.S. Department of Energy), "Final Environmental Impact Statement, Management of Commercially Generated Radioactive Waste," DOE/EIS-0046-F, October 1980.

ERDA, "Alternatives for Long-Term Management of Defense High-Level Radioactive Waste, Idaho Chemical Processing Plant, Idaho Falls, Idaho," ERDA 77-43, September 1977a.

ERDA "Final Environmental Impact Statement Waste Management Operations, Idaho National Engineering Laboratory Idaho," ERDA 1536, September 1977b.

APPENDIX D

ALTERNATE WASTE FORMS

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APPENDIX D
ALTERNATE WASTE FORMS

A decision on the final waste form for the Idaho Chemical Processing Plant (ICPP) waste, and the process by which it is produced, will await the outcome of ongoing research and development programs. However, in order to evaluate the environmental impacts of alternative strategies, three waste forms (stabilized calcine, pellets, and glass) have been used as representative of various possible forms for calculational purposes. Calcine has also been used to evaluate Alternative 1 (Leave-in-Place) (No-Action Alternative) since calcine is the existing waste form.

Although it is possible that the final waste form selected for ICPP wastes may be a form that is not yet developed, it is expected that the environmental impacts from whatever waste form is finally selected will not exceed those described in this report.

The purpose of this appendix is to explain the characteristics of a number of possible waste forms and to show that calcine, pellets, and glass are representative choices to use for purposes of analyzing alternative strategies. Waste forms other than calcine, pellets, and glass are described, and properties of all the waste forms are compared.

D.1 Description of Waste Forms

D.1.1 Glass Ceramic

The glass-ceramic waste form has generated more interest in Germany than in the United States (ERDA, 1977; De, et al., 1976, and De, et al., 1975). This form is defined by its developers as a ceramic product derived from a homogeneous parent glass by means of a special heat treatment consisting of two steps: annealing at the temperature of maximum nucleation rate, and annealing at the temperature of optimal crystal growth rate. The process is shown schematically in Figure D-1. One or more crystalline phases and a residual glass phase are contained in the glass ceramic. Certain fission

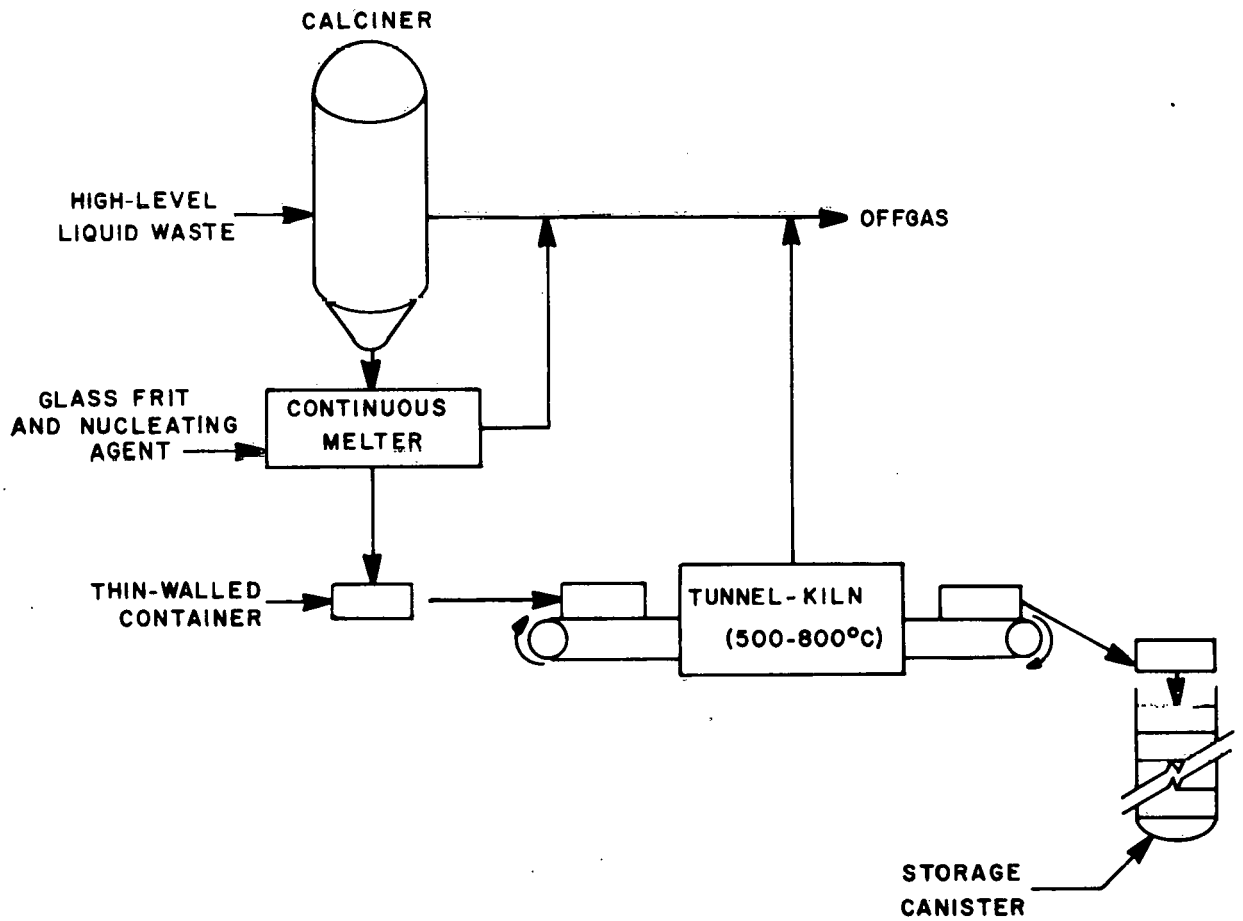


Figure D-1. Glass Ceramic Process

products have an affinity for particular crystalline phases. For example, cesium appears to concentrate in pollucite, and strontium in perovskite.

Due to a wide range of potential compositions, preparation of various types of ceramics is possible. However, to keep melting temperatures at a technically feasible level, the parent glass compositions should be chosen to allow for a process temperature of approximately 1200°C (2200°F) or less.

In a conceptual glass-ceramic process (ERDA, 1977), calcine, nucleating agents, and glass frit are fed into a continuous melter. The melted glass mixture is drained into shallow containers where it is heat treated. The depth of these containers is limited to about 3 cm (1.2 in.) to prevent large temperature differences within the molten material during the heat treatment. The process conditions during the heat treatment induce crystal growth until the parent glass mixture becomes primarily a fine-grained crystalline material with a residual glass phase. Caution must be used in the selection of glass constituents. Compositions that result in phase separation of the glass mixture can lead to the crystallization of highly leachable phases. Using the proper choice of constituents, a homogeneous glass ceramic can be made.

In tests of impact resistance (Staples, et al., 1981; De, et al., 1976), glass ceramics exhibit a considerable improvement in mechanical strength over the parent glass. A broken glass ceramic yields a small percentage of pieces, whereas approximately 50% by weight of a glass subjected to the same impact yields pieces less than 0.1 cm (0.04 in.) in diameter. The leach resistance of glass ceramics is comparable to that of the parent glass, although results show that the residual glass phase may leach preferentially.

The thermal conductivity of glass ceramics is 2 W/m°K, (1.2 Btu/hr ft°F) which is an increase in thermal conductivity relative to the parent glass. Also, the glass ceramics have a favorable thermal expansion of 1×10^{-5} cm/°C (2.2×10^{-6} in./°F).

D.1.2 Sintered Glass Ceramics

Sintered glass ceramics are prepared by sintering a mixture of calcine and fluxing agents. Two methods are proposed: high-pressure compaction and low-pressure molding (Samsel and Berreth, 1977).

In high-pressure compaction, 50 to 67% by weight calcine is mixed with 33 to 50% by weight flux and water and is then compacted in a steel die at 7×10^4 kPa (10^4 psi). The compacts are heated slowly and held for 6 hours within the sintering temperature range of 965 to 1070°C (1770 to 1960°F).

Low-pressure molding is better than high-pressure compaction from the standpoint of process simplicity. A mixture of calcine, flux, and water is fed into shallow containers and pressed at 70 kPa (10 psi) to provide the interparticulate contact necessary for sintering. After sintering for 3 to 5 hours, hot pressing at 70 to 350 kPa (10 to 50 psi) forms the sintered glass ceramic to the container walls. A controlled cooling period following the sintering of the mixture causes the formation of desirable crystalline forms.

The sintered glass ceramic material as a generic ceramic form has properties similar to other ceramic materials, including high resistance to impact, thermal shock, and aqueous dissolution. This high resistance is desirable for safe transport and storage. The sintered glass ceramic material appears suitable for storage at temperatures of at least 800°C (1470°F) (Staples, et al., 1981; De, et al., 1975). The volume of the waste form would be 20 to 80% greater than for calcine.

D.1.3 Metal Matrix

Several methods of incorporating calcine into a metal matrix have been tested on a bench scale. These include sintering a mixture of calcine and metal powder, and several variations of casting a matrix with calcine (preferably in pellet form) and a molten metal (Lamb, 1978).

Sintered matrices have been made from mixtures of powdered aluminum or iron and calcine (Van Geel, et al., 1975). The mixtures are compacted under

pressures of up to 5×10^5 kPa (7×10^4 psi) and sintered in an inert atmosphere at temperatures just below the melting point of the metal. Although sintered metal matrices have high thermal conductivity and strength comparable to that of concrete, they are not highly leach resistant. Also, sintered metal matrix processing steps are relatively sophisticated for remote operation. Because of processing complexities, sintered metal matrix is not a favored waste form (Van Geel, et al., 1976).

Several methods have been proposed for incorporating HLW waste forms in metal. One of these, the Eurochemic process (Van Geel, et al., 1975), incorporates glass beads into a lead matrix. The beads are forced by an inert carrier gas through a vertical tube into a pot of molten lead. Because of their low specific gravity relative to lead, the glass beads float in the molten lead. The beads are held below the surface by a screen that permits the carrier gas and lead overflow to escape. Figure D-2 is a schematic diagram of the Eurochemic process.

Experiments at the ICPP have been conducted to cast calcine and pelleted waste in a metal matrix in place of the glass beads (Lamb, 1978; Berreth, 1976). Problems with feed tube plugging and nonuniform metal distribution indicate that this process is not suited to casting calcine in a metal matrix but works well to cast pelleted waste.

The process for pelletizing calcine is discussed in Section 2. Testing at the ICPP has shown that a commercial aluminum casting alloy (A-380) is the preferred metal to form a matrix with pellets (Lamb, 1978). Aluminum has several advantages over lead. It is less expensive, more available, lighter in weight, mechanically stronger, about 6 times higher in thermal conductivity, and it melts at a higher temperature.

Properties of the cast matrices (e.g., matrix temperature stability, leachability, strength, and possible pellet-metal interactions and product shrinkage) need more investigation. The metal matrix appears best suited for the high-heat output of short-decay-time waste produced in commercial reactors. Since the ICPP wastes contain few heat-producing fission products, there is little justification for adopting this high-cost waste form for the ICPP HLW (Lamb, 1978; Berreth, 1976).

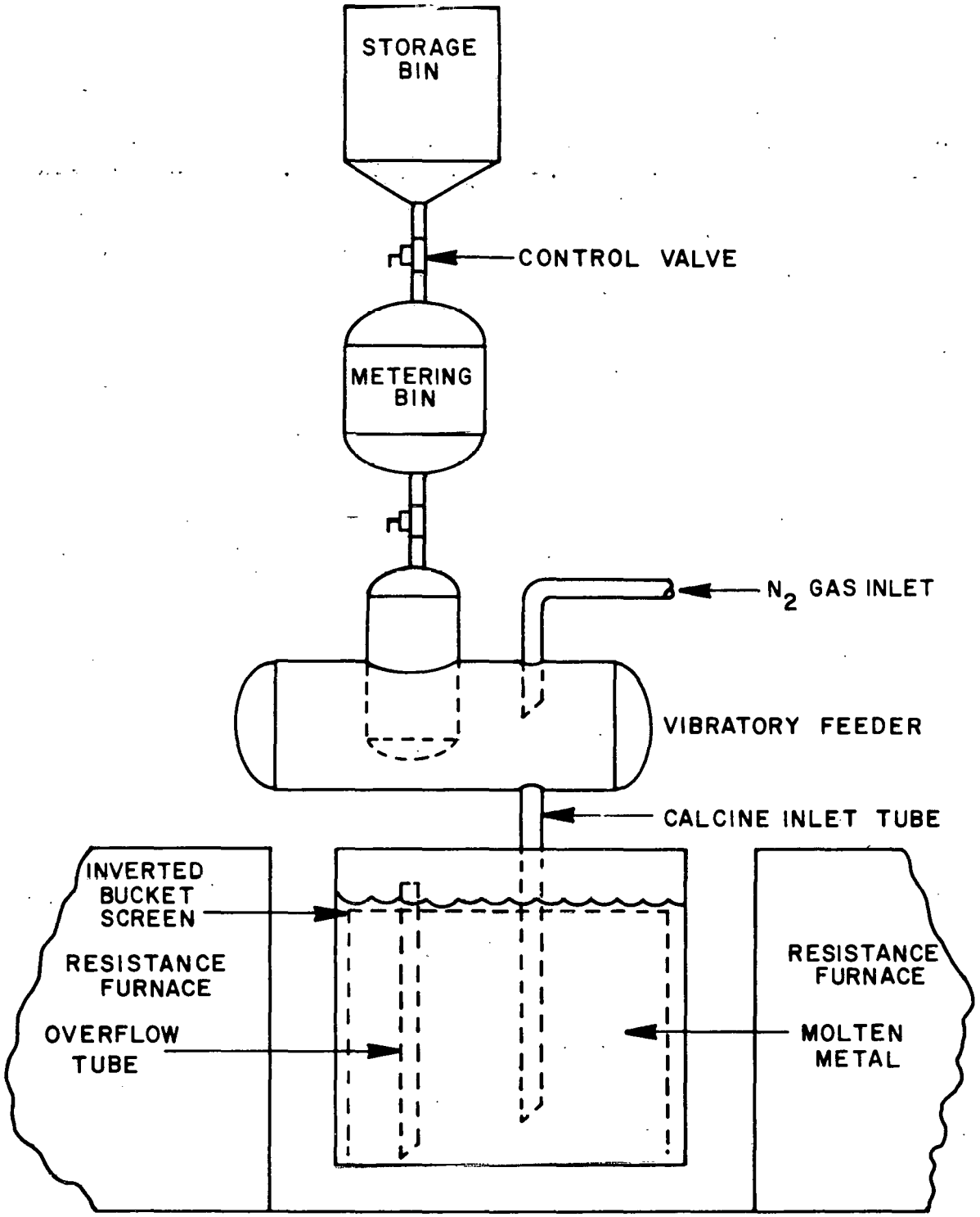


Figure D-2. Adaptation of the Eurochemic Method for Metal Matrix Formation

D.1.4 Concrete Matrix

Concrete as a matrix material for incorporating high-level waste has been evaluated at the ICPP (Berreth, 1976), and at the Savannah River Plant (Stone, 1977; Stone, 1978). Concrete may be suitable as a matrix for low heat-generating wastes because thermal conductivity is not an important factor in determining the final waste form. Concrete matrices can be made strong enough for safe handling and transportation.

Concrete produced from high-alumina cement is believed to be superior in strength and resistance to degradation by water to concrete produced from Portland cement. The thermal stability of concrete is controversial. Experience with alumina concrete structures in Europe shows that this material deteriorates severely when exposed to only slightly elevated temperatures. However, it is generally accepted that alumina concrete is resistant to temperatures of 225 to 270°C (440 to 520°F).

Concrete matrices with compressive strengths ranging from 2×10^4 to 4×10^4 kPa (3,000 to 6,000 psi) can be cast. This is considered adequate to inhibit breakage during handling.

Concrete matrices made with calcined waste show little improvement in leach resistance over calcine. The leachability of calcine-concrete matrices can be reduced by pelletizing the calcine prior to processing. Additives such as calcium chloride or additional sand tend to reduce the leachability of concrete matrices, but they can also reduce compressive strength.

Studies with radioactive tracers at the Savannah River Plant (Stone, 1977; Stone, 1978) show that concrete retains Sr-90 and alpha emitters very well, but that Cs-137 leaching is severe. The rate of Cs-137 leaching can be made satisfactory by the addition of sorbents, such as zeolites, to the concrete. The leachability of concrete matrices changes with prolonged exposure to high temperature, and some species of radionuclides are more leachable than others. Since the species behave differently, the changes are presumably due to chemical effects and not to a change in effective surface area (Stone, 1977; Stone, 1978).

Two important problems which could occur with concrete matrices are (1) the evolution of gases and water vapor in a sealed container and (2) the rapid setting of the concrete. The set time of concrete can be retarded by additives. Long-term studies would be necessary in order to determine the extent of radiolytic gassing in sealed containers.

D.1.5 The SYNROC Process

A recent strategy for the disposal of radioactive wastes is based on the geochemistry of natural rocks and minerals. Many natural minerals are thought to have the capacity to accept and retain radioactive waste elements in their crystal lattices. A man-made rock called SYNROC (Ringwood, 1978) has been proposed as a waste form for final disposal of radioactive wastes.

The proponents of the SYNROC waste form point out that all natural igneous rocks contain small amounts of radioactive elements (U, Th, K), as well as many other minor elements which are also present in radioactive wastes. As igneous rocks crystallize from molten material, these elements become distributed among the various mineral phases. Many mineral phases have retained radioactive species for periods exceeding 2×10^9 years.

The SYNROC process involves identifying combinations of mineral phases and radioactive elements that are thermodynamically compatible when melted together and allowed to crystallize, effectively immobilizing the radioactive species. The composition of SYNROC must be controlled rigorously because small compositional changes can have a profound effect on the composition of the last phase to solidify, which is usually the least leach-resistant phase (Lewis, 1978). Because of this sensitivity to composition, SYNROC formulations must be tailor-made to a particular waste and mineral phase.

Although a considerable reservoir of data in the fields of geochemistry and crystal chemistry is applicable to the problem of waste immobilization, most of the claims made in favor of the SYNROC waste form have not yet been proven with simulated or radioactive wastes. There are few experimental data on leach rates from SYNROC wastes. Preliminary experience with synthesized rock shows that leach rates are generally similar to the very best glass

formulations. Also, little is known about the behavior of synthetic rocks subjected to radioactivity and thermal stress. Until experiments on leach rates, radioactivity, and thermal stress are performed, it is debatable whether SYNROC offers an advantage over the vitrification of wastes.

D.2 Comparison of Waste Forms

Three waste forms were chosen for investigation in this report to envelop the impact of the many waste forms under investigation. These are glass, ceramic pellets, and stabilized calcine. These and other waste forms are compared in Table D-1.

Glass represents a waste form with extremely good characteristics which would be representative of the more stable materials. Stabilized calcine, on the other hand, has undesirable characteristics such as high leachability and a tendency to dust into airborne particles. Pelletized calcine is an intermediate form between glass and stabilized calcine.

By using these forms as representative waste forms, maximum and minimum environmental consequences have been determined. If a better waste form is later used, the environmental consequences will be less than those determined by the analyses in this report.

The following characteristics are important for a desirable waste form: high leach resistance to forestall dissolution of the waste into nearby water sources, high strength to resist breakage during transportation and handling, and high thermal conductivity to dissipate heat generated by radioactive decay.

The waste forms analyzed in this report, as seen by the entries in Table D-1, are representative of all waste forms in these areas, and an analysis based on these forms will provide an upper and lower limit for environmental effects.

Leachability is an important characteristic for wastes disposed above an aquifer. As shown in Table D-1, calcine leachability is high for certain

TABLE D-1

COMPARISON OF WASTE FORMS

Waste Form	Relative Cost	Process Complexity	Stage of Development	Process Temperature	Leachability	Thermal Conductivity	Product Density	Temperature Stability	Compressive Strength	Product Volume	Radiation Stability
Glass Ceramic	Moderate	Moderate	Laboratory	Melt - 1100°C Crystallize - 700-900°C	10^{-5} to 10^{-6} g/cm^2/day	2 W/m°K	3.0 g/cm^3	500°C	Stronger than parent glass.	1.5 to 2 × calcine volume	Radioactive materials may affect properties.
Sintered Glass Ceramic	High	High	Laboratory	Sinter - 900-1100°C	10^{-7} to 10^{-9} g/cm^2/day	0.7 W/m°K	2.6 to 3 g/cm^3	800°C	---	1 to 1.5 × calcine volume	---
Metal Matrix	High	High	Pilot plant	Lead alloy - 450°C Al alloy - 650°C	Approximately the same as waste form in matrix to a factor of 10 better.	Lead alloy 8.65 W/m°K, Al alloy 35 W/m°K	2.7 to 5 g/cm^3	Melting point of matrix.	---	1.25 to 2 × calcine volume	---
Concrete Matrix	Moderate to high	High	Pilot plant	Low temperature	Approximately the same as waste form in matrix.	~0.35 W/m°K	2.5 g/cm^3	Hydraulic bond failure 225-270°C.	Highly dependent on composition.	2 × calcine volume	Deterioration due to dehydration.
SYNROC	High	High	Laboratory	1100°C-1400°C	---	---	3 to 3.7 g/cm^3	---	---	5 × calcine volume	Radioactive materials may affect properties.
Super-Calcine	High	High	Pilot plant	Calcine 500-700°C pelletize and sinter - 1200-1400°C crystallize - 1100°C	6×10^{-5} g/cm^2/day	---	3 g/cm^3	800°C	---	1 to 2 × calcine volume	---
Glass	Moderate	Moderate	Pilot plant	1100°C	$10^{-5} \times 10^{-6}$ g/cm^2/day	~0.5 to 1 W/m°K	2.6 to 3 g/cm^3	500°C	---	1.5 to 2 × calcine volume	Good
Calcine	Low	Low	Plant	~500°C	High for Cs and Sr.	~0.24 W/m°K	1.3 g/cm^3	700°C	---	1 × calcine volume	Good
Stabilized Calcine	Low	Low	Pilot plant	700°C	Same as calcine.	Same as calcine	Same as calcine	700°C	---	1 × calcine volume	Good
Ceramic Pellets	Moderate	High	Pilot plant	Fire - 850°C	10^{-4} g/cm^2/day	---	Bulk ~1.2 g/cm^3	850°C	Highly dependent on composition.	~1.5 × calcine volume	Good

isotopes; other waste forms are much more leach resistant. The leach rate for ceramic pellets is much better (~10^{-4} g/cm^2/day). Glass leach rates are even better (10^{-5} to 10^{-6} g/cm^2/day) and are as good as any form presently available. Forms presently being developed may be even better (sintered glass ceramic, 10^{-7} to 10^{-9} g/cm^2/day), thus reducing the quantity of radionuclides that could be transported to the aquifer under accident conditions.

Specific information on compressive strength is often not available in the literature. The evaluated forms range from calcine, which can be broken relatively easily, to glass and ceramics, which, depending on their composition, can be relatively resistant to breaking. Other forms, such as glass ceramics or sintered glass ceramics, will likely be stronger in terms of compressive strength than the forms being analyzed. Thus, small particles which could be inhaled would be less likely to be formed during accidents.

All forms analyzed in this statement are relatively resistant to radiation damage. If other forms are chosen, detailed studies would have to be completed to ensure that the forms are sufficiently resistant to radiation damage to prevent the form from losing its integrity.

Thermal conductivity is an important waste characteristic if the waste has a high heat generation rate. Because the ICPP waste has a relatively low heat generation rate, thermal conductivity is not as important as, for example, for commercial waste. The forms evaluated in this report have relatively low, but similar, thermal conductivities. Other potential forms have generally higher conductivities, resulting in lower temperatures within the waste for the same conditions.

In summary, the characteristics of the waste forms analyzed in this appendix are typical but less desirable than for some of those forms which are presently being investigated. The analyses in this report are based on presently producible forms. It is possible that forms with better characteristics will be used, thus reducing environmental effects to levels less than those described.

REFERENCES FOR APPENDIX D

Berreth, J. R., et al., "Status Report: Development and Evaluation of Alternative Treatment Methods for Commercial and ICPP High-Level Solidified Wastes," ICP-1059, May 1976.

De, A. K., et al., "Studies on the Fixation of Fission Products in a Ceramic Material," paper presented to the European Nuclear Society, April 1975.

De, A. K., et al., "Development of Glass Ceramics for the Incorporation of Fission Products," The American Ceramic Society Bulletin, 55, 500, 1976.

ERDA (U.S. Energy Research and Development Administration), "Alternatives for Long-Term Management of Defense High-Level Radioactive Waste," Idaho Chemical Processing Plant, Idaho Falls, Idaho, ERDA 77-43, September 1977.

Lamb, K. M., "Final Report: Development of a Metal Matrix for Incorporating High-Level Commercial Waste," ICP-1144, March 1978.

Lewis, J. B., "Synthetic Rock Reconsidered," Nuclear Engineering International, November 1, 1978.

Ringwood, A. E., "Safe Disposal of High-Level Nuclear Reactor Wastes: A New Strategy," Australian National University Press, Canberra, Australia, July 1978.

Samsel, E. G. and J. R. Berreth, "Preparation and Characterization of Sintered Glass-Ceramics from Calcined Simulated High-Level Waste," Nuclear Technology, 33, 1, April 1977, pp. 68-75.

Staples, B.A., et al., "Evaluation of Ceramic Materials Developed to Immobilize ICPP Zirconia Calcine," ENICO-1095, September 1981.

Stone, J. A., "Evaluation of Concrete as a Matrix for Solidification of Savannah River Plant Waste," DP-1448, June 1977.

Stone, J. A., "Evaluation of Concrete as a Matrix for Solidification of Savannah River Plant Waste," a paper presented at the annual meeting of the American Ceramic Society, DP-MS-77-108, May 1978.

Van Geel, J., et al., "Conditioning of Solid High-Level Waste Products by Dispersion in Metal Matrices," 68th Annual AICHE Meeting, Los Angeles, November 16-20, 1975.

Van Geel, J., et al., "Conditioning High-Level Radioactive Wastes," Chemical Engineering Progress, March 1976, pp. 49-51.