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FOREWORD

FOREWORD

This document, Environmental Aspects of Commercial Waste Management is a detailed support document for the Generic Environmental Impact Statement - Management of Commercially Generated Radioactive Waste, DOE/EIS-0046-D.

It is based on the technology for the processes of waste treatment, interim storage, and final isolation of commercially generated radioactive wastes described in Technology for Commercial Radioactive Waste Management (DOE/ET-0028). Such wastes are the product of post-fission operations of the light-water reactor power industry postulated to exist through the year 2050, as presented in DOE/ET-0028. That document is in turn based on Alternatives for Managing Wastes from Reactors and Post-Fission Operations in the LWR Fuel Cycle (ERDA-76-43) plus substantial quantities of more recently developed information.

Calculations of environmental effects in this report are based on the facility descriptions, waste characteristics and volume predictions, and waste transportation requirements presented in DOE/ET-0028. For continuity and/or clarity, some information is repeated either in total or in abbreviated form from that report.

Although an environmental analysis has been prepared for each waste management alternative, the order of presentation differs from that of DOE/ET-0028. This is because the environmental analysis relates waste treatment and other waste management processes to systems within plants so that environmental effects may be summed at the plant level for the various reference* fuel cycle options. In addition, some environmental considerations (e.g., socioeconomic effects and environmental monitoring) would be meaningless if described alone for a single process.

This report has attempted to be self-contained at each level of analysis. That is, the same organization has been used throughout in presenting analytical results. As a consequence, Sections 4 through 9 will, in many places, contain repetition of material. However, this enables the reader of the GEIS to enter this document via the table of contents and go directly to a more detailed analysis of environmental effects for any process at virtually any point of interest. On the other hand, Sections 4 to 9 are not intended to be read sequentially. Sections 1 through 3, 10, and Appendices A and B or the GEIS itself are recommended to the reader who is not interested in the details of analysis at each step of waste management.

An independent analysis of the environmental effects arising from Waste Management as described in DOE/ET-0028 has been pursued throughout this document. Other sources of information used for guidance include:

Management of Commercial High Level and Transuranic-Contaminated Radioactive Waste, WASH-1539, U.S. Atomic Energy Commission, Washington, DC, September 1974 (including public and agency comments).

Environmental Survey of the Reprocessing and Waste Management Portions of the LWR Fuel Cycle — A Task Force Report, NUREG-0016 (Supplement 1 to WASH-1248), U.S. Nuclear Regulatory Commission, Washington, DC, October 1976 (including public and agency comments).

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* The choice of the so-called reference processes, systems, and options was based on a judgment of the engineering availability of a given process among its alternatives balanced against the estimated worth of the process in terms of waste management. The reference processes were established in DOE/ET-0028.

Proceedings of the International Symposium in the Management of Wastes from the LWR Fuel Cycle, July 11-16, 1976, Denver, Colorado, CONF-760701, Energy Research and Development Administration, Washington, DC, October 1976 (including public comments from the symposium).

Final Generic Environmental Statement in the Use of Recycle Plutonium in Mixed Oxide Fuel in Light Water Cooled Reactors, NUREG-002, U.S. Nuclear Regulatory Commission, Washington, DC, August 1976.

Proceedings of Conference on Public Issues in Nuclear Waste Management, Des Plaines, Illinois, October 1976, CONF-761075, Energy Research and Development Administration, Washington, DC, 1976 (including public comments from the conference).

Nuclear Power Issues and Choices, Nuclear Energy Policy Study Group (sponsored by The Ford Foundation, administrated by the MITRE Corporation), Ballinger Publishing Company, Cambridge, MA, 1977.

Contribution to Draft Generic Environmental Impact Statement on Commercial Waste Management: Radioactive Waste Isolation in Geologic Formations. Union Carbide, Office of Waste Isolation, Oak Ridge, TN, Y/OWI/TM-44, April 1978.

Report of Task Force for Review of Nuclear Waste Management, DOE/ER-004, Department of Energy, Washington, DC, 1978.

Report to the President by the Interagency Review Group on Nuclear Waste Management, TID 28817 (draft), Washington, DC, October 1978.

The environmental analysis was also guided by the experience gained by the Department of Energy and its predecessors (Energy Research and Development Administration and U.S. Atomic Energy Commission) in preparation of environmental impact statements following passage of The National Environmental Policy Act of 1969, as interpreted by the courts and by the Council on Environmental Quality.

1.0 INTRODUCTION

1. INTRODUCTION

At present there are more than 60 commercial nuclear power plants generating electricity in the United States and even more in other countries. The process by which electricity is produced by nuclear power differs from coal-fired and oil-fired power plants principally in the means of producing heat to turn the turbine generators. In a nuclear power plant heat energy is produced during the controlled fissioning of nuclear fuel in a reactor. As in all other activities, wastes are generated during the production of electrical power by the nuclear fissioning process. The fuel introduced into the reactors is only partly consumed because in the process of fissioning, various products result that greatly reduce the efficiency of the process. The fuel that is removed after its useful life in the reactor is usually referred to as spent fuel and if not reprocessed constitutes the major postfission waste from nuclear power production. In addition to radioactive fission products (the fragments of original uranium atoms), the nuclear power plant also produces radioactive activation products, that is, elements that have captured neutrons and become different elements. Neutron activation products occur in the fuel, in the hardware that contains the fuel, in cooling water near the reactor vessel, and in parts of the reactor itself.

At the time spent fuel is removed from a reactor, it is highly radioactive; that is, in addition to residual unused uranium fuel it contains an abundance of radioactive isotopes which decay with half-lives (times required for twofold reductions in radiation intensity) varying from fractions of seconds to millions of years. The dose or amount of radiation absorbed by tissues of an individual exposed to spent fuel at a given point for a given time depends on the age of the fuel as well as the kinds of radiation released during decay. To add to the complexity, some radionuclides (such as ^{239}Pu), if released from the spent fuel and if constrained to remain outside of the body, would produce no effect, whereas if inhaled in quantity might produce lethality or cancer or other forms of morbidity at later times.

There are two basic options for the use of spent fuel: 1) no use, which is called the once-through or throw-away fuel cycle option, and 2) a fuel reprocessing option to recover unused uranium and to recover plutonium that is produced while the reactor is operating, both of which can be used to produce new fuel for other reactors. The steps of waste management in these two options are illustrated in Figures 1.1 and 1.2 for the once-through option and uranium and plutonium reprocessing option respectively (in this report impacts are addressed for steps shown in the right hand columns only). In addition to the two basic options, a deferred isolation option is considered where spent fuel is stored in near surface engineered facilities until the year 2000, at which time disposal or reprocessing is chosen. Options of uranium recycle only with plutonium oxide stored at engineered surface facilities or with plutonium remaining in solidified waste are also considered. Although not strictly an option the lack of availability of a waste repository until the year 2000 and its impact are also addressed in integrated systems analysis.

In the once-through option, spent fuel is transported to a spent fuel storage and packaging facility where it is aged (cooled) and packaged for transport to a place of final isolation.

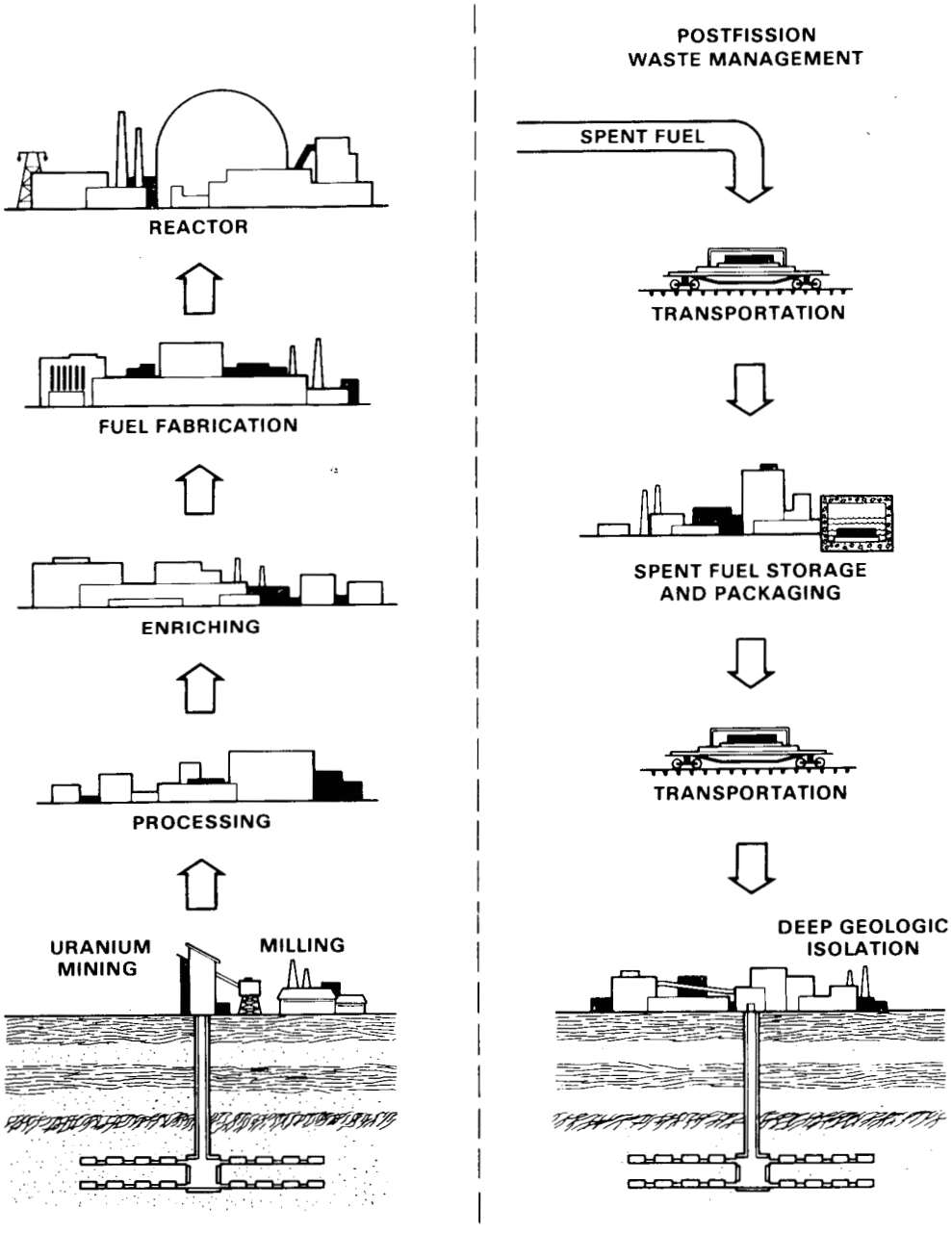

FIGURE 1.1. Major Steps of the Once-Through Fuel Cycle Option

In this report the reference final isolation option is disposal in a deep geologic repository in bedded salt. Environmental aspects of disposal in other geologic media such as granite, shale and basalt are contrasted with those of the reference media.

In the case of uranium and plutonium recycle, spent fuel is transported to a fuel reprocessing plant where uranium and plutonium are extracted from spent fuel for fabrication into new fuel. The wastes that exist in the spent fuel are thus separated from the resource that is considered waste in the once-through cycle. Acid is used to bring the fuel into solution; after the uranium and plutonium are removed, a highly radioactive solution remains, which is

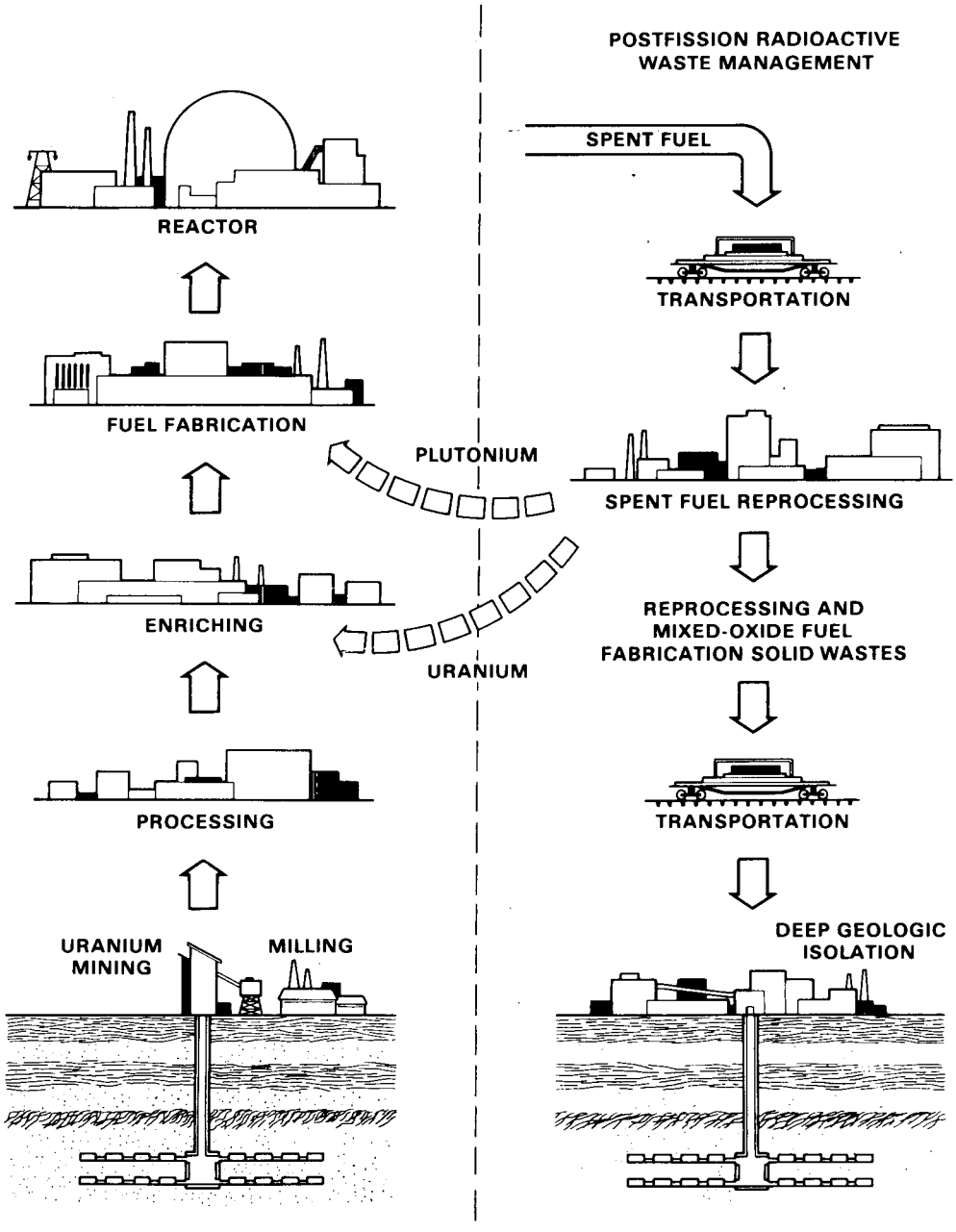

FIGURE 1.2 Major Steps of the Uranium and Plutonium Fuel Recycle Option

referred to as high-level liquid waste. Although the technology exists for storing this high-level waste in liquid form, current regulations stipulate that the waste must be solidified within five years of its formation. Several options are available for solidifying the waste. Following solidification and cooling (essentially to the same age out of reactor as for once-through spent fuel) the solidified high-level waste is isolated from the biosphere in a deep geologic repository.

During reprocessing, other wastes are generated that require, either by regulation and/or for sake of prudent management, additional treatment. Several radioactive gases evolve during the fuel dissolution process. Of these, ^{3}H, ^{85}Kr, and ^{129}I are particularly noteworthy. Systems are available to remove the bulk of ^{85}Kr and ^{129}I and to remove other radioactive materials associated with the dissolution process. However, there does not appear to be any practical method for removing ^{3}H from the process off-gas streams at this time. Other wastes are generated at the reprocessing plant and at the mixed-oxide fuel fabrication plant. Because of their potential for contamination with transuranic radionuclides, they are classed as transuranic wastes and after treatment are assumed to be isolated in a deep geologic repository.

Under either basic option the facilities will be decommissioned after they have fulfilled their useful lifetimes. Some parts of these facilities will require further radioactive waste management.

At the present, there are approximately 2300 MT[1]* of spent reactor fuel awaiting disposition in storage in reactor spent fuel storage basins. That amount of spent reactor fuel represents an approximate inventory of the following representative radionuclides:

	Ci
^{3}H	6×10^{5}
^{14}C	2×10^{2}
^{85}Kr	1×10^{7}
^{90}Sr	1×10^{8}
^{129}I	8×10^{1}
^{137}Cs	1×10^{8}
$^{239,240}Pu$	1×10^{6}**

Also included in the spent fuel are various quantities of other activation products, fission products, and transuranics. Thus, regardless of decisions for or against nuclear power and/or recycling of uranium and plutonium, a sizable inventory of radioactive substances from commercial power reactors requires management now.

The broad range of undesirable possibilities for hazardous interaction with the biosphere requires careful management of postfission radioactive wastes. The technological aspects of the treatment of wastes, their storage, and final disposition are presented in DOE/ET-0028, Technology for Commercial Radioactive Waste Management. Environmental aspects of waste management for generic integrated systems of postfission power production facilities are discussed in this report.

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* In this report the notation "MT" stands for metric ton which is equivalent to 1000 kg or one million grams. This notation follows that used in the basis document DOE/ET-0028.

** For perspective, about 4×10^{5} Ci of ^{239}Pu and ^{240}Pu were introduced into the atmosphere during weapons testing prior to the 1963 Test Ban Treaty.[2]

REFERENCES FOR SECTION 1

1. Report to the President by the Interagency Review Group on Nuclear Waste Management, TID-28817 (Draft), Washington, DC, October 1978.

2. B. G. Bennett, "Transfer of Plutonium from the Environment to Man," pp. 554-63 in Proceedings of the International Symposium on the Management of Wastes from the LWR Fuel Cycle, July 11-16, 1976, Denver, Colorado, CONF 76-0701, Energy Research and Development Administration, Washington, DC, 1976.

2.0 SUMMARY OF FINDINGS

2.0 SUMMARY OF FINDINGS

Environmental effects (including accidents) associated with facility construction, operation, decommissioning, and transportation in the management of commercially generated radioactive waste were analyzed for plants and systems assuming a light water power reactor scenario that produces about 10,000 GWe-yr through the year 2050. The following alternative fuel cycle modes or cases that generate post-fission wastes that requiring management were analyzed.

- A once-through option where
  - spent fuel discharged from reactors is disposed of in geologic repositories after 6 to 7 years of cooling;
  - the decision to dispose of spent fuel has been deferred until the year 2000; or
  - disposal of spent fuel has been delayed until the year 2000 because repositories are unavailable.
- A fuel reprocessing option for uranium and plutonium recycle where
  - high-level and non-high-level transuranic wastes are disposed of in geologic repositories after 6 to 7 years of cooling;
  - the decision to reprocess has been deferred until the year 2000; or
  - wastes are stored because of the unavailability of geologic repositories until the year 2000.
- A fuel reprocessing option for uranium-only recycle where
  - high-level and non-high-level transuranic wastes are disposed of in geologic repositories after 6 to 7 years' cooling for:

    plutonium contained in high-level waste; or

    PuO_2 stored separately as a resource.

Environmental effects of waste management systems associated with the above cases are presented in summary form in Tables 2-1 to 2-4 for reference repositories in salt, granite, shale, and basalt.

Environmental analysis of total waste management systems, including land use requirements involved in the conventional geologic disposal, show no clear environmentally based choice favoring one or the other fuel cycle option or repository medium. Short-term adverse impacts on wildlife can be expected during facility construction; however, long-term beneficial impacts on wildlife can be expected through the restriction of human activity on large amounts of land of which only small portions are devoted to waste management activities.

Adverse socioeconomic impacts are likely to be realized if any major facilities are built and operated beyond the commuting distance of a large resident labor force. The differences between construction and operating forces for a number of facilities are such that the potential for boom-bust economies is large. This, however, is no different than for other projects of similar size.

TABLE 2.1. Summary of Environmental Effects - Repositories in Salt

Effects Through Year 2050 (except as indicated)	Repository Startup Year - 1985			
	Once-Through	U and Pu Recycle	U Recycle Only Pu in SHLW	U Recycle Only PuO_2 Stored
	8 ISFSFs 8 Repositories	7 FRPs 10 MOX-FFPs 6 Repositories	7 FRPs 10 Repositories	7 FRPs 17 PuO_2 storage facilities 5 Repositories
	Transportation	Transportation	Transportation	Transportation
Land Use				
Surface facilities, buildings parking lots, ha	1×10^3	1×10^3	2×10^3	1×10^3
Access roads, railroads, etc., ha	2×10^2	5×10^1	8×10^1	4×10^1
Total property-restricted area, ha	1×10^4	5×10^3	8×10^3	2×10^4
Additional land on which only subsurface activities will be restricted, ha	3×10^4	1×10^4	3×10^4	2×10^4
Water use				
Construction, m^3 (about 10% is "consumed" in concrete)	3×10^6	3×10^6	4×10^6	2×10^6
Operations, m^3	6×10^7	9×10^7	9×10^7	9×10^7
Materials				
Concrete, m^3	1×10^6	2×10^6	2×10^6	2×10^6
Steel, MT	7×10^5	7×10^5	1×10^6	9×10^5
Copper, MT	2×10^3	3×10^3	4×10^3	5×10^3
Zinc, MT	1×10^3	1×10^3	1×10^3	2×10^3
Aluminum, MT	3×10^2	3×10^2	5×10^2	9×10^2
Lumber, m^3	4×10^3	5×10^4	6×10^4	9×10^4
Lead, MT	7×10^3	6×10^3	6×10^3	6×10^3
Depleted uranium, MT	3×10^3			
Energy				
Coal, MT	1×10^7	8×10^6	1×10^7	7×10^6
Propane, m^3	3×10^4	2×10^7	2×10^7	2×10^7
Diesel fuel, m^3	4×10^6	3×10^6	4×10^6	3×10^6
Gasoline, m^3	2×10^5	2×10^5	2×10^5	2×10^5
Electricity, kWh	2×10^{10}	3×10^{10}	4×10^{10}	3×10^{10}
Man-power, man-yr	2×10^5	2×10^5	4×10^5	3×10^5
Nonradiological Effluents				
Dust concentration at repository fence, $\mu g/m^3$ reference climate	7×10^1	7×10^1	7×10^1	7×10^1
Dust concentration at repository fence, $\mu g/m^3$ arid climate	8×10^2	9×10^2	9×10^2	9×10^2
Radiation dose (70-Year Total Body)				
Regional population, man-rem[b]	3×10^3	6×10^4	6×10^4	4×10^4
Naturally occurring sources, man-rem[b]	(1×10^7)	(1×10^7)	(1×10^7)	(1×10^7)
Worldwide population (~6 billion), man-rem	2×10^2	1×10^6	1×10^6	1×10^6
(Naturally occurring sources), man-rem	(4×10^{10})	(4×10^{10})	(4×10^{10})	(4×10^{10})
Work force, man-rem	8×10^4	2×10^5	2×10^5	2×10^5
"Health Effects"				
Regional population (2 million persons over 70 years), No.	0	6 to 5×10^1	6 to 5×10^1	6 to 5×10^1
Worldwide population (6 billion persons over 70 years), No.	0	1×10^2 to 8×10^2	1×10^2 to 8×10^2	1×10^2 to 8×10^2
Nonradiological accidents (construction and transportation)				
Disabling injuries	5×10^3	5×10^3	7×10^3	5×10^3
Fatalities	1×10^2	1×10^2	2×10^2	1×10^2

a. The impacts are expected to be the same for spent fuel waste repository startup in Year 2000 as for the case where the decision to dispose of spent fuel as waste or to reprocess for U and Pu is deferred until the Year 2000.

b. Dose to the regional population employs the simplifying assumption that all facilities are located at the same point in the center of the reference region having a population of 2 million persons.

TABLE 2.1. Summary of Environmental Effects - Repositories in Salt (Contd)

	Repository Startup Year - 2000		Decision Year - 2000
	Once-Through[a]	U and Pu Recycle	U and Pu Recycle
	8 ISFSFs 3 ESFSFs 8 Repositories	7 FRPs 10 MOX-FFPs 2 IRWSFs 6 Repositories	14 ISFSFs 8 ESFSFs 7 FRPs 6 MOX-FFPs 6 Repositories
	Transportation	Transportation	Transportation
Land Use			
Surface facilities, buildings parking lots, ha	2×10^3	2×10^3	2×10^3
Access roads, railroads, etc., ha	2×10^2	7×10^1	4×10^2
Total property-restricted area, ha	1×10^4	6×10^3	1×10^4
Additional land on which only subsurface activities will be restricted, ha	3×10^4	2×10^4	2×10^4
Water use			
Construction, m^3 (about 10% is "consumed" in concrete)	3×10^6	3×10^6	4×10^6
Operations, m^3	6×10^7	9×10^7	9×10^7
Materials			
Concrete, m^3	1×10^6	2×10^6	2×10^6
Steel, MT	8×10^5	1×10^6	7×10^5
Copper, MT	2×10^3	4×10^3	4×10^3
Zinc, MT	1×10^3	1×10^3	2×10^3
Aluminum, MT	3×10^2	7×10^2	3×10^2
Lumber, m^3	5×10^4	8×10^4	1×10^5
Lead, MT	7×10^3	6×10^3	6×10^3
Depleted uranium, MT	3×10^3		
Energy			
Coal, MT	1×10^7	8×10^6	1×10^7
Propane, m^3	3×10^4	2×10^7	3×10^7
Diesel fuel, m^3	4×10^6	3×10^6	3×10^6
Gasoline, m^3	2×10^5	2×10^5	3×10^5
Electricity, kWh	2×10^{10}	3×10^{10}	5×10^{10}
Man-power, man-yr	3×10^5	3×10^5	4×10^5
Nonradiological Effluents			
Dust concentration at repository fence, $\mu g/m^3$ reference climate	7×10^1	7×10^1	7×10^1
Dust concentration at repository fence, $\mu g/m^3$ arid climate	8×10^2	9×10^2	9×10^2
Radiation dose (70-Year Total Body)			
Regional population, man-rem[b]	3×10^3	2×10^4	2×10^4
Naturally occurring sources, man-rem[b]	(1×10^7)	(1×10^7)	(1×10^7)
Worldwide population (~6 billion), man-rem	2×10^2	1×10^6	1×10^6
(Naturally occurring sources), man-rem	(4×10^{10})	(4×10^{10})	(4×10^{10})
Work force, man-rem	8×10^4	2×10^5	3×10^5
"Health Effects"			
Regional population (2 million persons over 70 years), No.	0	$2 \times 2 \times 10^1$	2 to 2×10^1
Worldwide population (6 billion persons over 70 years), No.	0	1×10^2 to 8×10^2	1×10^2 to 8×10^2
Nonradiological accidents (construction and transportation)			
Disabling injuries	5×10^3	5×10^3	7×10^3
Fatalities	1×10^2	1×10^2	2×10^2

TABLE 2.2. Summary of Environmental Effects - Repositories in Granite

Effects Through Year 2050 (except as indicated)	Repository Startup Year - 1985			
	Once-Through	U and Pu Recycle	U Recycle Only Pu in SHLW	U Recycle Only PuO_2 Stored
	8 ISFSFs 3 Repositories	7 FRPs 10 MOX-FFPs 7 Repositories	7 FRPs 6 Repositories	7 FRPs 17 PuO_2 storage facilities 5 Repositories
	Transportation	Transportation	Transportation	Transportation
Land Use				
Surface facilities, buildings parking lots, ha	9×10^2	2×10^3	1×10^3	1×10^3
Access roads, railroads, etc., ha	1×10^2	6×10^1	5×10^1	4×10^1
Total property-restricted area, ha	6×10^3	6×10^3	5×10^3	2×10^4
Additional land on which only subsurface activities will be restricted, ha	1×10^4	2×10^4	2×10^4	2×10^4
Water use				
Construction, m^3 (about 10% is "consumed" in concrete)	3×10^6	5×10^6	4×10^6	2×10^6
Operations, m^3	6×10^7	9×10^7	9×10^7	9×10^7
Materials				
Concrete, m^3	1×10^6	3×10^6	2×10^6	2×10^6
Steel, MT	1×10^6	2×10^6	2×10^6	9×10^5
Copper, MT	2×10^3	5×10^3	4×10^3	2×10^3
Zinc, MT	1×10^3	2×10^3	2×10^3	9×10^3
Aluminum, MT	4×10^2	7×10^2	6×10^2	9×10^2
Lumber, m^3	5×10^4	7×10^4	6×10^4	9×10^4
Lead, MT	7×10^3	6×10^3	6×10^3	6×10^3
Depleted uranium, MT	3×10^3			
Energy				
Coal, MT	8×10^6	1×10^7	8×10^6	7×10^6
Propane, m^3	3×10^4	2×10^7	2×10^7	2×10^7
Diesel fuel, m^3	3×10^6	4×10^6	3×10^6	3×10^6
Gasoline, m^3	2×10^5	3×10^5	2×10^5	2×10^5
Electricity, kWh	2×10^{10}	4×10^{10}	3×10^{10}	3×10^{10}
Man-power, man-yr	2×10^5	4×10^5	3×10^5	3×10^5
Nonradiological Effluents				
Dust concentration at repository fence, $\mu g/m^3$ reference climate	2×10^2	1×10^2	1×10^2	1×10^2
Dust concentration at repository fence, $\mu g/m^3$ arid climate	2×10^3	2×10^3	2×10^3	2×10^3
Radiation dose (70-Year Total Body)				
Regional population, man-rem[b]	4×10^3	6×10^4	6×10^4	6×10^4
Naturally occurring sources, man-rem[b]	(1×10^7)	(1×10^7)	(1×10^7)	(1×10^7)
Worldwide population (~6 billion), man-rem	2×10^2	1×10^6	1×10^6	1×10^6
(Naturally occurring sources), man-rem	(4×10^{10})	(4×10^{10})	(4×10^{10})	(4×10^{10})
Work force, man-rem	8×10^4	2×10^5	2×10^5	2×10^5
"Health Effects"				
Regional population (2 million persons over 70 years), No.	0	6 to 5×10^1	6 to 5×10^1	6 to 5×10^1
Worldwide population (6 billion persons over 70 years), No.	0	1×10^2 to 8×10^2	1×10^2 to 8×10^2	1×10^2 to 8×10^2
Nonradiological accidents (construction and transportation)				
Disabling injuries	6×10^3	9×10^3	8×10^3	8×10^3
Fatalities	2×10^2	2×10^2	2×10^2	2×10^2

a. The impacts are expected to be the same for spent fuel waste repository startup in Year 2000 as for the case where the decision to dispose of spent fuel as waste or to reprocess for U and Pu is deferred until the Year 2000.

b. Dose to the regional population employs the simplifying assumption that all facilities are located at the same point in the center of the reference region having a population of 2 million persons.

TABLE 2.2. Summary of Environmental Effects - Repositories in Granite (Contd)

	Repository Startup Year - 2000		Decision Year - 2000
	Once-Through[a]	U and Pu Recycle	U and Pu Recycle
	8 ISFSFs 3 ESFSFs 3 Repositories	7 FRPs 10 MOX-FFPs 2 IRWSFs 7 Repositories	14 ISFSFs 8 ESFSFs 7 FRPs 6 MOX-FFPs 7 Repositories
	Transportation	Transportation	Transportation
Land Use			
Surface facilities, buildings parking lots, ha	1×10^3	2×10^3	3×10^3
Access roads, railroads, etc., ha	2×10^2	8×10^1	4×10^2
Total property-restricted area, ha	7×10^3	7×10^3	2×10^4
Additional land on which only subsurface activities will be restricted, ha	1×10^4	2×10^4	2×10^4
Water use			
Construction, m^3 (about 10% is "consumed" in concrete)	3×10^6	5×10^6	6×10^6
Operations, m^3	6×10^7	9×10^7	9×10^7
Materials			
Concrete, m^3	1×10^6	2×10^6	3×10^6
Steel, MT	1×10^6	2×10^6	8×10^5
Copper, MT	2×10^3	5×10^3	5×10^3
Zinc, MT	1×10^3	2×10^3	2×10^3
Aluminum, MT	4×10^2	1×10^2	7×10^2
Lumber, m^3	5×10^4	1×10^5	1×10^5
Lead, MT	7×10^3	6×10^3	6×10^3
Depleted uranium, MT	3×10^3		
Energy			
Coal, MT	8×10^6	1×10^7	1×10^7
Propane, m^3	3×10^4	2×10^7	3×10^7
Diesel fuel, m^3	3×10^6	4×10^6	4×10^6
Gasoline, m^3	2×10^5	3×10^5	4×10^5
Electricity, kWh	2×10^{10}	4×10^{10}	5×10^{10}
Man-power, man-yr	1×10^5	4×10^5	6×10^5
Nonradiological Effluents			
Dust concentration at repository fence, $\mu g/m^3$ reference climate	2×10^2	1×10^2	1×10^2
Dust concentration at repository fence, $\mu g/m^3$ arid climate	2×10^3	1×10^3	1×10^3
Radiation dose (70-Year Total Body)			
Regional population, man-rem[b]	4×10^3	2×10^4	2×10^4
Naturally occurring sources, man-rem[b]	(1×10^7)	(1×10^7)	(1×10^7)
Worldwide population (~6 billion), man-rem	2×10^2	1×10^6	1×10^6
(Naturally occurring sources), man-rem	(4×10^{10})	(4×10^{10})	(4×10^{10})
Work force, man-rem	8×10^4	2×10^5	3×10^5
"Health Effects"			
Regional population (2 million persons over 70 years), No.	0	2 to 2×10^1	2 to 2×10^1
Worldwide population (6 billion persons over 70 years), No.	0	1×10^2 to 8×10^2	1×10^2 to 8×10^2
Nonradiological accidents (construction and transportation)			
Disabling injuries	6×10^3	1×10^4	1×10^4
Fatalities	2×10^2	2×10^2	2×10^2

TABLE 2.3. Summary of Environmental Effects - Repositories in Shale

Effects Through Year 2050 (except as indicated)	Repository Startup Year - 1985			
	Once-Through	U and Pu Recycle	U Recycle Only Pu in SHLW	U Recycle Only PuO_2 Stored
	8 ISFSFs 6 Repositories	7 FRPs 10 MOX-FFPs 10 Repositories	7 FRPs 10 Repositories	7 FRPs 17 PuO_2 storage facilities 10 Repositories
	Transportation	Transportation	Transportation	Transportation
Land Use				
Surface facilities, buildings parking lots, ha	1×10^3	2×10^3	2×10^2	2×10^3
Access roads, railroads, etc., ha	2×10^2	8×10^1	8×10^1	8×10^1
Total property-restricted area, ha	8×10^3	8×10^3	8×10^3	2×10^4
Additional land on which only subsurface activities will be restricted, ha	2×10^4	3×10^4	3×10^4	3×10^4
Water use				
Construction, m^3 (about 10% is "consumed" in concrete)	3×10^6	4×10^6	4×10^6	4×10^6
Operations, m^3	6×10^7	9×10^7	9×10^7	9×10^7
Materials				
Concrete, m^3	1×10^6	2×10^6	2×10^6	2×10^6
Steel, MT	7×10^5	9×10^5	9×10^5	1×10^6
Copper, MT	2×10^3	4×10^3	4×10^3	7×10^3
Zinc, MT	1×10^3	1×10^3	1×10^3	2×10^3
Aluminum, MT	4×10^2	5×10^2	5×10^2	1×10^3
Lumber, m^3	4×10^4	6×10^4	6×10^4	1×10^5
Lead, MT	7×10^3	6×10^3	6×10^3	6×10^3
Depleted uranium, MT	3×10^3			
Energy				
Coal, MT	1×10^7	9×10^6	9×10^6	9×10^6
Propane, m^3	3×10^4	2×10^7	2×10^7	1×10^7
Diesel fuel, m^3	4×10^6	3×10^6	3×10^6	3×10^6
Gasoline, m^3	2×10^5	2×10^5	3×10^5	2×10^5
Electricity, kWh	2×10^{10}	3×10^{10}	3×10^{10}	3×10^{10}
Man-power, man-yr	2×10^5	3×10^5	3×10^8	4×10^5
Nonradiological Effluents				
Dust concentration at repository fence, $\mu g/m^3$ reference climate	8×10^1	7×10^1	7×10^1	7×10^1
Dust Concentration at repository fence, $\mu g/m^3$ arid climate	9×10^2	8×10^2	8×10^2	8×10^2
Radiation dose (70-Year Total Body)				
Regional Population, man-rem[b]	4×10^3	6×10^4	6×10^4	4×10^4
Naturally occurring sources, man-rem[b]	(1×10^7)	(1×10^7)	(1×10^7)	(1×10^7)
Worldwide population (~6 billion), man-rem	2×10^2	1×10^6	1×10^6	1×10^6
(Naturally occurring sources), man-rem	(4×10^{10})	(4×10^{10})	(4×10^{10})	(4×10^{10})
Work force, man-rem	8×10^4	2×10^5	2×10^5	2×10^5
"Health Effects"				
Regional population (2 million persons over 70 years), No.	0	6 to 5×10^1	6 to 5×10^1	6 to 5×10^1
Worldwide population (6 billion persons over 70 years), No.	0	1×10^2 to 8×10^2	1×10^2 to 8×10^2	1×10^2 to 8×10^2
Nonradiological accidents (construction and transportation)				
Disabling injuries	5×10^3	8×10^3	8×10^3	9×10^3
Fatalities	1×10^2	2×10^2	2×10^2	2×10^2

a. The impacts are expected to be the same for spent fuel waste repository startup in Year 2000 as for the case where the decision to dispose of spent fuel as waste or to reprocess for U and Pu is deferred until the Year 2000.

b. Dose to the regional population employs the simplifying assumption that all facilities are located at the same point in the center of the reference region having a population of 2 million persons.

TABLE 2.3. Summary of Environmental Effects - Repositories in Shale (Contd)

	Repository Startup Year - 2000		Decision Year - 2000
	Once-Through[a]	U and Pu Recycle	U and Pu Recycle
	8 ISFSFs 3 ESFSFs 6 Repositories	7 FRPs 10 MOX-FFPs 2 IRWSFs 10 Repositories	14 ISFSFs 8 ESFSFs 7 FRPs 6 MOX-FFPs 10 Repositories
	Transportation	Transportation	Transportation
Land Use			
Surface facilities, buildings parking lots, ha	2×10^3	2×10^3	3×10^3
Access roads, railroads, etc., ha	2×10^2	1×10^2	4×10^2
Total property-restricted area, ha	9×10^3	1×10^4	2×10^4
Additional land on which only subsurface activities will be restricted, ha	2×10^4	3×10^4	3×10^4
Water use			
Construction, m^3 (about 10% is "consumed in concrete)	3×10^6	5×10^6	6×10^6
Operations, m^3	6×10^7	9×10^7	9×10^7
Materials			
Concrete, m^3	1×10^6	3×10^6	2×10^6
Steel, MT	8×10^5	1×10^6	7×10^5
Copper, MT	2×10^3	5×10^3	5×10^4
Zinc, MT	1×10^3	1×10^3	2×10^3
Aluminum, MT	4×10^2	9×10^2	5×10^2
Lumber, m^3	4×10^4	$9x\ 10^4$	1×10^5
Lead, MT	7×10^3	6×10^3	6×10^3
Depleted uranium, MT	3×10^3		
Energy			
Coal, MT	1×10^7	9×10^6	1×10^7
Propane, m^3	3×10^4	2×10^7	3×10^7
Diesel fuel, m^3	4×10^6	3×10^6	4×10^6
Gasoline, m^3	2×10^5	3×10^5	4×10^5
Electricity, kWh	2×10^{10}	3×10^{10}	5×10^{10}
Man-power, man-yr	3×10^5	3×10^5	5×10^5
Nonradiological Effluents			
Dust concentration at repository fence, $\mu g/m^3$ reference climate	8×10^1	7×10^1	7×10^1
Dust concentration at repository fence, $\mu g/m^3$ arid climate	9×10^2	8×10^2	8×10^2
Radiation dose (70-Year Total Body)			
Regional population, man-rem[b]	4×10^3	2×10^4	2×10^4
Naturally occurring sources, man-rem[b]	(1×10^7)	$1 \times 10^7)$	(1×10^7)
Worldwide population6(~6 billion), man-rem	2×10^2	1×10^6	1×10^6
(Naturally occurring sources), man-rem	(4×10^{10})	(4×10^{10})	(4×10^{10})
Work force, man-rem	8×10^4	2×10^5	3×10^5
"Health Effects"			
Regional population (2 million persons over 70 years), No.	0	2 to 2×10^1	2 to 2×10^1
Worldwide population (6 billion persons over 70 years), No.	0	1×10^2 to 8×10^2	1×10^2 to 8×10^2
Nonradiological accidents (construction and transportation)			
Disabling injuries	6×10^3	8×10^3	1×10^4
Fatalities	1×10^2	2×10^2	2×10^2

TABLE 2.4. Summary of Environmental Effects - Repositories in Basalt

Effects Through Year 2050 (except as indicated)	Repository Startup Year - 1985			
	Once-Through	U and Pu Recycle	U Recycle Only Pu in SHLW	U Recycle Only PuO_2 Stored
	8 ISFSFs 3 Repositories	7 FRPs 10 MOX-FFPs 6 Repositories	7 FRPs 6 Repositories	7 FRPs 17 PuO_2 storage facilities 6 Repositories
	Transportation	Transportation	Transportation	Transportation
Land Use				
Surface facilities, buildings parking lots, ha	9×10^2	1×10^3	1×10^3	2×10^3
Access roads, railroads, etc., ha	1×10^2	5×10^1	5×10^1	5×10^1
Total property-restricted area, ha	6×10^3	4×10^3	5×10^3	2×10^4
Additional land on which only subsurface activities will be restricted, ha	1×10^4	2×10^4	2×10^4	2×10^4
Water use				
Construction, m^3 (about 10% is "consumed" in concrete)	3×10^6	4×10^6	4×10^6	4×10^6
Operations, m^3	6×10^7	9×10^7	9×10^7	9×10^7
Materials				
Concrete, m^3	1×10^6	2×10^6	2×10^6	3×10^6
Steel, MT	1×10^6	2×10^6	2×10^6	2×10^6
Copper, MT	2×10^3	4×10^3	4×10^3	7×10^3
Zinc, MT	9×10^2	1×10^3	1×10^3	2×10^3
Aluminum, MT	3×10^2	5×10^2	5×10^2	1×10^3
Lumber, m^3	4×10^4	6×10^4	6×10^4	1×10^5
Lead, MT	7×10^4	5×10^3	6×10^3	6×10^3
Depleted uranium, MT	3×10^3			
Energy				
Coal, MT	8×10^6	8×10^6	8×10^6	8×10^6
Propane, m^3	2×10^4	2×10^7	2×10^7	1×10^7
Diesel fuel, m^3	3×10^6	3×10^6	3×10^6	3×10^6
Gasoline, m^3	2×10^5	3×10^5	2×10^5	2×10^5
Electricity, kWh	2×10^{10}	3×10^{10}	5×10^{10}	3×10^{10}
Man-power, man-yr	2×10^5	4×10^5	4×10^5	4×10^5
Nonradiological Effluents				
Dust concentration at repository fence, $\mu g/m^3$ reference climate	2×10^2	1×10^2	1×10^2	1×10^2
Dust concentration at repository fence, $\mu g/m^3$ arid climate	2×10^3	2×10^3	2×10^3	2×10^3
Radiation dose (70-Year Total Body)				
Regional population, man-rem[a]	3×10^3	6×10^4	6×10^4	6×10^4
Naturally occurring sources, man-rem[b]	(1×10^7)	(1×10^7)	(1×10^7)	(1×10^7)
Worldwide population (~6 billion), man-rem	2×10^2	1×10^6	1×10^6	1×10^6
(Naturally occurring sources), man-rem	(4×10^{10})	(4×10^{10})	(4×10^{10})	(4×10^{10})
Work force, man-rem	8×10^4	2×10^5	2×10^5	2×10^5
"Health Effects"				
Regional population (2 million persons over 70 years), No.	0	6 to 5×10^1	6 to 5×10^1	6 to 5×10^1
Worldwide population (6 billion persons over 70 years), No.	0	1×10^2 to 8×10^2	1×10^2 to 8×10^2	1×10^2 to 8×10^2
Nonradiological accidents (construction and transportation)				
Disabling injuries	7×10^3	1×10^4	9×10^3	1×10^4
Fatalities	1×10^2	2×10^2	2×10^2	2×10^2

a. The impacts are expected to be the same for spent fuel waste repository startup in Year 2000 as for the case where the decision to dispose of spent fuel as waste or to reprocess for U and Pu is deferred until the Year 2000.

b. Dose to the regional population employs the simplifying assumption that all facilities are located at the same point in the center of the reference region having a population of 2 million persons.

TABLE 2.4. Summary of Environmental Effects - Repositories in Basalt (Contd)

	Repository Startup Year - 2000		Decision Year - 2000
	Once-Through[a]	U and Pu Recycle	U and Pu Recycle
	8 ISFSFs 3 ESFSFs 3 Repositories	7 FRPs 10 MOX-FFPs 2 IRWSFs 6 Repositories	14 ISFSFs 8 ESFSFs 7 FRPs 6 MOX-FFPs 6 Repositories
	Transportation	Transportation	Transportation
Land Use			
Surface facilities, buildings parking lots, ha	1×10^3	2×10^3	3×10^3
Access roads, railroads, etc., ha	2×10^2	7×10^1	4×10^2
Total property-restricted area, ha	7×10^3	3×10^3	1×10^4
Additional land on which only subsurface activities will be restricted, ha	1×10^4	2×10^4	2×10^4
Water use			
Construction, m^3 (about 10% is "consumed in concrete)	3×10^6	4×10^6	5×10^6
Operations, m^3	6×10^7	9×10^7	9×10^7
Materials			
Concrete, m^3	1×10^6	3×10^6	2×10^6
Steel, MT	1×10^6	2×10^6	7×10^5
Copper, MT	2×10^3	5×10^3	5×10^3
Zinc, MT	9×10^2	1×10^3	2×10^3
Aluminum, MT	3×10^2	9×10^2	5×10^2
Lumber, m^3	4×10^4	5×10^4	1×10^5
Lead, MT	7×10^3	6×10^3	6×10^3
Depleted uranium, MT	3×10^3		
Energy			
Coal, MT	8×10^6	8×10^6	1×10^7
Propane, m^3	3×10^4	2×10^7	3×10^7
Diesel fuel, m^3	3×10^6	3×10^6	4×10^6
Gasoline, m^3	2×10^5	3×10^5	4×10^5
Electricity, kWh	2×10^{10}	4×10^{10}	5×10^{10}
Man-power, man-yr	2×10^5	4×10^5	5×10^5
Nonradiological Effluents			
Dust concentration at repository fence, $\mu g/m^3$ reference climate	2×10^2	1×10^2	1×10^2
Dust concentration at repository fence, $\mu g/m^3$ arid climate	2×10^3	2×10^3	2×10^3
Radiation dose (70-Year Total Body)			
Regional population, man-rem[b]	3×10^3	2×10^4	2×10^4
Naturally occurring sources, man-rem[b]	(1×10^7)	(1×10^7)	(1×10^7)
Worldwide population (~6 billion), man-rem	2×10^2	1×10^6	1×10^6
(Naturally occurring sources), man-rem	(4×10^{10})	(4×10^{10})	(4×10^{10})
Work force, man-rem	8×10^4	2×10^5	3×10^5
"Health Effects"			
Regional population (2 million persons over 70 years), No.	0	2 to 2×10^1	2 to 2×10^1
Worldwide population (6 billion persons over 70 years), No.	0	1×10^2 to 8×10^2	1×10^2 to 8×10^2
Nonradiological accidents (construction and transportation)	7×10^3	1×10^4	1×10^4
Disabling injuries	2×10^2	2×10^2	3×10^2
Fatalities			

Water use is site specific in terms of environmental impact. Since it was shown that in every instance the requirements for water were insignificant fractions of the flow of the R River in the reference environment, it was concluded that as long as such streams are employed at the various facilities, water use will not be a determining factor in waste management. Water use varies no more than a factor of about three regardless of fuel cycle option or repository media.

In materials consumed for waste management functions there appears to be no important difference among fuel cycle options or repository media. Stainless steel, and consequently chromium and nickel, requirements were not identified in every case, and these resource commitments may be underestimated. These two metals could take on increased importance because they are not now produced in the U.S.

There are substantial differences in the use of propane in the various fuel cycles; propane is used extensively in waste management associated with fuel reprocessing. The fuel recycle options use about 100 times the propane used by the once-through cycle. The larger consumption is on the order of 0.5% of U.S. consumption as a whole (assuming constant national use over the period 1980-2050). Use of diesel fuel and gasoline is essentially invariant among fuel options and geologic media; their principal use is in transportation of wastes. The largest diesel fuel usage amounts to about 0.1% of the U.S. consumption as a whole.

The need for electricity varies by a factor of about 10 among fuel cycles and geologic media. The largest use amounts to about 0.06% of the total LWR scenario energy production of about 10,000 GWe-yr.

Various nonradioactive pollutants released with the burning of fuel associated with construction and operation of the various facilities were found to be within applicable standards. Rock and salt dust releases may be excessive, but engineered controls are believed to be available to bring these within applicable standards. The long-term impact of tens of millions of tons of residual salt (and possibly shale) left on the surface at each salt repository could, unless properly maintained, have adverse impacts on biota. There are, however, a number of ways that materials on the surface could be managed in an environmentally satisfactory way, e.g., sold to chemical industry, controlled release at sea, suitably over- and underlain to assure containment.

Health effects in the form of fatalities and disabling injuries which result from nonradiological accidents associated with transportation, repository mining, and facility construction to range from 130 to 230 fatalities or permanently disabling injuries and from 4700 to 9500 temporarily disabling injuries. These accidents would occur at the described levels of labor and transportation in any heavy industry; radiation itself is not responsible for the consequences.

The magnitude of radiation dose received by the work force, regional population, and worldwide population depends on whether spent fuel is reprocessed or not. During routine operation in the once-through cycle option, the dose received by the public is a small fraction of the

nominal variation in dose at a given location from naturally (undisturbed) occurring radioactive sources. Under normal operations radiation dose to the public is concluded to be an insignificant factor in waste management of spent fuel.

During fuel reprocessing, some radionuclides are released to the atmosphere and result in exposure of the public. The main contribution to this dose occurs during the fuel dissolution step in the FRP, and the principal contributor is the radionuclide tritium, for which there is presently no practical means of removal. Other radionuclides such as ^{14}C, ^{85}Kr, ^{129}I and particulates are removed to varying degrees in recovery processes and are stored (in the case of ^{85}Kr) or disposed of in repositories (^{14}C and ^{129}I). A 1000-fold reduction in the amount of ^{129}I released produces a 50-fold reduction in the thyroid dose of the "maximum individual." The residual dose is less than the variation in background mentioned before. The total regional population dose if all facilities were located in the same region would amount to about 50,000 man-rem over the 70-year reference period. During this same time the population would have received 14,000,000 man-rem from naturally occurring sources. (If facilities were not colocated, total population dose would still be the same but the population to be used for comparison with naturally occurring sources would increase.)

The dose to the world population from reprocessing would amount to about 1 million man-rem over the 70-year reference period. During this same time period, the worldwide population would have received about 45,000 million man-rem from naturally occurring sources.

The conversion of dose to so-called "health effects" using the relationship of 100 to 800 fatal health effects* per million man-rem would suggest that 6 to 48 health effects over 70 years might occur in the regional population. Over that same period, about 1,800,000 persons of the 2,000,000 regional population would have died from causes unrelated to fuel reprocessing waste management. Similarly, in terms of worldwide dose, 100 to 800 health effects might be attributable to the reference fuel reprocessing scenario whereas over the same period about five billion persons will have died from causes unrelated to fuel reprocessing waste management.

The radiological consequences to the public from management of reprocessing wastes as treated in the reference system are concluded to be acceptable in comparison to dose the public receives from naturally occurring sources. Thus, radiological consequences of routine operation are also concluded to form no realistic basis for choice among waste management alternatives.

Nonroutine operations and accidents for which the consequences were developed were postulated to be minor, moderate or severe and were analyzed for each waste management process, including treatment, transportation, interim storage, and isolation.

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* A detailed discussion of the relation of health effects to dose is given in Appendix B. In brief, a range of some of the commonly used conversion factors between dose and somatic effects (such as fatal cancers) is 50 to 500 such effects per million man-rem and between dose and genetic effects is 50 to 300 such effects over all generations per million man-rem. Other suggested conversion factors would indicate more and others less, not excluding zero effects.

TABLE 2.5. 70-Year Dose Commitments to Maximum Individual from Worst Design Basis Radiological Accidents(a)

Facility	Accident	Expected Frequency/Yr	Dose, rem
ISFSF - Interim Storage	Criticality in spent fuel storage		5×10^{-2}
ESFSF - Extended Storage	Package of 4 PWR elements leaks	0.1	1×10^{-6}
FRP - Waste Treatment	Contamination of secondary cooling water in SHLW storage basin		4
MOX - Waste Treatment	Rupture of failed fuel container by tornado		4×10^{-6}
Repository	SHLW canister drop		4×10^{-6}
Transportation	Spent Fuel - severe impact and fire	1×10^{-5}	130
	SHLW - severe impact and fire	1×10^{-6}	7

a. Dose to an individual from naturally occurring sources amounts to 7 rem over the same time period.

Table 2.5 shows the radiological impacts on the public from design basis operation accidents having the worst consequences for each facility in the reference system. Where expected frequencies are established in DOE/ET-0028, they are listed. The largest dose to the maximum individual from waste management, 130 rem, was found to result from a transportation accident involving spent fuel. The long-term consequences to the individual receiving such a dose are uncertain (this dose is about one-third of the dose for which the probability of early fatality is about 0.01). for these accidents most radioactive material is released at ground level and over a short time and most exposure to the public is to the persons nearby.* Moreover, the expected impact on society is small since the likelihood of occurrence of this accident is on the order of 1 in 10,000 over a 70-year period. Such an accident does not form a basis for choice of fuel cycle option because spent fuel must be transported in all fuel cycle options (either as waste or as a resource).

A 70-year dose commitment of 4 rem to the maximum individual (about the same as the annual occupational exposure limit) from the postulated worst accident at a fuel reprocessing plant is not large enough to preclude election of fuel reprocessing options for waste management reasons.

Impacts associated with highly improbable accidents that might breach a repository and cause part of its contents to reach the biosphere were estimated. Included among these accidents were: impact of a large meteorite (or detonation of a large nuclear weapon) at or near the repository site and dispersal of radioactivity into the atmosphere; intrusion of water into a repository (following rock faulting or other breaching mechanism) either as a stream or as

* The 70-year total-body dose to the regional population was 140 man-rem (excluding the maximum individual dose).

TABLE 2.6. Consequences and Societal Risk Associated with Breach of 50,000 MTHM Spent Fuel (or Equivalent of Reprocessing Waste) Repository up to About 1000 Years after Closure[a]

Event	70-Yr (Lifetime) Accumulated Total Body Dose to Exposed Population,[b] man-rem	Regional Health[c] Effects Over 70 Years	Probability of Accident	Societal Risk in Health Effects
Meteorite impact (also covers nuclear explosion and volcanism)			$\sim 2 \times 10^{-13}$/yr	
1% release				
Spent fuel	7×10^{7}	7×10^{3} to 6×10^{4}		1×10^{-9} to 1×10^{-8}
Reprocessing wastes, U and Pu recycle	6×10^{7}	6×10^{3} to 5×10^{4}		1×10^{-9} to 1×10^{-8}
Drilling through canister			$<5 \times 10^{-3}$	
Spent fuel[d]	1×10^{2}	$\leq 2 \times 10^{1}$		$\leq 1 \times 10^{-1}$
Reprocessing wastes, U recycle - Pu in HLW[e]	4×10^{3}	2×10^{1}		$\leq 1 \times 10^{-1}$
Faulting and flooding			$\sim 2 \times 10^{-13}$/yr	
Stream carrier 2.8 m^3/s				
Spent fuel	1×10^{8}	1×10^{4} to 8×10^{4}		2×10^{-9} to 2×10^{-8}
Reprocessing wastes, U and Pu recycle	4×10^{8}	4×10^{4} to 3×10^{5}		8×10^{-9} to 6×10^{-8}
Groundwater carrier 100 m/yr[f]				
Spent fuel	2×10^{7}	2×10^{3} to 2×10^{4}		4×10^{-10} to 3×10^{-9}
Reprocessing wastes, U and Pu recycle	2×10^{7}	2×10^{3} to 2×10^{4}		4×10^{-10} to 3×10^{-9}
Solution mining in salt, reprocessing only			Unknown (≤ 1)	
Spent fuel	2×10^{7}	2×10^{3} to 2×10^{4}		$\leq 2 \times 10^{3}$ to $\leq 2 \times 10^{4}$ (g)
Reprocessing wastes, U and Pu	4×10^{6}	4×10^{2} to 3×10^{3}		$\leq 4 \times 10^{2}$ to $\leq 3 \times 10^{3}$

a. Independent of repository media except as noted.
b. Two million persons, except 40 million persons for solution mining.
c. Health effects as discussed in Appendix B; 100 to 800 health effects per million man-rem to the exposed population.
d. Dose to about 20 individuals residing on contaminated land of 13 rem/yr or about three times permissible occupational limit.
e. Dose to about 20 individuals residing on contaminated land of 150 rem/yr, probable significant life shortening.
f. All wastes leached out at once, a pulse release.
g. Probability of one used.

slowly moving groundwater which leaches radionuclides from waste and transports them to the biosphere; inadvertent drilling through a canister and bringing some waste to the surface in the drilling mud; and inadvertent solution mining for salt in the repository which leaches waste and carries it with the brine to the surface, where salt and radionuclides enter humans via food pathways. These accidents, although believed highly unlikely, give some indication of the long-term risks of geologic isolation of wastes. A tabular summary of the nondesign basis accidents, postulated frequencies, consequences, and estimates of societal risk is presented in Table 2.6.

To provide some perspective for the risks tabulated in the preceding tables, it is useful to examine accident statistics recognizable by most people. For example, the societal risk (for the 2 million person regional population) from death as a result of automobile accidents is currently on the order of 30,000 deaths over 70 years, and the societal risk of death from being struck by lightning is on the order of 80 deaths over 70 years.[1]

If a population of 40 million persons is assumed as in the solution mining accident, the societal risk from automobile accidents and lightning becomes 6×10^5 and 2×10^3 deaths, respectively. The largest societal risk tabulated was that for solution mining of salt and would not amount to more than 2×10^3 to 2×10^4 health effects. Assuming the solution mining accident did happen, this translates to 1×10^3 to 1×10^4 cancer deaths or one-half to five times the societal risk from death by lightning. It is, of course, believed that the probability of a solution mining venture penetrating the salt repository would be far less than one. Even if the probability were one (that is, a certainty) the societal risk is on the order of that experienced for lightning. It is doubtful that anyone seriously considers death by lightning as a significant societal impact.

For all other accident scenarios the societal risk was orders of magnitude less than that from the postulated solution mining scenario.

At about 1.4 million years after repository closure, the 70-year accumulated total body dose to the regional population from groundwater transport of radioactive material from a repository containing 50,000 MTHM or equivalent was estimated to be 2×10^7 man-rem for spent fuel waste and 3×10^5 man-rem for reprocessing wastes from uranium and plutonium recycle. These doses would occur regardless of fraction of inventory released per year (from 100% to 0.01%/yr) or the time the repository is breached (year filled and up to 100,000 years later). The dose at a million years or so is due chiefly to ^{226}Ra from the very long-lived ^{238}U plus an addition from ^{234}U.* Presumably the release of radioactive material to the biosphere could occur over thousands of years and thus the stated population dose would apply to each generation. The societal risk from such an event if it were to continue for 10,000 years would result in a total man-rem dose (assuming a 2 million person population replaced every 70 years)

* It should be noted that the ^{226}Ra and ^{238}U are from unburned fuel and are not a product of nuclear power. This material was in the earth, mined and returned (in a form less likely to migrate to the biosphere than in its original condition).

of about 3×10^9 man-rem for spent fuel to 4×10^7 man-rem for reprocessing wastes. These doses related to 3×10^5 to 2×10^6 and 4×10^3 to 3×10^4 health effects, respectively. At an estimated frequency of occurrence of 2×10^{-13}/yr (2×10^{-9} over 10,000 yr) a societal risk of death due to this accident would amount to about 6×10^{-4} to 5×10^{-3} and 8×10^{-6} to 6×10^{-5}, respectively. The societal risk over this same time period from lightning would be about 1×10^4. The risk to society in this accident scenarios is thus less than 1×10^{-6} of that from lightning. It is concluded that even if there are man orders of magnitude of error associated with the parameters used in this accident scenario, the long-term societal risk from accidents associated with deep geologic isolation is insignificant.

This generic environmental analysis finds no compelling environmental reasons, including public health, that should preclude disposal of spent fuel, with or without interim storage, in deep geologic repositories. Similarly, it is concluded that wastes associated with fuel reprocessing for either uranium-only or uranium and plutonium recycle can be treated, stored, transported, and disposed of in deep geologic repositories without significant impact of radiation on the public now or through any foreseeable accidents in the future.

REFERENCES FOR SECTION 2.0

1. National Safety Council, Accident Facts, 1974 Edition.

3. APPROACH TO ASSESSMENT OF ENVIRONMENTAL EFFECTS FROM RADIOACTIVE WASTE MANAGEMENT

The approach to environmental assessment used in this report follows the procedure of investigating potential effects associated with construction of waste management facilities, operation of the facilities, postulated accidents, transportation of wastes and decommissioning of facilities and equipment. This report is in support of the generic environmental impact statement, Management of Commercially Generated Radioactive Waste, and therefore, is not site specific.

One approach to generic environmental impact statements is to identify practices necessary to prevent potentially undesirable effects. Such an approach has been used in this report where other methods were not applicable. The principal approach used was to assess the effects of various waste management alternatives on a representative or hypothetical environment that may be assumed common to all waste management facilities. A reference environment was developed for this purpose; a detailed description of the environment is presented in Appendix A. The reference environment is typical of certain regions of the north central United States and provides the necessary description of environmental characteristics (e.g., climate, land use, surface waters, and plant and animal communities) that can serve generally as a baseline for estimating the ecological impacts of waste management. The use of the reference environment should not, however, be construed as an endorsement of any particular region for siting of radioactive waste management facilities but rather as a mechanism for dealing with site-specific aspects of comparative environmental assessment. For some analyses a single reference environment is inadequate. In such cases, relevant portions of other environments are presented. An example is the socioeconomic effect of the demands of construction workers and their families on community services. The effects can be markedly different where the construction force can be drawn from an established work force in a nearby metropolitan area in contrast to construction in a remote location where a large work force must be integrated into small communities.

In the case of no fuel reprocessing (once-through option), all nuclear facilities (postfission-except reactors) are considered waste management facilities for which full environmental analysis is necessary. In the case of any of the recycle modes, analysis of environmental effects is not made for those portions of facilities that involve spent fuel as a resource. For example, construction and operating effects (resource commitments, manpower, etc.) are not considered for the production portion of a fuel reprocessing plant.

Although the environmental effects of constructing and operating a fuel reprocessing plant and a mixed-oxide fuel fabrication plant are not within the scope of this report, a brief analysis of each of these plants has been made to give perspective to construction and operation effects that may be expected from plant-related waste management practices. For example, if a fuel reprocessing plant were built and the decision made to include a waste solidification facility, a comparison of construction requirements for the two facilities would provide a measure of the incremental impact of the solidification facility. Without a

reprocessing plant, the solidification facility would not be built. Thus, the construction of the main plant would in many cases result in the same effects with or without construction of the waste treatment facility. Decommissioning of a fuel reprocessing plant is, however, part of waste management and a description of the effects of managing decommissioning wastes is provided.

In addition to postulated accidents and decommissioning, aspects considered in the construction and operation of waste management facilities include resource commitments, such as land, water, building materials, and manpower; atmospheric effects, including secondary effects such as pollutants released during work force transportation; ecological effects; and radiological effects including health effects. Aspects that may be viewed as significant enough to bear on decision-making are emphasized whereas aspects of marginal importance, including declaration of no releases, are stated without further comment.

3.1 ACCIDENT ANALYSIS

In most cases, conscientious operation of a well-designed plant will avoid important adverse environmental effects. Where review of designs or of operating records show an important effect, or potential effect, redesign, revision of procedures, or retraining can usually eliminate the effect. This iterative improvement mechanism is also applicable to a large extent to accidents. Indeed, if an accident potential is recognized, internal or regulatory procedures will usually require corrective steps be taken to minimize the likelihood of occurrence. Thus it is expected that some accidents postulated in this report would be obviated by the time the process is fully implemented.

Accidents analyzed in this report are fully described in DOE/ET-0028 (Technology for Commercial Radioactive Waste Management)[1] and the so-called umbrella concept, wherein one accident may be considered typical for several processes, is described in detail. The umbrella concept was developed to simplify accident analysis. For a given waste management facility, engineers familiar with the processes involved assess the possibilities for accidents. This analysis results in a list of accidents and expected frequencies of occurrence. From this list, accidents are categorized as likely to have minor, moderate, or severe environmental consequences. For moderate or severe accidents one accident is chosen which is expected to result in the most serious consequences. That accident is analyzed as being representative of the set of accidents and is called the umbrella accident.

From the list of minor accidents a radionuclide release source term is developed, based on an annual proration of radioactive material released per accident and the expected frequency of occurrence. This prorated source term is added to the planned annual releases, thus producing source terms for routine operation which take into account the likelihood of process upsets that could result in larger source terms than originally engineered. In many cases, the additions are insignificant compared with routine releases; however, in some instances the reverse is true and the accident source term dominates.

Postulating very serious or non-design basis accidents involves a different procedure. Usually as the severity of the postulated accident increases, the expected frequency decreases and the certainty that can be associated with a given expected frequency also decreases. Because large uncertainties exist in the "remote likelihood" categories of accidents, some accidents are described on a "what if" basis. For these cases, the consequences are estimated but the likelihood of actual occurrence of the postulated event is given only in qualitative terms. In an absolute sense, the consequences of such "what if" accidents are not too meaningful in the absence of an expected frequency. However, they can be important when relating consequences of accidents that are common to several waste management actions such as isolation of spent fuel versus high-level waste in deep geologic repositories.

Where feasible, risk, defined as the product of the probability of an event and the consequences of the event, is addressed. Where probabilities are vague or uncertain other comparisons are used to provide perspective. For example, the probability of a meteorite of sufficient size being able to penetrate a deep geologic repository and cause dispersal of part of the inventory is at least as small if not substantially smaller than the probability

of the same size meteorite striking one of our large metropolitan areas. A comparison of the consequences of these two events can provide some perspective on the risk to human life from such events.

In considering probabilities, it should be noted that an accident postulated to occur once in a million years has far less likelihood of occurring in the same time frame important to commercial waste management than does one which is postulated to occur once each thousand years. The intervals between occurrences may be essentially correct, but there is no assurance whatever that either event will not take place during this or any other year.

All accidents in this report (except those dealing with a tornado hitting a salt storage pile and with the release of nitrogen oxides) involve radiological consequences. Engineered storage of such chemicals as acids and caustics has not been described for the various facilities in sufficient detail to permit analysis of impacts from accidents related to chemical storage. There appears to be ample engineering expertise to prevent serious environmental effects from these kinds of accidents and that the decision-making process will not be impaired if further consideration of these accidents is deferred until such time as site-specific environmental impact statements are prepared.

3.2 ATMOSPHERIC EFFECTS

Atmospheric effects evaluated in this report are centered on a reduction in ambient air quality caused by emissions to the atmosphere during construction and operation of the facilities. Secondary emissions from construction force vehicles and construction equipment were also included in the emissions inventory. Since heat is a by-product of each process, its effect on the biosphere, whether released directly or via cooling tower, was also investigated.

Using a Gaussian dispersion model, which is based on a statistical theory of diffusion, downwind concentrations for nonradioactive pollutants released from various facilities were computed by using data for wind speed and direction as functions of atmospheric stability as given in the reference environment (Appendix A). Annual average dispersion factors ($\overline{\chi}/Q'$) for material released to the atmosphere from various locations were calculated for the major facilities. For accidents having short-term releases, dispersion factors as set forth in U.S. Atomic Energy Commission Regulatory Guide 1.3[2] were used.

Once predictions of downwind concentrations were obtained, the values were compared with the Federal air quality standards[3] or threshold limit values. (Threshold limit values were established primarily for occupational exposure. These values, if established for environmental exposure, would likely be less by one or more orders of magnitude.) If neither an air quality standard nor a threshold limit value exists for a pollutant, comparison was made to naturally occurring background concentrations.

Data from eight reactor sites around the country were analyzed and compared with dispersion factors for the reference environment to investigate the variation of dispersion of pollutants based on geographical location. Six sites showed dispersion factors within a factor of 2 for those predicted for the reference site. The dispersion factors of the other two reactor sites are within a factor of 4 and 6. In all cases, however, dispersion factors at the other sites were greater than those predicted for the reference environment. This was not quite the result expected; however, the reference environment had been developed before this exercise was conducted. Regardless, multiplication of dispersion factors for the reference environment by 10 would include all those factors from all sites investigated.*

Effects resulting from secondary emissions (i.e., automobiles, space heat, and construction activities) were evaluated in the same manner as were routine and accidental releases. Evaluation of automobile emissions resulting from construction workers traveling to and from work involved a transportation dispersion model using a mixed-cell approach. Nonradioactive pollutants resulting from construction activities and space heating were treated as an area source. This type of analysis considered two scenarios: 1) relatively few workers would move into the area of facility construction and 2) a boom town would be generated from a large worker influx. These two types of scenarios were also evaluated for different geographical regions using dispersion data for the eight reactor sites.

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* The implication is that for the eight reactor sites considered, assuming all other factors are held constant, doses would not exceed a factor of 10 over those of the reference site, based on differences in annual average atmospheric dispersion.

Analyses of heat rejection to the biosphere either by cooling towers or by direct convection were conducted using both Gaussian models and numerical analysis, of which the latter method provides a more exact solution to the fundamental equations of motion. Analyses of cooling tower impacts include estimates of the length and persistence of visible plumes, prediction of fogging conditions, and analysis of drift deposition. For cooling systems that use natural convection as a mechanism for heat rejection, analyses were made on the magnitude of temperature change downwind of the facility and possible microclimatic changes. For perspective, these changes were compared with data obtained on temperature changes in the vicinity of shopping centers and data obtained on temperature changes associated with city size.

3.3 RESOURCE COMMITMENTS

The approach to presentation of environmental effects related to commitment of resources in most instances amounts to a description of the land and water required, materials needed, energy consumed, and manpower used for construction, operation, and decommissioning of the facilities. Resource commitments are combined by facilities to the reference plant level and also by plant to systems of waste management within fuel cycle options.

In fuel reprocessing options, land required for waste management facilities associated with waste treatment is insignificant in an absolute sense and is trivial when compared with the land required for the major plants. Land is needed temporarily (up to 50 years) in amounts of up to 8000 ha for deep geologic repositories in the reference scenario. Because land use is highly site specific, no conclusions are drawn about the withdrawal from present use to that associated with waste management. In the reference scenario, major waste management facilities are not located in the same region. This was assumed primarily for ease in making dose calculations and thus avoiding presentation of various combinations of plants.* In the case of repositories, such a restriction is probably unnecessary since after decommissioning it is presumed that all surface land could be returned to prior uses.

Water used for both construction and operation is assumed to be withdrawn from the R River (average annual flow 120 m^3/s) in the reference environment. Thus, in cases where facilities show no deleterious effects on the downstream use of water or on aquatic ecosystems for the R River, it is assumed for this generic analysis that similar effects could be expected on similar or larger bodies of water. The amount of cooling water needed is determined for each facility based on stylized mechanical-draft cooling towers.

Materials needed for construction and operation of waste management facilities are listed. The availability of selected resources is given in Appendix E. Energy resources required are noted and consist principally of propane, diesel oil, gasoline, and electricity. The significance of using these amounts of resources is not determined; however, perspective is provided for uses in integrated systems for various fuel cycles. Manpower is cited for each facility and aggregated for plant and system. No judgment is made on the effects of the stated manpower would have in precluding availability for other uses.

* At one point in the radiological assessment, all facilities are assumed to be colocated to establish an idea of the upper bound of population dose from waste management.

3.4 RADIOLOGICAL EFFECTS

Radiological effects of radioactive waste management are probably perceived as one of the most important aspects of nuclear power production. As a consequence, the bulk of this report addresses that subject. Radiological effects are described principally in terms of dose to workers and to the public (regional population described in Appendix A) using mathematical models described in Appendix B.

To provide a description of radiological effects over the reference scenario of 1980 to 2050, doses are presented from releases of radioactive material associated with routine operation and accidents for individual facilities, aggregation of reference facilities into reference plants, and aggregation of plants into systems. Amounts of radionuclide released are presented for each process. These source terms are derived from Waste Treatment Data Sheets that appear in Volume 5 Section 10 of DOE/ET-0028 or as otherwise specified. Inventories of radionuclides by waste type and radionuclide are presented in Appendix D for various times after placement in repositories. Doses are also given by decade and cummulatively for the various integrated systems (depending on the fuel cycle option) for the regional population and worldwide population in Appendix D.

Doses to the public from waste management operations arise mainly from inhalation of radionuclides and by direct radiation, but also from ingestion of food products (e.g., vegetables, meat, and dairy products) grown on land contaminated by radionuclides either deposited on the ground or deposited directly on the food products themselves. No releases of radionuclides to any body of water or to ground have been identified from routine operations.

Dose from exposure to ^{3}H, ^{14}C, and ^{85}Kr is addressed for three main categories of the public: the so-called maximum individual, the population within an 80-km radius of the plant ($\sim$ 2 million), and the world population ($\sim$ 6 billion in the year 2000). In selected instances dose to the population of the eastern half of the United States is also presented.

3.4.1 Maximum Individual

The maximum individual is a hypothetical area resident whose habits would tend to maximize his dose. The following assumptions govern the calculations of dose to this category:

- The individual resides at the point of the maximum offsite dispersion factor ($\overline{\chi}/Q'$).
- The individual continuously occupies this location (no allowance for possible shielding effects).
- Food is consumed and food products are produced at the point of residency.
- The maximum likely intake of foods is assumed.
- The individual is submersed in a semi-infinite cloud of gaseous effluents.
- The exposure patnways of interest are air submersion, inhalation, ingestion, and in some cases direct radiation.
- Environmental pathway parameters used are defined in the reference environment description.

- Points and manner of release of gaseous effluents are defined in the reference plant description.
- Organs of princpal interest are the total body, lung, thyroid, and bone.

Annual doses are given for the specified organs for the maximum individual and for the child's thyroid. These doses are presented for each facility (process or function) described and are summed for several facilities that may make up the waste management facilities at a given reference plant. In addition, a 70-year integrated dose for the maximum individual is calculated for each process and at the plant level for operation and decommissioning. The 70-year dose is based on the assumption that the maximum individual resides near the plant during its 30-year operating life and for 40 years thereafter. In essence, the 70-year integrated dose is a lifetime dose commitment.

In the case of accidents a first-year dose replaces the annual dose where the dose received in the first year may be large enough to warrant discussion of acute effects. Where the 70-year integrated dose is small neither a first year no annual dose is given.

3.4.2 Regional Population

Dose to the regional population is calculated using factors that may be described as average or typical rather than maximum. The following assumptions are used in calculating the regional population dose:

- Annual average dispersion factors ($\overline{\chi}/Q'$) are developed for annular sectors of residence in the reference environment (22.5° by 1.6-km increments from 1.6 to 8 km and 22.5° by 16-km increments from 8 to 80 km from the plant).
- Average food consumption rate and recreational use rates are assumed for the region.
- Consumption of food products in the region is linked to actual production specified for the reference environment.
- Pathways of interest are inhalation, air submersion, and ingestion. (Direct radiation is included in the case of transport of radioactive materials.)
- The organs of principal interest are total body, lung, thyroid, and bone.

Annual dose to the regional population is calculated for both the facilities (processes) and plants. A 70-year integrated dose is calculated for the regional population to include the period of reference plant operation, decommissioning, and 40 years thereafter. The 70-year integrated dose is considered to be that for one generation. Second and third generation doses are also calculated at the reference plant level. Although a generation in the usual sense is taken to be 30 years this analysis uses the simplifying assumption that the regional population consists of adults who reside in the region for 70 years, die and are instantly replaced by other adults for the next 70 years and so on (age related parameters are not used). Thus, the 30-year plant operation results in a 210-year population dose commitment (unless noted, the maximum individual is not a member of the regional population).

3.4.3 World Population

Dose to the worldwide population is calculated based on the following assumptions:

- ^{3}H, ^{14}C, and ^{85}Kr are uniformly and rapidly mixed after release to the atmosphere.
- Release rates for the thirtieth year of operation are used for individual facilities and for the total 30-year releases for plants.
- Pathways considered are inhalation, air submersion, and ingestion.

The annual dose, 70-year dose commitment from one year's release at the facility level, and 70-year accumulated dose for 30 years of plant operation at the plant level are presented. Second and third generation doses (70-year generation as noted above) are also calculated for the FRP.

3.4.4 Work Force

Waste management task descriptions as developed for DOE/ET-0028[1] were studied, discussions were held with those knowledgeable in a particular area, and related exposure experience was sought from similar work performed in managing radioactive defense wastes. In making dose computations the following assumptions were made:

- Sixty percent of the personnel associated with a task are assumed to perform radiation work while the remaining 40% are assigned management, supervisory, or clerical status and thus receive no exposure.
- All shielding walls are designed to meet Federal* design criteria (i.e., 1 rem/yr except as noted).
- All shipping containers are designed to meet Federal** dose rate criteria and in no instance should the dose rate exceed 0.2 rem/hr at the surface of the container.

Estimates of dose from maintenance operations are more uncertain than estimates of dose from routine operations. In many cases there was no experience on which to base an estimate of the extent of maintenance that might be required and without that basis no dose could be assigned. In some cases an estimate of dose for maintenance activities was possible and these cases are identified.

3.5 HEALTH EFFECTS

Health effects are calculated for regional or worldwide populations based on the dose received by these populations from the aggregation of facilities within plants. The doses calculated to result from individual facilities are usually too small to warrant discussion of health effects. A more detailed discussion of the meaning of and approach to health effects in this report is presented in Appendix B.

The radiation dose to man from ingestion, inhalation, or external exposure to specified quantities of radionuclides can be calculated with reasonable confidence. However, estimates of the amounts of radioactive material that may be released from waste management operations and fractions reaching man via various environmental pathways are not as well defined. Furthermore, the relationship of dose to so-called health effects is even less well defined. Thus, estimates of health effects that may result from radiation exposure from commercial radioactive waste management activities can be derived only from a chain of estimates of varying uncertainty. If an error is made in making these estimates, the usual practice is to make it in a way intended to overprotect the individual. As a consequence, if the chain of estimates is long there may be considerable overestimation in the final value.

Because releases of radioactive materials and the resulting dose to any individual are both small, the effects to be considered are long-delayed somatic and genetic effects. Such effects will occur, if at all, in a small fraction of the persons exposed. Except as a consequence of the unusually severe accident involving large doses, there can be no possibility of an acute radiation effect. The effects that must be considered are cancers that may result from 1) total-body exposures, and more specifically, from radioactive materials deposited in the lung, bone, and thyroid; and 2) germ cell exposures which are reflected as genetic effects in future generations.

Knowledge of effects caused by low doses of radiation is indirect because the incidence is too low to be observed against the much higher background incidence of similar effects from other causes. For example, it is not possible to attribute a specific number of human lung cancers to the plutonium from weapons-test fallout that is present in everyone's lungs because 1) lung cancers are known to be caused by other materials present in much more hazardous concentrations and 2) lung cancers occurred before there was any plutonium. Hence, one can only estimate a relationship between health effects and radiation dose, basing this estimate upon observations made at high exposure levels where effects have been observed in man and carefully studied in animal experiments.

In this report, 50 to 500 fatal cancers or 50 to 300 serious genetic defects in an exposed population, is assumed to result for each million man-rem of radiation exposure. The actual number of health effects for such exposure particularly as the amount per individual becomes less than background may in fact be zero.

An alternative approach to analysis of direct exposure involves comparison of the estimated radiation doses from waste management activities with the more accurately known radiation doses from other sources. This approach avoids the more uncertain step in estimating health effects (the dose-effect relationship) and provides a comparison with firmly established data on human exposure (i.e., the exposure to naturally occurring radiation and radioactive

materials). Thus it seems more reasonable to judge a risk's acceptability on knowledge that the risk is a certain fraction of an unquantifiable but unavoidable natural risk, than to base this judgment on an absolute estimate of future deaths that might be too high or too low by a factor of 100 or 100,000. Because of these judgmental problems it is the practice in this report to compare estimated radiation exposure from waste management activities with naturally occurring radiation exposures as well as to indicate estimates of cancer deaths and genetic effects.

3.6 ECOLOGICAL EFFECTS

The effects of the treatment, interim storage, transportation, and final deposition of radioactive wastes on natural ecosystems cannot be satisfactorily dealt with in detail in a generic sense because of the overriding influence of site-specific factors. For example, the expected effects of certain waste technologies on plant and animal communities in an area of high precipitation may be markedly different from those in an arid environment. The ability of natural systems to withstand stress will vary widely according to their environment. Similarly, the economic worth of the natural resources at risk will depend greatly on the region and the degree of change already induced by human activities.

In this report, the assumption is made that environmental releases of radioactive wastes that are within the acceptable standards designed to protect man will also be within limits tolerable to natural plant and animal populations. In general, man is believed to be more sensitive to radiation than are other biota. Thus the discussion of potential radiation effects on plants and animals, other than man, is not considered appropriate on a generic basis. Consequently, discussion of the ecological impacts of radioactive waste management are confined mainly to 1) the effects on the use of land and surface water and 2) the impacts resulting from the release of nonradioactive chemicals and heat to the air and to surface water.

Acceptable air and water quality standards are used as the basis for estimating the relative severity of impacts. On a facility or process basis, these releases are usually several orders of magnitude below Federal release standards.[3] Even when one considers the releases from the combined facilities that make up a plant (e.g., a fuel reprocessing plant or mixed-oxide fuel fabrication plant) environmental releases generally do not approach the limits set forth in Federal standards. When the pollutant concentrations in the gaseous and liquid effluents approach those set by standards, they are related to published toxic effects for specific kinds of biota and an estimate of impact is given. In other cases pollutant concentrations are related to naturally occurring concentrations. The intent is to provide the reader with a perspective and basis for judging, in a general way, the potential ecological impacts that may result from the various waste management technologies.

3.7 SOCIOECONOMIC EFFECTS

Socioeconomic effects associated with the construction and operation of radioactive waste management facilities depend largely on the number of persons who move into the surrounding area. Accordingly, the size of the population influx was forecasted and estimates of their needs for local social services were determined. These social services include medical care, schools, police and fire protection, and utilities. Methods and models used to arrive at the magnitude of services required are described in detail in Appendix C. Other nontechnical issues are discussed in detail in another report in this series.[4] Specific economic impacts such as changes in regional income, taxes, and local property values are not treated because they are too dependent on local characteristics.

A general assessment of socioeconomic effects implies that various sites may be under construction for nuclear waste management facilities. Since the potential sites may differ considerably in their characteristics (e.g., population size, composition, and distribution; industrial composition of the labor force; and availability of social services), it is necessary to examine the potential effects of energy facilities on several alternative sites. Thus it is reasonable to assume that a highly urbanized community offering a wide range of services to residents will experience fewer negative effects from the construction and operation of a project than will a sparsely populated rural community. Therefore, three reference sites were chosen based on differences in population size and population density and degree of urbanization (Appendix C). These sites should provide a reasonable range of socioeconomic effects for the present generic analysis.

3.8 UNCERTAINTIES IN DOSE CALCULATIONS

Radiation doses were calculated using methods described in Appendix B. These methods employ models, as noted previously, to develop total doses by summing radiation doses from various radionuclides entering (or externally exposing) the human body. Each step in developing dose has uncertainty associated with it. It has been common radiation protection practice to assign values to parameters used in dose calculation that, if uncertain, will tend to overstate rather than understate the resulting dose.

For the doses calculated in this report, a consensus of the uncertainty associated with the calculated dose was obtained from contributors to the report. This consensus was obtained in lieu of statistical analysis of uncertainties at each step of the dose calculation. Even such an analysis would require subjective assignment of uncertainty to certain of the basic parameters. The final declaration of uncertainty may have the appearance of rigor because of extensive mathematical manipulation, but may actually be no more "correct" than a consensus of those familiar with the calculational process. Consequently, no attempt at a statistical analysis of uncertainties of dose calculation was made for this report. The consensus of those contributing to dose assessments is that for any given dose estimate, the actual dose that would be received by the regional population in the reference environment would not be more than 10 times the stated value, nor would it be less than 1/100 of the stated value. This range of uncertainty cannot be quantitatively supported, but in most cases where predictive models have been used and subsequent field measurements made, the predictive models overestimated the field measurements.[5,6,7,8] Thus, the likelihood of actual values exceeding estimates is low, whereas the likelihood of values actually being substantially less than estimated is rather high.

Because of additional uncertainties in modeling for a worldwide dose, the consensus is that doses received by the worldwide population would not be more than 100 times the estimate given, nor less than 1/1000 of the value given.

The above consensus concerning uncertainties assumes that the release of radionuclides from a given process is known with certainty. If the amount of material released is uncertain, that uncertainty would apply to the overall uncertainty in the doses calculated.

It should be noted that doses presented in this report are best estimates of the doses; it would be improper to multiply all doses by 10 when it is just as likely that the true dose is 1/100 of the stated dose.

3.9 PERSPECTIVE FOR DOSE AND HEALTH EFFECTS

In this report radiological effects are given in terms of dose and in some cases in terms of health effects (as explained in Appendix B). The principal basis for comparison of doses calculated for processes, plants and systems is the dose received from naturally occurring sources. No position is taken here as to whether or not natural radioactivity is responsible for deleterious health effects in man. A brief discussion of different points of view is presented below.

Some authors[9,10] have contended that a linear dose-effect curve without a threshold for effects can result in prediction of increased health effects at radiation levels less than or equal to those from natural sources, but that such findings are without observational support. In fact, their observation of actual populations at risk shows a decrease in health effects at these levels, leading these authors to conclude that low-level, low dose rate radiation probably does not constitute a significant environmental hazard.[9,10]

On the other hand, another study relating background radiation and other parameters to the incidence of cancer concludes that between 40 and 50% of human cancer may be attributable to background radiation.[11] Thus, health effects from natural radiation could account for from 0 to 50% of observable cancers in the U.S.

In the case of large doses (which were found to be associated only with certain accidents) a comparison of calculated dose is usually made in this report to the maximum permissible limit for occupational dose, 5 rem/yr.[12] In some instances accident doses were large enough to make some general remarks as to acute and long-term effects for individuals so exposed.

In this report, from 50 to 500 fatal cancers or 50 to 300 serious genetic defects are postulated to result per million man-rem. (See Appendix B). On this basis and on the basis of a nominal annual per capita dose of 0.1 rem, the number of health effects postulated to result from natural background radiation for the U.S. population would amount to about 2000 to 20,000 per year. Experience indicates that about 200,000 individuals are born each year in the U.S. with some type of physical or mental defect [13] and that about 340,000 malignancies occur each year.[14]

Where numbers of health effects are calculated for accidents and a probability or frequency of occurrence of the accident is estimated, a societal risk is stated. The societal risk is defined as the consequences of the event times the probability or postulated frequency of the event. In this case the societal risk is in some cases contrasted with the societal risk from automobile travel (30,000 deaths over a 70-year period in the 2 million-person reference population) or from fatalities from lightning (80 deaths). These events were chosen for comparison not because of any relevance to nuclear power or waste management but because most individuals can relate them to their perception of acceptable and unacceptable risks.

Although individual risk is not addressed in the body of the report, an example of its use may be illustrative. For individuals about 25 years of age, the risk of death from all causes is about 1×10^{-3}/yr (at 50 years of age it is about 1×10^{-2}/yr).[15] The risk of death by automobile is about 2.5×10^{-4}/yr and the risk of death by lightning is about 6×10^{-7}/yr.[14]

Assuming that a waste management accident having a postulated frequency of occurrence of 2×10^{-13}/yr would result in the death of 1000 individuals in the 2 million person reference population, the individual's probability of death would be on the order of 5×10^{-4} times 2×10^{-13}/yr or 1×10^{-16}/yr. Such an individual risk, even if in error by several orders of magnitude, would not seem signficant in comparison to other risks.

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4.0 ENVIRONMENTAL EFFECTS RELAYED TO RADIOACTIVE MANAGEMENT IN A ONCE-THROUGH FUEL CYCLE

4.1 TRANSPORTATION OF SPENT FUEL

4. ENVIRONMENTAL EFFECTS RELATED TO RADIOACTIVE MANAGEMENT IN A ONCE-THROUGH FUEL CYCLE

In the reference once-through fuel cycle, spent fuel is not reprocessed. It is removed from reactors and placed in reactor spent fuel storage basins for a minimum of 6 months. Spent fuel is assumed to be cooled for at least 6-1/2 years before packaging and delivery to a Federal geologic waste repository. It is assumed that 25% of reactors will not have onsite storage capacity for cooling fuel. Fuel from these reactors is therefore assumed to be shipped to an independent spent fuel storage facility (ISFSF) for storage prior to packaging. The other 75% of reactor fuel is sent from the reactors to an ISFSF only for packaging for isolation. The once-through mode assumes that spent fuel will always be waste and that retrieval as a resource from geologic repositories will not occur. (Retrieval because of unacceptability of the repository is, however, a contingency for about 5 years.) Waste flow from this mode is illustrated in Figure 4.1.1-1.

Plants and/or functions for which environmental impacts from management of radioactive wastes are considered in the reference once-through option are, in order from the reactor:

- transport of spent fuel to an ISFSF
- interim storage (6 years) for 25% of the spent fuel
- packaging of all fuel for disposal
- rail transport of packaged spent fuel to a waste repository
- disposal at a Federal geologic waste repository (salt).

It is assumed that reactors are located 1600 km from an ISFSF with packaging capability and that a Federal geologic waste repository is located 2400 km from an ISFSF.

4.1 TRANSPORTATION OF SPENT FUEL (DOE/ET-0028 Sec. 6.2)

Spent fuel has been shipped in the United States for many years. A limited number of massive, heavily shielded casks are available for both truck and rail transport of high-burnup fuel from the current generation of light-water reactors. Most spent fuel casks will accept either pressurized water reactor (PWR) or boiling water reactor (BWR) spent fuel by using different fuel baskets; however, some casks are designed only for a particular fuel type. Table 4.1.1-1 gives information about casks that are currently available or licensed for spent fuel shipments in the United States.

Several factors can influence the choice of rail or truck casks for use in the shipment of spent fuel. Rail casks have a significantly larger payload than truck casks. About ten times as much fuel can be shipped in a rail cask with an increase in shielding weight of only about a factor of 4 over the amount of shielding required for a truck cask. On the other hand, truck shipments normally require less time for completion than rail shipments. About 56% of the reactors now operating in the United States or scheduled for completion by 1980 do not have rail spurs at the site. Many of these reactors without rail spurs can be serviced by intermodal casks that require overweight permits for shipment by truck to the nearest rail siding.

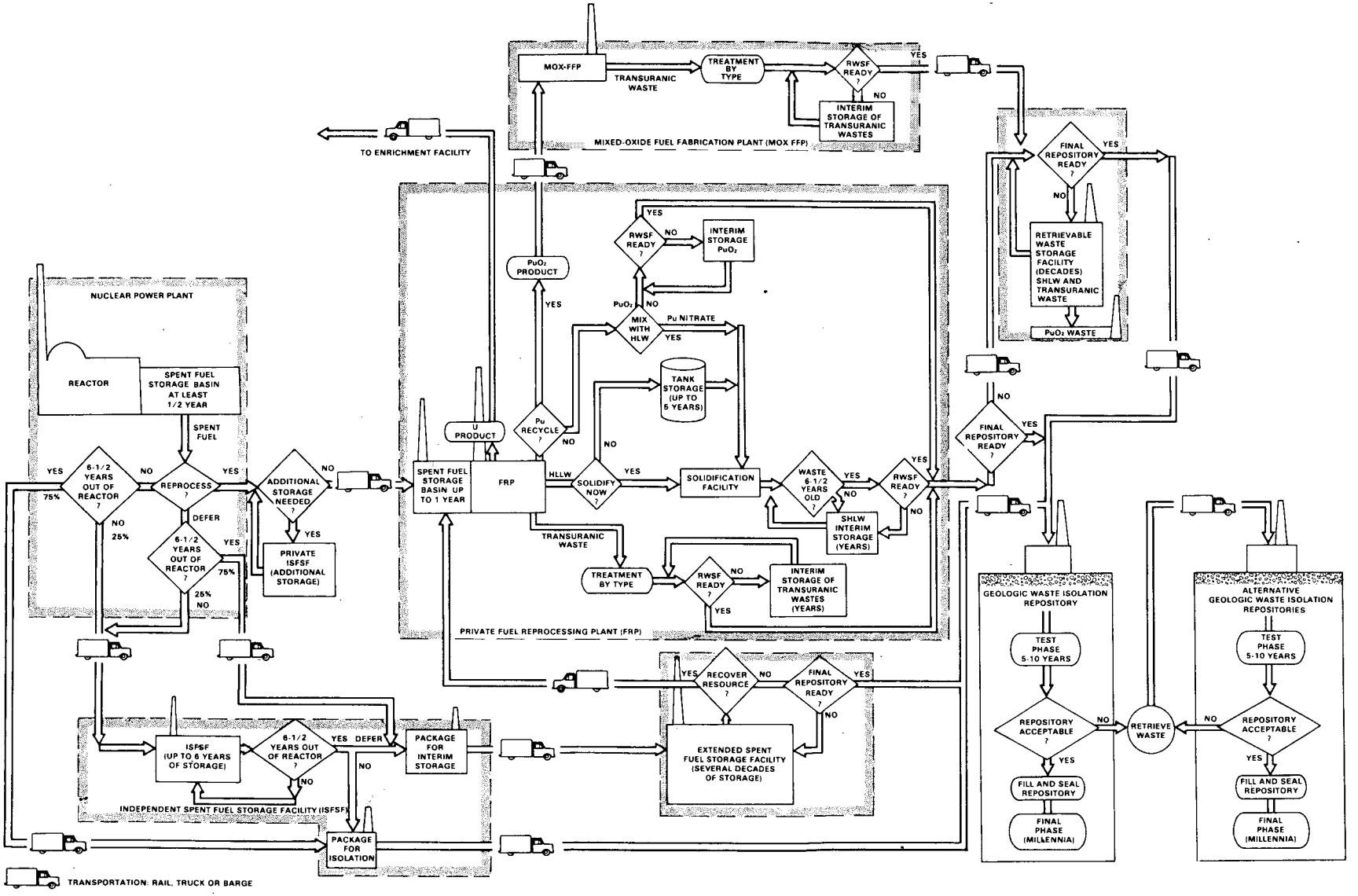

FIGURE 4.1.1-1. Flow of Spent Fuel (Waste) in Once-Through Cycle

TABLE 4.1.1-1. Licensed and Available Shipping Casks for Current-Generation LWR Spent Fuel

Cask Designation	Number of Assemblies PWR	Number of Assemblies BWR	Approximate Loaded Cask Weight, MT	Usual Transport Mode	Shielding Gamma	Shielding Neutron	Cavity Coolant	Maximum Heat Removal, Rate MJ/hr	Status
NFS-4 (NAC-1)	1	2	23	Truck	Lead and steel	Borated water and antifreeze	Water	41	6 casks available
NLI 1/2	1	2	22	Truck	Lead, uranium, and steel	Water	Helium	38	3 casks available
NLI 10/24	10	24	88	Rail	Lead and steel	Water	Helium	350	Licensed
TN-8	3		36	Truck[a]	Lead and steel	Borated solid resin	Air	130	Licensed
TN-9		7	36	Truck[a]	Lead and steel	Borated solid resin	Air	88	Licensed
IF-300	7	18	63	Rail[b]	Uranium and steel	Water and antifreeze	Water	270	4 casks available

a. Overweight permit required.
b. Truck shipment for short distances with overweight permit.
c. Licensed decay heat load is 220 MJ/hr
d. Licensed decay heat load is 250 MJ/hr

Spent fuel casks currently available are designed for fuel assemblies that are not contained in canisters. Spent fuel shipments from interim storage to permanent isolation facilities will require use of rail casks that can accept assemblies in canisters. The size of proposed canisters would necessitate some changes in existing rail cask designs. Casks would have to be about 0.6 m longer, and fuel baskets for holding canistered fuel in a cask cavity would need modification.

In the reference case 45% of spent fuel is transported from reactors to an independent spent fuel storage facility (ISFSF) and packaging facility in an NLI 10/24 cask and 45% is transported in an IF-300 cask; 10% is shipped by truck (Section 4.1.2). Spent fuel is transported from the packaging facility to the waste repository in a modified NLI 10/24 that will accept seven packaged PWR or 17 packaged BWR fuel assemblies.

Safety during transport of radioactive material depends primarily on packaging. The packaging must meet standards established by the Department of Transportation and the Nuclear Regulatory Commission. Packages containing significant amounts of radioactive material must prevent loss of dispersal of the radioactive contents, retain shielding efficiency, ensure nuclear criticality safety, and provide adequate heat dissipation under normal conditions of

transport and under specified (hypothetical) accident damage test conditions.[1] Package contents must also be limited to meet standards for external radiation levels, temperature, pressure, and containment.

Shipment of radioactive wastes must meet Department of Transportation limitations on radiation levels outside the packaging and transport vehicle.[2] These wastes are normally shipped in exclusive-use trucks and railcars. Thus special provisions of the Department of Transportation regulations apply which limit radiation levels outside the transport vehicle to 1.0×10^{-2} rem/hr at a distance of 1.8 m from the edge of the vehicle.[2] For simplicity, all shipments are assumed to produce radiation levels at this upper limit, even though such levels are unlikely, especially in shipment of low-level wastes. Department of Transportation regulations limit radiation levels in the truck cab to 2×10^{-3} rem/hr. For this analysis the radiation level in the cab of the truck carrying high-level wastes and transuranics is assumed to be 2×10^{-3} rem/hr. For low-level wastes, most drums will contain such small quantities of radioactive material that the radiation level in the truck cab will not exceed 2×10^{-4} rem/hr.[3]

Accidents can be expected to occur during shipment by rail or truck whether or not radioactive material is involved. In the analyses that follow, the number of fatalities per million vehicle (truck or railcar) kilometers was taken to be 0.039 in the case of rail transport and 0.045 in the case of truck transport. The number of serious injuries per million vehicle kilometers was taken to be 0.36 in the case of rail transport and 0.44 in the case of truck transport.[4] Accident, injury, and fatality rates for transportation vary by factors of 2 to 10, depending on assumptions.[3-6] The rates used in this report are believed to be representative. In the analyses to follow, the total round-trip mileage is used because the empty shipping casks must be returned.

4.1.1 Environmental Effects Related to Rail Transport of Spent Fuel

Some aspects of transporting spent fuel by rail may have an effect on the environment and natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the environmental impact of transporting spent fuel by rail.

4.1.1.1 Resource Commitments Associated with Fabrication of Equipment

Materials committed for the fabrication of casks for transporting spent fuel are given in Table 4.1.1-2. These quantities do not include allowances for rail cars, support systems, or other equipment. Resources required for a single cask are judged to be insignificant in terms of resource use. The total resource requirements for the peak years 2010 to 2020 are not likely to significantly affect United States industry needs when distributed over a period of about 15 to 25 years.

4.1.1.2 Environmental Effects Related to Routine Operation

The routine shipment of spent nuclear fuel is expected to have some minor effects on the environment. The information that follows is provided to form a basis for evaluating the impact of routine shipments.

TABLE 4.1.1-2. Resource Commitments Associated with Cask Fabrication for Rail Transport of Spent Fuel

Resource	One Cask, MT	Total Required in Year 2000 (36 Casks), MT	Total Required During Peak Years 2010 to 2020 (53 Casks), MT
		NLI 10/24 Cask	
Stainless steel (SS)	26	940	1,400
Chromium (in SS)	5	180	260
Nickel (in SS)	2.6	94	140
Lead	65	2,300	3,400
Depleted uranium	5	180	270
		IF-300 Cask	
Stainless steel	18	880	1,300
Chromium (in SS)	3.4	170	250
Nickel (in SS)	1.8	88	130
Depleted uranium	37	1,800	2,700
		Modified NLI 10/24 Cask	
Stainless steel	29	3,700	6,800
Chromium (in SS)	5.5	710	1,300
Nickel (in SS)	2.9	370	680
Lead	51	6,600	1,200
Depleted uranium	10	1,300	2,400
		Total Rail Transport Requirements	
Stainless steel	73	5,500	9,500
Chromium (in SS)	14	1,060	1,800
Nickel (in SS)	7.3	550	950
Lead	97	8,300	14,000
Depleted uranium	57	3,500	5,600

The number of shipments required by cask type are presented in Table 4.1.1-3. Table 4.1.1-4 gives the distances traveled.

TABLE 4.1.1-3. Shipments of Spent Fuel Required by Cask Type

	NLI 10/24 Cask (45% of fuel)	IF-300 Cask (45% of fuel)	Modified NLI 10/24 Cask (all packaged fuel)
Year 2000, no. per year	620	860	1,700
Peak years (2010 to 2020), no. per year	910	1,300	2,900
Total through year 2050	37,000	52,000	120,000

TABLE 4.1.1-4. Round-Trip Distances Traveled During Shipment of Spent Fuel by Cask Type

	NLI 10/24 Cask	IF-300 Cask	Modified NLI 10/24 Cask	Total
Year 2000, km/yr	2.0×10^6	2.8×10^6	7.7×10^6	1.2×10^7
Peak years, km/yr	2.9×10^6	4.2×10^6	1.4×10^7	2.1×10^7
Through year 2050, km	1.2×10^8	1.7×10^8	5.8×10^8	8.7×10^8

Resource Commitments. Fuel requirements for rail transport are based on 7.7×10^4 MT-km/m^3 of diesel fuel.[7] Fuel required for the 152 MT NLI 10/24 shipping cask and vehicle is obtained by multiplying the assumed shipping distance of 3200 km (round trip) between reactor and ISFSF by the number of shipments and dividing by 500 km/m^3. Fuel required for the 102-MT IF-300 shipping cask and vehicle is obtained by multiplying 3200 km (round trip) by the number of shipments and dividing by 750 km/m^3. It is assumed that the total weight of the modified NLI 10/24 cask is not significantly different from 152 MT; hence the diesel consumption rate is 500 km/m^3. The round-trip distance between the ISFSF and waste repository is assumed to be 4800 km.

Fuel requirements are presented in Table 4.1.1-5.

TABLE 4.1.1-5. Diesel Fuel Requirements for Rail Transport of Spent Fuel

	NLI 10/24 Cask	IF-300 Cask	Modified NLI 10/24 Cask	Total
Year 2000, m^3/yr	4.0×10^3	3.7×10^3	1.5×10^4	2.3×10^4
Peak year, m^3/yr	5.8×10^3	5.6×10^3	2.8×10^4	3.9×10^4
Total through 2050, m^3	2.4×10^5	2.2×10^5	1.2×10^6	1.7×10^6

Transport Effluents. Heat generated by the radioactive materials in each shipment will be equal to or less than 190 MJ/hr and 270 MJ/hr for the IF-300 and NLI 10/24 casks respectively. Nonradioactive materials released to the atmosphere will consist of combustion products normally associated with rail transport. Table 4.1.1-6 gives estimated average locomotive emissions. No effluents will be released to ground or water.

Physical, Chemical, and Thermal Effects. Heat rejected during rail transport of spent fuel is less than three orders of magnitude of the stationary facility heat load considered to have only microclimatic effects; as a consequence, no significant atmospheric effects are postulated for rail transport of spent fuel. Both the heat loads and combustion product releases amount to a small increment over total present releases associated with rail transport.

Radiological Effects. Under normal operating circumstances, no radioactive materials will be released to the atmosphere, ground, or water. However, individuals will receive doses from the direct radiation from a passing rail shipment of spent fuel.

3.0 APPROACH TO ASSESSMENT OF ENVIRONMENTAL EFFECTS FROM RADIOACTIVE WASTE MANAGEMENT

TABLE 4.1.1-6. Average Locomotive Emissions Attributable to Rail Transport of Spent Fuel(a)

Pollutant	Release Factors, MT/Cask Car-km		Release, MT		
	NLI 10/24 Cask(b)	IF-300 Cask	Year 2000	Peak Year	Total Through Year 2050
Particulates	5.9×10^{-6}	4.0×10^{-6}	6.8×10^{1}	1.2×10^{2}	4.8×10^{3}
Sulfur oxides	1.4×10^{-5}	8.7×10^{-6}	6.3×10^{1}	2.8×10^{2}	1.1×10^{4}
Carbon monoxide	3.1×10^{-5}	2.1×10^{-5}	1.4×10^{2}	6.1×10^{2}	2.5×10^{4}
Hydrocarbons	3.5×10^{-5}	1.4×10^{-5}	3.8×10^{2}	6.5×10^{2}	2.7×10^{4}
Nitrogen oxides	8.7×10^{-5}	5.8×10^{-5}	7.0×10^{2}	1.7×10^{3}	6.1×10^{4}
Aldehydes	1.3×10^{-6}	9.0×10^{-7}	1.5×10^{1}	8.6×10^{1}	1.1×10^{3}
Organic acids	1.7×10^{-6}	1.1×10^{-6}	2.0×10^{1}	3.4×10^{1}	1.4×10^{3}

a. Based on references 4 and 7.
b. Also applies to modified NLI 10/24 cask used for shipping packaged fuel.

Total-body dose is generally calculated for radiation workers (occupational exposure) and for members of the general population based on amounts of radioactive material released from nuclear facilities. In the case of transportation, a railroad employee or trucker will usually receive the highest dose but may not be classified as a radiation worker.

The direct radiation doses to railroad employees were calculated assuming that the employee spends up to 10 min in the vicinity of the waste shipment for an average exposure of 1×10^{-3} rem. It was assumed that the employee is involved in about 20 shipments per year and that he is employed at the same job for 30 years. Thus, the railroad employee receives about 0.02 rem annually and accumulates 0.6 rem during his career.

Direct radiation doses received by members of the general population from direct radiation of a passing rail shipment of spent fuel were calculated based on the speed of the train (13 km/hr), distance of the shipment (1600 km from reactor to ISFSF, 2400 km from ISFSF to repository), and the population density (90 persons/km^2) along the railroad right-of-way. The calculation of direct radiation dose to the maximum individual was based on location of the individual's residence 30 m from the center of the railroad track. The dose to the maximum individual amounts to 5.8×10^{-7} rem per shipment. The dose to the population along the railroad is 7.8×10^{-6} man-rem/km. Doses to the maximum individual, the public, and the transport work force are given in Table 4.1.1-7.

Ecological Effects. Some particulates and gases will be released to the atmosphere from combustion of fossil fuels during normal locomotive operation; however, these releases are not expected to be of ecological significance.

TABLE 4.1.1-7. Direct Radiation Doses Received from Rail Transport of Spent Fuel

Group	Year 2000	Peak Year	Total Through Year 2050
Maximum individual,[a] rem	9.3×10^{-4}	1.7×10^{-3}	7.0×10^{-2}
Population,[b] man-rem	4.7×10^{1}	1.6×10^{2}	3.2×10^{3}
Transport work force,[c] man-rem	3.8×10^{1}	6.1×10^{1}	2.5×10^{3}

a. Assuming all shipments between the independent spent fuel storage basin and waste repository pass by this individual.
b. The annual dose to the population along the transport route from naturally occurring sources would be 3.6×10^{4} man-rem.
c. Assumes one brakeman is exposed to the waste each 200 km of a shipment.

4.1.1.3 Environmental Effects Related to Postulated Accidents

Several minor accidents associated with rail transport of spent fuel were identified that could be expected to lead to releases of radioactive materials. Scenarios for these accidents are provided in DOE-ET/0028[8]. The accidents are listed below.

Accident Number	Description
6.2.1	Train derailment involving spent fuel cask
6.2.2	Train derailment and 30-min fire involving spent fuel cask
6.2.3	Undetected leakage of coolant from cask cavity (and/or surface contamination washoff)

No release of radioactive material was postulated for Accidents 6.2.1 and 6.2.2. Radioactive material released in Accident 6.2.3 is presented in Table 4.1.1-8. This accident is postulated to occur twice per year. Doses to the maximum individual resulting from these releases are given in Table 4.1.1-9. The maximum individual is defined as a bystander 100 m downwind of the accident where the time-integrated atmospheric dispersion factor (E/Q) is 3×10^{-2} sec/m^3.

Several accidents are postulated to release radioactive material in amounts larger than those released by minor accidents. These are classified as moderate and severe accidents and are listed below.

Accident Number	Description
	Moderate
6.2.4	Loss of neutron shielding from spent fuel rail cask
6.2.5	Activation of rail cask cavity overpressurization relief valve
6.2.6	Damage to rail cask mechanical cooling system
	Severe
6.2.7	Spent fuel rail cask subjected to severe impact and fire
6.2.8	Cavity coolant lost from spent fuel rail cask; no emergency action taken

TABLE 4.1.1-8. Radionuclides Released to the Atmosphere from Minor Accidents During Rail Transport of Spent Fuel

Radionuclide	Release, Ci
^{3}H	1.9×10^{-9}
^{85}Kr	4.3×10^{-8}
^{90}Sr	2.8×10^{-7}
^{90}Y	2.8×10^{-7}
^{91}Y	4.0×10^{-7}
^{95}Zr	7.3×10^{-7}
^{95}Nb	1.4×10^{-6}
^{106}Ru	1.4×10^{-6}
^{129}I	1.4×10^{-13}
^{125m}Te	1.2×10^{-8}
^{127m}Te	1.8×10^{-8}
^{134}Cs	7.3×10^{-7}
^{137}Cs	4.0×10^{-7}
^{144}Ce	2.6×10^{-6}

TABLE 4.1.1-9. One-Year Dose and 70-Year Dose Commitment to the Maximum Individual Resulting from a Minor Accident During Rail Transport of Spent Fuel

Organ	Dose, rem	
	1-Year	70-Year
Total body	1.9×10^{-6}	1.6×10^{-5}
Thyroid	3.2×10^{-7}	3.2×10^{-7}
Lung	9.8×10^{-5}	6.4×10^{-4}
Bone	1.5×10^{-5}	5.2×10^{-5}
Skin	6.5×10^{-8}	6.5×10^{-8}

Note: The maximun individual is defined as a bystander 100 m downwind of the accident where the time-integrated atmospheric dispersion factor (E/Q) is 3×10^{-2} sec/m^3.

Of the moderate accidents, damage to rail cask mechanical cooling system (Accident 6.2.6) was judged to be the most severe and was taken as a representative of the set. For this accident it was assumed that venting of a 4-MTHM cask occurs at ground level without off-gas control. Assuming 0.25% of the fuel rods exhibit failed cladding, the releases to the atmosphere were determined and are given in Table 4.1.1-10. The postulated frequency of this accident is 2×10^{-2} per year. The one-year dose and the 70-year dose commitment to the maximum individual were calculated for the moderate spent fuel rail transportation accident and are presented in Table 4.1.1-11.

Of the severe accidents, cavity coolant lost from spent fuel rail cask with no emergency action taken (Accident 6.2.8) was judged to be the most severe and was taken as representative of the set. In this accident self-heating of the fuel causes ground level release of radioactive material over a 6-hr period. The releases are given in Table 4.1.1-12. The postulated frequency of this accident is 2×10^{-5} per year. The 1-year dose and the 70-year dose commitment to the maximum individual were calculated for the severe spent fuel transportation accident and are presented in Table 4.1.1-13. The total-body dose of 120 rem is about 24 times greater than the permissible annual occupational exposure. Though no acute health effects would be expected in the exposed individual, long-term effects may include radiation-related illness.

A first year and 70 year accumulated total body dose to the regional population was also calculated. In this instance the population density was taken as 130 persons per km^2 in an area within an 80 km radius (2.6 million persons). The population total body doses amounted to 130 and 140 man-rem respectively. This calculation does not include the maximum-individual for which a different set of assumptions and method of calculation are used.

Consequences Expected from Nonradiological Accidents. Through the year 2050 about 870 million km will have been traveled in the course of moving waste spent fuel from reactors to waste repositories. At an injury rate of 0.36 per million km about 310 injuries could be expected. At a fatality rate of 0.039 per million km about 34 fatalities would be expected.

Adding the injuries and fatalities from the 10% of waste spent fuel (Section 4.1.2) shipped by truck results in a total of about 430 injuries and 47 fatalities that could be expected from transportation of spent fuel.

If all waste spent fuel is shipped by rail about 340 injuries and 38 fatalities would be expected through the 70-year period ending in the year 2050.

Ecological Effects. No accidents or unusual events have been identified that would result in detrimental effects to terrestrial or aquatic ecosystems.

TABLE 4.1.1-10. Radionuclides Released to the Atmosphere from Moderate Accidents During Rail Transport of Spent Fuel

Radionuclide	Release, Ci
^{3}H	1.8×10^{-2}
^{85}Kr	1.5
^{90}Sr	1.0×10^{-3}
^{95}Zr	2.6×10^{-3}
^{95}Nb	5.0×10^{-3}
^{106}Ru	5.2×10^{-3}
^{125m}Te	4.3×10^{-5}
^{127m}Te	1.4×10^{-5}
^{129}I	1.3×10^{-6}
^{134}Cs	2.6×10^{-3}
^{137}Cs	1.4×10^{-3}
^{144}Ce	9.3×10^{-3}
^{238}Pu	4.7×10^{-5}
^{239}Pu	4.4×10^{-6}
^{241}Pu	1.7×10^{-3}
^{242}Cm	2.4×10^{-4}

TABLE 4.1.1-11. One-Year Dose and 70-Year Dose Commitment to the Maximum Individual Resulting from a Moderate Accident During Rail Transport of Spent Fuel

Organ	Dose, rem	
	1-Year	70-Year
Total body	1.2×10^{-2}	1.2×10^{-1}
Thyroid	1.2×10^{-3}	1.3×10^{-3}
Lung	8.5×10^{-1}	1.3
Bone	1.5×10^{-1}	1.8
Skin	2.4×10^{-3}	2.4×10^{-3}

TABLE 4.1.1-12. Radionuclides Released to the Atmosphere from a Severe Accident During Rail Transport of Spent Fuel

Radionuclide	Release, Ci
^{3}H	9.0×10^{1}
^{85}Kr	5.3×10^{3}
^{129}I	7.0×10^{-3}
^{137}Cs	1.1×10^{2}
^{134}Cs	2.0×10^{2}

TABLE 4.1.1-13. One-Year Dose and 70-Year Dose Commitment to the Maximum Individual Resulting from Severe Accidents During Rail Transport of Spent Fuel

	Dose, rem	
Organ	1-Year	70-Year
Total body	1.2×10^{2}	1.3×10^{2}
Thyroid	5.3×10^{-1}	6.1×10^{-1}
Lung	4.0×10^{1}	4.3×10^{1}
Bone	1.1×10^{2}	1.2×10^{2}
Skin	1.1×10^{1}	1.1×10^{1}

REFERENCES FOR SECTION 4.1.1

1. Title 10, Code of Federal Regulations, Part 71, Appendix B.
2. Title 10, Code of Federal Regulations, Part 173.
3. Environmental Survey of Transportation of Radioactive Materials to and from Nuclear Power Plants, WASH-1238, U.S. Atomic Energy Commission, Washington, DC, December 1972.
4. Final Environmental Statement, Light Water Breeder Reactor Program, ERDA-1541, Energy Research and Development Administration, Washington, DC, June 1976.
5. Environmental Survey of the Reprocessing and Waste Management Portions of the LWR Fuel Cycle, NUREG-00.6, Nuclear Regulatory Commission, Washington, DC, October 1976.
6. R. K. Clarke, J. T. Foley, W. F. Hartman, and D. W. Larson, Severities of Transportation Accidents, SLA-74-0001, Sandia Laboratories, Albuquerque, NM, July 1976.
7. Modern Energy Technology, Research and Education Association Energy Efficiency Staff, New York, NY, 1975, vol. 1, p. 33.
8. Technology for Commercial Radioactive Waste Management, DOE-ET/0028, Department of Energy, Washington, DC, in press.

4.1.2 Environmental Effects Related to Truck Transport of Spent Fuel

In the reference case 10% of all spent fuel is shipped from reactors to independent spent fuel storage facilities (ISFSF) for storage or packaging. The reference truck cask will carry one pressurized water reactor fuel assembly or two boiling water reactor fuel assemblies. The information that follows is provided to form a basis for evaluating the environmental impact of shipping spent fuel by truck.

4.1.2.1 Resource Commitments Associated with Fabrication of Equipment

Resource commitments are restricted to diesel fuel consumed during transportation and those resources associated with cask construction. The reference truck cask used for the transport of spent fuel is a water-filled cask mounted on a special lightweight trailer. Resource commitments for cask construction are as follows:

	One Cask, MT	Total Required in Year 2000 (28 Casks), MT	Total Required in Peak Year 2010 (40 Casks), MT
Stainless steel (SS)	3.0	84	120
Chromium (in SS)	0.54	15	22
Nickel (in SS)	0.24	6.7	9.6
Lead	20	560	800

These quantities do not include allowances for highway trailers, support systems, or other equipment. Resources required for a single cask are judged to be insignificant in terms of resource use. The total resource requirements in the year 2010 are not likely to significantly affect United States industry needs when distributed over a period of about 15 to 25 years.

4.1.2.2 Environmental Effects Related to Routine Operation

The routine shipment of spent nuclear fuel is expected to have some minor effects on the environment. The information that follows is provided to form a basis for evaluating the impact of routine truck shipments.

Resource Commitments. Fuel requirements for truck transport are based on 2.2×10^4 MT-km per m^3 of diesel fuel.[1] For an average combined shipment weight of the 33 MT spent fuel shipping cask and vehicle, the fuel required is obtained from an assumed shipping distance of 3200 km (round trip) between reactors and the ISFSF, multiplied by the number of shipments, and divided by 690 km/m^3 of diesel fuel. Fuel requirements are given in Table 4.1.2-1.

TABLE 4.1.2-1. Diesel Fuel Needed for Transporting Spent Fuel by Truck

	Year 2000	Peak Years, 2010 to 2020	Total Through Year 2050
Shipments	1.5×10^3	2.2×10^3	8.9×10^4
Distance, km	4.7×10^6	6.9×10^6	2.8×10^8
Diesel fuel required, m^3	7.0×10^3	1.0×10^4	4.1×10^5

Transport Effluents. The heat generated by the spent fuel in each shipment will be about 25 MJ/hr. Nonradioactive materials released to the atmosphere will consist of combustion products normally associated with truck transport. Table 4.1.2-2 gives estimated average diesel engine emissions. No nonradioactive effluents will be released directly to ground or water.

TABLE 4.1.2-2. Nonradioactive Pollutants Released During Truck Transport of Spent Fuel

Pollutant	Release Rate, MT/million km	Year 2000, MT	Peak Year 2010, MT	Total Through Year 2050, MT
Carbon monoxide	40	1.9×10^2	2.8×10^2	1.1×10^4
Hydrocarbons	6.8	3.2×10^1	4.7×10^1	1.9×10^3
Nitrogen oxides	68	3.2×10^2	4.7×10^2	1.9×10^4
Sulfur oxides	4.8	2.2×10^1	3.3×10^1	1.4×10^3
Particulates	2.3	1.1×10^1	1.6×10^1	6.5×10^2

Source: Computations were based on 1) emission factors in Final Environmental Statement, Light Water Breeder Reactor Program, ERDA-1541, Energy Research and Development Administration, Washington, DC, June 1976, vol. 4, Table IX, G(A)-3, and 2) energy efficiency factors in Modern Energy Technology, Research and Education Association Energy Efficiency Staff, New York, NY, 1975, vol. 1, p. 23.

Physical, Chemical, and Thermal Effects. Heat rejected during truck transport of spent fuel is less than four orders of magnitude of the stationary facility heat loads considered to have only microclimatic effects; as a consequence, no significant atmospheric effects are postulated for truck transport of spent fuel. Both the heat loads and combustion product releases amount to a small increment over total present releases associated with truck transport.

Radiological Effects. Under normal operating circumstances, no radioactive material will be released to the atmosphere, water, or ground. However, individuals will receive doses from the direct radiation from passing truck shipments of spent fuel.

Total-body dose is generally calculated for radiation workers (occupational exposure) and for members of the general population based on amounts of radioactive material released from nuclear facilities. In the case of transportation, a railroad employee or trucker will usually receive the highest dose but may not be classified as a radiation worker.

The direct radiation doses to truck drivers were calculated assuming that the individual spends about 33 hr in the truck cab and 1 hr at an average distance of 2 m from the cargo per 1600 km traveled. Radiation levels in and around the truck are assumed to conform to Department of Transportation standards. A truck driver on a 1600-km trip would be expected to receive 7.8×10^{-2} rem. The trucker is assumed to be involved in about 25 shipments per year and employed at the same job for 30 years. Thus, the truck driver receives about 2 rem annually and accumulates 58 rem during his career.

Total-body doses received by members of the general population from direct radiation of a passing truck shipment of spent fuel were calculated based on the speed of the truck (50 km/hr), distance of the shipment (1600 km), and an assumed population density (90 persons/km^2) along the highway. The population dose was calculated to be 2.2×10^{-6} man-rem/km.

Calculation of direct radiation dose to the maximum individual was based on location of the individual's residence 30 m from the center of the highway. The dose to the maximum individual from direct radiation was calculated to be 1.6×10^{-7} rem/shipment. Doses to the maximum individual, the public, and the transport work force are given in Table 4.1.2-3.

TABLE 4.1.2-3. Direct Radiation Dose Received from Transport of Spent Fuel by Truck

Group	Year 2000	Peak Year 2010	Total Through Year 2050
Maximum individual,[a] rem	2.3×10^{-4}	3.5×10^{-4}	1.4×10^{-2}
Population,[b] man-rem	5.2	7.6	3.1×10^{2}
Transport work force,[c] man-rem	2.3×10^{2}	3.4×10^{2}	1.4×10^{4}

a. Assuming that each shipment passes the same individual.
b. The annual dose to the population along the transport route from naturally occurring sources would be 1.4×10^{4} man-rem.
c. It is assumed that two individuals are assigned per truck to alternate driving and resting.

4.1.2.3 Environmental Effects Related to Postulated Accidents

A number of minor accidents associated with truck transport of spent fuel were identified that could be expected to lead to releases of radioactive material. Scenarios for these accidents are provided in DOE-ET/0028[2]. The accidents are as follows:

Accident Number	Description
6.2.9	Truck collision or overturn accident involves spent fuel cask
6.2.10	Truck collision or overturn accident and 30 min (or less) fire involves spent fuel cask
6.2.11	Undetected leakage of coolant from cask cavity (and/or surface contamination washoff)

No release of radioactive materials was postulated for Accidents 6.2.9 and 6.2.10. Radioactive material released in Accident 6.2.11 is listed in Table 4.1.2-4. This accident is postulated to occur twice per year. Doses resulting from this release are given in Table 4.1.2-5.

TABLE 4.1.2-4. Radionuclides Released to the Atmosphere from Minor Accidents During Truck Shipment of Spent Fuel

Radionuclide	Release, Ci
^{3}H	4.8×10^{-10}
^{85}Kr	1.0×10^{-8}
^{90}Sr	7.3×10^{-8}
^{90}Y	7.3×10^{-8}
^{91}Y	1.0×10^{-7}
^{95}Zr	1.8×10^{-7}
^{95}Nb	3.6×10^{-7}
^{106}Ru	3.7×10^{-7}
^{125m}Te	3.0×10^{-9}
^{127m}Te	4.6×10^{-9}
^{129}I	3.6×10^{-14}
^{134}Cs	1.8×10^{-7}
^{137}Cs	1.0×10^{-7}
^{144}Ce	6.7×10^{-7}

TABLE 4.1.2-5. One-Year Doses and 70-Year Dose Commitments to the Maximum Individual Resulting from Minor Accident Releases During Truck Transport of Spent Fuel

Organ	Dose, rem	
	1-Year	70-Year
Total body	4.9×10^{-7}	2.8×10^{-6}
Thyroid	8.2×10^{-8}	8.2×10^{-8}
Lung	2.5×10^{-5}	3.5×10^{-5}
Bone	3.9×10^{-6}	1.6×10^{-5}
Skin	1.7×10^{-8}	1.7×10^{-8}

Note: The maximum individual is defined as a bystander 100 m downwind of the accident where the time-integrated atmospheric dispersion factor (E/Q) is 3×10^{-2} sec/m^3.

There are several accidents postulated to release radioactive material in amounts larger than those released from minor accidents. These are classified as moderate and severe accidents and are listed below.

Accident Number	Description
	Moderate
6.2.12	Loss of neutron shielding from spent fuel truck cask
6.2.13	Truck cask cavity overpressurizes; relief valve operates
	Severe
6.2.14	Spent fuel truck cask is subjected to severe impact and fire

Of the moderate accidents, truck cask cavity overpressurizes and relief valve operates (Accident 6.2.13) was judged to be most severe and was taken as the representative of the set. In this accident venting of a 0.4-MTHM cask occurs at ground level for 1 hr without off-gas control, and 0.25% of the fuel rods are assumed to exhibit failed cladding. The radioactive material released during this accident is given in Table 4.1.2-6. The postulated frequency of this accident is $\sim 2 \times 10^{-2}$ per year.

TABLE 4.1.2-6. Radionuclides Released to the Atmosphere from a Moderate Accident During Truck Transport of Spent Fuel

Radionuclide	Release, Ci
^{3}H	4.4×10^{-5}
^{85}Kr	2.8×10^{-3}
^{90}Sr	2.2×10^{-6}
^{95}Zr	5.7×10^{-6}
^{95}Nb	1.0×10^{-5}
^{106}Ru	1.0×10^{-5}
^{125m}Te	8.5×10^{-8}
^{127m}Te	1.3×10^{-7}
^{129}I	3.3×10^{-9}
^{134}Cs	5.2×10^{-6}
^{137}Cs	2.9×10^{-6}
^{144}Ce	1.9×10^{-5}
^{238}Pu	9.4×10^{-8}
^{239}Pu	8.8×10^{-9}
^{241}Pu	3.3×10^{-6}
^{242}Cm	4.9×10^{-7}

The 1-year doses and the cumulative 70-year dose commitments to the maximum individual were calculated for the moderate trucking accident and are presented in Table 4.1.2-7.

TABLE 4.1.2-7. One-Year Doses and 70-Year Dose Commitments to the Maximum Individual Resulting from a Moderate Accident During Truck Transport of Spent Fuel

Organ	Dose, rem	
	1-Year	70-Year
Total body	2.4×10^{-5}	2.3×10^{-4}
Thyroid	2.5×10^{-6}	2.5×10^{-6}
Lung	1.7×10^{-3}	2.6×10^{-3}
Bone	3.0×10^{-4}	3.6×10^{-4}
Skin	4.5×10^{-6}	4.5×10^{-6}

Note: The maximum individual is defined as a bystander 100 m downwind of the accident where the time-integrated atmospheric dispersion factor (E/Q) is 3×10^{-2} sec/m^3.

The severe accident, a spent fuel truck cask subjected to severe impact and fire (Accident 6.2.14), is postulated to release mixed fission products and actinides at ground level for 15 min. The releases are given in Table 4.1.2-8. The postulated frequency of this accident is 2×10^{-5} per year. The one-year doses and the 70-year dose commitments to the maximum individual are given in Table 4.1.2-9.

TABLE 4.1.2-8. Radionuclides Released to the Atmosphere from a Severe Accident During Truck Transport of Spent Fuel

Radionuclide	Release, Ci
^{90}Sr	7.0×10^{-2}
^{90}Y	7.0×10^{-2}
^{125m}Te	3.0×10^{-4}
^{134}Cs	7.7×10^{-3}
^{137}Cs	1.0×10^{-1}
^{238}Pu	4.0×10^{-3}
^{239}Pu	4.0×10^{-4}
^{241}Pu	9.5×10^{-2}
^{241}Am	3.8×10^{-3}
^{244}Cm	1.2×10^{-3}

TABLE 4.1.2-9. One-Year Doses and 70-Year Dose Commitments to the Maximum Individual Resulting from a Severe Accident During Truck Transport of Spent Fuel

Organ	Dose, rem	
	1-Year	70-Year
Total body	3.7×10^{-1}	1.0×10^{1}
Thyroid	1.5×10^{-3}	1.5×10^{-3}
Lung	2.4×10^{1}	5.9×10^{1}
Bone	5.0	1.6×10^{2}
Skin	1.3×10^{-3}	1.3×10^{-3}

Note: The maximum individual is defined as a bystander 100 m downwind of the accident where the time-integrated atmospheric dispersion factor (E/Q) is 3×10^{-2} sec/m^3.

Consequences Expected from Nonradiological Accidents. Shipment of 10% of spent fuel from reactors to ISFSFs over the 70-year period ending in 2050 would result in about 280 million km traveled. At an injury rate of 0.44 per million kilometers about 120 injuries would be expected; at a rate of 0.045 fatalities per million kilometers about 13 fatalities could be expected.

Ecological Effects. No accidents or other unusual events have been identified that would have detrimental effects on terrestrial or aquatic ecosystems.

REFERENCES FOR SECTION 4.1.2

1. Modern Energy Technology, Research and Education Association Energy Efficiency Staff, New York, NY, 1975, vol. 1, p. 33.

2. Technology for Commercial Radioactive Waste Management, DOE-ET/0028, Department of Energy, Washington, DC, in press.

4.1.3 Barge Transport of Spent Fuel

Technological data on proposed barge transport of spent fuel in the reference LWR scenario is not available at this writing. As a consequence, no independent evaluation of a reference barge mode of transportation is provided in this report. A brief treatment of barge transport of spent fuel is given in Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes, NUREG 0170, U.S. Nuclear Regulatory Commission, Washington, DC, December 1977.

4.1.4 Environmental Effects Related to Decommissioning of Equipment

At this writing no plans have been released for decommissioning spent fuel transport casks. It is reasonable to assume, however, that whenever casks become obsolete either by design, regulation, or damage that important metals such as chromium and nickel will be recycled or placed in storage until recovery becomes cost effective. Some cask components could in some instances become contaminated in such a fashion that decontamination for general use would not be possible. In that case these parts would, if sufficiently contaminated with transuranium elements, qualify for disposal in a geologic waste repository. The equipment would most likely be handled as failed equipment, the environmental effects of which are covered in Section 5.2.5. There appear to be no unique properties of failed casks that would require additional treatment or disposal methods.

4.1.5 Summary of Adverse Environmental Effects Associated with Transport of Spent Fuel

The most important adverse environmental impact associated with the reference mode transport of spent fuel is the number of serious injuries and fatalities that are predicted because of the distance traveled. Injury and fatality statistics indicate that about 430 disabling injuries and 47 fatalities can be expected through the year 2050. These estimates are based on experience with the transportation industry; therefore, unlike the potential health effects from radiation dose, these accident consequences will surely occur unless significant improvements in traffic safety can be made.

One obvious way to reduce traffic injuries and fatalities is to reduce the shipping distance since the rates are based on distance traveled. This method may be feasible to some extent by determining optimum locations for the various facilities in terms of distances from reactors to ISFSFs and from ISFSFs to the waste repositories. A dose of 14,000 man-rem to the transportaion work force (most of which comes from truck transportation of spent fuel) might result in the occurence of one health effect among the workers.

4.2 ENVIRONMENTAL EFFECTS RELATED TO WASTE MANAGEMENT AT AN INDEPENDENT SPENT FUEL STORAGE FACILITY

(DOE/ET-0028 Section 5.7.2)

4.2 ENVIRONMENTAL EFFECTS RELATED TO WASTE MANAGEMENT AT AN INDEPENDENT SPENT FUEL STORAGE FACILITY (Including Spent Fuel Packaging) (DOE/ET-0028 Sec. 5.7.2)

The independent spent fuel storage facility (ISFSF) provides storage for spent reactor fuel until the fuel has aged for at least 6.5 years, at which time the fuel is packaged for extended storage or disposal. The ISFSF in the reference system uses storage in water basins for 3000 MTHM of unpackaged fuel. Not all spent fuel will be sent to the ISFSF for storage (it is assumed that about 75% of reactors will have the storage capacity necessary for the 6.5-year storage). All fuel, however, will be sent to an ISFSF for packaging. The packaging facility is rated at 2000 MTHM/yr. A water basin storage facility and a modified water basin storage facility connecting to a packaging facility and the packaging facility itself are also described. For purposes of environmental analysis, the modified water basin storage facility and the packaging facility are treated as one unit.

Treatment of process off gas (released from cask venting, for example) is discussed separately, although source terms for releases of radionuclides are also included in the discussion of the combined ISFSF.

4.2.1 Environmental Effects Related to Facility Construction

Some aspects of site preparation and reference facility construction may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of construction activities.

4.2.1.1 Resource Commitments

The ISFSF will occupy an area of about 405 ha. Approximately 10 ha will be cleared for facility installations. An additional 4 ha will be cleared for construction storage, work yards, temporary buildings, and labor parking.

Approximately 1.6 km of new road will be required to provide automobile and truck access from the nearest U.S. highway to the site. Approximately 3.2 km of new railroad spur will be required for site railroad service.

Water used during construction of the storage and packaging facility will be about 1.0×10^5 m^3, which will be supplied from the R River near the reference site. Withdrawal of this amount of water from the R River described in the reference environment (average flow of 1.0×10^7 m^3/day), is judged to be insignificant with respect to other downstream uses.

Materials committed for construction of the ISFSF (including the modified water basin spent fuel storage facility and packaging facility) are listed in Table 4.2.1-1.

4.2.1.2 Physical and Chemical Effects

Nonradioactive pollutants will be released to the atmosphere from the combustion of gasoline and diesel fuel in construction equipment, fugitive dust from clearing and excavation, and particulate emissions from concrete batching operations. The annual quantities of these materials discharged to the atmosphere are given in Table 4.2.1-2.

TABLE 4.2.1-1. Materials Committed for Construction of the Independent Spent Fuel Storage Facility

	Storage	Packaging	Total
Resource			
Concrete, m^3	2.3×10^4	2.3×10^4	4.6×10^4
Steel, MT	1.1×10^4	4.5×10^3	1.5×10^4
Stainless steel, MT	6.1×10^3		6.1×10^3
Copper, MT	2.7×10^1	1.8×10^1	4.5×10^1
Zinc, MT	6.5×10^1		6.5×10^1
Lumber, m^3	1.3×10^3	1.9×10^3	3.2×10^3
Energy			
Propane, m^3	5.7×10^2	3.8×10^2	9.5×10^2
Diesel fuel, m^3	5.7×10^3	3.8×10^3	9.5×10^3
Gasoline, m^3	3.8×10^3	2.6×10^3	6.4×10^3
Electricity			
Peak demand, kW	1.5×10^3	1.3×10^3	2.8×10^3
Total consumption, kWh	2.8×10^6	1.8×10^6	4.6×10^6
Manpower			
Manual labor, man-hr	9×10^5	5.7×10^5	1.4×10^6
Nonmanual labor, man-hr	4.1×10^6	2.6×10^6	6.7×10^6
Total	5.0×10^6	3.1×10^6	8.1×10^6

TABLE 4.2.1-2. Pollutants Released to the Atmosphere During Construction of the Independent Spent Fuel Storage Facility

Pollutant	Construction and Vehicle Travel to Site, MT/yr	Air Concentrations On Site	Standards,[a] $\mu g/m^3$
Carbon monoxide	560	2000 $\mu g/m^3$, construction; 15,000 $\mu g/m^3$, vehicle travel	40,000 (1 hr standard)
Hydrocarbons	26	0.7% of rural area emissions	
Nitrogen oxides	110	1.4% of rural area emissions	
Sulfur dioxide	6.9	3.2 $\mu g/m^3$	80
Particulates	530	65 $\mu g/m^3$	75

a. Source: A. C. Stern, H. C. Wohlers, R. W. Boubel, and W. P. Lowery, Fundamentals of Air Pollution, Academic Press, New York, 1973.

The impact of these emissions on the ambient air quality were predicted using an established modeling procedure.[2] All emissions are below applicable Federal standards or are small percentages of background concentrations of pollutants.

4.2.1.3 Ecological Effects

Construction of the ISFSF will remove permanently (for the life of the plant) about 10 ha from its present use for agriculture and wildlife at the reference site. While this change in land use will eliminate its utility as habitat for wildlife, no significant ecological impacts to the region are expected. Disturbance of animals from fugitive dust, noise, and human activities during construction will be confined mainly to the 405-ha ISFSF restricted area. Erosion from run-off may deposit silt in nearby surface waters unless drainage is controlled by proper ditching, grading, and silt catchment. After construction is completed and vegetation is reestablished or surfacing is completed in the disturbed areas, the erosion problem will be reduced or eliminated.

The ISFSF will require about 1.0×10^5 m^3 of water during construction. This water requirement will be spread over a 3 yr construction period and will constitute less than 0.02% of the recorded 40-year minimum low flow of the R River or less than 0.001% of the average river flow. Removal of this volume of water from the R River will have an insignificant impact on the stream biota.

A common water intake from the R River will supply the construction and operational water needs of the ISFSF. This intake should be located to minimize any alteration of flow patterns and properly screened to reduce the number of aquatic organisms entrained in the ISFSF water system. Procedures will be required to keep the disturbance of the river bottom to a minimum during intake construction.

The maximum concentrations of particulates, sulfur dioxide, and carbon monoxide will occur within the 405-ha ISFSF restricted area. Particulate concentrations at the construction site are estimated to be within Federal ambient air standards. Calculated levels of carbon monoxide and hydrocarbon are only a small fraction of the existing rural air concentrations near the reference site. Concentrations of the other materials are less than applicable standards. Consequently, no measurable detrimental effects on the terrestrial ecosystem are anticipated.

REFERENCES FOR SECTION 4.2.1

1. Technology for Commercial Radioactive Waste Management, DOE/ET-0028, Department of Energy, Washington, DC, in press.

2. Compilation of Air Pollutant Emission Factors, AP 42, Environmental Protection Agency, Research Triangle Park, NC, April 1973.

4.2.2 Environmental Effects Related to Facility Operation

Some aspects of facility operation may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effects of operation.

4.2.2.1 Resource Commitments

Resources required during planned operation of the ISFSF are listed in Table 4.2.2-1.

TABLE 4.2.2-1. Utilities and Materials Required for Planned Operation of the Independent Spent Fuel Storage Facility

Resource	Average Annual Use		
	Storage	Packaging	Total
Electricity, kWh	2.6×10^7	8.7×10^6	3.4×10^7
Water consumed, m^3	2.5×10^5	3.0×10^3	2.5×10^5
Coal, MT	4.9×10^3	4.0×10^3	8.9×10^3
5% NaOH, m^3	5.7×10^2		5.7×10^2
5% HNO_3, m^3	3.8×10^2		3.8×10^2
Detergent, m^3	1.5×10^1	1.3×10^1	2.8×10^1
Helium, m^3		1.1×10^3	1.1×10^3
Steel (packaging canisters and overpacks), MT		1.3×10^3	1.3×10^3
Manpower, man-yr	8.0×10^1	7.8×10^1	1.6×10^2

4.2.2.2 Process Effluents

Sources and potential sources of radioactive material released to the atmosphere include an excess water vaporizer (DOE/ET-0028, Section 4.6.1),[1] the process off-gas system (DOE/ET-0028, Section 4.10.2)[1] of the fuel storage and packaging facilities, and the heating and ventilating systems.

The atmospheric protection system for the ISFSF consists of a roughing filter followed by two high-efficiency particulate air (HEPA) filters with a combined decontamination factor (DF) of 1×10^3 and an iodine scrubber system (principally for ^{129}I) with a DF of 1×10^3. This system is used to treat air in areas that have a high potential for release of gaseous fission products (such as cask venting and leaking fuel assemblies). In the event that radioactive material enters the ventilation system, the air stream may also be directed through the atmospheric protection system. The off-gas treatment is vented to the atmosphere through a stack 45 m high, which operates at a flow rate of 120 m^3/sec and a linear velocity of 15 m/sec.

The amounts of radioactive materials released to the atmosphere from planned operation of the ISFSF are given in Table 4.2.2-2.

Nonradioactive effluents will be released by traffic traveling to and from work. These secondary emissions will be considerably less than those analyzed for construction activities.

About 5×10^8 MJ/yr of waste heat from the radioactive decay process will be rejected to the atmosphere through a mechanical-draft cooling tower during operation of the ISFSF.

TABLE 4.2.2-2. Radionuclides Released to the Atmosphere During Planned Operation of the Modified Independent Spent Fuel Storage Facility

Radionuclide	Releases, Ci/yr			
	Receiving	Storage	Packaging	Total
^{3}H	1.3	1.1	1.3	5.9
^{14}C	3.3×10^{-3}	1.9×10^{-5}	6.6×10^{-3}	1.0×10^{-2}
^{58}Co	6.3×10^{-4}			6.3×10^{-4}
^{60}Co	1.6×10^{-3}		6.3×10^{-4}	2.2×10^{-3}
^{85}Kr	8.7×10^{2}	1.7×10^{1}	8.1×10^{2}	1.7×10^{3}
^{90}Sr	2.0×10^{-4}	3.8×10^{-5}	9.9×10^{-5}	4.1×10^{-4}
^{91}Y	2.9×10^{-4}			2.9×10^{-4}
^{95}Zr	1.7×10^{-3}			1.7×10^{-3}
^{95}Nb	3.0×10^{-3}			3.0×10^{-3}
^{106}Ru	1.0×10^{-3}		2.6×10^{-4}	1.3×10^{-3}
^{125m}Te	1.4×10^{-5}			1.4×10^{-5}
^{127m}Te	1.3×10^{-5}			1.3×10^{-5}
^{129}I	5.0×10^{-5}	8.9×10^{-7}	9.9×10^{-4}	1.0×10^{-3}
^{134}Cs	1.8×10^{-2}		7.2×10^{-3}	1.9×10^{-2}
^{137}Cs	9.9×10^{-3}	2.4×10^{-3}	5.4×10^{-3}	2.3×10^{-2}
^{144}Ce	1.8×10^{-3}	2.5×10^{-5}	3.9×10^{-4}	2.2×10^{-3}

About 3.5×10^{4} m^3/yr of water at 17°C above ambient will be released from the cooling tower as blowdown. About 1.0×10^{2} m^3/yr of water at 28°C above ambient will leave the cooling tower as drift.

4.2.2.3 Physical, Chemical, and Thermal Effects

The release of about 5×10^{8} MJ/yr of heat through the cooling tower is not expected to have any significant thermal effects, nor any measurable micrometeorological effects.

Predicted air concentrations from ISFSF operations will be considerably below applicable Federal air quality standards or naturally occurring gaseous concentrations.

Operational water requirements for the ISFSF (cooling tower makeup) will be about 2.5×10^{5} m^3/yr. This water will be withdrawn from the R River near the reference site; it will amount to about 0.001% of the average (3.9×10^{9} m^3/yr) and 0.02% of the 40-year minimum recorded low flow. This withdrawal is not expected to have any effect on downstream uses. The release of 3.5×10^{4} m^3/yr of water at 17°C above ambient is expected to have no significant effect on the R River, whose average flow is about 4×10^{9} m^3/yr. There are no planned releases of radioactive liquid effluents to the river.

4.2.2.4 Radiological Effects

Doses to individuals in the vicinity of the ISFSF were calculated based on the radionuclides released from waste management facilities, as listed in Table 4.2.2-2; exposure pathways, demography, and other parameters described for the reference environment in Appendix A; and mathematical models relating dose to man from radionuclides released (Appendix B). For planned operation of the ISFSF, the only exposure pathway to man is via airborne effluents; there are no planned releases to ground or water.

The annual doses to individuals whose habits tend to maximize their doses ("maximum individual") are shown in Table 4.2.2-3. For comparison, the dose to an individual from naturally occurring radioactive source averages about 0.1 rem/yr.

TABLE 4.2.2-3. Annual Doses to the Maximum Individual from Gaseous Effluents Released from the Modified Independent Spent Fuel Storage Facility (rem)

Pathway	Total Body	Thyroid (child)[a]	Thyroid[b]	Lung	Bone
Air submersion	8.2×10^{-3}	8.2×10^{-8}	8.2×10^{-3}	8.2×10^{-8}	8.2×10^{-8}
Inhalation	5.6×10^{-8}		1.5×10^{-7}	1.5×10^{-6}	7.5×10^{-8}
Ingestion	4.7×10^{-7}	1.4×10^{-7}	1.5×10^{-5}	1.3×10^{-7}	3.5×10^{-7}
Total	6.1×10^{-7}	2.2×10^{-7}	1.5×10^{-5}	1.7×10^{-6}	5.1×10^{-7}

Note: The maximum individual is defined as a permanent resident at a location 1600 m southeast of the stack with the highest annual average dispersion factor ($\overline{\chi}$ Q') of 9.9×10^{-8} sec/m^3.

a. Thyroid dose is calculated for a 1-year-old child breathing air containing radioactive effluents and consuming 1 ℓ of milk per day from cows grazing 7 months/yr at the site boundary. Inhalation dose is <2% of total dose.

b. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

The combined dose from gaseous effluents to the population living within an 80-km radius of the plant was calculated using the projected year 2000 population data given in the reference environment. Table 4.2.2-4 summarizes the annual doses received by this population. The annual total-body population dose from naturally occurring sources to the approximately 2 million persons living within an 80-km radius of the plant in the year 2000 would be about 200,000 man-rem compared with about 0.03 man-rem received from process sources as given in Table 4.2.2-5.

TABLE 4.2.2-4. Annual Doses to the Population (within 80 km) from Gaseous Effluents Released from the Independent Spent Fuel Storage Facility (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
Air submersion	5.9×10^{-3}	5.9×10^{-3}	5.9×10^{-3}	5.9×10^{-3}
Inhalation	4.0×10^{-7}	1.1×10^{-2}	1.1×10^{-1}	2.6×10^{-3}
Ingestion	1.5×10^{-2}	4.5×10^{-1}	4.0×10^{-3}	1.3×10^{-2}
Total	2.5×10^{-2}	4.7×10^{-1}	1.2×10^{-1}	2.0×10^{-2}

TABLE 4.2.2-5. Summary of Annual Total-Body Doses Received from Operation of the Independent Spent Fuel Storage Facility and from Naturally Occurring Sources

	Dose, man-rem
ISFSF	
Process work force	120
Population (within 80 km)	0.03
Naturally occurring sources	
Population (within 80 km)	200,000
Worldwide population	
(30th year of operation)	1.4

The estimated annual total-body dose to the work force associated with the ISFSF was 120 man-rem, based on permissible exposure limits and experience of operating plants. The annual worldwide population dose from naturally occurring sources (0.1 rem/yr) would be 6.4×10^8 man-rem compared with the 1.4 man-rem given in Table 4.2.2-5 for the ISFSF. Table 4.2.2-5 also summarizes the annual total-body dose to the work force and the general population from process and naturally occurring sources in the year 2000.

The 70-year doses to the maximum individual and to the population (first, second, and third generations)* within 80 km of the facility are given in Tables 4.2.2-6 and 4.2.2-7

TABLE 4.2.2-6. 70-Year Doses to the Maximum Individual from Gaseous Effluents Released from the Independent Spent Fuel Storage Facility (rem)

Pathway	Total Body	Thyroid[a]	Lung	Bone
Air submersion	2.5×10^{-6}	2.5×10^{-6}	2.5×10^{-6}	2.5×10^{-6}
Inhalation	2.3×10^{-6}	4.6×10^{-6}	1.4×10^{-5}	5.1×10^{-6}
Ingestion	3.5×10^{-5}	1.0×10^{-3}	5.2×10^{-6}	8.1×10^{-5}
First generation total	4.0×10^{-5}	1.0×10^{-3}	2.2×10^{-5}	8.9×10^{-5}
Second generation total	2.7×10^{-6}	2.6×10^{-4}	3.3×10^{-6}	3.0×10^{-8}
Third generation total	4.8×10^{-7}	6.6×10^{-5}	5.1×10^{-7}	5.7×10^{-9}

Note: The maximum individual is defined as a permanent resident at a location 1600 m southeast of the stack with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 9.9×10^{-8} sec/m^3.

a. Thyroid dose is calculated for the adult inhalation pathway consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

* For these estimates the population is assumed to be made up of adults who live in the reference area for 70 years, die, and are replaced by a second generation of individuals, who live in the reference area for 70 years and are similarly replaced by a third generation. In the case of the maximum individual the second generation dose was about 6% of the first generation dose. Population doses were 0.6 and 0.1% of the first generation dose for second and third generations respectively. The total dose in man-rem over 210 years may be obtained by adding the doses from each of the generations. Exposure to the second and third generations is principally through food pathways and ground contamination. A $\overline{\chi}/Q'$ of 1.5×10^{-8} sec/m^3 was used to calculate second and third generation doses to the maximum individual, and a $\overline{\chi}/Q'$ of 1.8×10^{-9} sec/m^3 was used to calculate second and third generation doses to the regional population.

TABLE 4.2.2-7. 70-Year Doses to the Population (within 80 km) from Gaseous Effluents Released from the Independent Spent Fuel Storage Facility (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
Air submersion	1.8×10^{-1}	1.8×10^{-1}	1.8×10^{-1}	1.8×10^{-1}
Inhalation	1.7×10^{-1}	3.2×10^{-1}	1.0	3.7×10^{-1}
Ingestion	1.0	3.0×10^{1}	1.7×10^{-1}	2.0
First generation total	1.4	3.0×10^{1}	1.4	2.6
Second generation total	9.6×10^{-3}	1.8×10^{-2}	1.1×10^{-2}	9.3×10^{-5}
Third generation total	1.8×10^{-3}	4.8×10^{-3}	1.7×10^{-3}	1.9×10^{-5}

respectively. A summary of the 70-year total-body doses to the work force and the population is given in Table 4.2.2-8. For comparison, the population dose from naturally occurring sources is also given for the year 2000 and amounts to about 14,000,000 man-rem compared with 1.6 man-rem received from the ISFSF.

TABLE 4.2.2-8. Summary of 70-Year Total-Body Doses Received from Operation of the Independent Spent Fuel Storage Facility and from Naturally Occurring Sources

	Dose, man-rem
ISFSF	
Process work force	3,600
Population (within 80 km)	1.4
Naturally occurring sources	
Population (within 80 km)	14,000,000
Worldwide population (30th year of operation)	70

All doses calculated for the maximum individual and population include doses from routine releases and from minor accidents within the ISFSF.

In this report, 100 to 800 health effects are postulated to occur in the exposed population per million man-rem. No health effects are calculated to result from doses to the regional population or worldwide population from planned operation of the ISFSF.

4.2.2.5 Ecological Effects

The release of about 5×10^{8} MJ/yr of waste heat to the atmosphere via the ISFSF cooling tower is not expected to have any ecological impact. Blowdown from the cooling tower would amount to about 1 ℓ/sec. If this stream enters the R River at minimum flow, it will be diluted by 6200 ℓ/sec of river water. At average annual flow the blowdown will be diluted by 120,000 ℓ/sec. Based on these dilution rates, the relatively small amount of blowdown and a ΔT of 17°C are not expected to adversely affect river biota outside of a small mixing zone. Even though no significant effects are expected, the release of blowdown to an evaporation pond would be preferable.

REFERENCES FOR SECTION 4.2.2

1. Technology for Commercial Radioactive Waste Management, DOE/ET-0028, Department of Energy, Washington, DC, in press.

4.2.3 Environmental Effects Related to Postulated Accidents

Statistics on the construction industry suggest that at a disabling injury rate of 13.6 per million man-hours of construction effort, 110 disabling injuries can be expected during construction of the ISFSF. Similarly, at a fatal accident rate of 0.17 fatalities per million man-hours, one fatality may be expected as a result of an accident during construction of the ISFSF.

Minor, moderate, and severe accidents were examined for each facility within the reference ISFSF for the release of radioactive material. Based on the anticipated releases of the minor accidents weighted by their expected frequency of occurrence, an average annual release was postulated. This minor accident contribution was included with the planned annual release source terms for the ISFSF (Section 4.2.2.4). In cases where more than one moderate, or severe accident was identified, one was chosen as representative. A list of these accidents is given in Table 4.2.3-1 along with their associated facilities and expected frequencies. More detailed descriptions of the accidents are given in Sections 4.8.4 and 5.7 of DOE/ET-0028.[1] In cases where no accident was identified that would release radioactive material, no accident is listed.

TABLE 4.2.3-1. Postulated Accidents at the Independent Spent Fuel Storage Facility Resulting in the Release of Radionuclides

Facility	Accident Number	Description	Annual Frequency
Spent fuel storage	5.7.9	Rail cask venting (moderate)	4×10^{-5}
	5.7.12	Design basis tornado (severe)	1×10^{-5}
	5.7.13	Criticality event (severe)	1×10^{-5}
Spent fuel packaging	5.7.18	Fuel handling accident — rupture of some cladding (moderate)	1.3
	5.7.20	Dropped fuel assembly — rupture of all pins (severe)	1×10^{-2}
Vessel off-gas system	4.10.3	Process off-gas treatment failure (moderate)	

The postulated worst-case moderate accident in the ISFSF would occur in the vessel off-gas treatment system in the event of a process failure (Accident 4.10.3). The worst-case severe accident would occur in the spent fuel storage facility in the event of a criticality accident (Accident 5.7.13). Source terms for worst-case moderate and severe accidents are

given in Table 4.2.3-2. The associated first-year dose and 70-year dose commitment to the maximum individual from these accidents are given in Tables 4.2.3-3 and 4.2.3-4 respectively. The 70-year dose commitment is essentially the same as the first-year dose because the radionuclides are short-lived; thus the effective half-life in the body is short.

TABLE 4.2.3-2. Radionuclides Released During Worst-Case Moderate and Severe Accidents at the Independent Spent Fuel Storage Facility (Ci)

Radionuclide	Moderate Accident (off-gas treatment failure)	Severe Accident (criticality event)
^{3}H	1.2×10^{1}	
^{85}Kr	6.5×10^{2}	1.6×10^{-3}
^{87}Kr		1.0×10^{3}
^{88}Kr		6.6×10^{2}
^{89}Kr		4.1×10^{4}
^{90}Sr	2.3×10^{-9}	
^{90}Y	2.2×10^{-9}	
^{129}I	1.6×10^{-3}	4.3×10^{-10}
^{131}I		1.8
^{133}I		3.5×10^{1}
^{134}I		4.8×10^{2}
^{135}I		1.2×10^{2}
^{137}Cs	3.5×10^{-9}	
^{138}Xe		1.1×10^{4}
^{154}Eu	1.9×10^{-10}	

TABLE 4.2.3-3. First-year Dose to the Maximum Individual from Worst-Case Accidents at the Independent Spent Fuel Storage Facility (rem)

Pathway	Skin	Total Body	Thyroid	Lung	Bone
		Moderate Accident[a]			
Air submersion	4.5×10^{-3}	4.8×10^{-5}	4.8×10^{-5}	4.8×10^{-5}	4.8×10^{-5}
Inhalation		9.6×10^{-5}	5.4×10^{-4}	9.9×10^{-5}	7.9×10^{-11}
Total	4.5×10^{-3}	1.4×10^{-4}	5.9×10^{-4}	1.5×10^{-4}	4.8×10^{-5}
		Severe Accident[b]			
Air submersion	7.5×10^{-2}	4.9×10^{-2}	4.9×10^{-2}	4.9×10^{-2}	4.9×10^{-2}
Inhalation		3.0×10^{-4}	1.0×10^{-1}	3.2×10^{-3}	9.9×10^{-5}
Total	7.5×10^{-2}	4.9×10^{-2}	1.5×10^{-1}	5.2×10^{-2}	4.9×10^{-2}

Note: The maximum individual is defined as a permanent resident at a location 1600 m southeast of the stack with the time-integrated atmospheric dispersion coefficient (E/Q) of 1.5×10^{-4} sec/m^3.
a. Accident 4.10.3, off-gas treatment failure.
b. Accident 5.7.10, criticality event.

TABLE 4.2.3-4. 70-Year Dose Commitments to the Maximum Individual from Worst-Case Accidents at the Independent Spent Fuel Storage Facility (rem)

Pathway	Skin	Total Body	Thyroid	Lung	Bone
		Moderate Accident[a]			
Air submersion	4.5×10^{-3}	4.8×10^{-5}	4.8×10^{-5}	4.8×10^{-5}	4.8×10^{-5}
Inhalation		9.6×10^{-5}	6.2×10^{-4}	9.9×10^{-5}	1.5×10^{-9}
Total	4.5×10^{-3}	1.4×10^{-4}	6.7×10^{-4}	1.5×10^{-4}	4.8×10^{-5}
		Severe Accident[b]			
Air submersion	7.5×10^{-2}	4.9×10^{-2}	4.9×10^{-2}	4.9×10^{-2}	4.9×10^{-2}
Inhalation		3.0×10^{-4}	1.0×10^{-1}	3.2×10^{-3}	9.9×10^{-5}
Total	7.5×10^{-2}	4.9×10^{-2}	1.5×10^{-1}	5.2×10^{-2}	4.9×10^{-2}

Note: The maximum individual is defined as a permanent resident at a location 1600 m southeast of the stack with the time-integrated atmospheric dispersion coefficient (E/Q) of 1.5×10^{-4} sec/m^3.
a. Accident 4.10.3, off-gas treatment failure.
b. Accident 5.7.13, criticality event.

Doses received by the maximum individual as a result of the moderate accident at the ISFSF are less than the nominal annual variation in doses received from naturally occurring sources and are thus taken to be insignificant. Doses received by the maximum individual as a result of the severe accident are from one-half to one and one-half times the nominal annual dose due to naturally occurring sources. In terms of accident exposure these doses are also considered to be insignificant.

REFERENCES FOR SECTION 4.2.3

1. Technology for Commercial Radioactive Waste Management, DOE/ET-0028, Department of Energy, Washington, DC, in press.

4.2.4 Process Off-Gas Treatment at an Independent Spent Fuel Storage Facility (DOE/ET-0028 Sec. 4.10.2)

A process off-gas system at the reference independent spent fuel storage facility is provided to treat off-gas from cask venting, leaking fuel assemblies, and other areas with high potential for release of gaseous fission products. The process includes systems for iodine and particle removal.

The following assumptions were made in the design of the reference process off-gas system:

- The process off-gas treatment system operates 365 days per year and treats off-gas from a 3000-MTHM independent spent fuel storage facility.
- The design volumetric flow is approximately 7 m^3/min.
- The facility is designed as an integral part of the storage basin.
- The facility recovers only iodine and particles.

4.2.4.1 Environmental Effects Related to Facility Construction

Some of the factors relating to site preparation and reference facility construction may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of construction activities.

Resource Commitments. This system will be an integral part of the reference storage facility whose structures will occupy about 10 ha.

Water used during construction is estimated to be 1.1×10^3 m^3. Withdrawal of this amount of water from the R River, described in the reference environment (average flow of 1.0×10^7 m^3/day), is judged to be insignificant with respect to other downstream uses. During the construction period, wells can probably supply the required amount of water without consequence.

Materials committed for construction of the process off-gas system are:

Steel	80 MT
Copper	0.4 MT
Lumber	15 m^3
Concrete	380 m^3

Energy resources committed for construction are:

Propane	11 m^3
Diesel fuel	110 m^3
Gasoline	76 m^3
Electricity	
Peak demand	125 kW
Total consumption	60,000 kWh

Manpower requirements for construction of the process off-gas system amount to 105,000 man-hr, which will likely be integrated with labor schedules for the independent spent fuel storage facility.

No specific transportation requirements for the process off-gas system have been identified beyond those for the storage facility. No other site-specific requirements have been identified.

Physical and Chemical Effects. The effects on air quality from construction of the process off-gas system represent only a fraction of the impact of construction of the independent spent fuel storage facility (Section 4.2.1). Similarly, the effects on water quality, water use, and land use will be negligible.

Ecological Effects. There will be no construction impacts from the process off-gas system apart from those of the reference independent spent fuel storage facility. Land area requirements are included with those of the storage facilities.

Water used during construction of the entire independent spent fuel storage facility is about 5.3×10^4 m^3 and will be withdrawn from the R River at the reference site. This

withdrawal will amount to less than the 0.002% of the river low flow and will not have an impact on the river biota. Since construction water used for the process off-gas system is only a small fraction of that required for the entire independent spent fuel storage facility, no ecological impacts are anticipated.

A common system will probably be constructed to supply water to all the facilities within the storage facility complex. Procedures will be required to minimize any disruption of current patterns and disturbance of the river bottom during the construction of the intake for this system.

4.2.4.2 Environmental Effects Related to Facility Operation

Some of the factors relating to facility operation may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of operation.

Resource Commitments. Resources required during planned operation of the process off-gas system are as follows:

	Average Annual Use
Electricity, kWh	1.6×10^5
Manpower, man-yr	2.5

Process Effluents. The amounts of radioactive materials that reach the biosphere after leaving the process off-gas system and passing through the atmospheric protection system at the reference independent spent fuel storage facility are shown in Table 4.2.4-1. The radionuclides listed are those that will contribute at least 1% to the total dose to a given organ from any pathway or that are otherwise of interest.

TABLE 4.2.4-1. Radionuclides Released to the Biosphere from the Process Off-Gas System at the Independent Spent Fuel Storage Facility

Radionuclide	Release, Ci/yr	
	With Treatment	Without Treatment
^{3}H	3.4×10^{-1}	3.4×10^{-1}
^{129}I	2.1×10^{-7}	2.1×10^{-4}
^{85}Kr	2.2×10^{2}	2.2×10^{2}

The radioactive material is entrained in air derived from vessel storage ventilation and is released via the 45-m stack at the storage facility. There will be no planned releases of radioactive material to the biosphere via liquid waste streams.

During normal operation of the process off-gas system, no nonradioactive materials will be released to the atmosphere. There will be no direct releases of nonradioactive liquid or solid wastes to surface or groundwaters or land. All liquid and solid waste disposal for the system is part of the overall operation of the independent spent fuel storage facility.

Physical, Chemical, and Thermal Effects. There are no direct releases of nonradioactive liquid, solid, or gaseous wastes to the atmosphere, surface or groundwaters, or land from the process off-gas system. All liquid and solid waste disposal for the system is part of the overall operation of the independent spent fuel storage facility.

There are no operational water requirements for the process off-gas facility.

Radiological Effects. Doses to individuals in the environs of the process off-gas system were calculated based on the releases of radionuclides as listed in Table 4.2.4-1; pathways, demography, and other parameters as described in Appendix A; and mathematical models relating dose to man from radionuclide releases (Appendix B). For planned operation of the process off-gas system, the only pathway for radionuclides to man is via airborne effluents; there are no planned releases to ground or water. Doses presented in this section are included with those listed in Section 4.2.2.4 for the independent spent fuel storage facility.

The annual doses to individuals whose habits tend to maximize their dose ("maximum individual") are shown in Table 4.2.4-2. For perspective, the dose to an individual from naturally occurring radioactive sources averages about 0.1 rem/yr.

TABLE 4.2.4-2. Annual Doses to the Maximum Individual from Gaseous Effluents Released by the Process Off-Gas Facility at the Independent Spent Fuel Storage Facility (rem)

Pathway	Total Body	Thyroid[(a)]	Lung	Bone
		With Treatment		
Air submersion	1.1×10^{-8}	1.1×10^{-8}	1.1×10^{-8}	1.1×10^{-8}
Inhalation	1.2×10^{-9}	1.2×10^{-9}	1.2×10^{-9}	0
Ingestion	1.0×10^{-9}	1.1×10^{-9}	1.0×10^{-9}	1.3×10^{-13}
Total	1.3×10^{-8}	1.3×10^{-8}	1.3×10^{-8}	1.1×10^{-8}
		Without Treatment		
Air submersion	1.1×10^{-8}	1.1×10^{-8}	1.1×10^{-8}	1.1×10^{-8}
Inhalation	1.2×10^{-9}	8.5×10^{-9}	1.2×10^{-9}	0
Ingestion	9.0×10^{-9}	1.3×10^{-6}	2.3×10^{-8}	8.0×10^{-10}
Total	2.1×10^{-8}	1.3×10^{-6}	2.5×10^{-8}	1.2×10^{-8}

Note: The maximum individual is defined as a permanent resident at a location 1600 m southeast of the stack with the highest annual average dispersion factor ($\bar{\chi}/Q'$) of 9.9×10^{-8} sec/m^3.

a. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr). Dose to a childs thyroid would not be substantially different from that of the adult (see for example Table 5.2.1-3).

The combined dose from gaseous effluents to the population living within an 80-km radius of the plant was calculated using the projected year 2000 population data given in the reference environment section. Table 4.2.4-3 summarizes the annual doses received by this population.

TABLE 4.2.4-3. Annual Doses to the Population (within 80 km) from Gaseous Effluents Released by the Process Off-Gas Facility at the Independent Spent Fuel Storage Facility (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
		With Treatment		
Air submersion	7.8×10^{-4}	7.8×10^{-4}	7.8×10^{-4}	7.8×10^{-4}
Inhalation	8.7×10^{-5}	8.7×10^{-5}	8.7×10^{-5}	0
Ingestion	1.0×10^{-4}	1.1×10^{-4}	1.0×10^{-4}	1.2×10^{-8}
Total	9.7×10^{-4}	9.8×10^{-4}	9.7×10^{-4}	7.8×10^{-5}
		Without Treatment		
Air submersion	7.8×10^{-4}	7.8×10^{-4}	7.8×10^{-4}	7.8×10^{-4}
Inhalation	8.7×10^{-5}	6.1×10^{-4}	8.9×10^{-5}	0
Ingestion	2.4×10^{-4}	3.1×10^{-2}	2.0×10^{-4}	2.2×10^{-5}
Total	1.1×10^{-3}	3.2×10^{-2}	1.1×10^{-3}	1.1×10^{-3}

The annual total-body population dose from naturally occurring sources to the approximately 2 million persons living within an 80-km radius of the plant in the year 2000 would be about 200,000 man-rem compared with about 9.7×10^{-4} man-rem received from process sources as given in Table 4.2.4-3.

The annual total-body dose to the work force associated with the process off-gas system was estimated based on permissible exposure limits and experience of operating plants. The annual occupational dose was calculated to be 20 man-rem. Table 4.2.4-4 summarizes the annual total-body dose to the work force and the general population from process and naturally occurring sources in the year 2000.

TABLE 4.2.4-4. Summary of Annual Total-Body Doses Received from Operation of the Process Off-Gas System at the Independent Spent Fuel Storage Facility and from Naturally Occurring Sources

	Dose, man-rem
Process off-gas system	
Process work force	20
Population (within 80 km)	<0.001
Naturally occurring sources	
Population (within 80 km)	200,000

The 70-year doses to the maximum individual and to the population within 80 km of the facility are given in Tables 4.2.4-5 and 4.2.4-6 respectively. A summary of the 70-year total-body doses to the work force and the population is given in Table 4.2.4-7. For perspective,

TABLE 4.2.4-5. 70-Year Doses to the Maximum Individual from Gaseous Effluents Released by the Process Off-Gas System at the Independent Spent Fuel Storage Facility (rem)

Pathway	Total Body	Thyroid[a]	Lung	Bone
		With Treatment		
Air submersion	3.3×10^{-7}	3.3×10^{-7}	3.3×10^{-7}	3.3×10^{-7}
Inhalation	3.7×10^{-8}	3.7×10^{-8}	3.7×10^{-8}	0
Ingestion	3.4×10^{-8}	3.6×10^{-8}	3.4×10^{-8}	3.9×10^{-12}
Total	4.0×10^{-7}	4.0×10^{-7}	4.0×10^{-7}	3.3×10^{-7}
		Without Treatment		
Air submersion	3.3×10^{-7}	3.8×10^{-7}	3.8×10^{-7}	3.8×10^{-7}
Inhalation	3.7×10^{-8}	2.7×10^{-7}	3.7×10^{-8}	0
Ingestion	2.7×10^{-7}	5.2×10^{-5}	2.2×10^{-7}	2.5×10^{-8}
Total	6.4×10^{-7}	5.2×10^{-5}	6.4×10^{-7}	4.3×10^{-7}

Note: The maximum individual is defined as a permanent resident at a location 1600 m southeast of the stack with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 9.9×10^{-8} sec/m^3.

a. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

TABLE 4.2.4-6. 70-Year Doses to the Population (within 80 km) from Gaseous Effluents Released by the Process Off-Gas System at the Independent Spent Fuel Storage Facility (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
		With Treatment		
Air submersion	2.3×10^{-2}	2.3×10^{-2}	2.3×10^{-2}	2.3×10^{-2}
Inhalation	2.6×10^{-3}	2.6×10^{-3}	2.6×10^{-3}	0
Ingestion	3.1×10^{-3}	5.6×10^{-3}	3.1×10^{-3}	3.9×10^{-7}
Total	2.9×10^{-2}	3.1×10^{-2}	2.9×10^{-2}	2.3×10^{-2}
		Without Treatment		
Air submersion	2.3×10^{-2}	2.3×10^{-2}	2.3×10^{-2}	2.3×10^{-2}
Inhalation	2.6×10^{-3}	1.9×10^{-2}	2.7×10^{-3}	0
Ingestion	9.0×10^{-3}	1.6	6.5×10^{-3}	7.5×10^{-4}
Total	3.5×10^{-2}	1.6	3.1×10^{-2}	2.3×10^{-2}

the population dose from naturally occurring sources is also given for the year 2000 and amounts to about 14,000,000 man-rem compared with 2.9×10^{-2} man-rem received from the process off-gas system.

TABLE 4.2.4-7. Summary of 70-Year Total-Body Doses Received from Operation of the Process Off-Gas System at the Independent Spent Fuel Storage Facility and from Naturally Occurring Sources

	Dose, man-rem
Process off-gas system	
Process work force (30 yr)	600
Population (within 80 km)	0.029
Naturally occurring sources	
Population (within 80 km)	14,000,000

Health effects for the regional population are discussed at the plant level where several processes within the plant are combined. In general, doses at the individual process level are too small for a meaningful discussion of health effects. In this report, one health effect per year, either cancer mortality or serious genetic effect, is postulated to occur in the exposed population per 10,000 man-rem.

Ecological Effects. No adverse effects are expected from routine operation of the process off-gas system. Nonradioactive chemicals that are potentially harmful to terrestrial plants and animals will not be released to the environment. Releases of radioactive materials to the environment will be of low concentration, and no effects will be observed.

4.2.4.3 Environmental Effects Related to Postulated Accidents

Minor accidents and process upsets associated with the process off-gas system of the independent spent fuel storage facility have not been described individually, but the downtime of the system was postulated from operational experience with related systems. The resultant releases were estimated and included in the planned annual releases.

More severe accidents have not been considered explicitly but the radiological effects should be no worse than the release of all vessel off-gas effluents without treatment as presented in Tables 4.2.4-2, 4.2.4-3, 4.2.4-5, and 4.2.4-6.

REFERENCES FOR SECTION 4.2.4

1. Technology for Commercial Radioactive Waste Management, DOE/ET-0028, Department of Energy, Washington, DC, in press.

4.2.5 Socioeconomic Impacts of Construction and Operation of an Independent Spent Fuel Storage Facility

Socioeconomic impacts associated with construction and operation of an independent spent fuel storage facility depend largely on the numbers of persons who move into the county in which the facility will be located. Because of this, the size of the local population influx was forecasted and estimates of their need for locally provided social services were determined.*

* The employment level forecasted for the construction period (1980 to 1984) associated with an independent spent fuel storage facility was 1350 persons and the level for operations from 1985 on was 301 persons.

Specific economic impacts attributed to the development of once-through facilities will not be treated here because they are too dependent on local site characteristics to allow for generalization.

Socioeconomic impacts also depend on site characteristics and the assumptions used in the forecasting model (described more fully in Appendix C). Site characteristics that are especially important in influencing the size of the impacts forecasted include the availability of the local labor force having the required skills, secondary employment, proximity to a metropolitan area, and demographic diversity (population size, degree of urbanization, etc.) of counties in the commuting region. An additional factor in the generation of impacts is the time pattern of project-associated population change. For example, a large labor force buildup followed closely by rapidly declining project employment demand could cause serious economic and social disruptions near the site and elsewhere within the commuting region.

Impacts are estimated for three reference sites identified as Southeast, Midwest, and Southwest. These areas were chosen because siting of facilities in those regions is plausible and they differ substantially in demographic characteristics, thus providing a reasonable range of socioeconomic impacts.

The socioeconomic model used in this analysis forecasts a regional population in five-year intervals in the absence of any project activities. This population forecast serves both as a comparative baseline and as a source for a portion of the postulated future project employment. The model takes account of both primary and secondary employment effects (such as additional retail store clerks) and incorporates as separate components spouses of members of the labor force and other dependents. Regional migrants associated with the project are distributed residentially to counties throughout the commuting region. The model accounts for separation and retirement from project employment and replacement by a new labor force. It also specifies the tendency of workers and their dependents to leave the region upon job completion.

In the following analysis, impacts are presented in terms of an expected level of impact and as a maximum level of impact. The expected impact condition is based on the most likely value of the model assumptions, whereas the maximum impact condition places an extreme but credible value on the model assumptions. Table 4.2.5-1 presents estimates of the cumulative in-migrants for the facilities for the three reference sites over time. The forecasted values include primary and secondary employment and associated household dependents. All are in-migrants, since impacts are assumed to be generated primarily by new in-migrants. Over time, some of the persons who separate from the facility will stay in the site county and some will leave. Those who stay are contained in the forecasted values until they leave the area. Thus, not all the forecasted populations are actually working on or directly associated with the project at the time indicated. Nevertheless, the presence of each of these persons was determined by the existence of the project, and they would not likely be present if the project had not occurred. The percentages associated with each population in these tables reflect the size of the in-migrant group relative to the baseline population in the respective sites. Since these baseline populations vary by site, the relative impact of a similar in-migrant group can vary greatly.

TABLE 4.2.5-1. Population Forecasts for Independent Spent Fuel Storage Facility (persons)

Site	Year 1980	1985	2000	2015
		Expected Condition		
Southeast	234 (1.1%)	255 (1.1%)	299 (1.1%)	334 (1.2%)
Midwest	40 (0.1%)	478 (0.7%)	560 (0.6%)	631 (0.6%)
Southwest	4180 (8.6%)	2765 (5.7%)	3822 (6.2%)	3604 (6.2%)
		Maximum Condition		
Southeast	3090 (12.7%)	2615 (10.2%)	3130 (10.6%)	3394 (10.6%)
Midwest	914 (1.5%)	1501 (2.0%)	1789 (1.9%)	2006 (2.0%)
Southwest	6272 (12.4%)	4574 (9.0%)	5511 (9.9%)	5956 (9.8%)

Note: The numbers in parentheses denote the percentage of the incoming population based on the existing population.

The expected socioeconomic impacts of the independent spent fuel storage facility on the Southeast and Midwest sites are judged to be insignificant. The total numbers of forecasted new in-migrants equal about 1% in the construction (1980 to 1984) and operations phases (1985 to 2015). In addition, there are no very large transitions over time; the expected number of in-migrants increases steadily over the life of the project.

The effect of the project is substantially different in the Southwest site. The number of in-migrants during construction is three times the level of primary employment demand (4180 vs 1250). As a percent of project baseline population size, the potential for significant impacts is much greater in the Southwest. There is a substantial drop in the size of the in-migrant population over the transition from construction to operations. This decline in population influx of about one-third sets the stage for a boom and bust type of effect in the Southwest reference site.

The maximum impact condition for the independent spent fuel storage facility produces substantially larger project-induced in-migrant flow for each site compared with the expected condition. Maximum impacts associated with the independent spent fuel storage facility in the Southwest reference site are the largest obtained for the facility. The transition from construction to operation produces the same relative decline as was found under expected conditions but at a higher absolute level. This is reflected in the larger relative (to baseline) impacts (for example, 12.4% vs 8.6% in the Southwest case).

Translating forecasted project-related in-migration into socioeconomic impacts is complex and imprecise. Estimates of the level of demand that will be placed on the community to provide social services to the new workers and their families were made by applying a set of factors (Appendix C) to the project in-migration values. The product of these factors indicates how many units of each social service would be "expected" by the in-migrants. The significance of the impacts is primarily related to the capacity of the site county to meet these expectations.

The calculated levels of likely and maximum social service demands at the three reference sites are given in Table 4.2.5-2 for the year 2000.

TABLE 4.2.5-2. Selected Social Service Demands Associated with Local In-Migration Caused by Construction and Operation of the Independent Spent Fuel Storage Facility

Selected Social Services	Year 2000					
	Expected Demand			Maximum Demand		
	Southeast Site	Midwest Site	Southwest Site	Southeast Site	Midwest Site	Southwest Site
Health						
Physicians	0	1	3	3	2	5
Nurses	1	3	9	9	9	14
Dentists	0	0	1	1	1	2
Hospital beds	1	3	11	12	11	18
Nursing care beds	1	3	7	6	10	11
Education						
Teachers (K-12)	4	7	43	40	20	71
Classroom space, m^2 (9-12)	480	960	5180	4800	2560	8470
Sanitation, m^3/day						
Water treatment	170	320	1890	1780	1010	3130
Liquid waste	110	210	1260	1180	670	2090
Safety						
Firemen	0	0	2	2	1	4
Policemen	1	1	7	6	4	11
Recreation, ha						
Neighborhood parks	0	1	3	3	2	5
Government						
Administrative staff	0	1	3	3	2	5
Other social impacts						
Crimes (7 crime index)	14	24	194	145	77	322

4.2.6 Environmental Effects Related to Decommissioning of the Reference Independent Spent Fuel Storage Facility (DOE/ET-0028 Sec.8.4)

Some aspects of decommissioning an independent spent fuel storage facility may have an effect on the environment and natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effects of decommissioning activities.

4.2.6.1 Decommissioning Alternatives

Two decommissioning modes were chosen for this analysis: dismantlement and entombment (hardened safe storage).

With dismantlement, all potentially hazardous amounts of radioactive material are removed from the site to an approved disposal facility. Some nonradioactive portions of the facility may be removed to ensure removal of all radioactive materials.

Entombment involves preparation of the facility to be left in place until all radioactive material has decayed to innocuous levels. All such material in the facility is consolidated in areas of relatively high contamination. Permanent physical barriers are erected between the radioactive material and the environment. A surveillance and environmental monitoring program is established to ensure the continued protection of the public and environment from the radioactive material in the entombed structure.

The data presented in this section assume that the facility shutdown activities have been completed when decommissioning begins. Waste treatment facilities are shut down during the latter stages of decommissioning operations.

The reference independent spent fuel storage facility site consists of a 405-ha plot with a 10-ha exclusion area that contains the facility. Dismantlement allows the site to be released for alternative uses as the owner desires following dismantlement. Entombment requires that the 10-ha exclusion area of the facility site be occupied indefinitely by the entombed facility. The remaining 395 ha of the site can be released for alternative uses at the discretion of the facility owner. Activities at the site may be restricted to ensure the continued integrity of the entombed structure.

4.2.6.2 Resource Commitments

Water used during decommissioning is less than that required for facility operation ($2.5 \times 10^5 m^3/y$). Withdrawal of this amount of water from the R River described in the reference environment (average flow of 1.0×10^7 m^3/day), is judged to be insignificant with respect to other downstream uses. After chemical decontamination is completed, water requirements will be limited to sanitary needs of a work force of 50 people during the remainder of the dismantling or entombment process (about 1 1/2 years).

Materials committed for decommissioning of the reference independent spent fuel storage facility are:

	Dismantlement	Entombment
Steel shipping containers, MT	800	50
Paper, wood, plastic, MT	30	20
Equipment (mostly steel), MT	80	5

Energy resources committed for decommissioning are:

	Dismantlement	Entombment
Electricity, MWh	5	3

Manpower requirements for dismantling the independent spent fuel storage facility are 95 man-yr, while entombment will require 60 man-yr plus 0.3 man-yr for each year of surveillance. Surveillance will be required for 100 years or more. Including surveillance, the total manpower required for entombment is at least 90 man-yr.

4.2.6.3 Effluents

Liquid releases caused by drainage of the fuel storage basins during decommissioning will amount to 18,000 m^3 of slightly contaminated water to the R River. Radioactive material released during drainage of fuel storage basins and atmospheric releases of gases and particulates through the facility ventilation system are summarized in Table 4.2.6-1.

TABLE 4.2.6-1. Radionuclides Released to the Biosphere During Decommissioning of the Independent Spent Fuel Storage Facility

	To Atmosphere		To Water	
Radionuclide	Dismantlement	Entombment	Dismantlement	Entombment
^{55}Fe			6.5×10^{-3}	6.5×10^{-3}
^{60}Co	1.9×10^{-8}	1.9×10^{-10}	9.5×10^{-3}	9.5×10^{-3}
^{89}Sr			4.7×10^{-5}	4.7×10^{-5}
^{90}Sr	7.2×10^{-9}	7.2×10^{-11}	3.6×10^{-3}	3.6×10^{-3}
^{127m}Te	4.8×10^{-11}	4.8×10^{-13}	2.4×10^{-5}	2.4×10^{-5}
^{129m}Te			2.3×10^{-6}	2.3×10^{-6}
^{134}Cs	4.1×10^{-8}	4.1×10^{-10}	2.0×10^{-2}	2.0×10^{-2}
^{137}Cs	4.3×10^{-7}	4.3×10^{-9}	2.2×10^{-1}	2.2×10^{-1}

4.2.6.4 Physical, Chemical, and Thermal Effects

Effects on air quality from decommissioning of the independent spent fuel storage facility will vary with the mode of decommissioning. During demolition and site restoration, fugitive dust will be generated. Vehicle effluents from heavy equipment will also be produced during the six months required for demolition and site restoration. During entombment of the independent spent fuel storage facility no noticeable effects on air quality are expected. The primary source of effluents during decommissioning will be from traffic from waste transport and employee transportation.

During dismantling of the independent spent fuel storage facility about 20 m^3 of combustible non-transuranic wastes will be generated after the waste treatment facilities have been shut down. However, discussion of these wastes is not within the scope of this analysis. If the entombment mode is chosen for decommissioning, 270 m^3 of non-transuranic wastes will be generated during the latter stages of the operation. Less than 1 m^3/yr of radioactive waste will be generated during the surveillance period.

4.2.6.5 Radiological Effects

Doses to individuals in the vicinity of the independent spent fuel storage facility during decommissioning were calculated based on the releases of radionuclides listed in Table 4.2.6-1; exposure pathways, demography, and other parameters described for the reference environment in Appendix A; and mathematical models relating dose to man from radionuclide releases (Appendix B). Exposure pathways to man will exist for radioactive effluents released to the environment via air and water.

The annual doses to individuals whose habits tend to maximize their dose ("maximum individual") are shown in Table 4.2.6-2. For comparison, the dose to an individual from naturally occurring radioactive sources averages about 0.1 rem/yr.

TABLE 4.2.6-2. Annual Doses to the Maximum Individual from Decommissioning of the Independent Spent Fuel Storage Facility (rem)

Pathway	Total Body	Thyroid (child)[a]	Thyroid[b]	Lung	Bone
		Dismantlement			
Air submersion	8.1×10^{-15}	8.1×10^{-15}	8.1×10^{-15}	8.1×10^{-15}	8.1×10^{-15}
External	8.3×10^{-7}		8.3×10^{-7}	8.3×10^{-7}	8.3×10^{-7}
Inhalation	3.3×10^{-13}		1.5×10^{-15}	1.3×10^{-11}	6.1×10^{-13}
Ingestion	6.4×10^{-5}		1.0×10^{-10}	9.6×10^{-6}	6.1×10^{-5}
Total	6.5×10^{-5}	8.1×10^{-15}	8.3×10^{-7}	1.0×10^{-5}	6.9×10^{-5}
		Entombment			
Air submersion	8.1×10^{-17}	8.1×10^{-17}	8.1×10^{-17}	8.1×10^{-17}	8.1×10^{-17}
External	8.3×10^{-7}		8.3×10^{-7}	8.3×10^{-7}	8.3×10^{-7}
Inhalation	3.3×10^{-15}		1.5×10^{-17}	1.3×10^{-13}	6.1×10^{-15}
Injection	6.4×10^{-5}		1.0×10^{-10}	9.6×10^{-6}	6.1×10^{-5}
Total	6.5×10^{-5}	3.3×10^{-1}	8.3×10^{-7}	1.0×10^{-5}	6.9×10^{-5}

Note: The maximum individual is defined as a permanent resident at a location 1600 m southeast of the stack with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 9.9×10^{-8} sec/m^3.

a. Thyroid dose is calculated for a 1-year-old child breathing air containing radioactive effluents and consuming 1 ℓ of milk per day from cows grazing 7 months/yr at the site boundary. Inhalation dose is <2% of total dose.

b. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

The combined dose to the population living within an 80-km radius of the plant was calculated using the projected year 2000 population data given in the reference environment (Appendix A). Table 4.2.6-3 summarizes the annual doses received by this population. The annual total-body population dose from naturally occurring sources to the approximately 2 million persons living within an 80-km radius of the plant in the year 2000 would be about 200,000 man-rem compared with about 9 man-rem received from decommissioning sources.

The annual total-body dose to the work force associated with decommissioning was estimated based on permissible exposure limits and experience of decommissioning plants. The annual occupational dose was calculated to be 69 man-rem for dismantlement and 24 man-rem for entombment. Table 4.6.6-4 summarizes the annual total-body dose to the work force and the general population from decommissioning and naturally occurring sources in the year 2000.

TABLE 4.2.6-3. Annual Doses to the Population (within 80 km) from Decommissioning of the Independent Spent Fuel Storage Facility (man-rem)

Pathway	Total Body	Thyroid[a]	Lung	Bone
		Dismantlement		
Air submersion	5.8×10^{-10}	5.8×10^{-10}	5.8×10^{-10}	5.8×10^{-10}
External	3.4×10^{-2}	3.4×10^{-2}	3.4×10^{-2}	3.4×10^{-2}
Inhalation	2.4×10^{-8}	1.1×10^{-10}	9.2×10^{-7}	4.3×10^{-8}
Ingestion	9.1	4.8×10^{-5}	1.4	8.6
Total	9.1	3.4×10^{-2}	1.4	8.6
		Entombment		
Air submersion	5.8×10^{-12}	5.8×10^{-10}	5.8×10^{-10}	5.8×10^{-10}
External	3.4×10^{-2}	3.4×10^{-2}	3.4×10^{-2}	3.4×10^{-2}
Inhalation	2.4×10^{-10}	1.1×10^{-12}	9.2×10^{-9}	4.3×10^{-10}
Ingestion	9.1	4.8×10^{-5}	1.4	8.6
Total	9.1	3.4×10^{-2}	1.4	8.6

a. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

TABLE 4.2.6-4. Summary of Annual Total-Body Doses from Decommissioning of the Independent Spent Fuel Storage Facility and from Naturally Occurring Sources

	Dose, man-rem	
	Dismantlement	Entombment
Independent spent fuel storage facility		
Decommissioning work force	69	24
Population (within 80 km)	9.1	9.1
Naturally occurring sources		
Population (within 80 km)	200,000	200,000

The 70-year doses to the maximum individual and to the population within 80 km of the facility are given in Tables 4.2.6-5 and 4.2.6-6 respectively. A summary of the 70-year total-body doses to the work force and the population is given in Table 4.2.6-7.

TABLE 4.2.6-5. 70-Year Doses to the Maximum Individual from Decommissioning of the Independent Spent Fuel Storage Facility (rem)

Pathway	Total Body	Thyroid[a]	Lung	Bone
		Dismantlement		
Air submersion	8.1×10^{-15}	8.1×10^{-15}	8.1×10^{-15}	8.1×10^{-15}
External	8.3×10^{-7}	8.3×10^{-7}	8.3×10^{-7}	8.3×10^{-7}
Inhalation	8.0×10^{-13}	1.5×10^{-15}	2.3×10^{-12}	2.6×10^{-12}
Ingestion	1.7×10^{-4}	2×10^{-10}	2.7×10^{-5}	2.2×10^{-4}
Total	1.7×10^{-4}	8.3×10^{-7}	2.8×10^{-5}	2.2×10^{-4}
		Entombment		
Air submersion	8.1×10^{-17}	8.1×10^{-17}	8.1×10^{-17}	8.1×10^{-17}
External	8.3×10^{-7}	8.3×10^{-7}	8.3×10^{-7}	8.3×10^{-7}
Inhalation	8.0×10^{-15}	1.5×10^{-17}	2.3×10^{-14}	2.6×10^{-14}
Ingestion	1.7×10^{-4}	2.0×10^{-10}	2.7×10^{-5}	2.2×10^{-4}
Total	1.7×10^{-4}	8.3×10^{-7}	2.8×10^{-5}	2.2×10^{-4}

Note: The maximum individual is defined as a permanent resident at a location 1600 m southeast of the stack with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 9.9×10^{-8} sec/m^3.

a. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

TABLE 4.2.6-6. 70-Year Doses to the Population (within 80 km) from Decommissioning of the Independent Spent Fuel Storage Faciltiy (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
Air submersion	5.8×10^{-10}	5.8×10^{-10}	5.8×10^{-10}	5.8×10^{-10}
External	3.4×10^{-2}	3.4×10^{-2}	3.4×10^{-2}	3.4×10^{-2}
Inhalation	5.7×10^{-8}	1.1×10^{-10}	1.7×10^{-7}	1.8×10^{-7}
Ingestion	9.8×10^{1}	1.9×10^{-4}	1.5×10^{1}	1.4×10^{2}
Total	9.8×10^{1}	3.4×10^{-2}	1.5×10^{1}	1.4×10^{2}
		Entombment		
Air submersion	5.8×10^{-10}	5.8×10^{-10}	5.8×10^{-10}	5.8×10^{-10}
External	3.4×10^{-2}	3.4×10^{-2}	3.4×10^{-2}	3.4×10^{-2}
Inhalation	5.7×10^{-10}	1.1×10^{-12}	1.7×10^{-9}	1.8×10^{-9}
Ingestion	9.8×10^{1}	1.9×10^{-4}	1.5×10^{1}	1.4×10^{2}
Total	9.8×10^{1}	3.4×10^{-2}	1.5×10^{1}	1.4×10^{2}

TABLE 4.2.6-7. Summary of 70-Year Total-Body Doses from Decommissioning of the Independent Spent Fuel Storage Facility and from Naturally Occurring Sources

	Dose, man-rem	
	Dismantlement	Entombment
Independent spent fuel storage facility		
Decommissioning work force[a]	69	24
Population (within 80 km)	6.2	6.2
Naturally occurring sources		
Population (within 80 km)	14,000,000	14,000,000

a. Essentially all of the worker dose is received during the first year of decommissioning.

In this report, 100 to 800 health effects are postulated to occur in the exposed population per million man-rem. A population dose of 6 man-rem/yr from decommissioning will result in no health effects.

4.2.6.6 Environmental Monitoring

During surveillance an environmental monitoring program will be maintained for the reference independent spent fuel storage facility. This environmental program will contain most of the characteristics of the program in force during plant operation. The significant change will involve placing distant sampling points closer to the plant. There will be no significant reduction in the number of samples collected until evidence of confinement of radioactive material is gathered.

4.2.6.7 Ecological Effects

No adverse effects are expected from decommissioning of the reference independent spent fuel storage facility. Chemicals used during decontamination that are potentially harmful to terrestrial plants and animals will be processed through the waste treatment facility. Water used during decommissioning will be withdrawn from the R River; this withdrawal is judged to be insignificant with respect to other downstream uses and no effects are expected on aquatic ecosystems.

Injuries and fatalities associated with nonradiological decommissioning accidents are calculated using an injury rate of 13.6 per million man-hours and a fatality rate of 0.17 per million man-hours. The results are presented below:

	Million Man-hours	Injuries	Fatalities
Dismantlement	0.2	3	none
Entombment[a]	0.18	2	none

a. Includes 100 years of surveillance.

4.2.6.8 Postulated Accidents

Quantities of radioactive materials contained in facilities to be decommissioned will be several orders of magnitude less than those present during operation of the facility. The potential for significant releases of radioactive material to the biosphere during decommissioning would be small when compared with similar accidents occurring during operation of the facility. Therefore, no accident scenarios are included for facility decommissioning operations.

Accident scenarios associated with transportation of non-high-level transuranic wastes generated by decommissioning activities are included in Section 7.3.2.

4.2.7 Summary of Adverse Environmental Impacts

If the reference independent spent fuel storage facility is built and operated in the manner described in Section 5.7 of DOE/ET-0028, the following environmental effects which may be determined to be adverse will occur.

- the release of small quantities of radionuclides to the biosphere, the consequences of which are an insignificant addition to the dose the regional and worldwide population will receive from naturally occurring sources (2.6×10^{-5} percent and 1.9×10^{-9} percent, respectively);
- the accumulation in one relatively small area ($\sim$10 ha) of about 3000 MT of spent fuel containing significant quantities of radionuclides, the handling and storage of which carries the potential for accidental release to the biosphere; plausible accidents were postulated and resulting population doses were no larger than the dose received from one year's exposure to naturally occurring sources;
- consumption of the following energy sources:

Propane, m^3	9.5×10^2
Diesel fuel, m^3	9.5×10^3
Gasoline, m^3	6.4×10^3
Electricity, kWh	4.0×10^7

- the release of about 4.2×10^8 MJ/yr of waste heat to the atmosphere via evaporation of water from a mechanical draft cooling tower;
- the occurrence of 110 disabling injuries and one fatality as a result of construction of the independent spent fuel storage facility.

4.3 ENVIRONMENTAL EFFECTS RELATED TO EXTENDED STORAGE OF SPENT FUEL

4.3 ENVIRONMENTAL EFFECTS RELATED TO EXTENDED STORAGE OF SPENT FUEL (Includes the Spent Unreprocessed Fuel Facility)

In the event that there is a delay of prompt reprocessing or disposal of spent fuel after the initial 6-1/2 year cooling period, facilities will be required to provide extended storage of this fuel. Although concepts for extended storage extend for about 100 years into the future, the reference system assumes that the decision is made in the year 2000 whether to reprocess or to dispose of the spent fuel. Thus the nominal life for the extended storage facilities is on the order of 30 years.

The reference extended storage facility consists of a fuel receiving facility where packaged fuel is received, checked for contamination or leakage, repackaged if necessary, and prepared for the dry caisson concept for storage of packaged spent fuel. Alternative storage concepts include water basin storage, air-cooled vault, and surface cask storage. The reference extended fuel storage facility will be located on a 405-ha site in the reference environment.

4.3.1 Independent Spent Fuel Receiving Facility for Extended Storage (DOE/ET-0028 Sec. 5.7.4)

After spent fuel is packaged for extended storage, it could be shipped to a separate site for storage. In this case an independent spent fuel receiving facility receives the packaged spent fuel and transfers it to the storage facility.

The independent spent fuel receiving facility receives packaged LWR spent fuel in railcar shipping casks; unloads these casks and removes the packaged spent fuel; examines and tests the integrity of the containers; and, if satisfactory, loads the packaged spent fuel into a conveyance for transfer to the associated storage facility. The facility has the capacity to receive and transfer packaged spent fuel to the associated storage facility at a rate of 2000 MTHM/yr on the basis of 300 operating days per year. All spent LWR fuel is received in rail casks that transport either 7 packaged pressurized water reactor fuel assemblies or 17 packaged boiling water reactor fuel assemblies. Failed containers are overpacked prior to storage; the receiving facility is capable of regularly overpacking up to 2% of the spent fuel packages received.

The independent spent fuel receiving facility comprises the major fuel receiving and support facilities building, personnel support facilities, and service areas. A plot plan of the facility is shown in Figure 4.3.1-1. Figure 4.3.1-2 shows an operations flowsheet of the facility. The cask transfer tunnel and the cask transfer carriage system, the spent fuel receiving cell, the overpacking cell, the spent fuel transfer tunnels, the control and operating areas, the cell ventilation filter and fan building, the emergency generator area, the maintenance counting room and lab, and the waste handling and treating area are constructed in conformance with design basis earthquake and tornado requirements. The remainder of the buildings are standard industrial construction. In the rail cask receiving, handling, and unloading area two parallel railcar unloading tracks are provided, served by a 125-ton overhead bridge crane. Casks are transferred via a motor-driven cask carriage through an underground air tunnel. In the packaged spent fuel receiving and transfer area, all packaged spent fuel is handled remotely, using an overhead bridge crane, power and slave manipulators, and shielded viewing

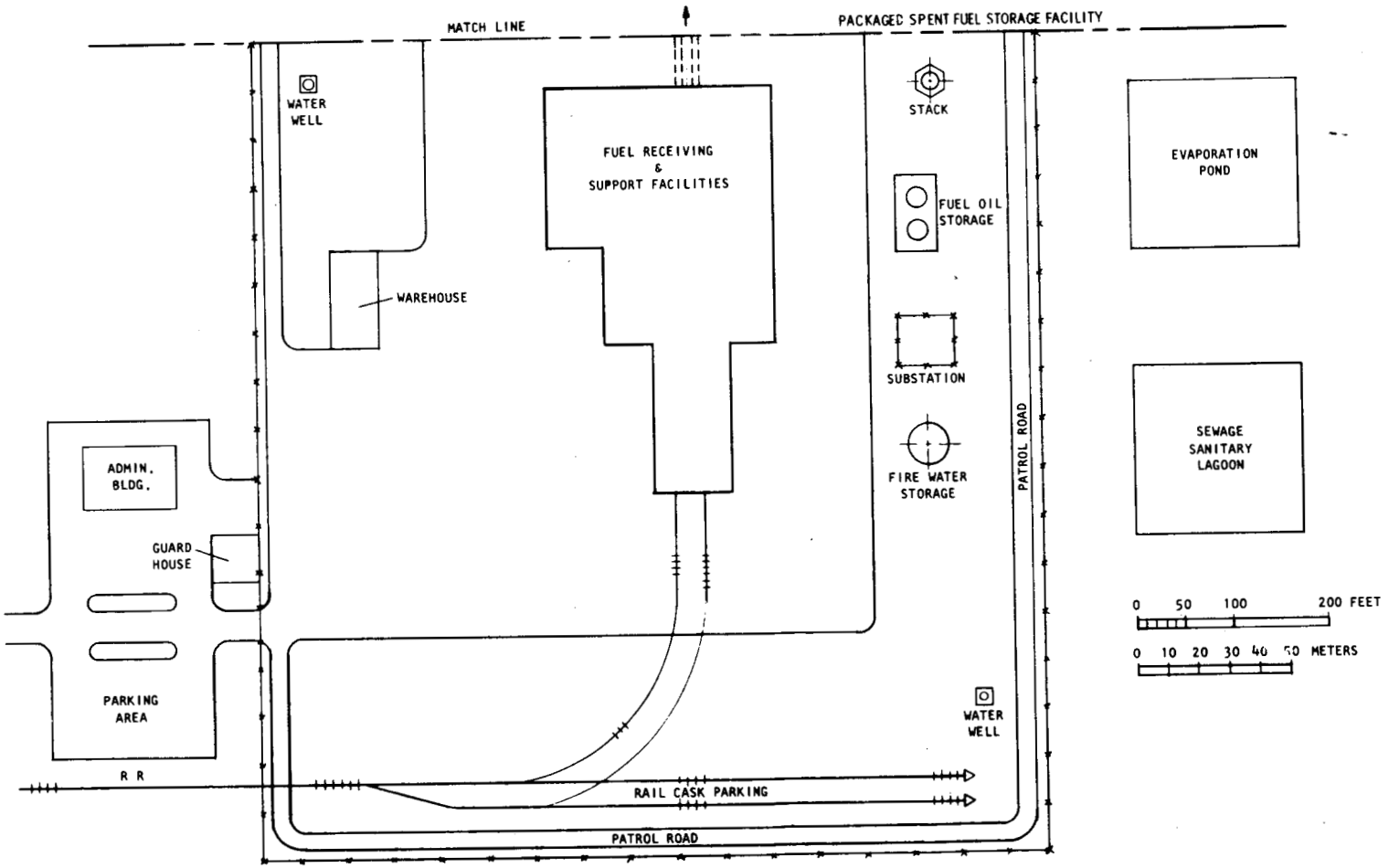

FIGURE 4.3.1-1. Plot Plan for the Independent Spent Fuel Receiving Facility and Support Facilities

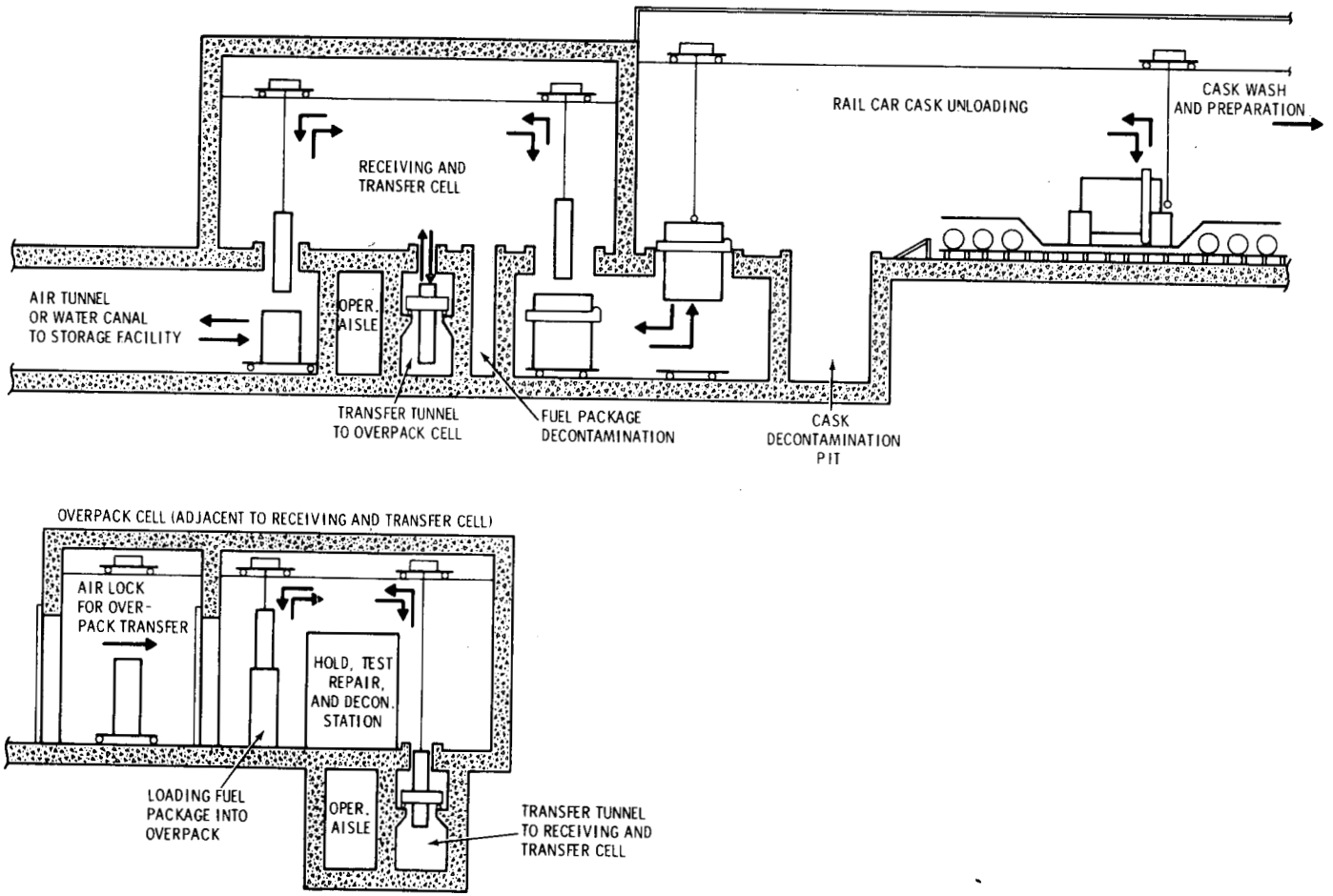

FIGURE 4.3.1-2. Operations Flowsheet for the Independent Spent Fuel Receiving Facility

windows. Decontamination pits are provided, as are cooling wells, to ensure complete examination and conditioning before the packaged fuel is released. Any packaged spent fuel with faulty containers is placed through a hatch opening into a motorized carrier and transferred to the overpacking cell. In the spent fuel overpacking area, equipment items include an overhead bridge crane, storage racks for the packaged spent fuel before and after overpacking, a decontamination station, and remote welding and weld-test equipment. A shielding door is located at one end of the cell, through which the fresh overpack containers are transferred on a motorized cart from an adjacent air lock and supply storage area.

4.3.1.1 Environmental Effects Related to Facility Construction

Some aspects of site preparation and reference facility construction may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of construction activities.

Resource Commitments. The independent spent fuel receiving facility, which is specified for extended spent fuel storage, is located on a 405-ha site. The facility will occupy about 10 ha of the site. An additional 3.2 ha will be required for construction storage, work yards, temporary building, and labor parking. Storage facilities will occupy additional onsite land, as described in Sections 4.3.2, 4.3.3, and 4.3.4.

Water used during construction is estimated to be 3×10^4 m^3. Withdrawal of this amount of water from the R River, described in the reference environment (average flow of 1.0×10^7 m^3/day), is judged to be insignificant with respect to other downstream uses. During the construction period wells can probably supply the required amount of water without consequence.

Materials committed for construction of the independent spent fuel receiving facility are:

Steel	3,300 MT
Copper	18 MT
Aluminum	9 MT
Lumber	1,000 m^3
Concrete	16,000 m^3

Energy resources committed for construction are:

Propane	265 m^3
Diesel fuel	2,600 m^3
Gasoline	1,700 m^3
Electricity	
Peak demand	680 kW
Total consumption	130,000,000 kWh

Manpower requirements for construction of the independent spent fuel receiving facility will amount to 2,300,000 man-hr.

No unusual transportation requirements have been identified.

Physical and Chemical Effects. Nonradioactive pollutants released to the atmosphere during construction of the independent spent fuel receiving facility will result from combustion

of gasoline and diesel fuel in construction equipment, fugitive dust from clearing and excavation, and particulate emissions from concrete batching operations. Concentrations of carbon monoxide, hydrocarbons, nitrogen oxides, and sulfur oxides in air will be below applicable Federal air quality standards. Particulate concentrations at the construction site may exceed the Federal ambient air quality standard of 75 $\mu g/m^3$; however, this will not likely be exceeded off site.(2)

Ecological Effects. Construction will remove permanently (for the life of the plant) about 13 ha from its present use for agriculture and wildlife at the reference site. While this change in land use will eliminate its utility as habitat for wildlife, no significant ecological impacts to the region are expected. Disturbance of animals from fugitive dust, noise, and human activities during construction will be mainly confined to the 13 ha. Erosion caused by run-off may deposit silt in nearby surface waters unless attention is given to control drainage by proper ditching, grading, and silt catchment. After construction is completed and vegetation is re-established or surfacing is completed in the disturbed areas, this problem will be reduced.

The independent spent fuel receiving facility will require about 3×10^4 m^3 of water for construction. Average annual water use during the 2.5 year construction period is less than 0.001% of the recorded mean flow of the R River. Removal of this volume of water from the R River will have an insignificant impact on the stream biota.

A common water intake from the R River will probably supply the construction and operational water needs of the independent spent fuel receiving facility. This intake should be located to minimize any alteration of flow patterns and properly screened to reduce the numbers of aquatic organisms entrained in the water system. Procedures will be required to keep the disturbance of the river bottom to a minimum during intake construction.

The maximum concentrations of particulates, sulfur dioxide, and carbon monoxide will occur within the 10-ha restricted area. Calculated carbon monoxide and hydrocarbon levels are only a small fraction of the existing rural air concentrations near the reference site. Concentrations of the other materials are less than applicable standards. Consequently, no measurable detrimental effects on the terrestrial ecosystem are anticipated.

4.3.1.2 Environmental Effects Related to Facility Operation

Some aspects of facility operation may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effects of operation.

Resource Commitments. No significant amounts of resources are anticipated for use during operation of the independent spent fuel receiving facility. Table 4.3.1-1 presents the resource requirements for operation of the facility.

Process Effluents. Radioactive materials that reach the atmosphere from the independent spent fuel receiving facility are processed through a HEPA filtration system. The annual releases of radioactive material from the independent spent fuel receiving facility are 1.3×10^{-2} Ci of ^{85}Kr and 7.0×10^{-8} Ci of ^{129}I. There are no planned releases of radioactive material to the biosphere via liquid effluent streams.

effluent streams.

TABLE 4.3.1-1. Utilities and Materials Required for Operation of the Independent Spent Fuel Receiving Facility

Resource	Average Annual Use
Coal, MT	5.0×10^3
Electricity, kWh	7.2×10^6
Water, m^3	1.0×10^4
Manpower, man-yr	4.9×10^1

Nonradioactive effluents released to the biosphere include 1.0×10^4 m^3 of water from the sanitary sewer and 1.0×10^2 m^3 from the chemical sewer.

About 3.2×10^7 MJ of waste of heat will be rejected from the facility annually.

Physical, Chemical, and Thermal Effects. The release of 2.8×10^7 MJ/yr of excess heat from the reference facility is not expected to produce any significant thermal effects.

Water required during operation of the independent spent fuel receiving facility will be about 1.0×10^4 m^3/yr. This water will be withdrawn from the R River near the reference site and amounts to about 0.001% of the average flow of the river. In the absence of releases of radioactive materials there will be no radiological effects.

No hazardous chemicals will be released from the facility.

Radiological Effects. Doses to individuals in the vicinity of the independent spent fuel receiving facility were calculated based on the release of 1.2×10^{-2} Ci of ^{85}Kr and 7.0×10^{-8} Ci of ^{129}I; exposure pathways, demography, and other parameters described for the reference environment in Appendix A; and mathematical models relating dose to man from radionuclides released (Appendix B). For planned operation of the receiving facility, the only exposure pathway to man is via airborne effluents; there are no planned releases to ground or water.

The annual doses to individuals whose habits tend to maximize their doses ("maximum individual") are shown in Table 4.3.1-2. For perspective, the dose to an individual from naturally occurring radioactive source averages about 0.1 rem/yr.

TABLE 4.3.1-2. Annual Doses to the Maximum Individual from Gaseous Effluents Released from the Independent Spent Fuel Receiving Facility (rem)

Pathway	Total Body	Thyroid[a]	Lung	Bone
Air submersion	5.8×10^{-13}	5.8×10^{-13}	5.8×10^{-13}	5.8×10^{-13}
Inhalation	1.2×10^{-14}	9.0×10^{-12}	6.9×10^{-14}	0
Ingestion	1.0×10^{-12}	9.4×10^{-10}	0	5.5×10^{-13}
Total	1.0×10^{-12}	8.5×10^{-10}	6.5×10^{-13}	1.1×10^{-12}

Note: The maximum individual is defined as a permanent resident at a location 1600 m southeast of the stack with the highest annual average dispersion factor ($\bar{\chi}/Q'$) of 9.9×10^{-8} sec/m^3.

a. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

The combined dose from gaseous effluents to the population living within an 80-km radius of the plant was calculated using the projected year 2000 population data given in the reference environment. Table 4.3.1-3 summarizes the annual doses received by this population. The annual total-body population dose from naturally occurring sources to the approximately 2 million persons living within an 80-km radius of the plant in the year 2000 would be about 200,000 man-rem compared with about 9×10^{-8} man-rem received from the receiving facility.

TABLE 4.3.1-3. Annual Doses to the Population (within 80 km) from Gaseous Effluents Released from the Independent Spent Fuel Receiving Facility (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
Air submersion	4.2×10^{-8}	4.2×10^{-8}	4.2×10^{-8}	4.2×10^{-8}
Inhalation	8.4×10^{-10}	6.5×10^{-7}	4.9×10^{-9}	0
Ingestion	4.3×10^{-8}	3.4×10^{-5}	0	2.3×10^{-8}
Total	8.6×10^{-8}	3.5×10^{-5}	4.7×10^{-8}	6.5×10^{-8}

The 70-year doses to the maximum individual and to the population with 80 km of the facility are given in Tables 4.3.1-4 and 4.3.1-5 respectively.

TABLE 4.3.1-4. 70-Year Doses to the Maximum Individual from Gaseous Effluents Released from the Independent Spent Fuel Receiving Facility (rem)

Pathway	Total Body	Thyroid	Lung	Bone
Air submersion	1.7×10^{-11}	1.7×10^{-11}	1.7×10^{-11}	1.7×10^{-11}
Inhalation	3.7×10^{-13}	2.9×10^{-10}	2.0×10^{-12}	0
Ingestion	9.1×10^{-11}	7.0×10^{-8}	0	3.3×10^{-11}
Total	1.0×10^{-10}	7.0×10^{-8}	1.9×10^{-11}	5.0×10^{-11}

Note: The maximum individual is defined as a permanent resident at a location 1600 m southeast of the stack with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 9.9×10^{-8} sec/m^3.

a. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

TABLE 4.3.1-5. 70-Year Doses to the Population (within 80 km) from Gaseous Effluents Released from the Independent Spent Fuel Receiving Facility (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
Air submersion	1.2×10^{-6}	1.2×10^{-6}	1.2×10^{-6}	1.2×10^{-6}
Inhalation	2.7×10^{-8}	2.1×10^{-5}	1.5×10^{-7}	0
Ingestion	2.8×10^{-6}	2.2×10^{-3}	0	9.8×10^{-7}
Total	4.0×10^{-6}	2.2×10^{-3}	1.4×10^{-6}	2.2×10^{-6}

All annual total body doses to the maximum individual or the regional population are less than 1×10^{-6} rem/yr and 1×10^{-6} man-rem/yr, respectively, and the release of the stated quantities of krypton and iodine are believed to be insignificant. All doses calculated for the maximum individual and population include doses from routine releases and from minor accidents with the independent spent fuel receiving facility.

In this report, 100 to 800 health effects are postulated to occur in the exposed population per million man-rem. No health effects are calculated to result from doses to the regional population or worldwide population from the planned operation of the independent spent fuel receiving facility.

4.3.1.3 Environmental Effects Related to Postulated Accidents

There are five accident cases described for the independent spent fuel receiving facility. Scenarios are provided in Section 5.7 of DOE/ET-0028[1] and the accidents are listed below.

Accident Number	Description
	Minor
5.7.15	Loss of normal electrical power
5.7.16	Loss of normal cooling air supply
5.7.17	Equipment failure – fuel assembly suspended in air
	Moderate
5.7.18	Fuel handling accident – rupture of some cladding
5.7.19	Shipping cask dropped into cask well
	Severe
5.7.20	Dropped fuel assembly – rupture of 20% of pins

These accidents are the same as those postulated for spent fuel packaging. The dropped fuel assembly and rupture of pins (Accident 5.7.20) was judged to be the most severe and was taken as representative of the set.

For this accident it was assumed that all volatile isotopes were vented to the facility stack. The venting occurred over a 30-day period with a frequency of occurrence once every 10 years. The radioactive material associated with such an event is given in Table 4.3.1-6. The first-year and 70-year dose commitments to the maximum individual were calculated and are presented in Table 4.3.1-7. Numerically, the largest of these dose values are less than 5% of the dose the individual would have received from naturally occurring sources during the period. Non-design basis accidents were not considered.

TABLE 4.3.1-6. Radionuclides Released to the Atmosphere During a Serious Accident at the Independent Spent Fuel Receiving Facility

Radionuclide	Release, Ci
^{3}H	2.4
^{85}Kr	1.3×10^{1}
^{90}Sr	4.4×10^{-10}
^{90}Y	4.4×10^{-10}
^{129}I	3.2×10^{-4}
^{137}Cs	6.8×10^{-10}
^{154}Eu	3.8×10^{-11}

TABLE 4.3.1-7. Dose Commitments to the Maximum Individual from a Serious Accident at the Independent Spent Fuel Receiving Facility (rem)

	1-Year Dose	70-Year Dose
Total body	2.8×10^{-5}	2.8×10^{-5}
Bone	9.6×10^{-6}	9.6×10^{-6}
Lung	3.0×10^{-5}	3.0×10^{-5}
Thyroid	1.2×10^{-4}	1.3×10^{-4}
Skin	9.0×10^{-4}	9.0×10^{-4}

Note: The maximum individual is defined as a permanent resident at a location 1600 m southeast of the stack with a time-integrated atmospheric dispersion coefficient (E/Q) of 1.5×10^{-4} sec/m^3.

REFERENCES FOR SECTION 4.3.1

1. Technology for Commercial Radioactive Waste Management, DOE/ET-0028, Department of Energy, Washington, DC, in press.

2. U.S. Congress, Clean Air Act Amendments 1977, Public Law 95-95, U.S. Government Printing Office, Washington, DC, August 1977.

4.3.2 Dry Caisson Storage of Packaged Spent Fuel (DOE/ET-0028 Sec. 5.7.7)

The caisson concept for storage of packaged spent fuels relies upon the soil to conduct the radiogenic heat from spent fuel to the earth's surface, where it is dissipated to the atmosphere. The canistered fuel is placed in an underground steel caisson that is closed with a concrete plug. This concept for fuel storage is similar to that being used to store high-temperature gas reactor fuel and to a technique being used to store Canadian reactor fuels. This approach has not been used for storage of commercial light-water reactor fuels, but it is a direct application of available technology and has been studied for this use.

Figure 4.3.2-1 shows the details of the caisson construction. Carbon steel pipe caissons are placed in drilled holes and concrete is poured between the pipe and the soil to provide

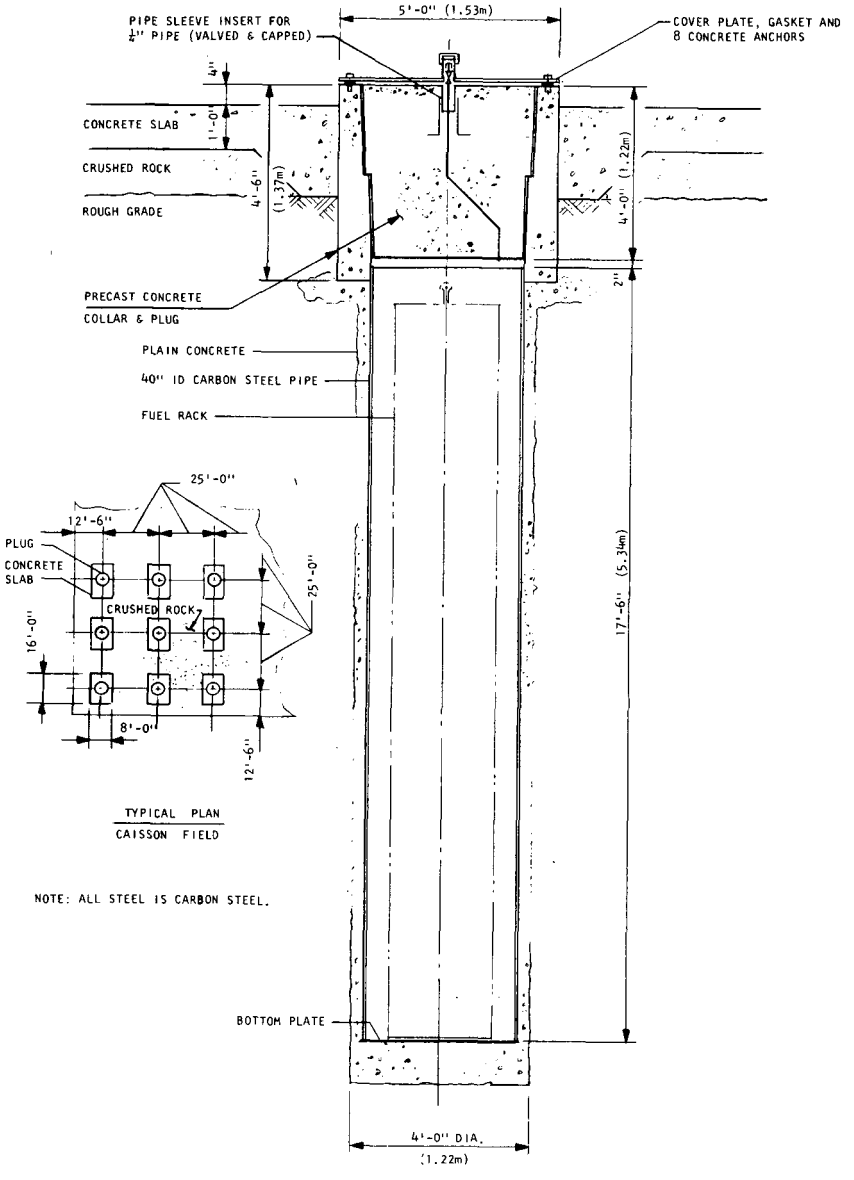

FIGURE 4.3.2-1. Detail of a Dry Caisson Used for Storage of Packaged Spent Fuel

corrosion protection. A precast concrete collar and a matching shielding plug are placed on top of the caisson, and a concrete slab is poured around each hole to provide the foundation for the shielding cask.

Figure 4.3.2-2 shows an operations flow diagram of the storage facility. Operations at this facility consist of fuel transfer from an adjacent independent spent fuel receiving facility to the storage area, fuel placement in a caisson, and monitoring of the filled caisson and storage area. In the unlikely event that fuel package integrity is compromised during these operations, the package would be returned to the packaging facility for inspection and repackaging or overpacking if necessary. All caissons are identical and will store either three or six boiling water reactor (BWR) assemblies. A carbon steel rack supports the fuel assemblies in each caisson. The dry caisson facility will have the capacity to receive and store packaged

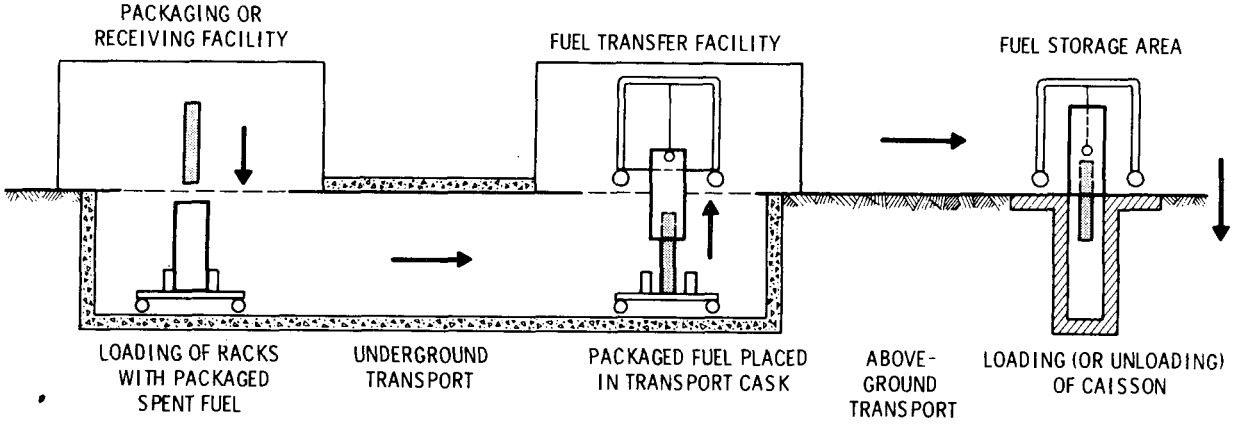

FIGURE 4.3.2-2. Operations Flowsheet for the Dry Caisson Storage Facility for Packaged Spent Fuel

fuel elements at a rate of 2000 MTHM/yr [2690 pressurized water reactor (PWR) assemblies and 4030 BWR assemblies]. This requires about 1570 caissons per year, of which 900 will be for PWR elements and 670 for BWR elements. The design capacity provided is 1570 caissons per year for 10 years for a planned storage capacity of 15,700 caissons.

The dry caisson storage facility has two main components: the fuel transfer facility where the spent fuel assemblies are transferred in their storage racks to the caisson, and the fuel storage area where the assemblies are stored. The fuel transfer facility is a steel building that houses the fuel rack receiving and storage areas, the fuel transfer station, and the administrative and personnel area. A crane serves the receiving and storage areas. A self-propelled gantry crane equipped with a shielded transfer cask and hoists is used to transfer the fuel from the fuel transfer facility to the caisson in the storage area. Figure 4.3.2-3 is a plot plan of the facility.

When completed, the fuel storage area will consist of ten storage areas. Each area will be drained independently with surface ditches that connect to the retention pond, where runoff will be monitored before release. The carbon steel caissons, 1 m in diameter by 6.7 m long, are placed in the storage area on square arrays that are 7.6 by 7.6 m. Each storage area contains 1570 caissons. Each caisson is plugged with a concrete plug to provide radiation shielding and partial contamination control. A small mobile crane in the fuel storage area is used to handle the caisson plug and other equipment during placement of a filled storage rack in the caisson.

In this report the dry caisson storage concept is the reference concept for extended storage of spent fuel.

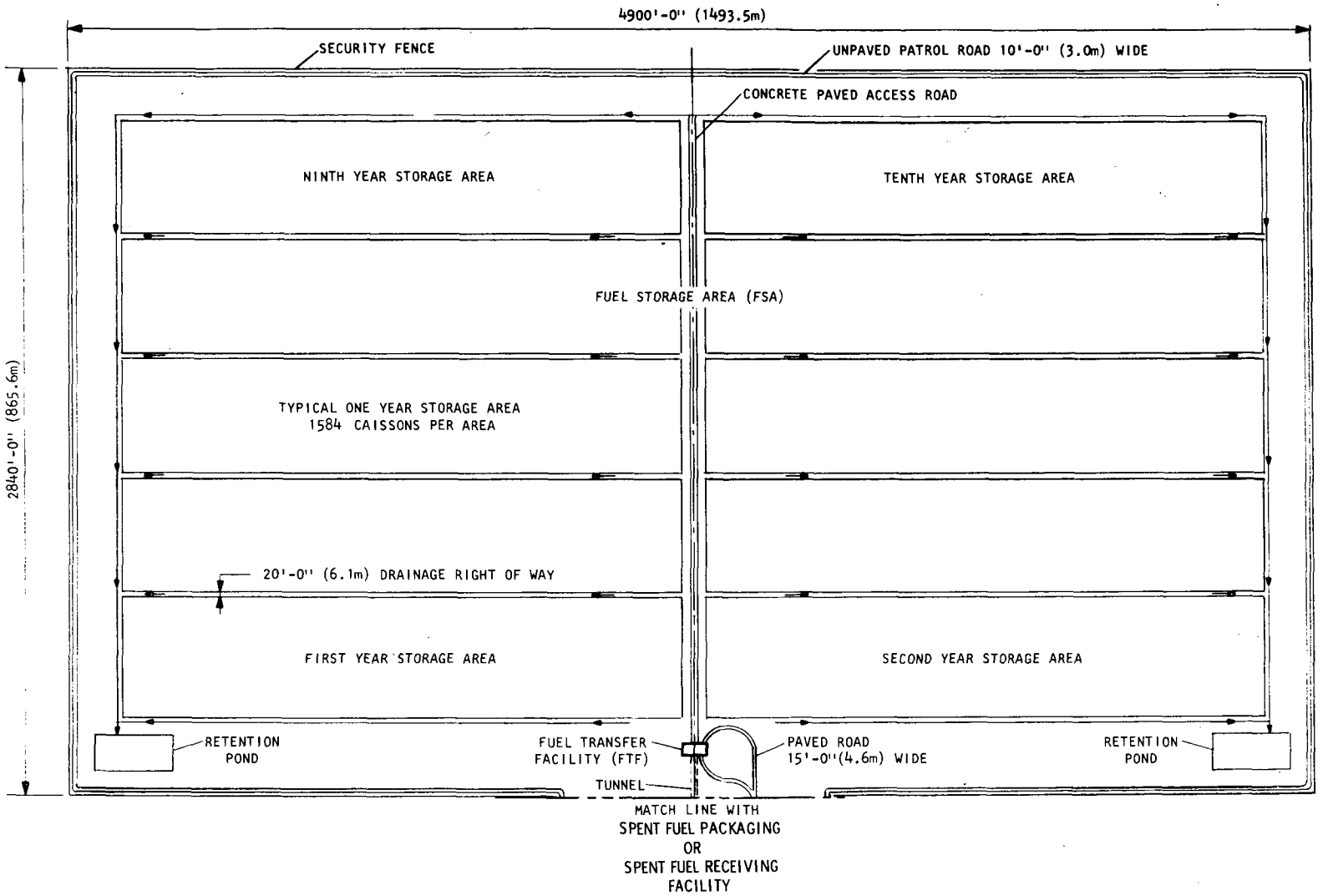

FIGURE 4.3.2-3. Plot Plan of the Dry Caisson Storage Facility for Packaged Spent Fuel

4.3.2.1 Environmental Effects Related to Facility Construction

Some aspects of site preparation and reference facility construction may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effects of construction activities.

Resource Commitments. The dry caisson storage facility will be located on a 405-ha site established for extended spent fuel storage. The dry caisson storage facility will occupy about 130 ha, and the receiving facilities will occupy additional land at the reference site as described in Section 4.3.1.

The facility will be designed and constructed on the same schedule with the reference independent spent fuel receiving facility. The dry caisson storage facility will be built in modules with construction of the initial module concurrent with the receiving facility. Modules will be added yearly thereafter up to a total of ten units with a storage capacity for 15,700 caissons.

Water used during the initial construction period will be approximately 1.5×10^4 m^3. Thereafter, the annual requirements for construction will be 5.9×10^3 m^3. Withdrawal of this amount of water from the R River, described in the reference environment (average flow of 1.0×10^7 m^3/day), is judged to be insignificant with respect to other downstream uses.

Materials committed for construction of the dry caisson storage facility are:

	Initial Construction	Annual Additions for 9 Years
Concrete, m^3	16,000	14,000
Steel, MT	3,200	2,600
Lead, MT	63	
Lumber, m^3	100	10

Energy resources committed for construction are:

	Initial Construction	Annual Additions for 9 Years
Propane, m^3	110	76
Diesel fuel, m^3	1,150	760
Gasoline, m^3	750	490
Electricity		
Peak demand, kW	300	200
Total consumption, kWh	550,000	370,000

Manpower requirements for construction of the dry caisson storage facility will amount to 470 man-yr for initial construction 320 man-yr for annual additions for 9 years. No unusual transportation requirements have been identified.

Physical and Chemical Effects. Nonradioactive pollutants released to the atmosphere during construction will result from combustion of gasoline and diesel fuel in construction equipment, fugitive dust from clearing and excavation, and particulate emissions from concrete batching operations. Air concentrations of carbon monoxide, hydrocarbons, nitrogen oxides, and sulfur

oxides will be below applicable Federal air quality standards. Particulate concentrations on the construction site may exceed the Federal ambient air quality standard of 75 $\mu g/m^3$.[2]

Ecological Effects. Construction will remove permanently (for the life of the plant) about 130 ha from its present use for agriculture and wildlife at the reference site. While this change in land use will eliminate its utility as habitat for wildlife, no significant ecological impacts to the region are expected. Disturbance of animals by fugitive dust, noise, and human activities during construction will be mainly confined to the 130-ha restricted area. Erosion caused by run-off may deposit silt in nearby surface waters unless attention is given to control drainage by proper ditching, grading, and silt catchment. After construction is completed and vegetation is reestablished or surfacing is completed in the disturbed areas, this problem will be reduced.

The dry caisson storage facility will require about 1.5×10^4 m^3 of water for initial construction and 5.9×10^3 m^3/yr for 10 additional years of construction. If, as a worst case, it is assumed that construction could be completed in one year, the water used would constitute less than 0.02% of the recorded minimum low flow of the R River or less than 0.001% of the average river flow. Removal of this volume of water from the R River should have an insignificant impact on the stream biota.

Presumably a common water intake from the R River will supply the construction and operational water needs of the dry caisson storage facility. This intake should be located to minimize any alteration of flow patterns and properly screened to reduce the numbers of aquatic organisms entrained in the water system. Procedures should be required to keep the disturbance of the river bottom to a minimum during intake construction.

The maximum concentrations of particulates, sulfur dioxide, and carbon monoxide will occur within the 130-ha restricted area. Calculated carbon monoxide and hydrocarbon levels are only a small fraction of the existing rural air concentrations near the reference site. Concentrations of the other materials are less than applicable standards. Consequently, no measurable detrimental effects on the terrestrial ecosystem are anticipated.

4.3.2.2 Environmental Effects Related to Facility Operation

Some aspects of facility operation may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effects of operation.

Resource Commitments. No significant amounts of essential materials are anticipated for use at the facility. Table 4.3.2-1 presents the resource requirements for operation of the reference facility.

Process Effluents. The fuel storage area is a passive system; the safe storage of spent fuel does not depend on any operation of mechanical equipment. No releases of radioactive material are postulated except in the case of moderate accidents, which are discussed in Section 4.3.2.3.

TABLE 4.3.2-1. Utilities and Materials Required for Operation of the Dry Caisson Storage Facility

Resource	Average Annual Use
Electricity, kWh	5.2×10^6
Diesel fuel, m^3	1.2×10^2

Nonradioactive effluents released to the biosphere include water from a sanitary sewer system to accommodate a work force of 22 people and a maximum annual release of 7.0×10^8 MJ/yr of decay heat from the fuel when the storage facility is at full capacity.

Physical, Chemical, and Thermal Effects. The microclimatic effect of the dry caisson storage facility was evaluated using a point source model. Neuman,[3] in studying industrial pollutants, states that a point source having a source strength of the entire area source can be used to estimate the temperatures downwind of an area source. This procedure is generally applied to large downwind distances from an area source. However, at intermediate distances the point source approach will produce a conservative estimate (an estimate not likely to be exceeded) of temperature increases at the receptors. Using this point source approach and a Gaussian diffusion model,[4] downwind temperature changes were calculated to increase less than 1°C within 1 km downwind and less than 0.5°C beyond this. The annual release of 7×10^8 MJ/yr of fuel decay heat is not expected to produce any significant thermal effects.

Operational water requirements for the dry caisson storage facility will be only that needed for sanitary purposes by the work force about 3.8×10^3 m^3/yr. This water will be withdrawn from the R River near the reference site and will have an imperceptible effect on other uses of river water.

No hazardous chemicals will be released from the facility.

Radiological Effects. In the absence of radioactive material released during routine operation, no radiological effects are anticipated.

4.3.2.3 Environmental Effects Related to Postulated Accidents

Two accidents are postulated for the dry caisson storage facility that could lead to releases of radioactive material. Scenarios are provided in Section 5.7 of DOE/ET-0028[1] and the accidents are listed below.

Accident Number	Description
	Minor
5.7.34	Flooding of one caisson
5.7.35	Dropped fuel rack in transfer tunnel
	Moderate
5.7.36	Packaged element fails in storage

The packaged element failure in storage (Accident 5.7.36) was judged most severe and will be taken as representative of the set. This accident involves the failure, caused by corrosion,

of a package containing four pressurized water reactor elements. The accident will result in the release of 7 Ci of ^{85}Kr and 2×10^{-5} Ci of ^{129}I over a 1-hr period. The postulated frequency of occurrence is once every 10 years.

The one-year dose and 70-year dose commitment to the maximum individual were calculated and are presented in Table 4.3.2-2. Numerically, the largest dose is less than 1% of the dose the individual would have received from naturally occurring sources during the period.

No severe accidents have been postulated. Non-design basis accidents were not considered.

TABLE 4.3.2-2. 1-Year Dose and 70-Year Dose Commitment to the Maximum Individual Resulting from a Fuel Package Failure Accident at the Dry Caisson Storage Facility (rem)

Pathway	Skin	Total Body	Thyroid	Lung
		1-Year Dose		
Air submersion	1.0×10^{-4}	1.1×10^{-6}	1.1×10^{-6}	1.1×10^{-6}
Inhalation		1.1×10^{-8}	8.9×10^{-6}	7.3×10^{-8}
Total	1.0×10^{-4}	1.1×10^{-6}	1.0×10^{-5}	1.1×10^{-6}
		70-Year Dose		
Air submersion	1.0×10^{-4}	1.1×10^{-6}	1.1×10^{-6}	1.1×10^{-6}
Inhalation		1.3×10^{-8}	1.1×10^{-5}	7.3×10^{-8}
Total	1.0×10^{-4}	1.1×10^{-6}	1.2×10^{-5}	1.1×10^{-6}

Note: The maximum individual is defined as a permanent resident at a location 1600 m southeast of the stack with a time-integrated atmospheric dispersion coefficient (E/Q) of 1.5×10^{-4} sec/m^3.

REFERENCES FOR SECTION 4.3.2

1. Technology for Commercial Radioactive Waste Management, DOE/ET-0028, Department of Energy, Washington, DC, in press.

2. U.S. Congress, Clean Air Act Amendments 1977, Public Law 95-95, U.S. Government Printing Office, Washington, DC, August 1977.

3. J. Neuman, "Turbulent Diffusion of Pollutants from Some Plane Area Sources," Atmospheric Environment 9:785-92, 1975.

4. D. B. Turner, Workbook of Atmospheric Dispersion Estimates, Public Health Service Publication No. 999-AP-26, U.S. Government Printing Office, Washington, DC, 1969.

4.3.3 Water Basin Storage of Packaged Spent Fuel (DOE/ET-0028 Sec. 5.7.5)

The concept of storing packaged spent fuel in a water basin is the same as that for unpackaged spent fuel except that the fuel is placed in a stainless steel canister that provides additional fuel protection, radionuclide containment barriers, and contamination control. The packaged fuel is stored under water in a reinforced concrete pool lined with stainless steel. The water provides shielding for operating personnel and a medium by which the radionuclide decay heat can be removed.

The storage of packaged spent fuel has not been practiced routinely. However, fuel has been overpacked and stored when leaking fuel elements have been detected. The technology is considered to be reasonably well established, based on water basin storage of unpackaged fuel.

Figure 4.3.3-1 shows a simplified operations flow diagram of the water basin storage facility. Packaged spent fuel is transferred from an independent spent fuel receiving facility to a water basin for storing packaged fuel. The transfer is accomplished by directing a basket containing four PWR or nine BWR fuel assemblies through a water-filled canal. The fuel is moved to its storage position in the water basin by a crane. Demineralized water is circulated within the water basin storage building through a heat exchanger, a filter, and an ion exchanger for removal of heat and radioactive contamination. Cooling towers are provided as a secondary cooling water circuit for heat dissipation.

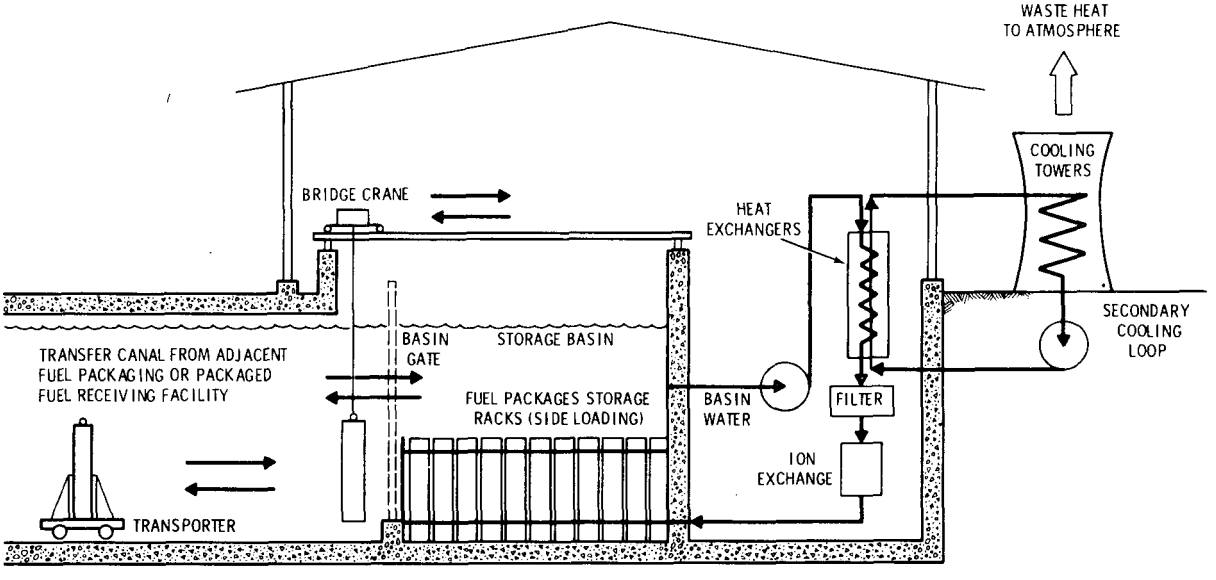

FIGURE 4.3.3-1. Simplified Operations Flow Diagram of the Water Basin Storage Facility for Packaged Spent Fuel

Spent LWR fuel assemblies, packaged in stainless steel containers, are received at a rate of 2000 MTHM/yr. The assumed annual storage rate of spent fuel is 680 PWR baskets containing 2720 PWR fuel assemblies in canisters (of which a maximum of 54 may be overpacked) plus 450 BWR baskets containing 4050 BWR fuel assemblies in canisters (of which a maximum of 81 may be overpacked). Storage basin modules of 2000 MTHM capacity are added as needed up to a total capacity of 20,000 MTHM. In the reference facility it is assumed that these storage modules are constructed at the rate of one per year for ten years.

The water basin storage facility does not use any major chemical processes. It shares common use of the short-term independent spent fuel storage facility or the independent spent fuel receiving facility utilities, services, and support facilities, such as personnel areas, laboratories, health physics, warehousing, shops, and maintenance. The facility includes cooling towers, a control house, the ventilation filter and blower building, and stack. The

water basin storage facility includes a central water canal extending from the fuel transfer facility or independent spent fuel receiving facility. The ten water storage basins are located adjacent to this canal, five on each side. Packaged spent fuel is moved under water from the canal into each storage basin through gateway openings in the canal wall.

Figure 4.3.3-2 shows the typical arrangement of the 2000-MTHM water storage basin and associated facilities. Each basin contains a system of single-tiered, side-entering stainless steel storage racks for 1120 storage baskets. The racks consist of 16 open rows running longitudinally the length of the basin, through which the baskets are moved one at a time. The water basin storage arrangement does not provide transfer aisles. Therefore, retrievability within each of the 16 rows is limited to a first-in, last-out mode. However, rows can be selected on a first-in, first-out basis. Each basin module is covered by an insulated building that houses a crane for handling the storage baskets and the basin water cooling and treating equipment. The cooling tower for each basin is located outside the building and adjacent to the cooling equipment. The water from each basin system is cooled by rejecting heat to the atmosphere using a secondary heat exchanger and a cooling tower.

4.3.3.1 Environmental Effects Related to Facility Construction

Some aspects of site preparation and reference facility construction may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of construction activities.

Resource Commitments. The water basin storage facility for packaged spent fuel will occupy 6.4 ha of the 405-ha site designated for extended storage of spent fuel.

Water used during the initial phase of construction is estimated to be 1.5×10^4 m^3. During construction of Phases 2 through 10, 1.1×10^4 m^3/yr of water will be required for the next 9 years. Withdrawal of this amount of water from the R River, described in the reference environment (with an average flow of 1.0×10^7 m^3/day), is judged to be insignificant with respect to other downstream uses. During the construction period, wells could probably supply the required amount of water without consequence to groundwater supplies.

As discussed in Section 4.3.3, storage modules will be added to the reference water basin storage facility at the rate of one per year for 10 years (Phases 1-10). Materials committed for construction of the water basin storage facility are:

	Phase 1	Phase 2	Phase 3	Phase 4
Concrete, m^3	5300	3400	4200	3400
Steel, MT	1700	1100	1200	1000
Copper, MT	18	14	14	14
Zinc, MT	4.5	4	4	3
Lumber, m^3	470	260	310	260

Resources needed for Phases 5, 7, and 9 are the same as those needed for Phase 3; resources for Phases 6, 8, and 10 are the same as those for Phase 4.

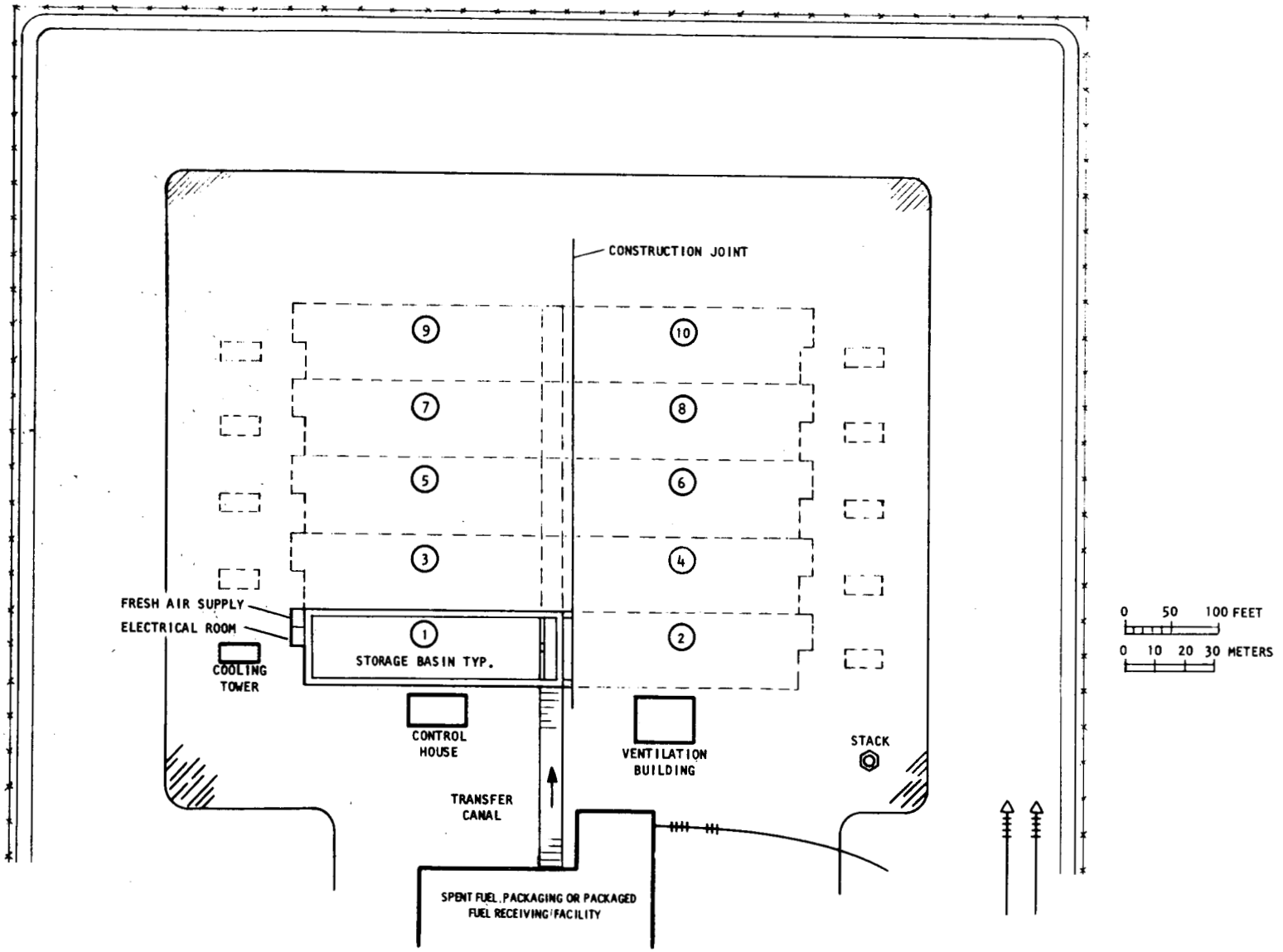

FIGURE 4.3.3-2. Plan View of Water Basin Storage Facility for Packaged Spent Fuel

Energy resources used during construction are:

	Phase 1	Phase 2	Phase 3	Phase 4
Propane, m^3	130	75	100	75
Diesel fuel, m^3	1,325	760	950	760
Gasoline, m^3	850	570	610	530
Electricity				
Peak demand, kW	1,000	600	700	600
Total consumption, kWh	650,000	400,000	450,000	380,000

Resources needed for Phases 5, 7, and 9 are the same as those needed for Phase 3; resources for Phases 6, 8, and 10 are the same as those for Phase 4.

The initial construction phase of the water basin storage facility will be simultaneous with construction of the independent spent fuel receiving facility. Manpower requirements for initial (Phase 1) construction of the facility will amount to 560 man-yr, which will be integrated with labor schedules for the independent spent fuel receiving facility. Manpower requirements for the Phase 2 (second year) addition of one in-line storage module will amount to 350 man-yr. Construction for the Phase 3 (third year) addition of one parallel storage vault module will require 400 man-yr of labor, which will also apply to construction during Phases 5, 7, and 9. Labor requirements for the Phase 4 (fourth year) addition of one in-line storage vault module will amount to 340 man-yr, which will also apply to construction during Phases 6, 8, and 10.

No specific transportation requirements for the water basin storage facility have been identified. No other site-specific requirements have been identified.

Physical and Chemical Effects. Effects on air quality will derive principally from excavation and combustion of fuel used by construction equipment. Although the standard of 75 $\mu g/m^3$[2] for particulates will likely be exceeded on site, no effects from this or from combustion products are expected off site.

Ecological Effects. The water basin storage facility for packaged spent fuel will require about 6.4 ha or less than 2% of the 405-ha area designated for extended storage of spent fuel. Plant and animal communities within the construction area will be disturbed or destroyed. Fugitive dust, surface run-off, and noise may also have an adverse effect on the area adjacent to the construction zone. Surface run-off will be controlled by ditching and shaping of stock piles to limit erosion on sedimentation of nearby surface waters. Impacts to the terrestrial ecosystem will be confined to the construction area and to the adjoining land on site.

Approximately 1.5×10^4 m^3 of water will be required during construction and will be supplied from the R River. Phase 2 through 10 construction water needs will be 1.1×10^4 m^3 for each phase. This withdrawal will constitute less than 1% of the minimum recorded low flow and will not adversely affect the river ecosystem.

4.3.3.2 Environmental Effects Related to Facility Operation

Some aspects of facility operation may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effects of operation.

Resource Commitments. No significant amounts of essential materials are anticipated for use at the water basin storage facility. Resource requirements for operation of the facility are presented in Table 4.3.3-1.

TABLE 4.3.3-1. Utilities and Materials Required for Operation of the Water Basin Storage Facility for Packaged Spent Fuel (maximum at end of fill period)

Resource	Average Annual Use
Electricity, kWh	2.6×10^7
Water, m^3	
Cooling	3.8×10^5
Sanitary	6.1×10^3
Process	1.1×10^4
Steam, MT	2.3×10^4
Coal, MT	2.3×10^3

Process Effluents. The water basin storage facility for packaged spent fuel will produce a maximum of 7×10^8 MJ/yr of heat to be rejected to the atmosphere by a cooling tower. About 5.5×10^4 m^3/yr of water elevated in temperature by about 17°C will be released as blowdown. About 3.2×10^5 m^3/yr of water will be evaporated and 1.5×10^3 m^3/yr of water will occur as drift. No other radioactive or nonradioactive effluents have been identified.

Physical, Chemical, and Thermal Effects. The potential microclimatic effect from operation of the 7×10^8 MJ/yr cooling tower was evaluated using a point source model; the temperature elevation was less than 1°C, which is not considered a significant environmental effect of the water basin storage facility.

There will be no direct releases of nonradioactive liquid or solid wastes from the facility to the ground. All liquid and solid waste disposal for the process is part of the overall operation of the independent spent fuel storage facility.

Radiological Effects. There are no identifiable radioactive source terms for normal operation of this facility.

Ecological Effects. Approximately 7×10^8 MJ/yr of waste heat will be released to the atmosphere from the water basin storage facility via the cooling tower. The estimated increase in air temperature from this rejected heat will be less than 1°C at 1 km downwind from the cooling towers and less than 0.5°C at distances greater than 1 km. These temperature increases will not produce a significant effect on the environment.

A total water volume of approximately 8×10^4 m^3 will be needed to fill the the ten pools. This water will be withdrawn from the R River near the reference site and will constitute less than 1% of the minimum river flow. Less than 1% of the minimum river flow will be required to fill all ten pools during a 24-hr period. However, because the pools will not all be built and put into use simultaneously, there will be no need to fill the pools in a period as short as 24 hr. No ecological impacts will result from this withdrawal of surface water.

Approximately 3.8×10^5 m^3 of water will be needed annually to make up for water loss through evaporation, drift, and blowdown in the cooling towers. This represents about 2% of the minimum river flow and less than 0.1% of the average flow. Removal of this volume of water from the R River is not expected to be detrimental to the environment.

4.3.3.3 Environmental Effects Related to Postulated Accidents

Several accidents have been identified for the water basin storage facility for packaged spent fuel that could lead to releases of radioactive material. The accident scenarios are provided in DOE/ET-0028[1] and the accidents are as follows:

Accident Number	Description
	Minor
5.7.21	Loss of normal electrical power
5.7.22	Loss of normal cooling water supply
5.7.23	Reduction of normal cooling water supply
5.7.24	Ventilation system failure
5.7.25	Leak in water treatment system
5.7.26	Dropped fuel rack in transfer tunnel
	Severe
5.7.27	Design basis tornado
5.7.28	Criticality event
5.7.29	Loss of cooling water supply

No release of radioactive material was postulated for the minor accidents. No moderate accidents were postulated. Accident 5.7.28 is considered the worst-case minor accident.

For the severe accident (criticality event) it is assumed that a criticality event equal to 10^{19} fissions releases material to facility filters over a period of 15 min. Approximately 200 g of actinides plus the material listed in Table 4.3.3-2 are thus released to the biosphere.

The 70-year dose commitment to the maximum individual was calculated and is presented in Table 4.3.3-3. The largest dose, the 70-yr dose commitment was 50% higher than the nominal thyroid dose from naturally occurring sources.

TABLE 4.3.3-2. Radionuclides Released to the Biosphere from a Criticality Accident in the Water Basin Storage Facility for Packaged Spent Fuel

Radionuclide	Release, Ci
^{85}Kr	1.6×10^{-3}
^{87}Kr	1.0×10^{3}
^{88}Kr	6.6×10^{2}
^{89}Kr	4.1×10^{4}
^{129}I	4.3×10^{-10}
^{131}I	1.8
^{133}I	3.5×10^{1}
^{134}I	4.8×10^{2}
^{135}I	1.2×10^{2}
^{138}Xe	1.1×10^{4}

TABLE 4.3.3-3. 70-Year Dose Commitment to the Maximum Individual from a Severe Accident Involving a Criticality Event at the Water Basin Storage Facility for Packaged Spent Fuel (rem)

Pathway	Skin	Total Body	Bone	Lung	Thyroid
Air submersion	7.5×10^{-2}	4.9×10^{-2}	4.9×10^{-2}	4.9×10^{-2}	4.9×10^{-2}
Inhalation		3.0×10^{-4}	9.9×10^{-5}	3.2×10^{-3}	1.0×10^{-1}
Total	7.5×10^{-2}	4.9×10^{-2}	4.9×10^{-2}	5.2×10^{-2}	1.5×10^{-1}

Note: The maximum individual is defined as a permanent resident at a location 1600 m southeast of the stack with a time-integrated atmospheric dispersion coefficient (E/Q) of 1.5×10^{-4} sec/m^3.

REFERENCES FOR SECTION 4.3.3

1. Technology for Commercial Radioactive Waste Management, DOE/ET-0028, Department of Energy, Washington, DC, in press.

2. U.S. Congress, Clean Air Act Amendments 1977, Public Law 95-95, U.S. Government Printing Office, Washington, DC, August 1977.

4.3.4 Air-Cooled Vault Storage of Packaged Spent Fuel (DOE/ET-0028 Sec. 5.7.6)

In the air-cooled vault storage concept, spent fuel assemblies are packaged in carbon steel canisters and placed vertically in carbon steel sleeves. The sleeves are part of near-grade structures containing storage cells covered with concrete shielding plugs. Cooling air enters the sleeves through side inlets in the structure and a bottom distribution plenum. The air passes upward through annuli formed by the storage units and sleeves. This concept uses the decay heat of the waste and the engineered design of the vault to induce air flow by natural draft to maintain permissible temperatures. The heated air is discharged through a short exhaust port to the atmosphere. The structure will provide all requirements for biological shielding and protection from natural phenomena. To date, this concept has not been used for

fuel storage, but the technology is based on established engineering practice and related experience. This concept is illustrated in Figure 4.3.4-1.

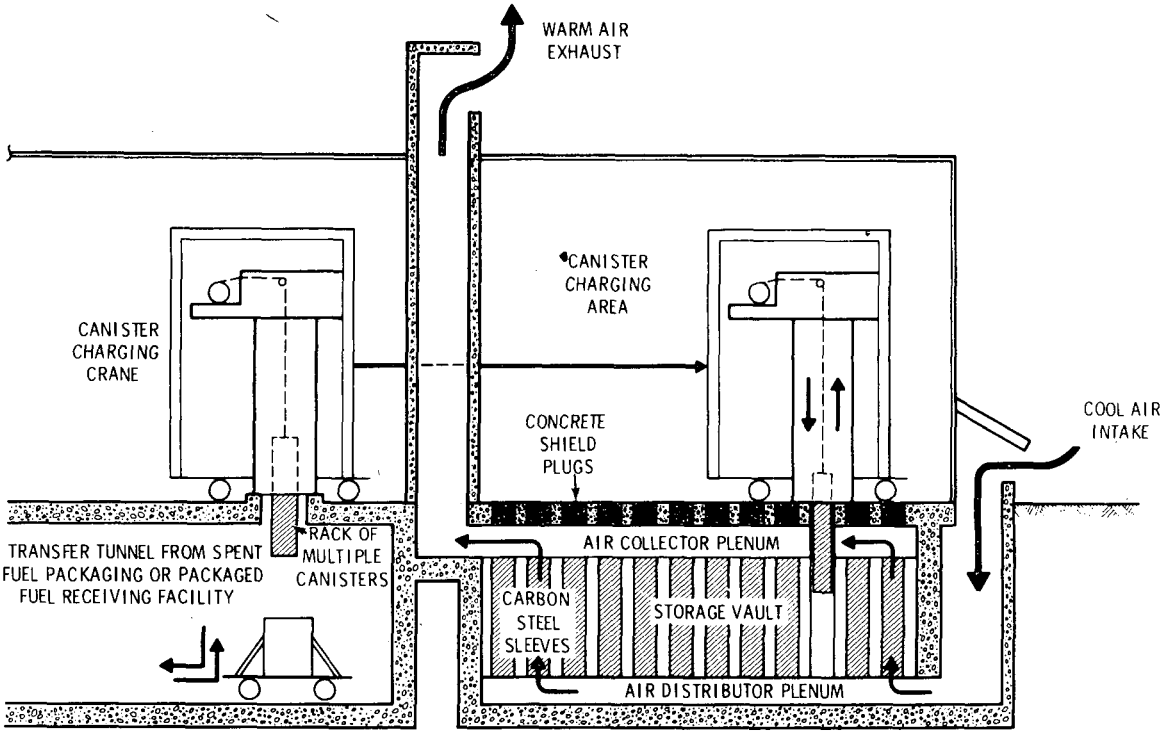

FIGURE 4.3.4-1. Operations Flowsheet for Air-Cooled Vault Storage of Packaged Spent Fuel

The reference facility receives packaged spent LWR fuel assemblies in racks of four PWR or nine BWR fuel assemblies. These assemblies are transported through an air tunnel on a remotely operated track-mounted cart from an adjacent independent spent fuel receiving facility. The fuel is picked up in a bottom loading cask supported by a self-propelled crane. The crane and cask are moved to an empty storage location where the packaged spent fuel is lowered into the carbon steel storage sleeves. A shielding plug is inserted after the spent fuel is in place.

The storage vaults are modular units each of which has a storage capacity of 2000 MTHM. It is assumed that additional vaults will be built at the rate of one per year for ten years for a total capacity of 20,000 MTHM. A system is provided to monitor the exit air for helium and fission products. A standby forced-air cooling system with provision to filter the exhaust air is also provided in the event airborne radioactive material is detected. The vault design provides for ready retrieval of the fuel packages at any time. Packaged fuel assemblies are received from the adjacent facility at a maximum rate of 2000 MTHM/yr. The assumed annual storage rate of spent fuel is 2690 PWR fuel assemblies and 4030 BWR fuel assemblies packaged in canisters with a maximum of 54 PWR and 81 BWR failed assemblies doubly contained in canisters and overpacks.

The air-cooled vault storage facility includes the transfer tunnel, up to ten 2000-MTHM storage vaults, and one or two emergency sand filters. Figure 4.3.4-2 shows the arrangement of the storage vault modules. The transfer air tunnel and the air-cooled storage vault are massive reinforced concrete structures constructed to meet design basis earthquake and tornado standards and provide biological shielding from the radiation of the spent fuel. The top surface of the main storage vault is about 0.3 m above grade with the remainder of the vault buried. Spent fuel packages are stored vertically and are supported from the bottom.

4.3.4.1 Environmental Effects Related to Facility Construction

Some aspects of site preparation and reference facility construction may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of construction activities.

Resource Commitments. The air-cooled vault storage facility will occupy 13 ha of the 405-ha site for extended storage of spent fuel. Water use for the 10 phases of construction is 2.0×10^5 m^3.

Materials committed for construction of the air-cooled vault storage facility are:

	Phase 1	Phase 2	Phase 6	Phase 7
Concrete, m^3	17,500	13,800	14,500	10,700
All steel, MT	4,600	3,900	4,100	3,400
Copper, MT	7	2	2	2
Lead, MT	10			
Lumber, m^3	1,200	900	950	700

Energy resources used during construction are:

	Phase 1	Phase 2	Phase 6	Phase 7
Propane, m^3	208	170	170	140
Diesel fuel, m^3	2,080	1,700	1,700	1,400
Gasoline, m^3	1,400	1,140	1,140	930
Electricity				
Peak demand, kW	800	700	700	550
Total consumption, kWh	1,050,000	850,000	860,000	700,000

Resources used during Phases 3, 4, and 5 are the same as those needed during Phase 2, and resources for Phases 8, 9, and 10 are the same as those for Phase 7.

Manpower requirements for initial (Phase 1) construction of the air-cooled vault storage facility will amount to 920 man-yr. Manpower requirements estimated for the yearly addition of one storage vault module will amount to 740 and 620 man-yr respectively for Phases 2 through 5 and 6 through 10, respectively. During Phase 6, the addition of one sand filter and blower installation will amount to 140 man-yr.

No specific transportation requirements have been identified for this facility. No site-specific requirements have been identified.

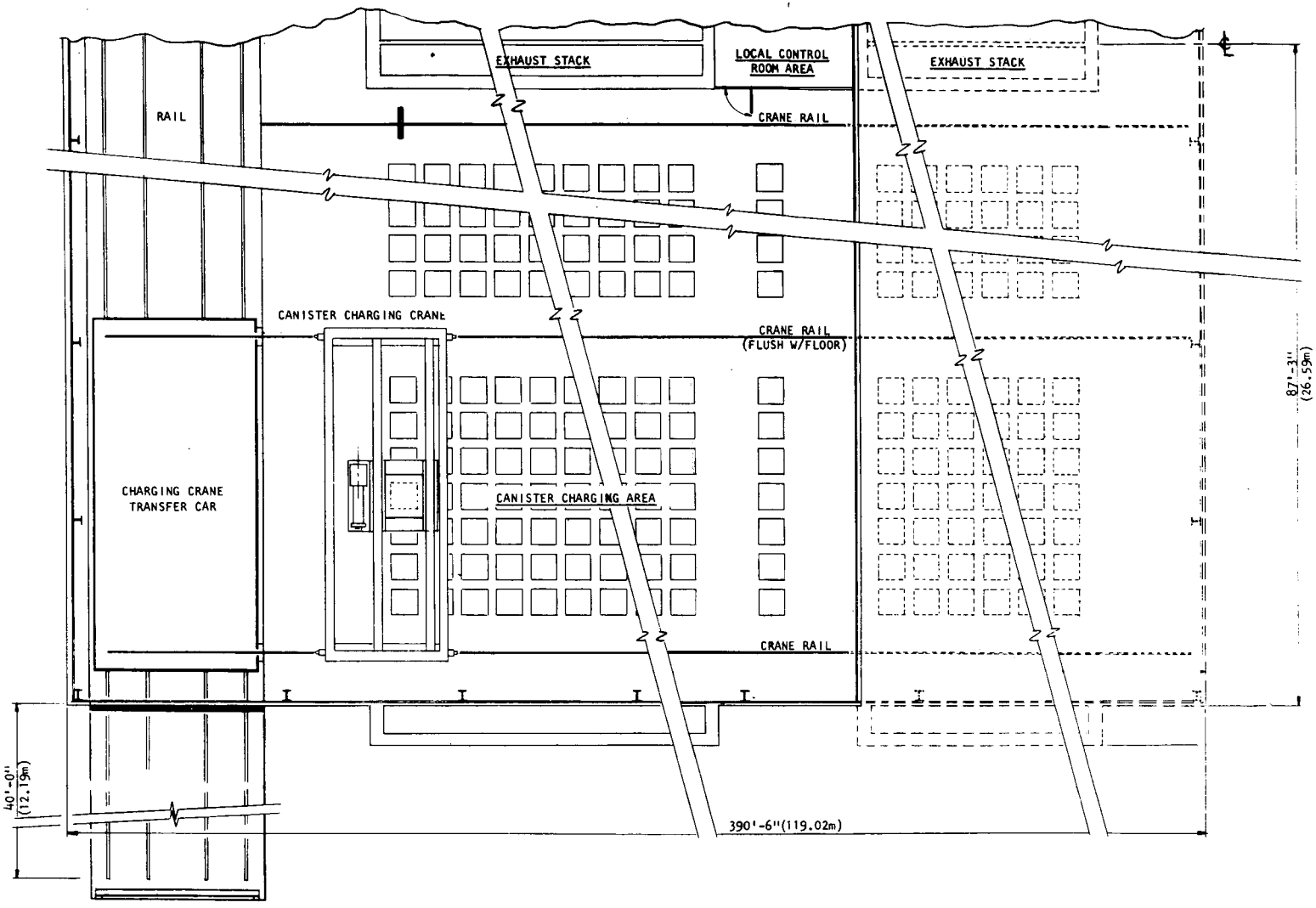

FIGURE 4.3.4-2. Plan View of Air-Cooled Vault Storage Facility for Packaged Spent Fuel

Physical and Chemical Effects. Effects on air quality will derive principally from excavation and from combustion of fuel used by construction equipment. Although the standard for particulates of 75 $\mu g/m^3$(2) will likely be exceeded on site, no effects from this or from combustion products are expected off site.

Ecological Effects. The air-cooled vault storage facility will be located adjacent to the independent spent fuel receiving facility. Construction of the facility's ultimate storage capacity of 20,000 MTHM will be accomplished by the initial construction of one 2000-MTHM module and the yearly addition of a similar module for nine years.

Approximately 13 ha of land will be required for the air-cooled vault storage facility and will be included in the land commitments of the reference independent spent fuel receiving facility. The ecological effects on the local terrestrial ecosystem will include destruction of vegetation and animal habitat and the disturbance of nearby animals from noise, dust, and human activity.

During the initial (Phase 1) construction period, about 2.5×10^4 m^3 of water will be used. For each of Phases 2 through 5 about 2.0×10^4 m^3 of water will be used. Phase 4, which includes the construction of a second sand filter, will require 2.1×10^4 m^3 of water. This water will be supplied from the R River near the reference site. The maximum water use will occur during construction of the first module and will be less than 1.0×10^{-4} of the minimum 40-year recorded low flow of the R River.

The overall ecological impacts of facility construction are judged to be insignificant.

4.3.4.2 Environmental Effects Related to Facility Operation

Some aspects relating to facility operation may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effects of operation.

Resource Commitments. Resources required for normal operation of the air-cooled vault storage facility are shown in Table 4.3.4-1.

TABLE 4.3.4-1. Resources Required During Operation of the Air-Cooled Vault Storage Facility for Packaged Spent Fuel

Resource	Average Annual Use
Electricity, kWh	5.2×10^6
Gasoline, m^3	4.0×10^1
Manpower, man-yr	2.3×10^1

Process Effluents. No radioactive effluents are associated with normal facility operation.

The air-cooled vault storage facility will produce a maximum of 7×10^8 MJ/yr of waste heat, which will be discharged directly to the atmosphere.

Physical, Chemical, and Thermal Effects. The microclimatic effects of this storage facility were evaluated using a point source model. The temperature was elevated less than 1°C within 1 km downwind and less than 0.5°C beyond 1 km. This effect of the air-cooled vault facility is not considered to be significant.

Radiological Effects. No airborne, liquid, or solid radioactive effluents are produced during normal facility operation. Therefore, no radiological effects will result.

Ecological Effects. The effects to the terrestrial and aquatic environment by the facility will be negligible. A maximum of 7×10^8 MJ/yr of waste heat will be discharged directly to the atmosphere. At a distance of 1 km downwind, the temperature will be elevated less than 1°C. The only water required for the facility is that for normal personnel consumption. No process effluents will be discharged to the aquatic environment.

4.3.4.3 Environmental Effects Related to Postulated Accidents

Several accidents have been postulated for the air-cooled vault storage facility. Scenarios are provided in DOE/ET-0028[1] and the accidents are as follows:

Accident Number	Description
	Minor
5.7.30	Loss of cooling air flow
5.7.31	Flooding of storage vault
5.7.32	Dropped fuel rack in transfer tunnel
	Moderate
5.7.33	Packaged element fails in storage

None of the minor accident scenarios described for the air-cooled vault storage facility will result in any releases of radioactive or nonradioactive material to the biosphere.

The failure of a packaged element in storage (Accident 5.7.33) was judged most severe and is taken as representative of the set. This accident involves the failure, caused by corrosion, of a package containing four PWR fuel elements. The accident results in the release of 7 Ci of ^{85}Kr and 2×10^5 Ci of ^{129}I over a period of 1 hr. The postulated frequency of occurrence is once every ten years.

The one-year dose and 70-year dose commitment to the maximum individual were calculated and are presented in Table 4.3.4-2.

Numerically, the largest dose is less than 1% of the dose the individual would have received from naturally occurring sources during the period.

TABLE 4.3.4-2. 1-Year Dose and 70-Year Dose Commitments to the Maximum Individual Resulting from a Packaged Fuel Failure Accident at the Air-Cooled Vault Storage Facility (rem)

Pathway	Skin	Total Body	Thyroid	Lung
		1-Year Dose		
Air submersion	1.0×10^{-4}	1.1×10^{-6}	1.1×10^{-6}	1.1×10^{-6}
Inhalation		1.1×10^{-8}	8.9×10^{-6}	7.3×10^{-8}
Total	1.0×10^{-4}	1.1×10^{-6}	1.0×10^{-5}	1.1×10^{-6}
		70-Year Dose		
Air submersion	1.0×10^{-4}	1.1×10^{-6}	1.1×10^{-6}	1.1×10^{-6}
Inhalation		1.3×10^{-8}	1.1×10^{-5}	7.3×10^{-8}
Total	1.0×10^{-4}	1.1×10^{-6}	1.2×10^{-5}	1.1×10^{-6}

Note: The maximum individual is defined as a permanent resident at a location 1600 m southeast of the stack with a time-integrated atmospheric dispersion coefficient (E/Q) of 1.5×10^{-4} sec/m^3.

REFERENCES FOR SECTION 4.3.4

1. Technology for Commercial Radioactive Waste Management, DOE/ET-0028, Department of Energy, Washington, DC, in press.

2. U.S. Congress, Clean Air Act Amendments 1977, Public Law 95-95, U.S. Government Printing Office, Washington, DC, August 1977.

4.3.5 Surface Cask Storage of Packaged Spent Fuel (DOE/ET-0028 Sec. 5.7.8)

In the reference surface cask storage concept, spent fuel assemblies in carbon steel canisters are placed in vertical concrete radiation shields located outdoors on concrete pads. Heat is removed from the casks by natural convective air flow through the annulus between the cask and the radiation shield. The storage units furnish both radiation shielding and confinement of waste. To date the concept has not been used for storage of spent reactor fuels or high-level waste, but the concept is a simple extension of existing technology. A similar concept is being used in Canada to store reactor fuels. The major difference between the concepts is that in the Canadian concept the heat generated from the fuel is conducted through the concrete shield instead of being removed by air convection.

The operations in the surface cask storage facility consist of receiving the packaged fuel, inserting the packaged fuel in a storage cask assembly, transporting the cask assembly, placing the assembly in the storage area, and receiving and inspecting new storage casks. Monitoring capability may be provided on individual storage units to detect radionuclide leakage and also to detect any air port pluggage as exhibited by an increase in exit air temperature. Automatic surveillance instruments in the storage area will be monitored from a central location. Should radionuclides escape from a storage unit, the storage assembly is returned to the packaging facility for inspection and repair or replacement as necessary. Figure 4.3.5-1 shows an operations flow diagram of the surface cask storage facility.

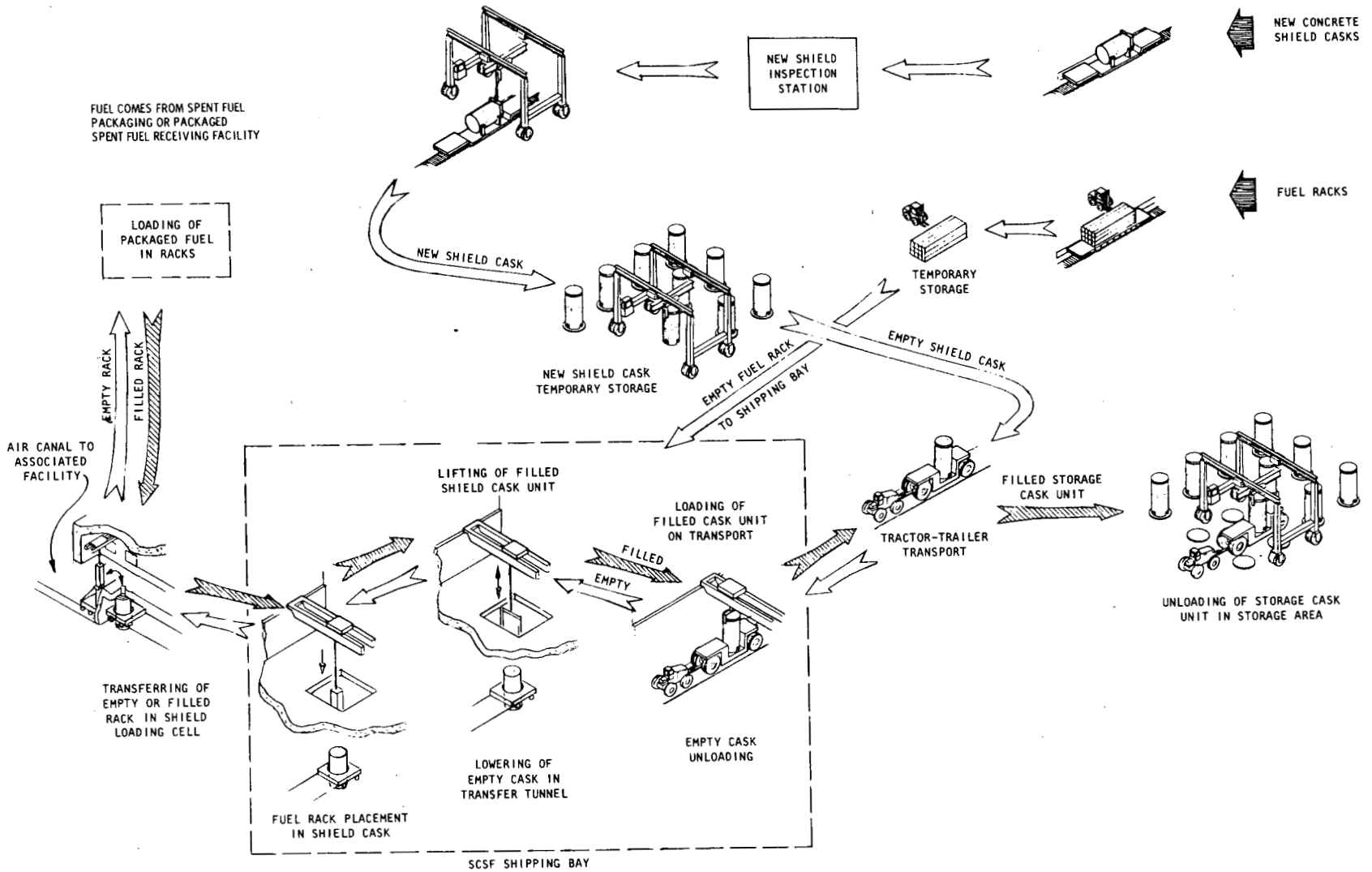

FIGURE 4.3.5-1. Operations Flow Diagram of the Surface Cask Storage Facility for Packaged Spent Fuel

The surface cask storage facility is capable of receiving the packaged fuel elements from the associated packaging or receiving facility at a rate of 2000 MTHM/yr (2690 PWR fuel assemblies and 4030 BWR fuel assemblies); it has the capacity to store a total of 20,000 MTHM of spent fuel. The storage facility is designed to handle storage cask units about 3.3 m in diameter and 7.6 m high. Each unit provides a storage envelope about 1 m in diameter by 5 m high and contains either four PWR or nine BWR fuel assemblies (1.7 MTHM). Figure 4.3.5-2 illustrates the detail of a surface storage cask. The initial storage area provides for the storage of 1120 units and has provisions for incremental expansion of the storage area up to the total of 11,200 storage units. The storage area is subdivided into 20 lots which will accommodate 560 storage units per lot.

The building for the loading and assembly of storage casks houses the storage cask loading cell, the cask transfer tunnel, operating and control room, and the shipping bay. Except for the shipping bay, all functional areas are within a reinforced concrete structure. The storage cask receiving area provides a rail spur, a storage cask receiving and inspection station, and an interim storage area for a 30-day supply of new storage casks and fuel rack supplies. The inspection station is a structural-steel-framed building with both ends opened to allow railcars to pass through. The casks are unloaded by the yard gantry crane. Figure 4.3.5-3 is a plot plan showing the general site arrangement of the storage cask loading and assembly building, the storage cask receiving area, and the storage area.

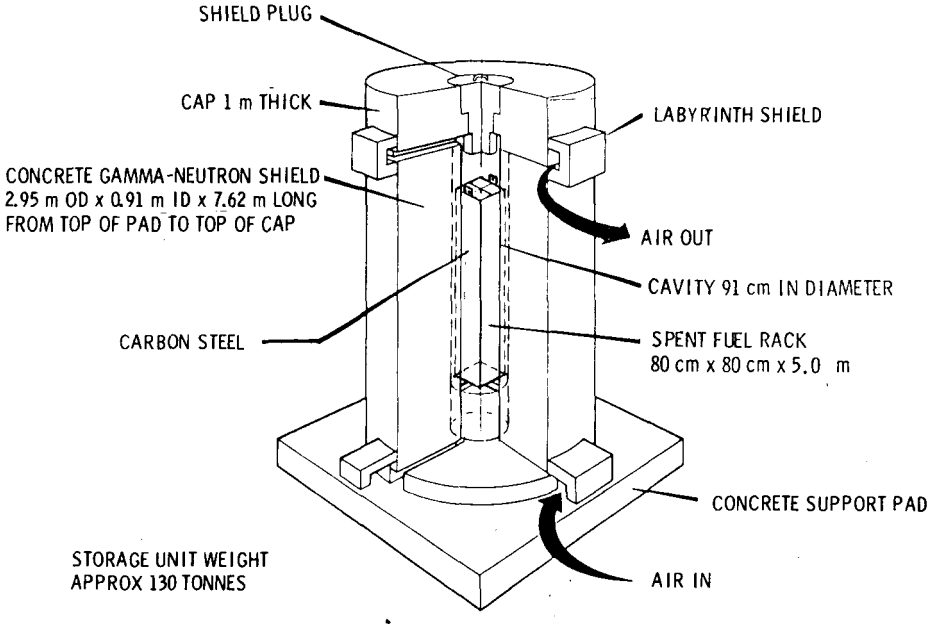

FIGURE 4.3.5-2. Storage Unit Used in the Surface Cask Storage Facility for Spent Fuel

The storage system is completely passive. The heat generated from the fuel is conducted and radiated to the air flow channel between the packaged fuel and shield. The heat is then transferred to the air flowing through the channel. The natural convection air flow through

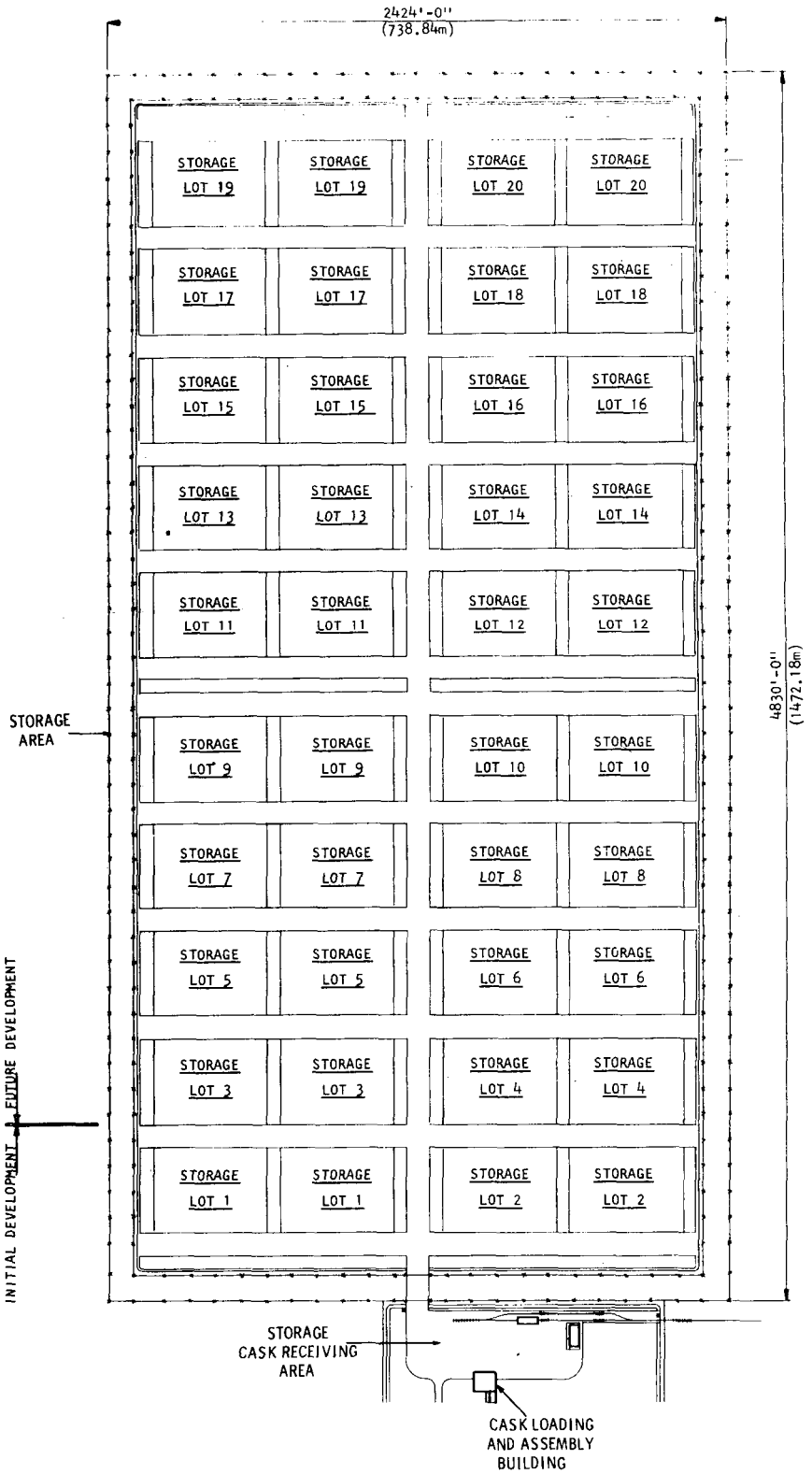

FIGURE 4.3.5-3. Plot Plan of the Surface Cask Storage Facility for Packaged Spent Fuel

channel is induced by heating it in the channel, which produces a chimney effect. Radiation is prevented from streaming through the inlet and exit air ports through the use of labyrinth air channels. Under steady conditions, a filled storage yard generates 7×10^8 MJ/yr of radionuclide decay heat.

4.3.5.1 Environmental Effects Related to Facility Construction

Some aspects of site preparation and reference facility construction may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effects of construction activities.

Resource Commitments. The surface cask storage facility is located on a 405-ha site for extended storage of spent fuel. The storage facility will occupy about 100 ha.

Water used during the initial construction period will be approximately 1.4×10^4 m^3. Thereafter, the annual requirements for construction over a ten-year period will be 7.5×10^3 m^3. Withdrawal of this amount of water from the R River, described in the reference environment (average flow of 1.0×10^7 m^3/day), is judged to be insignificant with respect to other downstream uses.

Materials committed for construction of the surface cask storage facility are:

	Initial Construction	Annual Additions (for 9 years)
Concrete, m^3	4800	400
Steel, MT	1200	180
Copper, MT	4.5	4.5
Lumber, m^3	200	12

Energy resources committed for construction are:

	Initial Construction	Annual Additions (for 9 years)
Propane, m^3	130	75
Diesel fuel, m^3	1,300	720
Gasoline, m^3	870	490
Electricity		
Peak demand, kW	350	570
Total consumption, kWh	675,000	360,000

Manpower requirements for construction of the surface cask storage facility will amount to 590 man-yr for initial construction and 320 man-yr for annual additions for nine years.

No unusual transportation requirements have been identified.

Physical and Chemical Effects. Nonradioactive pollutants released to the atmosphere during construction will result from combustion of gasoline and diesel fuel in construction equipment, fugitive dust from clearing and excavation, and particulate emissions from concrete batching operations. Air concentrations of carbon monoxide, hydrocarbons, nitrogen oxides, and sulfur oxides will be below applicable Federal air quality standards. However, particulate

concentrations on the construction site may exceed the Federal ambient air quality standard of 75 $\mu g/m^3$.[2] Particulate concentrations are not expected to exceed this standard off site.

Ecological Effects. Construction will remove permanently (for the life of the plant) about 100 ha from its present use for agriculture and wildlife at the reference site. While this change in land use will eliminate its utility as habitat for wildlife, no significant ecological impacts to the region are expected. Disturbance of animals from fugitive dust, noise, and human activities during construction will be mainly confined to the 100-ha restricted area. Erosion caused by run-off may deposit silt in nearby surface waters unless attention is given to control drainage by proper ditching, grading, and silt catchment. After construction is completed and vegetation is reestablished or surfacing is completed in the disturbed areas, this problem will be reduced.

The surface cask storage facility will require about 1.4×10^4 m^3 of water for initial construction and 7.5×10^3 m^3/yr for ten years of additional construction. If, as a worst case, it is assumed that construction could be completed in only 1 year, the water use would constitute less than 0.02% of the recorded minimum low flow of the R River or less than 0.001% of the average river flow. Removal of this volume of water from the R River should have an insignificant impact on the stream biota.

A common water intake from the R River will probably supply the construction and operational water needs of the surface cask storage facility. This intake should be located to minimize any alteration of flow patterns and properly screened to reduce the numbers of aquatic organisms entrained in the water system. Procedures will be required to keep the disturbance of the river bottom to a minimum during intake construction.

The maximum concentrations of particulates, sulfur dioxide, and carbon monoxide will occur within the 100-ha restricted area. Calculated carbon monoxide and hydrocarbon levels constitute only a small fraction of the existing rural air concentrations near the reference site. Concentrations of the other materials are within acceptable standards. Consequently, no measurable detrimental effects on the terrestrial ecosystem are anticipated.

4.3.5.2 Environmental Effects Related to Facility Operation

Some of the factors related to facility operation may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effects of operation.

Resource Commitments. No significant amounts of essential resources are anticipated for use during operation at the surface cask storage facility. Table 4.3.5-1 gives the materials required for operation of the facility.

Process Effluents. The fuel storage area is a passive system; the safe storage of fuel does not depend on any operation of mechanical equipment. No releases of radioactive material are postulated except in the case of moderate accidents, which are discussed in Section 4.3.5.3.

Nonradioactive effluents released to the biosphere include a maximum of 7.0×10^8 MJ/yr of fuel decay heat when the storage facility is operating at capacity.

TABLE 4.3.5-1. Utilities and Materials Required for Operation of the Surface Cask Storage Facility for Packaged Spent Fuel

Resource	Average Annual Use
Electricity, kWh	5.2×10^6
Gasoline, m^3	6.0×10^1
Manpower	6.0×10^1

Physical, Chemical, and Thermal Effects. The release of 7×10^8 MJ/yr of fuel decay heat is not expected to produce any significant thermal effects.

No hazardous chemicals will be released from the facility.

Radiological Effects. No radioactive material will be released during normal operation of the surface cask storage facility; therefore, no radiological effects are expected.

4.3.5.3 Environmental Effects Related to Postulated Accidents

Two minor accidents are postulated for the surface cask storage facility. Scenarios are provided in DOE/ET-0028[1] and the accidents are as follows:

Accident Number	Description
	Minor
5.7.37	Loss of cooling air flow
5.7.38	Filled fuel rack dropped in transfer tunnel
	Moderate
5.7.39	Packaged fuel element fails in storage

The packaged fuel element failure in storage (Accident 5.7.39) was judged most severe and will be taken as representative of the set. This accident involves the failure, caused by corrosion, of a package containing four PWR fuel elements. The accident will result in the release of 7 Ci of ^{85}Kr and 2×10^{-5} Ci of ^{129}I over a period of 1 hr. The postulated frequency of occurrence is once every ten years.

The 1-year dose and 70-year dose commitment to the maximum individual were calculated and are presented in Table 4.3.5-2.

Numerically, the largest dose is less than 1% of the dose the individual would have received from naturally occurring sources during the period.

No severe accidents have been postulated. Non-design basis accidents were not considered.

TABLE 4.3.5-2. 1-Year Dose and 70-Year Dose Commitment to the Maximum Individual Resulting from a Packaged Fuel Element Failure at the Surface Cask Storage Facility for Packaged Spent Fuel (rem)

Pathway	Skin	Total Body	Thyroid	Lung
		1-Year Dose		
Air submersion	1.0×10^{-4}	1.1×10^{-6}	1.1×10^{-6}	1.1×10^{-6}
Inhalation		1.1×10^{-8}	8.9×10^{-6}	7.3×10^{-8}
Total	1.0×10^{-4}	1.1×10^{-6}	1.0×10^{-5}	1.1×10^{-6}
		70-Year Dose		
Air submersion	1.0×10^{-4}	1.1×10^{-6}	1.1×10^{-6}	1.1×10^{-6}
Inhalation		1.3×10^{-8}	1.1×10^{-5}	7.3×10^{-8}
Total	1.0×10^{-4}	1.1×10^{-6}	1.2×10^{-5}	1.1×10^{-6}

Note: The maximum individual is defined as a permanent resident at a location 1600 m southeast of the stack with a time-integrated atmospheric dispersion coefficient (E/Q) of 1.5×10^{-4} sec/m^3.

REFERENCES FOR SECTION 4.3.5

1. Technology for Commercial Radioactive Waste Management, DOE/ET-0028, Department of Energy, Washington, DC, in press.

2. U.S. Congress, Clean Air Act Amendments 1977, Public Law 95-95, U.S. Government Printing Office, Washington, DC, August 1977.

4.3.6 Socioeconomic Impacts of Construction and Operation of Extended Storage Facilities for Spent Fuel

For this impact analysis, the reference facilities site consists of a water basin storage facility for storage of spent fuel up to 6 1/2 years, an adjoining spent fuel packaging facility, and a colocated dry caisson independent spent fuel storage facility. Extended storage of spent fuel, followed by the decision to isolate the spent fuel in the year 2000 within deep geologic repositories is referred to as the deferred isolation fuel cycle.

Socioeconomic impacts associated with extended storage of spent fuel depend largely on the numbers of persons who move into the county in which the reference facility will be located. To determine socioeconomic impacts, the size of the local population influx was forecasted, and estimates of the need for local social services were determined. Specific economic impacts attributable to the development of the deferred isolation cycle facilities will not be treated here because they are too dependent on local site characteristics to allow for generalization.

Employment levels for construction and operation of the reference facility for the deferred isolation cycle are 1690 and 361 persons, respectively. Since impacts are region specific, this analysis addresses single facility components associated with this fuel cycle. In addition, the analysis assumes a specified time frame for the construction and operation of this facility.

The socioeconomic impacts presented in this analysis also depend on site characteristics and the assumptions used in the forecasting model (Appendix C). Site characteristics that are especially important in influencing the size of the impacts forecasted include the availability of a local labor force having the required skills, secondary employment, proximity to a metropolitan area, and demographic diversity (e.g., population size and degree of urbanization) of counties in the commuting region. An additional factor in the generation of impacts is the time pattern of project-associated population change. For example, a large labor force buildup followed closely by rapidly declining project employment demand could cause serious economic and social disruptions near the site and elsewhere within the commuting region.

Impacts are estimated for three reference sites identified as Southeast, Midwest, and Southwest. These areas were chosen because siting of facilities in these regions is plausible, and they differ substantially in demographic characteristics, thus providing a reasonable range of socioeconomic impacts. The existing populations in the reference sites are forecasted by the socioeconomic model described in Appendix C. The model accounts for various factors that can affect the population at given times.

Socioeconomic impacts are presented in terms of an expected level of impact as well as a maximum level of impact. The expected impact condition is based on the most likely value of the model assumptions; the maximum impact condition places an extreme but credible value on the model assumptions. Table 4.3.6-1 presents estimates of the cumulative project-related in-migrants for the facilities for the three reference sites over time. The forecasted values include primary and secondary employment and associated household dependents. All are in-migrants, since impacts are assumed to be generated primarily by new in-migrants. In time, some of the persons who separate from the facility will stay in the site county and some will leave. (Those

TABLE 4.3.6-1. Population Forecasts for the Extended Fuel Storage System (persons)

Site	1980	1985	2000	2015
		Expected Impact Condition		
Southeast	326 (1.5%)	322 (1.4%)	377 (1.4%)	420 (1.4%)
Midwest	100 (0.2%)	613 (0.8%)	719 (0.8%)	911 (0.8%)
Southwest	5333 (10.8%)	3617 (7.3%)	4350 (7.9%)	4712 (7.9%)
		Maximum Impact Condition		
Southeast	4132 (6.3%)	3642 (13.6%)	4368 (14.3%)	4725 (14.2%)
Midwest	1576 (2.5%)	2292 (3.1%)	2712 (2.9%)	3057 (3.0%)
Southwest	7927 (15.2%)	5779 (11.1%)	6956 (12.1%)	7513 (12.1%)

Note: Percentages reflect the size of the in-migrant group relative to the baseline population.

who leave are no longer included in the forecasted values.) Thus, not all the forecasted populations are actually working on or directly associated with the project at each time period. Nevertheless, the presence of each of these persons was determined by the existence of the project, and they would not likely be present if the project had not occurred. The percentages associated with each population in these tables reflect the size of the in-migrant group relative to the baseline population in the respective sites. Since these baseline populations vary by site, the relative impact of a similar in-migrant group can vary greatly across sites.

The expected socioeconomic impacts (Table 4.3.6-1) associated with construction and operation of facilities for the extended fuel storage system indicate that the total numbers of forecasted new in-migrants in the Midwest are less than 1% of the site county populations during the construction (1980-1985) and operation (1985-2020) phases. In the Southeast site in-migrants number less than 1.3% of the site county population. These levels of in-migration are not likely to produce significant impacts. The effect of the facilities is substantially different in the Southwest site. The number of in-migrants during construction is over three times the level of primary employment demand (5333 vs 1690). As a percent of projected baseline population size, the potential for significant impacts is much greater in the Southwest. There is a sharp drop in the size of the in-migrant population over the transition from construction to operation. This decline in population influx of about one-third sets the stage for a boom and bust type of effect in the Southwest reference site.

The maximum impact condition for the extended fuel storage system (Table 4.3.6-1) produces substantially larger project-induced in-migrant flows for each site compared with the expected condition. Although the numbers of in-migrants are smaller, the potential for impacts in the Southeast maximum impact condition is actually greater than the potential in the Southwest site under the expected impact conditions. This is because the base population in the Southwest site is roughly twice that in the Southeast site; therefore, the Southwest is capable of absorbing greater population influx.

The time pattern of project-related in-migration is heavily influenced by the assumptions underlying the two impact conditions. For example, the forecasted population declines by about one-eighth in the Southeast site from construction to operation under maximum impact conditions. For the same site under expected impact conditions, the change over the same period is negligible. Between 1980 and 2000, the number of project-induced migrants in the Southeast site increases slightly under both expected and maximum impact conditions. However, because the baseline population is also forecasted to grow during this interval independently of the project, the relative impacts in each case actually decline. The larger community at the later date can absorb more people with less apparent impact. Maximum impacts associated with the extended fuel storage system in the Southwest reference site are the largest obtained for the facilities.

Translating forecasted project-related in-migration into socioeconomic impacts is complex and imprecise. Estimates of the level of demand that will be placed on the community to provide social services to the new workers and their families were made by applying a set of factors to the project in-migration values. The product indicates how many units of each social service

would be "expected" by the in-migrants. The severity or significance of these impacts is primarily related to the capacity of the site county to meet these expectations. The calculated level of likely and maximum social services at the three reference sites is given for the year 2000 in Table 4.3.6-2.

TABLE 4.3.6-2. Selected Social Service Demands Associated with In-Migration Related to the Extended Fuel Storage Facilities

	Year 2000					
	Expected Demand			Maximum Demand		
Selected Social Services	Southeast Site	Midwest Site	Southwest Site	Southeast Site	Midwest Site	Southwest Site
Health						
Physicians	0	1	4	4	4	7
Nurses	1	4	11	13	13	18
Dentists	0	0	1	1	2	2
Hospital beds	1	4	14	16	16	23
Nursing care beds	1	4	9	8	15	14
Education						
Teachers (K-12)	4	9	56	56	31	90
Classroom space, m^3 (9-12)	590	1210	6750	6660	4020	10670
Sanitation, m^3/day						
Water treatment	210	410	2470	2480	1540	3950
Liquid waste	140	270	1650	1650	1030	2630
Safety						
Firemen	0	1	3	3	2	5
Policemen	1	1	9	9	5	14
Recreation, ha						
Neighborhood parks	0	1	4	4	2	6
Government						
Administrative staff	0	1	4	4	2	6
Other Social Impacts						
Crimes (7 crime index)	17	31	254	203	117	406

Identification of social services that would likely be required establishes the potential for the extent of socioeconomic impacts. The ability of communities to provide services identified here, with or without financial assistance, is highly site-specific and is beyond the scope of this document.

In general, the reference Southwest site is more likely to sustain significant socioeconomic impacts compared with the other two sites because it has a smaller available unemployed construction labor force, lacks a nearby metropolitan center, and is subject to the generation of greater secondary employment growth compared with the other sites.

4.3.7 Comparison of Environmental Effects Among Alternatives for Storing Packaged Spent Unreprocessed Fuel

A comparison of environmental effects is made among the following extended storage alternatives for packaged spent unreprocessed fuel:

- water basin storage facility
- air-cooled vault storage facility
- surface cask storage facility
- dry caisson storage facility

The storage facilities for spent unreprocessed fuel will be designed for 100 years of operation, although the use period is expected to be significantly less. After storage the packaged fuel will be retrieved for shipment to a repository or reprocessing facility.

4.3.7.1 Environmental Effects Related to Facility Construction

Resource commitments for construction of alternative spent unreprocessed fuel facilities are given in Table 4.3.7-1. The resources listed are those committed for construction of facilities that will have a storage capacity of 20,000 MTHM.

TABLE 4.3.7-1. Comparison of Resource Commitments for Construction of Alternatives Facilities for Storing Packaged Spent Unreprocessed Fuel (20,000-MTHM capacity)

Resource	Water Basin Storage	Air-Cooled Vault Storage	Surface Cask Storage	Dry Caisson Storage
Land, ha	6.4	1.3×10^{1}	1.1×10^{2}	1.3×10^{2}
Water, m^3	1.1×10^{5}	2.0×10^{5}	8.2×10^{4}	3.9×10^{4}
Concrete, MT	3.9×10^{4}	1.3×10^{5}	8.4×10^{3}	2.7×10^{4}
Steel, MT	1.2×10^{4}	3.8×10^{4}	2.8×10^{3}	
Copper, MT	1.4×10^{2}	2.5×10^{1}	4.5×10^{1}	
Zinc, MT	3.6×10^{1}			
Lead, MT		1.0×10^{1}		6.3×10^{1}
Lumber, m^3	3.1×10^{3}	8.6×10^{3}	3.1×10^{2}	1.9×10^{2}
Propane, m^3	9.0×10^{2}	1.6×10^{3}	8.0×10^{2}	7.6×10^{2}
Diesel fuel, m^3	8.9×10^{3}	1.6×10^{4}	7.8×10^{3}	8.0×10^{3}
Gasoline, m^3	6.0×10^{3}	1.1×10^{4}	5.3×10^{3}	5.2×10^{3}
Electricity, kWh	4.4×10^{6}	8.1×10^{6}	3.9×10^{6}	3.9×10^{6}
Manpower, man-yr	3.8×10^{3}	6.5×10^{3}	3.5×10^{3}	3.4×10^{3}

Nonradioactive pollutants released to the atmosphere during construction of these facilities will result from combustion of gasoline and diesel fuel in construction equipment, fugitive dust from clearing and excavation, and particulate emissions from concrete batching operations. Atmospheric concentrations of carbon monoxide, hydrocarbons, nitrogen oxides, and sulfur oxides will be below applicable Federal standards in any case.

The removal of water from the R River for construction of these facilities will have an insignificant impact on stream biota. Construction activities will eliminate some land as habitat for wildlife; however, most of the land committed will be closed to human activities and will thus provide for additional protected terrestrial habitat. No significant adverse ecological impacts to the region are expected.

4.3.7.2 Environmental Effects Related to Facility Operation

Table 4.3.7-2 presents the resources required during operation of the alternative facilities for storing spent unreprocessed fuel. The resources listed represent annual requirements after the facility has reached its 20,000-MTHM storage capacity.

TABLE 4.3.7-2. Comparison of Resources Needed for Annual Operation of the Alternative Facilities for Storing Packaged Spent Unreprocessed Fuel

Resource	Water Basin Storage	Air-Cooled Vault Storage	Surface Cask Storage	Dry Caisson Storage
Water, m^3				
Cooling tower makeup	3.8×10^5			
Coal, MT	2.3×10^3			
Gasoline, m^3		4.0×10^1	6.0×10^1	
Diesel fuel, m^3				1.2×10^2
Electricity, kWh	2.6×10^7	5.3×10^6	5.3×10^6	5.3×10^6
Manpower, man-yr	5.0×10^1	2.3×10^1	6.0×10^1	3.2×10^1

About 7×10^8 MJ/yr of waste heat would be released to the atmosphere from each of the storage facilities; the result will be a temperature increase of <1°C at 1 km downwind. Water use during facility operation would be greatest for the water basin storage facility where water drawn from the R River will be used for the storage pools and the cooling tower. This water use will represent about 2% of the minimum river flow and would result in no significant ecological impacts. The other storage facilities (air-cooled vault, surface cask, and dry caisson) would require water only for sanitary uses. Thus in areas of abundant water there are no operating requirements that clearly favor one option over the others. In areas without abundant water, the water basin storage concept may not be practical.

No hazardous chemicals will be released from any of the storage facilities during operation.

There are no identifiable releases of radioactive material for normal operation of these storage facilities. The estimated annual occupational doses are presented in Table 4.3.7-3. There are no clear choices to be made on the basis of occupational dose.

4.3.7.3 Environmental Effects Related to Postulated Accidents

Postulated minor accidents for the spent unreprocessed fuel storage facilities include loss of normal electrical power, loss of normal cooling water supply, failure of ventilation system,

TABLE 4.3.7-3. Annual Occupational Doses Received During Operation of the Alternative Facilities for Storing Packaged Spent Unreprocessed Fuel

Facility	Occupational Dose, man-rem/yr
Water basin storage	98
Air-cooled vault storage	49
Surface cask storage	78
Dry caisson storage	41

loss of cooling air, and flooding of storage vault. However, none of these accidents are expected to result in any releases of radioactive material to the environment.

The worst-case moderate accident is a packaged fuel element failure in storage, which corresponds to Accidents 5.7.33 and 5.7.39 respectively. Releases of radionuclides for the postulated moderate accidents at all the facilities are listed below:

Radionuclide	Storage Facilities, Ci
^{85}Kr	6.9
^{129}I	1.5×10^{-5}

The same source term is estimated for the packaged fuel element failure accident for the storage alternatives and thus does not provide a basis for selection among these options.

The first-year dose and 70-year dose commitment to the maximum individual for the worst-case postulated moderate accident at the air-cooled vault, surface cask, and dry caisson storage facilities are presented in Table 4.3.7-4 and 4.3.7-5, respectively. The first-year total-body dose to the maximum individual would be 1.1×10^{-6} rem compared with 0.1 rem received from naturally occurring sources over the same period. The worldwide 70-year dose commitment to the population would be 3.2×10^{-3} man-rem compared with 4.5×10^{10} man-rem received from naturally occurring sources over the same period.

TABLE 4.3.7-4. First-Year Dose to the Maximum Individual Resulting from a Moderate Accident at the Air-Cooled Vault, Surface Cask, and Dry Caisson Storage Facilities for Packaged Spent Unreprocessed Fuel (rem)

Pathway	Skin	Total Body	Thyroid	Lung	Bone
Air submersion	1.0×10^{-4}	1.1×10^{-6}	1.1×10^{-6}	1.1×10^{-6}	1.1×10^{-6}
Inhalation		1.1×10^{-8}	8.9×10^{-6}	7.3×10^{-8}	
Total	1.0×10^{-4}	1.1×10^{-6}	1.0×10^{-5}	1.1×10^{-6}	1.1×10^{-6}

Only one credible severe accident has been postulated for the storage facilities and involves a design basis tornado at the water basin storage facility (Accident 5.7.27). Releases of radionuclides for this accident are presented in Table 4.3.7-6. The first-year dose and 70-year dose commitment to the maximum individual are presented in Tables 4.3.7-7 and 4.3.7-8, respectively.

TABLE 4.3.7-5. 70-Year Dose Commitment to the Maximum Individual Resulting from a Moderate Accident at the Air-Cooled Vault, Surface Cask, and Dry Caisson Storage Facilities for Packaged Spent Unreprocessed Fuel (rem)

Pathway	Skin	Total Body	Thyroid	Lung	Bone
Air submersion	1.0×10^{-4}	1.1×10^{-6}	1.1×10^{-6}	1.1×10^{-6}	1.1×10^{-6}
Inhalation		1.3×10^{-8}	1.1×10^{-5}	7.3×10^{-8}	
Total	1.0×10^{-4}	1.1×10^{-6}	1.0×10^{-5}	1.1×10^{-6}	1.1×10^{-6}

TABLE 4.3.7-6. Radionuclides Released During a Severe Accident at the Water Basin Storage Facility for Packaged Spent Unreprocessed Fuel

Radionuclide	Release, Ci
^{3}H	1.8×10^{-2}
^{85}Kr	1.4
^{90}Sr	9.4×10^{-4}
^{95}Zr	2.6×10^{-3}
^{95}Nb	5.0×10^{-3}
^{125m}Te	4.7×10^{-5}
^{127m}Te	6.7×10^{-5}
^{129}I	1.4×10^{-6}
^{134}Cs	2.6×10^{-3}
^{137}Cs	1.4×10^{-3}
^{144}Ce	9.0×10^{-3}
^{238}Pu	8.2×10^{-5}
^{239}Pu	5.5×10^{-6}
^{241}Pu	2.7×10^{-3}
^{242}Cm	7.1×10^{-4}
^{244}Cm	1.1×10^{-4}

TABLE 4.3.7-7. First-Year Dose to the Maximum Individual Resulting from a Severe Accident at the Water Basin Storage Facility for Packaged Spent Unreprocessed Fuel (rem)

Pathway	Skin	Total Body	Thyroid	Lung	Bone
Air submersion	2.2×10^{-3}	1.1×10^{-4}	1.1×10^{-4}	1.1×10^{-4}	1.1×10^{-4}
Inhalation		2.0×10^{-2}	1.3×10^{-3}	1.8	2.9×10^{-1}
Total	2.2×10^{-3}	2.0×10^{-2}	1.3×10^{-3}	1.8	2.9×10^{-1}

TABLE 4.3.7-8. 70-Year Dose Commitment to the Maximum Individual Resulting from a Severe Accident at the Water Basin Storage Facility for Packaged Spent Unreprocessed Fuel (rem)

Pathway	Skin	Total Body	Thyroid	Lung	Bone
Air submersion	2.2×10^{-3}	1.1×10^{-4}	1.1×10^{-4}	1.1×10^{-4}	1.1×10^{-4}
Inhalation		2.0×10^{-1}	1.3×10^{-3}	2.8	3.5
Total	2.2×10^{-3}	2.0×10^{-1}	1.4×10^{-3}	2.8	3.5

The first-year total-body dose to the maximum individual would be 0.02 rem compared with 0.1 rem received from naturally occurring sources over the same period. The 70-year dose commitment to the worldwide population is estimated to be 8.2×10^{-4} man-rem compared with 4.5×10^{10} man-rem received from naturally occurring sources over the same period.

Although a dose of 2 rem to the lung of the maximum individual was calculated for a severe accident at the water basin storage facility, this dose is less than one-half of the permissible annual dose to radiation workers and is believed to be without significance in terms of accidental exposure.

4.4 ENVIRONMENTAL EFFECTS RELATED TO GEOLOGIC DISPOSAL OF SPENT FUEL

4.4 Environmental Effects Related to Geologic Disposal of Spent Fuel (DOE/ET-0028 Sec. 7.4)

Geologic formations judged potentially acceptable as waste repository media for which conceptual repository descriptions have been developed for this report, are salt, granite, shale, and basalt.

Conceptually, a repository operating in the once-through fuel cycle receives, repackages (when necessary), and places canistered PWR and BWR spent fuel elements in mined repositories located 460 to 610 m below the surface of the earth. The characteristics of these wastes and projected annual quantities delivered to the repository are described in DOE/ET-0028 Section 3.

Canistered spent fuel elements arrive by rail at the repository's surface facilities, in shipping casks designed for fuel transport. These casks are lifted by crane from the rail cars to shielded transfer cells for remote removal of the spent fuel canisters. The canisters are examined for external contamination and signs of damage. In the unlikely event of either contamination or damage contaminated canisters are cleaned; damaged canisters are returned to their casks, transferred to the over-pack cell, and encased in appropriately sized overpack canisters. The canisters are then transported to the canistered waste shaft and lowered into the repository. All spent fuel is handled remotely.

The spent fuel canisters are received at subsurface transfer stations where shielded transporters remotely remove the canisters from the transfer stations for delivery to an emplacement area.

At repositories located in salt or shale formations, individual PWR and BWR canisters are lowered into vertical holes drilled into the floors of emplacement rooms. The number of canisters that can be placed in a single room is limited by the minimum hole spacing of 1.8 m (6 ft) center to center or the allowable thermal density (kW/acre)* whichever is more restrictive. The minimum hole spacing limit is based on local rock strength. The thermal density, calculated by summing the thermal output of the wastes (kW/canister) over the room and pillar area, is limited by room and pillar stability or by thermal expansion limits for the formation above the repository.

Repositories located in granite and basalt provide for emplacement of PWR canisters in holes as described for the salt and shale repositories. However, BWR canisters are placed vertically in trenches running the length of the emplacement rooms. Steel racks are used in the trenches to maintain the canisters in an upright position. The storage rack arrangement allows a minimum 1 m (3 ft) center-to-center spacing transversely within the trench and 0.6 m (2 ft) longitudinally. This decreased minimum spacing permits waste emplacement more closely approaching the allowable thermal density for these formations.

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* For these repository designs the allowable thermal density for emplacement of wastes is conservatively set at two-thirds of the calculated maximum acceptable density. Basically waste placement spacing is a balance of cost of mining against the estimated heat load that the host rock can contain without compromising the integrity of the repository. Additional details on thermal criteria are provided in DOE/ET-0028, Section 7.3.

Initially, the reference repository will probably be operated in a readily retrievable mode. This means that all wastes could be removed from the repository at about the same rate and with about the same effort as for emplacement. To assure their retrievability under these conditions, corrosion or other damage to waste canisters must be minimized. Canisters placed into holes during this retrievable period are protected by first lining the hole with a steel sleeve. Canisters in trenches are provided with modified storage racks with sleeves. These sleeves encase the spent fuel canisters and prevent contact between the canisters and potentially corrosive backfill materials. Concrete plugs are used to seal the sleeves and provide shielding. Retrievable emplacement spans the initial five years of repository operations, providing a period for observation of waste-rock interactions and repository operations.

In the event that conditions during the retrieval period lead to the conclusion that the repository location is unacceptable for waste isolation, retrieval operations would be initiated. This would involve returning to the emplacement rooms, removing the spent fuel canister from its sleeved hole, transporting the canisters to the receiving stations where they are hoisted to the surface, and providing some form of interim storage for the canisters until another repository is ready to receive the spent fuel. (Environmental aspects of such handling and storage are not treated in this report).

After the retrievability period and when a room is filled to its capacity with canisters, the room is backfilled to within 0.6 m (2 ft) of the room ceiling with crushed rock from prior repository mining. The total amount of spent fuel to be contained in repositories in the reference scenario is 379,000 MTHM. Table 4.4-1 lists the contents of conceptual repositories located in salt, granite, shale, and basalt formations.

TABLE 4.4.1. Contents of Reference Spent Fuel Repositories, MTHM[a]

Salt (8)	47,000
Granite (3)	126,000
Shale (6)	63,000
Basalt (3)	126,000

a. Note that the contents are based on the 800 ha reference repository and in actual practice the repositories in different media could contain the same quantity of waste (although non-salt repositories would probably be smaller rather than salt repositories larger.)

Surface facilities for the conceptual repository, as shown in Figure 4.4.1-1, are similar for all repositories regardless of geologic formation. These facilities and the mined rock storage pile constitute the only on site visible evidence of the repository and occupy an area of about 180 ha (440 acres) at the salt and shale repositories and 280 ha (700 acres) at the granite and basalt repositories. The additional 100 ha at the granite and basalt repositories are required for the larger amounts of rock that are mined from these formations and stored on the surface.

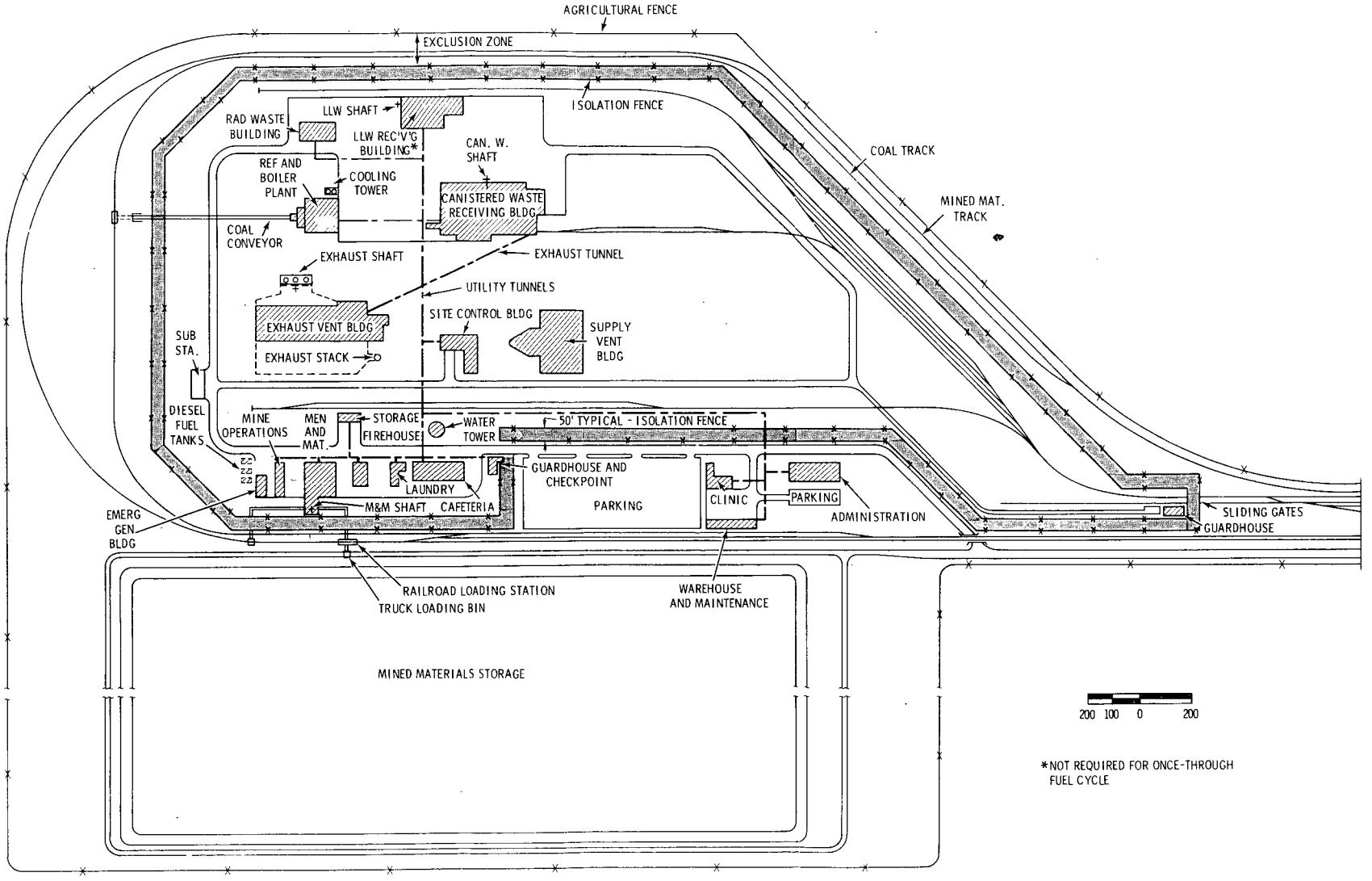

FIGURE 4.4.1-1. Plot Plan of a Geologic Repository

All surface structures handling radioactive wastes are operated at a negative pressure with respect to the atmosphere. Ventilation flows are controlled by pressure differential from areas of low contamination potential to areas of successively higher contamination potential. Exhaust air is processed through a roughing filter and two HEPA (high-efficiency particulate air) filter banks in series prior to discharge via a 110 m (360 ft) mine ventilation stack. Duplicate filter banks and exhaust fans are provided, with both fans connected to a standby emergency power distribution system. Except for final discharge into the mine exhaust stack, each structure has a ventilation system independent of other structures.

The canistered waste building provides facilities and equipment necessary to receive and handle the canistered spent fuel elements that, because of their radioactivity, require remote handling. This building is a two-story reinforced concrete structure; one story is above grade the other below.

The building is designed to withstand foreseeable natural phenomena according to criteria specified to 10 CFR part 50, Appendix A. All areas where the cansiters are handled outside of a shielded cask are shielded by reinforced concrete. All activities in these areas (transfer cells, canister storage and feed room, and shaft transfer room) are remotely monitored and controlled.

A personnel and materials building provides separate facilities such as locker rooms and showers for the mining, drilling, and backfilling crews, as well as offices, meeting rooms, check-in, and control facilities. It also provides covered access to a men and materials (M&M) shaft headhouse for transport of personnel, equipment, and materials to the mine. Excavated rock for backfill is transported through this building to the M&M shaft and into the mine.

A ventilation supply building provides fresh air for the underground mining, drilling, radioactive waste placement and backfilling operations. Tornado dampers are provided on air intakes to prevent the backflow of air from the mine.

A ventilation exhaust building houses exhaust fans and filters associated with ventilation of mining, drilling, and waste placement backfilling operations. Ventilation exhaust air is drawn from the mine through the ventilation exhaust shaft, into this building and then is discharged to the mine exhaust stack.

Excavation of repository shafts is begun five years prior to start of waste emplacement. Excavation of repository underground areas is begun two years prior to the start of waste emplacement operations and spans a seven-year period terminating in the fifth year of waste emplacement. Repositories located in salt formations are excavated with continuous mining machines while the repositories in granite, shale, and basalt are excavated by conventional drill and blast techniques.

Although each repository in the four rock media occupies an overall area of 800 ha, larger amounts of rock are excavated in constructing the repositories in granite and basalt. This is due in part to larger mining extraction ratios (ratio of mined to intact volume). The increased extraction ratios are possible because of greater rock strength that allows smaller pillar widths, resulting in more emplacement rooms per repository area and in more compact waste placement.

Table 4.4-2 compares mining and rock handling requirements for 800 ha reference repositories in the four geologic formations.

TABLE 4.4-2. Mining and Rock Handling Requirements at a Repository

	Repository Waste Capacity, MTHM	Mined Quantity (MT x 10^6)	Room Backfill (MT x 10^6)	Backfill (MT x 10^6)	Permanent Onsite Surface Storage (MT x 10^6)
Salt	(47,000 MTHM)	30	14	17	13
Granite	(126,000 MTHM)	77	29	38	39
Shale	(63,000 MTHM)	35	15	21	14
Basalt	(126,000 MTHM)	90	32	46	44

All mined rock is brought to the surface and stored onsite. The storage pile is constructed using standard earth moving equipment. Dust control is employed during construction at all repositories; salt and shale storage piles are also provided with runoff control. On completion of retrievable emplacement operations, a portion of the rock is expected to be returned to the mine as backfill. Present plans call for rock not used for backfill to remain piled on the surface. In the case of a salt repository it may be possible to dispose of the excess salt by placing it in an abandoned salt mine, by controlled disposal at sea, or by selling the salt for commercial use.

The conceptual repositories for the once-through fuel cycle in salt and shale formations require three shafts to support waste handling and mining operations. These are a canistered waste (CW) shaft, a men and materials (M&M) shaft, and a ventilation exhaust (VE) shaft. These shafts all differ in size, design, use and functional constraints.

The canistered waste shaft provides a means for transporting the canisters of spent fuel from the canistered waste building to the subsurface emplacement areas. The top of the shaft forms a integral part of the canistered waste building. At mine level the shaft provides access to a BWR waste receiving station at one elevation and a PWR waste receiving station 23 m (75 ft) lower. The PWR and BWR waste receiving stations and their respective mine areas are located on different elevations to provide space for routing men and materials corridors to each mine area. The receiving stations provide shielded facilities for the remote transfer of canisters from the shaft.

The men and materials shaft handles mine and storage personnel, equipment, ventilation air, and mined rock during excavation and backfilling. The M&M shaft contains a personnel and equipment cage, mined material hoisting skips, a manway and utility access space, and two auxiliary compartments for skip counterweights.

The ventilation exhaust shaft is divided into two compartments to provide separate exhaust for mining and for placement operations. The shaft discharges into the ventilation exhaust building.

For the reasons noted previously, substantially larger amounts of rock are to be excavated from granite and basalt than from salt or shale repositories. To accommodate the increased rock removal a fourth shaft, a mine production (MP) shaft, is provided for the granite and basalt repositories. This shaft contains skip hoist equipment for removal of mined rock to the surface and supplies additional ventilation air to the mine.

Underground layout at the reference repository is a conventional room and pillar arrangement that serves the need for repository ventilation, opening stability, control of thermal effects, and efficient use of excavated space. The overall underground area is bounded by an upper limit of 800 ha (2000 acre) set on the basis of reasonable waste storage capacity and waste transport efficiency. Of this 800 ha total area, spent fuel emplacement areas occupy 650 to 730 ha (1600 to 1800 acres), with the remaining 80 to 160 ha (200 to 400 acres) occupied by shafts, general service areas, main corridors and unmined areas within the repository. Mine areas for BWR and PWR waste emplacement are located on different elevations and are offset from each other so that there will be no overlapping or stacking of emplacement areas.

4.4.1 Environmental Effects Related to Facility Construction

Environmental impacts of repository construction relate principally to resource commitments, pollutants released from vehicles, and fugitive dust from surface handling operations of mined materials. In the reference scenario, the repository is mined out completely by the end of the initial five-year retrieval period. Construction impacts are those for surface facilities construction and mining of the entire repository: they do not include any impacts from spent fuel emplacement during the initial five-year retrieval period.

Resource Commitments

Resource commitments for the four geologic media are summarized in Table 4.4.1-1. Granite and basalt repositories require approximately 3-4 times the resources of salt and shale repositories. The same size repository (800 ha) is maintained in each rock medium; however, different thermal criteria allow spent fuel containers to be stored closer together in granite and basalt than in salt and shale. Thus greater quantities of spent fuel can be stored in granite and basalt repositories compared to salt and shale repositories (see Table 4.4.1-1).

Nonradiological Releases

Effluents from repository construction will include dust and pollutants from machinery operation during surface facility construction and mining operations. The burning of the quantities of fossil fuels listed in Table 4.4.1-2 will result in air pollutant emissions, but fenceline concentrations are not expected to result in any air quality effects in excess of regulatory limits.[1] Estimate of pollutant totals released to the atmosphere from operating equipment during construction are given in Table 4.4.1-2. These quantities are developed from the total quantities of fuel burned and emission factors for a given effluent[2].

TABLE 4.4.1-1. Resource Commitments for Construction of Geologic Repositories for Spent Fuel

	Salt (47,000 MTHM)	Granite (126,000 MTHM)	Shale (63,000 MTHM)	Basalt (126,000 MTHM)
Land Use				
Surface facilities, ha	180	280	180	280
Access roads and railroads, ha	8	8	8	8
Mineral and surface rights, ha (fenced restricted area)	810	810	810	810
Additional land on which only subsurface activities will be restricted, ha	3,200	3,200	3,200	3,200
Water Use, m^3	240,000	710,000	360,000	610,000
Materials				
Concrete, m^3	100,000	300,000	150,000	250,000
Steel, MT	16,000	48,000	24,000	40,000
Copper, MT	220	660	330	560
Zinc, MT	55	160	80	140
Aluminum, MT	41	120	64	110
Lumber, m^3	2,300	6,900	3,000	5,900
Energy Resources				
Propane, m^3	2,200	6,400	3,200	5,400
Diesel fuel, m^3	22,000	64,000	32,000	54,000
Gasoline, m^3	16,000	47,000	21,000	40,000
Electricity				
Peak demand, kW	3,400	11,000	5,100	8,800
Total consumption, kWh	14,000,000	43,000,000	21,000,000	36,000,000
Manpower, man-years	1.0×10^4	3.0×10^4	1.4×10^4	3.7×10^4

TABLE 4.4.1-2. Total Quantities of Effluents Released to the Atmosphere During Construction of a Geologic Repository for Spent Fuel as Waste

	Repository Media			
Pollutant MT	Salt	Granite	Shale	Basalt
CO	7,900	23,000	10,000	20,000
Hydrocarbons	360	1,100	480	890
NO_x	1,500	4,500	2,200	3,800
SO_x	92	270	130	230
Particulates	94	270	130	230

The primary concern during repository construction is the quantities of mined material brought to the surface during mining. Dust from mining and transport within the mine is removed by filters in the mine ventilation system. However, dust generated from surface operations and transport to storage is expected to result in the greatest dust generation. Potential dust emissions were determined using emission factors estimated by Cowherd, et.al.[3] These factors were measured for rock aggregate storage piles (not salt) under dry and windy conditions when dust generating potential was near maximum. Based on the maximum amount of material mined per day, Table 4.4.1-3 presents dust emissions for the various media for both the reference environment (moist regions) and arid regions.

TABLE 4.4.1-3. Maximum Dust Emissions From Surface Handling of Mined Material, MT/d

	Repository Media			
Climate	Salt	Granite	Shale	Basalt
Reference	3.1	7.9	3.7	9.3
Arid	44	110	51	130

The maximum and average concentrations of dust at the repository fenceline (1.6 km from repository center) were calculated using the annual average atmospheric dispersion factors ($\overline{\chi}/Q'$) values presented for the reference environment (Appendix A). Table 4.4.1-4 presents these concentrations for the four geologic media.

TABLE 4.4.1-4. Dust Concentrations at Repository Fenceline, $\mu g/m^3$

Repository Media	Maximum	Average
Salt		
• Reference	110	66
• Arid	1400	790
Granite		
• Reference	290	170
• Arid	3500	2100
Shale		
• Reference	130	79
• Arid	1600	930
Basalt		
• Reference	330	190
• Arid	4100	2400

The existing primary Federal air quality standard for suspended particulate matter computed as an annual geometric mean is 75 $\mu g/m^3$. Thus, for both the reference site and any proposed arid site, this limit would be exceeded if appropriate control techniques were not applied during surface handling of mined material.

To give perspective to the salt concentrations (in Table 4.4.1-4) at the repository fenceline it may be noted that salt concentrations near shore on the eastern seaboard average about 140 $\mu g/m^3$ at 0.5 km inland and about one-tenth of that 1 km inland. During persistently high on-shore winds, the concentration may be on the order of 380 $\mu g/m^3$ at 0.5 km and 60 $\mu g/m^3$ at 1 km[4].

Table 4.4.1-5 presents estimates of dust deposition rates from surface handling of mined material. Maximum deposition of dust would occur at a distance of 0.4 km from surface handling operations. At the repository fenceline (1.6 km from the handling operations) deposition is approximately a factor of 10 less. These depositions are based on the "worst case," which would consider the maximum salt removal rate for a year's period. Impacts of these depositions are discussed in the ecological section.

TABLE 4.4.1-5. Dust Depositions from Surface Handling of Mined Material gm/m^2-yr

Geologic Media	Distance from Handling Operations 0.4 Km	1.6 Km
Salt		
• Reference	70	8.4
• Arid	870	84
Granite		
• Reference	180	22
• Arid	2200	220
Shale		
• Reference	82	9.8
• Arid	1000	98
Basalt		
• Reference	210	25
• Arid	2600	250

Estimated dust deposition rates in Table 4.4.1-5 are based on surface transfer operations and do not include dust from rock crushing or transport. Dust emissions from accumulated surface storage of mined material are expected to be negligible under normal conditions as salt storage stockpiles crust quickly because of the ability of rock salt to absorb water vapor. Dust emissions from other media stored on the surface are not expected to be significant.

The main environmental impact from the surface storage of mined material is the possible contamination of surface waters by runoff from these stockpiles. Of major concern will be the salt stockpiles. After stockpile areas are graded, an impermeable lining of hypalon covered by 0.6 m of montmorillonite clay will be placed over the entire stockpile area before material

is stockpiled. The hypalon and clay will function as a ground water protection barrier. A trench with the same type of protection will be constructed all around the stockpile to collect the runoff water and transport it to the required treatment facility. If the mine is located in an arid area an evaporation pond may provide the required treatment. For other cases, the runoff water will be drained into a sump and pumped to a water treatment plant where dissolved salt would be removed from the water. Although salt stockpiles crust quickly and industry does not use any covering to prevent loss of salt through erosion, a cover of asphalt over the salt has been suggested and may be a prudent management measure.

Shale is a rock that conceivably could contain an important amount of soluble minerals. The surface waters will leach these minerals and could pollute streams and the ground waters. Moreover in a cold climate, freezing of the wet rock will result in a fragmentation and release of clay particles that may pollute streams.

The shale stockpile area would be covered with a blanket of montmorillonite clay and sloped toward a collecting ditch. The surface run-off would be drained into a settling pond to remove suspended silt and sands. From the pond it would be pumped to a water treatment plant where minerals in solution would be removed.

Granite and basalt are relatively insoluble; therefore, the stockpile area will not likely need special treatment and runoff water does not have to be contained.

Water used during construction of a repository will be 2.4×10^5 to 7.1×10^5 m^3 (depending on geologic media) over the 7-year construction period. This water will be supplied from the R River; water use will represent a small fraction (<0.001) of the average river flow and no significant impact will result from its withdrawal.

Sanitary waste will be collected in a sewer system that is connected to a local sewer trunk, if available, or given secondary treatment at the repository and disposed of in accordance with local and Federal regulations. Storm drains will be separate from the sanitary sewer system and will lead to a storm drainage pond in the general yard area.

Surface water runoff from excavation sites, drilling, and parking and laydown areas will be controlled to prevent it from reaching surface waters. One method of control is to direct runoff into a storm drainage pond.

Radiological Releases

Routine radiological releases from a geologic repository during construction will consist of naturally-occurring radon and its daughter products released during mining of the repository. Radionuclides released to the biosphere annually for the four geologic media are listed in Table 4.4.1-6.

Radiological Effects

Radiation doses in the vicinty of the repository during mining operations were calculated based on the release of radioactive material as listed in Table 4.4.1-7. Dispersion will occur from a mine stack 110 m high with a flow rate of about 40 m^3/sec and a release velocity of 10 m/sec. These doses are based on releases from mining operations and include naturally occurring radon and its decay products. Exposure pathways, demography, and other parameters

TABLE 4.4.1-6. Annual Radionuclide Releases to Air for Construction of Geologic Repository for Spent Fuel as Waste, Ci

Nuclide	Geologic Media			
	Salt	Granite	Shale	Basalt
^{220}Rn	9.3×10^{-4}	2.0×10^{1}	6.1	3.1
^{222}Rn	1.3×10^{-3}	1.9×10^{1}	7.0	2.7
^{210}Pb	1.1×10^{-7}	1.6×10^{-3}	5.9×10^{-4}	2.3×10^{-4}
^{212}Pb	1.4×10^{-6}	3.0×10^{-2}	9.2×10^{-3}	4.7×10^{-3}
^{214}Pb	1.3×10^{-3}	1.9×10^{1}	7.0	2.7
^{210}Bi	1.3×10^{-3}	1.9×10^{1}	7.0	2.7

TABLE 4.4.1-7. Annual Doses to the Maximum Individual[a] from Radon and Decay Products During Mining Operations at the Geologic Repository for Spent Fuel (rem)

Pathway	Total Body	Thyroid	Lung	Bone
	Salt (47,000 MTHM Waste Capacity)			
Air Submersion	2.1×10^{-11}	2.1×10^{-11}	2.1×10^{-11}	2.1×10^{-11}
Inhalation	1.0×10^{-9}		3.9×10^{-10}	1.7×10^{-8}
Total	1.0×10^{-9}	2.1×10^{-11}	4.1×10^{-10}	1.7×10^{-8}
	Granite (126,000 MTHM Waste Capacity)			
Air Submersion	3.0×10^{-7}	3.0×10^{-7}	3.0×10^{-7}	3.0×10^{-7}
Inhalation	1.5×10^{-5}		5.8×10^{-6}	2.5×10^{-4}
Total	1.5×10^{-5}	3.0×10^{-7}	6.1×10^{-6}	2.5×10^{-4}
	Basalt (126,000 MTHM Waste Capacity)			
Air Submersion	4.5×10^{-8}	4.5×10^{-8}	4.5×10^{-8}	4.5×10^{-8}
Inhalation	2.2×10^{-6}		8.4×10^{-7}	3.6×10^{-5}
Total	2.2×10^{-6}	4.5×10^{-8}	8.9×10^{-7}	3.6×10^{-5}
	Shale (63,000 MTHM Waste Capacity)			
Air Submersion	1.1×10^{-7}	1.1×10^{-7}	1.1×10^{-7}	1.1×10^{-7}
Inhalation	5.6×10^{-6}		2.2×10^{-6}	9.3×10^{-5}
Total	5.7×10^{-6}	1.1×10^{-7}	2.3×10^{-6}	9.3×10^{-5}

a. The maximum individual is defined as a permanent resident at a location 4000 m southeast of the stack with the highest annual average dispersion factor ($\overline{\chi}/Q^1$) of 1.3×10^{-8} sec/m^3.

described for the reference environment are presented in Appendix A. Mathematical models relating dose to man from radionuclide releases are given in Appendix B. For planned operation of the repository, the only exposure pathway to man and to the environment is via airborne effluents; there are no planned releases to ground or water.

The annual doses to an individual whose habits tend to maximize his dose ("maximum individual") are shown in Table 4.4.1-7. The largest annual total-body dose was calculated for mine operations and amounted to 1.5×10^{-5} rem compared with a dose of 0.1 rem that would otherwise result from undisturbed naturally occurring radioactive sources.

The combined dose from the mine effluents to the population living within an 80-km radius of the repository was calculated using the projected year 2000 population data (2×10^6 persons) given in the reference environment. Table 4.4.1-8 summarizes the annual doses received by this population. The largest annual total-body population dose from mining were from a granite repository and amounted to about 4 man-rem, compared with about 200,000 man-rem that would otherwise result from naturally occurring sources. The annual occupational dose is given in Table 4.4.1-9. Annual work force and population dose are summarized in Table 4.4.1-9.

TABLE 4.4.1-8. Annual Doses to the Population (within 80 km) from Radon and Decay Products During Mining Operations at a Geologic Repository for Spent Fuel (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
	Salt (47,000 MTHM Waste Capacity)			
Air Submersion	5.0×10^{-6}	5.0×10^{-6}	5.0×10^{-6}	5.0×10^{-6}
Inhalation	2.5×10^{-4}		9.5×10^{-5}	4.1×10^{-3}
Total	2.5×10^{-4}	5.0×10^{-6}	1.0×10^{-4}	4.1×10^{-3}
	Granite (126,000 MTHM Waste Capacity)			
Air Submersion	7.4×10^{-2}	7.4×10^{-2}	7.4×10^{-2}	7.4×10^{-2}
Inhalation	3.6		1.4	6.0×10^{1}
Total	3.6	7.4×10^{-2}	1.4	6.0×10^{1}
	Basalt (126,000 MTHM Waste Capacity)			
Air Submersion	1.1×10^{-2}	1.1×10^{-2}	1.1×10^{-2}	1.1×10^{-2}
Inhalation	5.2×10^{-1}		2.0×10^{-1}	8.7
Total	5.3×10^{-1}	1.1×10^{-2}	2.1×10^{-1}	8.7
	Shale (63,000 MTHM Waste Capacity)			
Air Submersion	2.8×10^{-2}	2.8×10^{-2}	2.8×10^{-2}	2.8×10^{-2}
Inhalation	1.4		5.2×10^{-1}	2.3×10^{1}
Total	1.4	2.8×10^{-2}	5.5×10^{-1}	2.3×10^{1}

TABLE 4.4.1-9. Summary of Annual Total-Body Doses Received From Mining Operations at a Geologic Repository for Spent Fuel and From Naturally Occurring Sources

	Dose, man-rem			
	Salt	Granite	Basalt	Shale
Repository				
Work Force	2.6×10^{-2}	720	880	270
Population (within 80 km)	<.001	3.6	0.53	1.4
Naturally occurring sources				
Population (within 80 km)		200,000		

The 70-year doses to the maximum individual and to the population within 80 km of the repository are given in Table 4.4.1-10 and 4.4.1-11 respectively. A summary of the 70-year total-body doses to the work force and population is given in Table 4.4.1-12.

TABLE 4.4.1-10. 70-Year Doses to the Maximum Individual From Radon and Decay Products During Mining Operations at a Geologic Repository for Spent Fuel (rem)

Pathway	Total Body	Thyroid	Lung	Bone
	Salt (47,000 MTHM Waste Capacity)			
Air Submersion	1.4×10^{-10}	1.4×10^{-10}	1.4×10^{-10}	1.4×10^{-10}
Inhalation	2.8×10^{-8}		3.0×10^{-9}	8.5×10^{-7}
Total	2.8×10^{-8}	1.4×10^{-10}	3.1×10^{-9}	8.5×10^{-7}
	Granite (126,000 MTHM Waste Capacity)			
Air Submersion	2.1×10^{-6}	2.1×10^{-6}	2.1×10^{-6}	2.1×10^{-6}
Inhalation	4.1×10^{-4}		4.5×10^{-5}	1.2×10^{-2}
Total	4.1×10^{-4}	2.1×10^{-6}	4.7×10^{-5}	1.2×10^{-2}
	Basalt (126,000 MTHM Waste Capacity)			
Air Submersion	3.1×10^{-7}	3.1×10^{-7}	3.1×10^{-7}	3.1×10^{-7}
Inhalation	5.9×10^{-5}		6.5×10^{-6}	1.8×10^{-3}
Total	5.9×10^{-5}	3.1×10^{-7}	6.8×10^{-6}	1.8×10^{-3}
	Shale (63,000 MTHM Waste Capacity)			
Air Submersion	7.8×10^{-7}	7.8×10^{-7}	7.8×10^{-7}	7.8×10^{-7}
Inhalation	1.5×10^{-4}		7.7×10^{-5}	4.7×10^{-3}
Total	1.5×10^{-4}	7.8×10^{-7}	1.8×10^{-5}	4.7×10^{-7}

TABLE 4.4.1-11 70-Year Doses to the Population (within 80 km) From Radon and Decay Products During Mining Operations at the Geologic Repository for Spent Fuel (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
	Salt (47,000 MTHM Waste Capacity)			
Air Submersion	3.5×10^{-5}	3.5×10^{-5}	3.5×10^{-5}	3.5×10^{-5}
Inhalation	6.8×10^{-3}		7.5×10^{-4}	2.1×10^{-1}
Total	6.8×10^{-3}	3.5×10^{-5}	7.9×10^{-4}	2.1×10^{-1}
	Granite (126,000 MTHM Waste Capacity)			
Air Submersion	5.1×10^{-1}	5.1×10^{-1}	5.1×10^{-1}	5.1×10^{-1}
Inhalation	1.0×10^{2}		1.1×10^{1}	3.0×10^{3}
Total	1.0×10^{2}	5.1×10^{-1}	1.2×10^{1}	3.0×10^{3}
	Basalt (126,000 MTHM Waste Capacity)			
Air Submersion	7.5×10^{-2}	7.5×10^{-2}	7.5×10^{-2}	7.5×10^{-2}
Inhalation	1.5×10^{1}		1.6	4.4×10^{2}
Total	1.5×10^{1}	7.5×10^{-2}	1.6	4.4×10^{2}
	Shale (63,000 MTHM Waste Capacity)			
Air Submersion	1.9×10^{-1}	1.9×10^{-1}	1.9×10^{-1}	1.9×10^{-1}
Inhalation	3.8×10^{1}		4.1	1.2×10^{3}
Total	3.8×10^{1}	1.9×10^{-1}	4.3	1.2×10^{3}

The 70-year total-body dose to the maximum individual from mining a model 50,000 MTHM capacity waste repository would amount to about 2.9×10^{-8}, 1.6×10^{-4}, 2.4×10^{-5} and 1.2×10^{-4} rem for salt, granite, basalt and shale respectively.

TABLE 4.4.1-12. Summary of 70-Year Total-Body Doses From Mining Operations at a Repository for Spent Fuel and from Naturally Occurring Sources

	Dose, man-rem			
	Salt	Granite	Basalt	Shale
Repository				
Work force (7 yr)	0.18	5040	6160	1916
Population (within 80 km)	0.007	100	15	38
Naturally occurring sources				
Population (within 80 km)		14,000,000		

The 70 year total body dose to the regional population from mining a model 50,000 MTHM waste capacity repository would amount to about 7.1×10^{-3}, 4.0×10^{1}, 6.0, 3.0×10^{1} man rem for salt, granite, basalt and shale repectively.

Worldwide population doses were not calculated for releases of radon and radon decay products.

Ecological Effects for Repository in Salt

Construction activities at the surface facilities will involve the removal of vegetation and displacement of birds and small mammals from the site areas. Weedy species of plants would invade cleared areas unless revegetation practices are applied. Localized dust problems would occur until vegetation cover is re-established.

Soil erosion control measures will be needed to prevent surface runoff from adding suspended solids to nearby land and surface waters. Assuming use of only reasonably good practices, effects from construction of the surface facilities on aquatic biota should be negligible.

The major ecological impact would be from fugitive dust depositions which might occur from surface handling operations of mined material. Of greatest concern is the estimated salt depositions at the repository fenceline of 8.4 and 84 g/m^2-yr for the reference and arid environment, respectively. These depositions were calculated from the 3.0×10^{7} MT of salt mined with 1.3×10^{7} MT remaining on the surface for final disposal.

The major ecological impact would be from the salt depositions from tailing piles.

Adverse biotic effects on vegetation will depend upon many factors, including rate of uptake, short and long-term sensitivity of species to effluent concentrations, period of exposure, the physiological condition of the vegetation during the time exposure and buildup of salt over time. Impingement upon vegetation with subsequent foliar absorption appears to be the most hazardous mode of entry. Uptake of salt solutions by foliage is a rapid and relatively efficient process[5]. Crops particularly sensitive to salt effects are alfalfa, oats, clover, wheat, Indian rye grass, and ponderosa pine. These plants are seriously damaged during germination and young-leaf sage development. Ornamental vegetation types that are susceptible to salt concentrations are dogwood, red-maple, Virginia creeper and wild black cherry. Visual symptoms of toxicity are foliar necrosis, short-time dieback and "molded" growth habits. Beans are particularly sensitive showing wilting of areas on primary leaves followed by necrosis of

previously wilted areas and chlorosis of young trifoliate leaves. Effects on vegetation will depend on air concentration and time of exposure as well as humidity. It is generally accepted that an air concentration above 10 $\mu g/m^3$ will alter distribution and growth of plants.[6] As fenceline ground level concentrations for salt dust released from surface storage and handling operations will exceed this level, a significant impact would be expected. The deposition rates are in the range of 40.5-94.5 $gm/m^2/yr$ for observable leaf-burn on such plants as beans. Based on the assumptions made for determining salt depositions, mitigating procedures would be needed to reduce salt dispersal at least two orders of magnitude to ensure that emission concentrations are well below toxic levels. Once contaminated, salt-affected soils will require special remedial measures and management practices to restore them to their original productivity

There would also be the potential for salt that is deposited as dust on the land to be transported by runoff to nearby surface waters. In the absence of specific information, such as the ability of site soils to retain salt and the magnitude of local runoff, it is difficult to predict quantitatively the potential impacts of salt on surface waters. Salt concentrations on the order of 8000 parts per million (ppm) are lethal to freshwater fish under conditions of acute exposure,[7] and the recommended limit for chronic exposure is 80 ppm or 0.01 of the acute toxicity level.[8] The possibility exists for surface waters, particularly shallow, catch-basin type ponds, to receive amounts of salt sufficient to damage indigenous aquatic plants and animals. There is also the possibility that resident species would be replaced by more salt-tolerant forms.

The direct effects of salt on animals are not generally considered significant. However, loss of vegetation from effects of salt would reduce cover and food supplies for mammals and birds and result in their displacement or elimination.

In addition to effect from dust depositon, localized effects would probably occur from leaching around the surface storage area. Annual leaching rates concommitant with control runoff conditions are not easily calculated or readily apparent. Fluctuations in concentrations of soil salinity will depend on precipitation, drainage, seepage, wind and rain erosion rates, and salt concentrations in water and air that come into contact with the soil. Increased salinity around the storage area would decrease or eliminate plant growth, because high salt soil concentrations reduce the rate at which plants absorb water. This would limit the use of vegetation to increase the aesthetic qualities of the storage area and to control dust.

Soluble salts are also potentially detrimental because they may increase salt concentrations of the soil solution and the saturation of the soil adsorption complex with sodium. The latter is a more pronounced and longer lasting effect because it persists even after most of the soluble salts are removed. Under humid conditions, soluble salts generally will be carried downward in the soil profile to groundwater and transported to surface waters. In arid regions, leaching and transportation of salts is less pronounced. Leaching is local in nature and soluble salts are not transported far. This is because of lower rainfall and high evaporation and plant transpiration rates in arid climates.

Ecological Effects for a Repository in Granite

A deep geologic radioactive waste repository in granite would be potentially less ecologically damaging than a salt repository. During construction, 7.7×10^7 MT of rock would be mined and 3.9×10^7 MT would require disposal. The granite would be crushed in the mine

before being brought to the surface, thereby, reducing the airborne contamination at the surface.

Possible methods of disposal include use in construction projects (e.g., dams, highways) or surface disposal. Neither of these alternatives pose serious ecological problems. Apart from land use associated with surface storage of the mined material, several hundred tons of airborne particulates may be released yearly. Environmental release of this material to land or surface water can be limited by establishing a vegetation cover for the stored rock, and by proper draining and ponding the surface runoff. In the granite repository, as with shale and basalt, water may enter either through downward flow from the overlying strata or through upwelling from the lower layers. The volume of water entering the repository is generally directly related to repository size and will be greatest during the last stages of construction-operation when the repository is near its maximum size. For granite the estimated inflow of water will be about 1500 m^3/day (400,000 gal/day). Much of this water will be removed as water vapor by the mine ventilation system although some of the water will probably require collection in sumps in the mine and pumping to the surface. This water will be retained in a holding pond to check for radionclide contamination, and to treat for radionuclide removal before being discharged to the environment. Nonradiological water quality standards will also have to be meet before this effluent is released to land or surface waters. Disposal of this water will only be necessary until the repository is sealed off.

The maximum volume of water that will need possible treatment and disposal probably will be less than 760 m^3/d and is not expected to create ecological problems.

Ecological Effects for a Repository in Shale

A deep geological repository in shale will have a small ecological impact during construction and operation because of changes in land use. About 3.5×10^7 MT of rock will be mined and 1.4×10^7 MT will require disposal. The mined material will be crushed before it is brought to the surface, a practice that will reduce the release of dust above ground. Several disposal methods may be applicable for that mined shale not required for backfilling of the mine. These methods are surface storage, ocean disposal, and placement in abandoned mines. Each of these alternatives has some potential for causing ecological impact. Mine storage may contaminate ground water supplies that may in turn impact ecological systems, some local but poorly defined impacts may result from ocean disposal, and surface storage may remove land from the available natural habitat and be a source of acid runoff.

Shale may contain up to 0.5% iron pyrite, which will produce sulfuric acid when exposed to oxygen and water. Runoff from storage piles, water pumped from the mine, leaching of abondoned mine storage, and ocean disposal may provide sources of this acid waste to the environment. The actual quantities and acidity of this waste water have not been defined. Potential ecological impacts will probably be localized and highly site specific. Factors such as the ambient pH of the soil and receiving water, their buffering capacity and the interaction with other physical and chemical parameters will be important in controlling impact. To afford a moderate level of protection for aquatic life, the pH of freshwater systems should be between pH 6.0 and 9.0, and there should be no change greater than 1.0 units outside the estimated seasonal maximum

and minimum[7]. In marine waters, the addition of foreign material should not drop the pH below 6.5 or raise it above 8.5, and within the normal range the pH should not vary by more than 0.5 units. Natural plant and animal communities are found on soils ranging from acid bogs to highly alkaline arid environments, and limits of release will be site specific.

As was the case with the granite repository, shaft and mine liquid effluents are expected to seep into the shale repository. The estimated maximum inflow during the last stages of operation will be about 19,000 m^3/d (5,000,000 gal/day). Most of this water will be collected in sumps, pumped to the surface and treated to remove radioactive contaminants. One or more holding ponds will be used to retain the water prior to clean-up and release to the environment. Discharge of this volume of water to the environment will require piping or ditching to reduce erosion, and will require sufficient clean-up and neutralization of acid to prevent environmental impact.

Ecological Effects for a Repository in Basalt

The expected ecological impacts from the construction and operation of a basalt geologic repository will be small and similar to that of a granite repository. There will be some impact from noise, dust, and disturbance of surface soil. This will be mainly confined within the 81 ha (200 acre) control zone.

About 9.0×10^7 MT of basalt rock will be mined and 4.4×10^7 MT will require disposal. Suggested disposal methods include surface storage and use in large construction projects (e.g., highways). There will be a release of up to several hundred tons of dust per year. This will be reduced by establishing vegetation on the spoils piles. Erosion through runoff will be controlled by ditching and catch basins. Environmental release of silts from runoff will be small because the basalt deposits under consideration for a repository are in arid regions. Land disposal will remove some land from its present use, but this could be handled within the 81 ha surface controlled zone. Except for land use considerations, the impacts of the basalt repository will be of little ecological consequence.

Containment of emissions from mined materials on the repository surface, particularly salt, will require thorough analysis if and when site - specific projects are developed. It is suggested that salt brought to the surface if not properly managed could be the most serious environmental impact associated with the waste repository.

Nonradiological Accidents

Table 4.4.1-13 summarizes the predicted injuries and fatalities associated with surface facility construction and underground mining operations for the various geologic media. These predictions are based on an injury rate of 13.6 disabling injuries per million hours of construction[9] on the surface facilities, and an injury rate of 25 disabling injuries per million man-hours of underground mining (other than coal). A fatality rate of 0.17 fatalities per million man-hours of construction[9] on the surface facilities and 0.53 fatalities per million man-hours of underground mining (other than coal) were also used.

TABLE 4.4.1-13. Nonradiological Disabling Injuries and Fatalities Associated With Repository Construction - Once Through Cycle

	Geologic Media			
	Salt	Granite	Shale	Basalt
Surface Facility Construction				
• Disabling Injuries	70	70	70	70
• Fatalities	1	1	1	1
Underground Mining Operations				
• Disabling Injuries	370	1400	580	1700
• Fatalities	8	30	12	37
Total				
• Disabling Injuries	440	1500	650	1800
• Fatalities	9	31	13	38

Tornado Strikes Salt Storage Area - Accident 7.7. One additional nonradiological accident was analyzed. In this accident, a tornado is postulated to strike a surface storage pile comprised of material from the geologic repository. The media of greatest impact would be salt because of its toxic properties; therefore, the following discussions will be concerned with a salt repository.

Repository design calls for the surface stored material to be covered with asphalt; however, it is assumed the salt cannot be covered as fast as it is mined and that one end of the salt pile, with dimensions 1000 m by 70 m wide and 18 m high, is uncovered. The salt was assumed to be made up of pieces, 5 to 15 cm in diameter.

The average frequency of a tornado in the general area (about 1900 km^2) of the reference site is 0.15 per year. The expected frequency of tornadoes striking within a given square kilometer in this region is 8×10^{-5} tornadoes per km^2 per year. A typical tornado that may be experienced at the reference site may be expected to have a ground-contact path area of 1.5 km^2, a path length of 8.5 km, and path width of 110 m.[10] A maximum wind speed of 40 m/s has been reported in the area as the result of a tornado. Theoretically, however, maximum tornado wind speeds may approach 130 m/s.

The amount of salt material suspended by a tornado will depend on a number of factors including size, intensity, and speed of the tornado; state or condition of the salt piles; threshold velocity of the salt aggregate; and pressure field in the tornado. An intense and large tornado will cause greater wind erosion of the salt material than a smaller and weaker system. Also, the ground speed and angle at which the tornado strikes the salt pile will determine the severity of erosion.

The threshold velocity of the gravel-sized salt material is the minimum wind velocity that would be required to start the salt material in motion. This velocity will depend on several factors such as diameter and weight of the salt aggregate, packing of the aggregate, turbulence,

moisture in the salt, and other factors. The threshold velocity of relatively dry salt aggregate will be easily exceeded by tornadic winds; however, if the salt is saturated with moisture prior to the tornado, the threshold velocity of the salt material will be increased substantially.

Tornadoes are accompanied by pressure drops on the order of 7000 Pa below normal atmospheric pressure (100,000 Pa). This rapid drop in air pressure (7000 Pa in 3 sec) may also contribute to the suspension of salt material if the excess air pressure within the salt piles cannot be released in a short time. Swelling or exploding of the salt piles is possible if a thick salt crust is present.

Tornadoes that touch the ground often form dust and debris cascades at their funnel base. These cascades will produce an abrasive action during contact with the salt piles and will thus contribute to wind erosion or the suspension process. As long as the tornado is in an active state this dust and debris cascade moves with the system until it weakens and dissipates. After the salt is airborne, the trajectory and fallout pattern of the material will generally depend on four principal forces acting in a tornado, i.e., drag, gravity, centrifugal force, and translational force.

Generally, a large share of the salt is entrained in the swirling dust and debris cascade at the base of the tornado funnel. However, a portion will be captured in the vortex and the strong updrafts will transport the material into the parent cloud system. The material in the dust and debris cascade will be centrifuged whenever the mass of the salt material becomes too great to permit the drag force to balance the centrifugal force on the aggregate. Therefore, except for material transported in the parent cloud system, the salt material will gradually be deposited along the track of the tornado until the supply is exhausted or the tornado weakens or dissipates. Material from the parent cloud system will be eventually scavenged out by rain or will settle out when the terminal velocity of the salt particles exceeds the vertical motion of the parent cloud system. This portion of the salt material will be deposited over a large area downwind from the storage site.

Estimates of material that would be removed from the salt piles and transported and dispersed in the atmosphere were made using observations of tornado strikes.[11] Assuming a dust loading of 1 kg/m^3 and a transitional speed of 32 km/hr, about 1% of the salt (2.2×10^4 MT) would be removed from the pile. However, because of possible variation in dust loading and tornado characteristics the estimate of the maximum amount of material that could be removed may range as high as 10%.

For particles diffusing in the parent cloud system for the system's lifetime and then diffusing into the troposphere, the maximum dispersion factor would occur about 40 to 60 km downwind from the tornado strike. For particles that are lifed above the ground outside the tornado core and then diffused, the maximum disperson factor would occur about 10 to 30 km downwind from the tornado strike. Maximum downwind ground level concentrations from the salt particles diffusing in the parent cloud could range from 4.4×10^{-2} g/m^3 to 6.6×10^{-3} g/m^3. Thus, concentrations of salt in the air would be expected to be about 400 times more than those occurring during normal operating fenceline conditions (1.1×10^{-4} g/m^3).

For the area in which this concentration exists, the deposition will also be 400 times higher. The effects on terrestrial and aquatic species would be considerably higher than those effects (which are considered detrimential) produced during routine operations. The size of the salt particles being deposited would determine the fraction deposited on foliage and thus the fraction falling on the ground and subsequently entering vegetation through root pathways. The resulting effects in the main deposition zone would be severe. The physical effects from a tornado striking rock storage piles at non-salt repositories would be expected to be similar to those for a salt repository. However, the long term ecological effects from chemical toxicity would not be expected.

Radiological Accidents

No radiological accidents are postulated for construction activities.

4.4.2 Environmental Effects Related to Facility Operation

The operational phase of a once-through cycle repository will include the receiving, handling, and placement of spent fuel elements into assigned subterranean storage areas and the subsequent backfilling of these areas when they reach storage. The maximum storage capacity of a geologic repository will be reached after approximately the following time periods for the various media considered:

Repository Media	Operational Phase (yr)
Salt	16
Granite	25
Shale	18
Basalt	25

Resource Commitments

The repository operates on a 5-day week, three shifts per day. Resource commitments for operation of the geologic repository are summarized in Table 4.4.2-1.

TABLE 4.4.2-1. Resource Commitments for the Operational Phase of Geologic Repositories

Materials	Salt	Granite	Shale	Basalt
PWR canister overpacks, steel, MT	2.5×10^1	5.4×10^1	2.8×10^1	5.4×10^1
BWR canister overpacks, steel, MT	2.8×10^1	6.2×10^1	3.6×10^1	6.2×10^1
PWR retrievability sleeves (5-yr only) steel, MT	8.8×10^3	8.8×10^3	8.8×10^3	8.8×10^3
BWR retrievability sleeves (5-yr only) steel, MT	1.0×10^4	$1.4 \times 10^{5(a)}$	1.0×10^4	$1.4 \times 10^{5(a)}$
PWR concrete plugs (5-yr only), MT	7.5×10^3	7.5×10^3	7.5×10^3	7.5×10^3
BWR concrete plugs (5-yr only), MT	7.4×10^3	7.4×10^3	7.4×10^3	7.4×10^3
Energy				
Electricity (kWh)	1.5×10^9	3.2×10^9	1.7×10^9	3.2×10^9
Diesel fuel (m^3)	2.1×10^5	3.2×10^5	2.3×10^5	3.2×10^5
Coal (MT)	1.2×10^6	1.8×10^6	1.3×10^6	1.8×10^6
Manpower (man-years)	1.1×10^4	2.0×10^4	1.3×10^4	1.9×10^4

a. Sleeves are required for total operation period.

Granite and basalt repositories have a longer operating period and 2-4 times greater resource commitments than salt and shale repositories because thermal criteria allow approximately twice as much spent fuel storage as in salt and shale repositories of the same area.

Nonradiological Releases

The major nonradiological effluent would be fugitive dust emissions from surface handling operations of mined materials, discussed under construction impacts. Other nonradiological pollutants released to the atmosphere during the repository's operational life are given in Table 4.4.2-2 for the various geologic media. These pollutants include combustion products from burning diesel fuel[2] during underground mining operations, and surface burning of coal.[12]

TABLE 4.4.2-2. Total Quantities of Effluents Released to the Atmosphere During Operation of a Geologic Repository for Spent Fuel as Waste

Effluent	Geologic Media			
	Salt	Granite	Shale	Basalt
Particulates, MT	430	670	480	670
SO_x, MT	9,700	15,000	11,000	15,000
CO, MT	2,400	3,700	2,700	3,700
Hydrocarbons, MT	870	1,400	980	1,400
NO_x, MT	15,000	24,000	17,000	24,000
Heat, MJ	3.9×10^8	9.3×10^8	4.9×10^8	9.3×10^8

For comparison, the emission from space heaters in a town of 30,000 was estimated for a 25 year period. Assuming that furnace oil was the fuel and that it had a sulfur content of 1%, the following total emissions were calculated:

Particulates, MT	570
SO_2, MT	7500
CO, MT	280
Hydrocarbons, MT	150
NO_x, MT	680

The estimated releases of pollutants from a geologic repository would not in any case result in Federal Air Quality Standards being exceeded at the repository boundary.

Heat released from buried nuclear waste will increase the temperature of the geologic formation in which it is buried and may alter the physical and chemical properties of the formation. The heat will eventually be transferred to the atmosphere and, if the temperatures and temperature gradients have not exceeded values that would cause damage to the formation or adversely affect the containment integrity or the environment, the formation will return essentially to its initial state.

Thermal effects that influence the allowable temperature rises and heat release rates include:

- thermal stability of the waste
- thermal stability of the formation
- movement of water in formation pores and openings
- structural integrity of the formation over its entire area
- temperature rise in any nearby freshwater aquifers
- heating of the earth's surface
- temperature increases beyond the boundaries of the disposal area.

Thermal criteria for limiting adverse thermal effects are a function of each particular formation and setting and are difficult to establish in a generic setting. Criteria, in terms of maximum temperature, were developed for bedded salt and applied to a proposed repository in Lyons, Kansas.[13] The criteria were established using waste canister centerline temperatures ranging from 650° to 1100°C. In general, 1% or less of the salt immediately surrounding the waste canister is

allowed to rise 210°C in temperature, and 25% or less of the salt is allowed to rise 160°C. These temperature rises correspond to limiting temperatures of 200°C and 250°C, respectively, for the proposed depths at which the ambient temperature is about 22°C.

From an environmental standpoint, maximum temperature increases from this analysis were 0.6°C at the surface, 28°C in assumed (hypothetical) stagnant freshwater aquifers above the repository, and 0.6°C in geologic formations at the outer edge of the repository buffer zone. Because of the low heat flux in the vicinity of the aquifers, only a small flow rate would keep the temperature rise well below that for a stagnant aquifer.

The thermal conductivity of the geologic medium is the most important single variable that controls the temperature distribution in the disposal medium. In general, the thermal conductivity of a salt formation is about twice that of other geologic materials and about twice the temperature rise would be expected in other materials for a given power output of the waste.

The water content of the rocks has a strong effect on the thermal conductivity and under certain conditions may produce hydrofracturing or water migration caused by thermal effects. The behavior of pore water, when a geologic formation is heated, is not completely understood. Water occurring as brine occlusions in salt is known to migrate upgradient toward the heat source. However, the small amount of brine (about 0.5%) present in occlusions is expected to have little effect on the thermal conductivity of the surrounding medium.

Effects at the ground surface from repository operations and final sealing for disposal are a combination of two effects: lowering of the surface caused by the plastic flow of salt into the mine area and a surface uplift from expansion caused by thermal effects. Results of preliminary calculations by the Office of Waste Isolation[14] using an arbitrary repository design indicate that a maximum surface subsidence of about 1.2 m would occur after extensive plastic flow in the mine pillars. The result would be a broad, flat saucer-shaped depression that would be created over the repository site. From the same calculations, excluding all other effects, it was estimated that thermal expansion of the entire rock column above and to some depth below the mine would cause the ground surface to first rise to a maximum of about 1.5 m after 200 years and then, as the heat dissipated, slowly return to its original position over several thousand years.

The actual ground surface behavior would result from a combination of effects of subsidence and gradual uplifting. Subsidence would be partially cancelled by upward movement from thermal expansion for 30 to 40 years, after which expansion effects would dominate, thus producing a net uplift of the surface which would reach a maximum of about 0.3 m about 200 years after repository operations begin. The surface would gradually subside, passing through its original position and, thousands of years later, reach a final position of about 1.2 m below the original elevation.

The broad slight subsidence indicated in this analysis is not believed to be a significant change in the landscape. The surface change is minor in scale and would occur so slowly that adjustments would probably take place during the process. For example, argillaceous materials such as shales and clays are known to exhibit slow plastic deformation over long periods of

time instead of fracturing. There are no indications that the overlying rock material would not be able to absorb the strains and displacements over the thousands of years during which they would occur.

For other settings and geologic media, rock deformation and its effects on the integrity of containment will depend on the rock material present at a given site and will need to be evaluated for that site.

The rock immediately surrounding spent fuel will be exposed to gamma rays and neutrons from the waste. The gamma ray energy deposited in the rock material surrounding the spent fuel will depend on the type of fission product activity, the age of the spent fuel in the canister, canister material and thickness, and the proximity of the rock to the canister.[15] The energy deposition and deposition rate will decrease exponentially with increasing distance from the surface of the waste canister. For example, with a canister 0.3 m in diameter the energy deposition at 0.15 m from the canister surface is one-tenth that at the surface.[16] The energy deposition in the rock from neutrons will be negligible.[16]

Gamma radiation produces lattice damage and thus causes the generation of stored energy in salt crystals. Under certain conditions the accumulation of stored energy can be appreciable. Experimental studies have been conducted to determine the amounts of gamma ray energy stored in salt under exposure conditions similar to those of a salt repository and also the release characteristics of this energy.[15] Some annealing or release of the stored energy will occur in the repository, depending on temperature and other factors. At 150°C and above, thermally activated annealing will be the dominant process and will limit the accumulation of stored energy. Rates of annealing at repository temperatures of <150°C are not well known.

In general, no conditions are known that would promote a sudden release of stored energy in repository salt other than rapid heating of the salt by several hundred degrees by a source other than the contained stored energy. No such source of external heat is apparent.[15] It was estimated that no serious adverse effects on waste containment and safe repository operation would result if, because of unforeseen circumstances, a release of the entire amount of stored energy in the waste within a canister and within the surrounding salt were to occur.[16]

Irradiated salt is known to yield hydrogen upon aqueous dissolution,[17] and there is evidence that irradiated salt may dissolve more rapidly than salt that has not been irradiated. However, unless the repository is breached and fresh water contacts the salt surrounding the canisters, no generation of hydrogen is expected.

Radiological Effects

Routine radiological releases from a geologic repository during normal operation will principally consist of naturally occurring radon and its daughter products. These releases will occur from backfilling operations and are assumed negligible compared to radon releases during repository construction. Resultant regional population doses also would come from that source and would be considered negligible. Failures of canisters (DOE/ET-0028 Accident 7.2) yield integrated annual releases of radioactive material on the order of 1×10^{-20} Ci.

The 70 year accumulated total body dose to the regional population was calculated to be many orders of magnitude less than 1×10^{-6} man-rem and is not considered a radiological impact.

Doses to the work force during repository operation will include contributions from receiving, handling, and placement of spent fuel canisters into proper subterranean storage areas. These doses are presented below for the various geologic repositories:

Geologic Media	70-Year Total Body Dose (man-rem)
Salt	4.3×10^3
Granite	1.1×10^4
Shale	5.6×10^3
Basalt	1.1×10^4

The 70-year work force total dose associated with a 50,000 MTHM model repository would amount to about 4.5×10^3 man-rem regardless of media.

Ecological Effects

The major ecological impact would be from any additional surface handling operations of mined material that would occur after mining of the repository is complete. Primarily, this would consist of loading and transporting mined material back into the mine to be used as backfill. Mitigating procedures may be necessary to maintain air concentrations below Federal Air Quality Standards.

Socioeconomic Effects

Socioeconomic impacts associated with the construction and operation of repositories are dependent largely on the number of persons who move into the county in which the facility will be located. Because of this, the size of the local project-generated population influx was forecast, and estimates of its needs for locally provided social services determined. Specific economic and fiscal impacts attributable to the development of the repository will not be treated here because they are too dependent on local site characteristics to allow for generalization.

Socioeconomic impacts also depend on site characteristics (see Appendix C) and the assumptions used in the forecasting model. Site characteristics that are especially important in influencing the size of the impacts forecast include the availability of a local labor force having the required skills, secondary employment, proximity to a metropolitan area, and demographic diversity (population size, degree of urbanization, etc.) of counties in the commuting region. An additional factor in the generation of impacts is the time pattern of project-associated population change. For example, a large labor force buildup followed closely by rapidly declining project employment demand could cause serious economic and social disruptions near the site and elsewhere within the commuting region.

Impacts are estimated for three reference sites identified as Southeast, Midwest, and Southwest. These areas were chosen because siting of facilities in those regions is plausible, and they differ substantially in demographic characteristics, thus providing a reasonable range of socioeconomic impacts.

The socioeconomic model employed in this analysis forecasts a regional population in five-year intervals in the absence of any project activities. This population forecast serves both as a comparative baseline and as a source for a portion of the postulated future project employment. The model takes account of both primary and secondary employment effects (such as additional retail store clerks), and incorporates as separate components spouses of members of the labor force, and other dependents. Regional migrants associated with the project are distributed residentially to counties throughout the commuting region. The model accounts for separation and retirement from project employment and replacement by new labor force members. It also specifies the tendency of workers and their dependents to leave the region upon job separation.

In the following analysis, impacts are presented in terms of an expected level of impact as well as a maximum level of impact. The expected impact condition is based on the most likely value of model assumptions, whereas the maximum impact condition places an extreme but credible value on the model assumptions.

Table 4.4.2-3 presents the manpower requirements for construction and operation of a single waste repository for spent fuel.*

TABLE 4.4.2-3. Manpower Requirements for Construction and Operation of a Single Waste Repository, Once-Through Cycle, by Disposal Medium (mean man-years per year)

Medium	Construction	Operation
Salt	1430	688
Granite	4290	800
Shale	2000	722
Basalt	5290	760

Tables 4.4.2-4 through 4.4.2-7 present estimates of the cumulative project-related in-migrants for the three reference repository sites in each of the four disposal mediums (salt, granite, shale, and basalt). The forecast values include primary and secondary workers and associated household dependents, all of whom are in-migrants. Some of the persons who separate from the facility will stay in the site county and some will leave. Those who stay are included in the forecast values. Thus, not all forecast populations are actually working on or directly associated with the project at each time period. Nevertheless, the presence of each of these persons was determined by the existence of the project, and they would not likely be present if the project had not occurred. The percentages associated with each population in these tables reflect the size of the in-migrant group relative to the base-line population in the respective sites. Since these baseline populations vary by site, the relative impact of a similar in-migrant group can vary greatly.

* Based on manpower requirements established in DOE/ET-0028.

TABLE 4.4.2-4. Forecasts of Population Influx for a Geologic Repository in Salt (47,000 MTHM Waste Capacity): Spent Fuel (Once-Through Cycle), Number of Persons and Percent of Base Population

Site	1980	1985	2000	2005
		Expected Impact Condition		
Southeast	260 (1.2%)	490 (2.1%)	570 (2.1%)	590 (2.1%)
Midwest	66 (0.1%)	1,100 (1.5%)	1,300 (1.4%)	1,300 (1.4%)
Southwest	4,400 (9.1%)	4,400 (3.6%)	5,200 (9.3%)	5,300 (9.3%)
		Maximum Impact Condition		
Southeast	3,300 (13.6%)	4,608 (16.5%)	5,500 (17.2%)	5,600 (17.1%)
Midwest	980 (1.6%)	2,600 (3.4%)	3,000 (3.3%)	3,200 (3.3%)
Southwest	6,700 (13.1%)	8,500 (15.6%)	10,000 (16.9%)	10,000 (16.7%)

TABLE 4.4.2-5. Forecasts of Population Influx for a Geologic Repository in Granite (126,000 MTHM Waste Capacity): Spent Fuel (Once-Through Cycle), Number of Persons and Percent of Base Population

Site	1980	1985	2000	2005
		Expected Impact Condition		
Southeast	1,000 (4.6%)	820 (3.4%)	960 (3.5%)	1,000 (3.6%)
Midwest	860 (1.4%)	1,800 (2.5%)	2,200 (2.4%)	2,400 (2.4%)
Southwest	14,000 (24.2%)	10,000 (17.9%)	12,000 (19.4%)	13,000 (19.2%)
		Maximum Impact Condition		
Southeast	12,000 (36.3%)	11,000 (33.1%)	14,000 (34.3%)	14,000 (34.2%)
Midwest	10,000 (14.2%)	14,000 (15.7%)	16,000 (15.5%)	17,000 (15.3%)
Southwest	20,000 (31.7%)	15,000 (29.2%)	18,000 (26.1%)	19,000 (25.9%)

TABLE 4.4.2-6. Forecasts of Population Influx for a Geologic Repository in Shale (63,000 MTHM Waste Capacity): Spent Fuel (Once-Through Cycle), Number of Persons and Percent of Base Population

Site	1980	1985	2000	2005
		Expected Impact Condition		
Southeast	410 (1.9%)	560 (2.4%)	660 (2.4%)	680 (2.4%)
Midwest	190 (0.3%)	1,200 (1.6%)	1,400 (1.6%)	1,500 (1.6%)
Southwest	6,400 (12.6%)	5,500 (10.7%)	6,600 (11.6%)	6,800 (11.6%)
		Maximum Impact Condition		
Southeast	5,100 (19.3%)	5,800 (20.1%)	6,900 (20.9%)	7,100 (20.9%)
Midwest	2,500 (4.0%)	4,300 (5.6%)	5,100 (5.4%)	5,200 (5.4%)
Southwest	9,400 (17.6%)	9,600 (17.3%)	12,000 (18.7%)	12,000 (18.6%)

TABLE 4.4.2-7. Forecasts of Population Influx for a Geologic Repository in Basalt (126,000 MTHM Waste Capacity): Spent Fuel (Once-Through Cycle), Number of Persons and Percent of Base Population

Site	1980	1985	2000	2010
		Expected Impact Condition		
Southeast	1,300 (5.8%)	890 (3.7%)	1,000 (3.8%)	1,100 (3.9%)
Midwest	1,200 (1.9%)	2,000 (2.7%)	2,400 (2.6%)	2,600 (2.6%)
Southwest	18,000 (28.4%)	12,000 (20.3%)	14,000 (22.0%)	15,000 (21.8%)
		Maximum Impact Condition		
Southeast	15,000 (41.6%)	14,000 (37.0%)	16,000 (38.4%)	17,000 (38.0%)
Midwest	13,000 (18.1%)	17,000 (19.3%)	21,000 (19.1%)	22,010 (18.9%)
Southwest	25,000 (36.5%)	17,000 (26.4%)	20,000 (28.4%)	21,000 (28.2%)

Manpower requirements for construction of disposal facilities are lowest for a repository in salt and highest for a repository in basalt. Impacts associated with these facilities will be discussed below; effects associated with the remaining two facilities fall between these two extreme cases. For a repository in salt, the total numbers of forecasted new in-migrants in the Southeast and Midwest sites under expected impact conditions are under 3% of the site county populations in the construction (1980-1984) and operation (1985-2005) phases. In-migration at this level is not likely to produce significant impacts. The effect of a repository in salt at the Southwest site is substantially different. The number of in-migrants during construction is over three times the level of primary employment demand (4451 versus 1430). As a percent of projected baseline population size, the potential for significant impacts is much greater in the Southwest. Project-related in-migration which exceeds 10% of the corresponding baseline population is considered to produce significant impacts. In-migration to the Southwest site is close to this level.

For a repository in basalt, expected impacts at the Southeast and Midwest sites are also judged to be non-significant. As a percent of the baseline population, the forecasted numbers of in-migrants barely exceed 4% in the operation phase at the Southeast site (Table 4.4.2-7). Again, the Southwest site is subjected to relatively large impacts, primarily because there is a scarcity of skilled available local labor.

The maximum impact condition (see Tables 4.4.2-4 and 4.4.2-7) produces substantially larger project-induced in-migrant flows for each site and disposal medium compared with the expected conditions. Very severe impacts are forecast for the Southeast and Southwest sites, though the likelihood of their occurrence is not great for two reasons. First, the manpower estimates and model assumptions have been set to produce an upper bound on social impacts. Second, in-migration at these levels would produce unacceptable local imbalances in the service infrastructure, which would result in greater turnover on the project and increased out-migration from the site county. These kinds of feedback effects are not modeled in the forecasting procedures used here. Although the numbers of in-migrants are smaller, the potential for impacts in the Southeast maximum impact condition is greater than the potential in the

Southwest site under expected conditions for each disposal medium. This is the case because the base population in the Southwest site is roughly twice that in the Southeast site; therefore, the Southwest is capable of absorbing greater population influx, other things being equal.*

The translation of forecasted project-related in-migration into socioeconomic impacts is complex and imprecise. Estimates of the level of demand that will be placed on the community to provide social services to the new workers and their families were made by applying a set of factors (see Appendix C) to the project in-migration values. The product indicates how many units of each social service would be "expected" by the in-migrants. The severity of these impacts is primarily related to the capacity of the site county to meet these expectations. To contain all of the spent fuel in the reference 10,000 GWe-yr scenario, eight reference repositories in salt, three in granite or basalt, or six in shale will be required; thus the impacts described would occur 8,3,or 6 times depending on the medium chosen for disposal.

The calculated level of expected and maximum need for additional social services at the three reference sites is given for the year 2000 for spent fuel and fuel reprocessing repositories in Tables 4.4.2-8 through 4.4.2-11. Identification of social services that would likely be required indicates the potential extent of socioeconomic impacts. The ability of communities to provide services identified here, with or without financial assistance, is highly site-specific and is beyond the scope of this document. Some of the social services listed can be described as operational, such as physicians and teachers. These needs are more easily met on a temporary, less costly basis than are those services that require major capital investment. The latter include hospital beds to the extent that hospital space is also needed, classroom space, and additional waste treatment capacity. Capital investment needs are forecast to be large, especially in the Southwest site, and to the extent that they persist over time, they will represent a serious challenge to community planners and local government. The increase in the local crime rate is only one indicator of the social disruption and a sense of a decline in social well-being experienced by community residents faced with large-scale development. This analysis does not address the site specific but very important impact of any major construction activity, and that is the impact of increased property values hence taxes and increased commodity prices on fixed income families.

In general, the reference Southwest site is more likely to sustain significant socioeconomic impacts compared with the other two sites because it has a smaller available unemployed construction labor force, lacks a nearby metropolitan center, and is subject to the generation of greater secondary employment growth compared with the other sites. If a repository were to be built in an area where demographic conditions approximated that of the Southwest site, a detailed analysis of site-specific socioeconomic impacts would be needed to help prevent serious disruptions in provision of necessary social services.

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* Both the absolute numbers of new in-migrants and the size of this in-migrant group relative to the size of the baseline county population are important factors in assessing impacts. In addition, the population size of the region which contains the site is important because it determines the non-migrant supply of labor for the project. The Southeast regional population is almost four times that in the Southwest region while the Southwest county population is more than double the county population in the Southeast county.

TABLE 4.4.2-8. Selected Social Service Demands Associated with Migration into the Site County Resulting from the Construction and Operation of a Geologic Repository in Salt (47,000 MTHM Waste Capacity): Spent Fuel (Once-Through Cycle)

	Year 2000					
	Expected Demand			Maximum Demand		
Selected Social Services	Southeast Site	Midwest Site	Southwest Site	Southeast Site	Midwest Site	Southwest Site
Health						
Physicians	1	2	5	5	4	10
Nurses	2	6	13	16	15	26
Dentists	0	1	2	2	2	3
Hospital beds	2	7	17	20	18	34
Nursing care beds	1	8	11	10	17	21
Education						
Teachers (K-12)	7	15	66	70	35	130
Classroom space, m^2 (9-12)	960	2,200	8,400	8,600	4,800	16,000
Sanitation, m^3/day						
Water treatment	320	710	3,000	3,100	1,700	5,800
Liquid waste	220	480	2,000	2,100	1,200	3,900
Safety						
Firemen	0	1	4	4	2	7
Policemen	1	3	10	11	6	20
Recreation, ha						
Neighborhood parks	1	1	4	5	3	9
Government						
Administrative staff	1	1	5	5	3	9
Other social impacts						
Crimes (7 crime index)	26	54	300	250	130	600

TABLE 4.4.2-9. Selected Social Service Demands Associated with Migration into the Site County Resulting from the Construction and Operation of a Geologic Repository in Granite (126,000 MTHM Waste Capacity): Spent Fuel (Once-Through Cycle)

	Year 2000					
	Expected Demand			Maximum Demand		
Selected Social Services	Southeast Site	Midwest Site	Southwest Site	Southeast Site	Midwest Site	Southwest Site
Health						
Physicians	1	3	12	12	22	17
Nurses	3	11	31	40	81	46
Dentists	0	1	4	4	9	6
Hospital beds	4	13	40	51	96	59
Nursing care beds	2	12	25	24	85	36
Education						
Teachers (K-12)	11	25	160	180	200	230
Classroom space, m^2 (9-12)	1,400	3,300	19,000	21,000	24,000	27,000
Sanitation, m^3/day						
Water treatment	540	1,200	6,900	7,800	9,300	10,000
Liquid waste	360	830	4,000	5,200	6,200	6,800
Safety						
Firemen	1	2	8	9	11	12
Policemen	2	4	24	28	33	36
Recreation, ha						
Neighborhood parks	1	2	10	11	14	15
Government						
Administrative staff	1	2	11	12	15	16
Other social impacts						
Crimes (7 crime index)	45	94	710	660	700	1,000

TABLE 4.4.2-10. Selected Social Service Demands Associated with Migration into the Site County Resulting from the Construction and Operation of a Geologic Repository in Shale (63,000 MTHM Waste Capacity): Spent Fuel (Once-Through Cycle)

	Year 2000					
	Expected Demand			Maximum Demand		
Selected Social Services	Southeast Site	Midwest Site	Southwest Site	Southeast Site	Midwest Site	Southwest Site
Health						
Physicians	1	2	6	6	7	11
Nurses	2	7	17	20	25	30
Dentists	0	1	2	2	3	4
Hospital beds	2	8	22	26	30	39
Nursing care beds	1	9	14	13	28	24
Education						
Teachers (K-12)	8	17	86	89	59	150
Classroom space, m^2 (9-12)	1,100	2,400	1,050	11,000	7,900	18,000
Sanitation, m^3/day						
Water treatment	370	810	3,800	3,900	2,900	6,600
Liquid waste	250	540	2,500	2,600	1,900	4,400
Safety						
Firemen	0	1	4	5	3	8
Policemen	1	3	13	14	10	23
Recreation, ha						
Neighborhood parks	1	1	6	6	4	10
Government						
Administrative staff	1	1	6	6	5	10
Other social impacts						
Crimes (7 crime index)	30	62	590	320	220	680

TABLE 4.4.2-11. Selected Social Service Demands Associated with Migration into the Site County Resulting from the Construction and Operation of a Geologic Repository in Basalt (126,000 MTHM Waste Capacity): Spent Fuel (Once-Through Cycle)

	Year 2000					
	Expected Demand			Maximum Demand		
Selected Social Services	Southeast Site	Midwest Site	Southwest Site	Southeast Site	Midwest Site	Southwest Site
Health						
Physicians	1	3	14	14	28	19
Nurses	3	12	37	48	104	52
Dentists	0	1	4	4	12	6
Hospital beds	4	14	47	61	124	66
Nursing care beds	2	13	29	29	108	41
Education						
Teachers (K-12)	12	27	180	210	270	260
Classroom space, m^2 (9-12)	1,500	3,500	22,000	24,000	30,000	30,000
Sanitation, m^3/day						
Water treatment	590	1,400	8,100	9,300	12,000	11,000
Liquid waste	390	900	5,400	6,200	8,000	7,600
Safety						
Firemen	1	2	10	11	14	13
Policemen	2	5	28	33	42	40
Recreation, ha						
Neighborhood parks	1	2	12	14	18	17
Government						
Administrative staff	1	2	13	15	19	18
Other social impacts						
Crimes (7 crime index)	48	103	830	760	900	1,200

Nonradiological Accidents

The postulated tornado strike of the uncovered surface storage piles could also occur during the operational phase of the repository prior to completion of mine backfilling. Impacts of this accident are presented under Construction Impacts (Section 4.4.1).

4.4.3 Environmental Effects Related to Postulated Radiological Accidents

Several moderate and non-design basis accidents that could result in the release of radionuclides were analyzed for the spent fuel repository in salt. The accidents were chosen on the basis of their probability of occurrence and radiological consequences. No severe accidents (as defined for this report) were identified for the repository. Scenarios are provided in DOE/ET-0028 and the accidents are listed in Table 4.4.3-1.

TABLE 4.4.3-1. Postulated Accidents for the Geologic Repository for Spent Fuel

Accident Number	Accident	Analyzed
	Minor	
7.2	Minor canister failure	Yes
	Moderate	
7.5	Canister drop in surface facility	No (No worse than Accident 7.6)
7.6	Canister drop down mine shaft	Yes
7.7	Tornado strikes salt storage area	Yes
	Non-Design Basis	
7.10	Nuclear warfare	No (No worse than Accident 7.11)
7.11	Repository breach by meteorite impact	Yes
7.12	Repository breach by drilling	Yes
7.13	Repository breach by faulting	Yes
7.14	Volcanism	No (No worse than Accident 7.11)

Canister Drop Down Mine Shaft - Accident 7.5. For the canister drop down mine shaft accident, radionuclides are assumed to be released to the mine atmosphere from the failed canister over a period of 1 hr. A canister of spent fuel will contain four fuel assemblies, consisting of 2 MTHM, that are assumed to be ten years out of the reactor. It is estimated that the 2 MT of spent fuel will release 30% of the ^{85}Kr 1% of the ^{3}H, 3% of the ^{14}C, 10% of the iodine, 1% of the contained solids, and 0.1% of the cladding to the mine filters. Frequency of occurrence of the accident is postulated to be 2.7×10^{-7} per year. Details of the accident are given in Section 7.3.1.9 of DOE/ET-0028.

Radiological Effects. The radioactive materials that would be released to the environment are presented in Table 4.4.3-2. The releases were determined using the assumption that material released in the mine shaft passes through a roughing filter and two HEPA filters (total DF for particulates of 10^{7}) prior to release to the environment through the 110-m stack.

TABLE 4.4.3-2. Radioactive Material Released to the Atmosphere from a Canister Drop Down Mine Shaft Accident at the Geologic Repository for Spent Fuel

Radionuclide	Release, Ci
^{3}H	1.7×10^{2}
^{14}C	2.0×10^{-1}
^{85}Kr	3.6×10^{3}
^{90}Sr	1.1×10^{-4}
^{90}Y	1.1×10^{-4}
^{129}I	1.8×10^{-2}
^{137}Cs	1.5×10^{-4}
^{238}Pu	3.9×10^{-6}
^{239}Pu	5.2×10^{-7}
^{240}Pu	8.4×10^{-7}
^{241}Pu	1.6×10^{-4}
^{241}Am	2.0×10^{-6}
^{244}Cm	1.8×10^{-6}

Based on these releases, the 70-year dose commitment to the maximum individual was calculated and is presented in Table 4.4.3-3. The 70-year total-body dose to the maximum individual would be 1.4×10^{-4} rem compared with 7.0 rem from naturally occurring sources. The 70-year total-body doses to the worldwide population would be 4.7 man-rem compared with 4.5×10^{10} man-rem from naturally occurring sources.

TABLE 4.4.3-3. 70-Year Doses to the Maximum Individual from a Canister Drop Down Mine Shaft Accident at the Geologic Repository for Spent Fuel (rem)

Pathway	Skin	Total Body	Thyroid	Lung	Bone
Air submersion	2.2×10^{-3}	2.3×10^{-5}	2.3×10^{-5}	2.3×10^{-5}	2.3×10^{-5}
Inhalation		1.2×10^{-4}	6.4×10^{-4}	1.5×10^{-4}	7.6×10^{-5}
Total	2.2×10^{-3}	1.4×10^{-4}	6.6×10^{-4}	1.7×10^{-4}	9.9×10^{-5}

Note: The maximum individual is defined as a permanent residence at a location 1600 m southeast of the stack with the time-integrated atmospheric dispersion factor (E/Q) of 1.3×10^{-5} sec/m^3.

Repository Breach by Meteorite Impact - Accident 7.11. Breach of the repository by a meteorite impact (non-design basis accident) would require that a meteorite strike the surface above the repository area and that the meteorite have sufficient mass and velocity to cause a crater with a depth of about 600 m. Based on a 3:1 ratio of crater diameter to depth for

large meteorites, a crater approximately 600 m deep would be expected to have a diameter of about 2 km. The probability of meteorites striking the surface over the repository area and producing a crater 2 km in diameter is 2×10^{-7} over a 1 million year period or 2×10^{-13} strikes per year.

Most large meteorites are composed of iron or nickel and iron with a density of about 8 g/cm^3. Assuming an impact velocity of 20 km/sec and following the 3:1 ratio of crater diameter to depth, a meteorite of at least 7×10^7 kg (about 25 m in diameter) would be required to form a crater 600 m deep. The kinetic energy of such a meteorite would be equivalent to that from about 3.5 million tons of TNT.

Temperatures at the point of impact would be in the millions of degrees, and most of the meteorite plus some of the surrounding rock would be vaporized. Some of the rock material would be pulverized and ejected into the air during fomation of the crater. Most of the ejected material would be expected to fall back into the crater and its immediate vicinity. Probably a small fraction of the waste contained in the repository would be ejected.

Physical and thermal effects of a meteorite strike at the geologic repository have been extrapolated from the effects expected from a 3.5 megaton nuclear explosion above ground. Several factors must be considered in making this extrapolation since the amount of initial energy from the meteorite that will be converted to air blast (shockwave), ground shock, and thermal energy is not known. For a nuclear explosion about 50% of the energy is converted to air blast and ground shock and about 35% is converted to thermal energy.[18] For a TNT explosion about 100% of the energy is converted to air blast and ground shock with minimal conversion to thermal energy.[18] Therefore, if the effects of a meteorite strike are extrapolated from those of a 3.5-megaton nuclear explosion, physical effects from air blast and ground shock could be underestimated by a factor of 2 should the meteorite strike actually resemble more closely a 3.5-megaton TNT blast. Thermal effects could be considerably overestimated from the same extrapolation.

The major physical damage from a meteorite impact will be caused by air blast energy from the impact. Energy will also be spent in producing a crater and shock (or pressure) waves in the ground. Table 4.4.3-4 presents predicted damage from the meteorite strike for selected structures and objects at various distances from the point of impact. Structural damage would be light beyond 16 km from the point of impact. Between 16 km and 3.2 km, damage increases steadily until complete destruction (Type A) would be expected within 3.2 km from impact. One exception would be the blast-resistant reinforced-concrete windowless buildings that would not be expected to undergo Type A destruction unless located within 1.6 km from the point of impact.

Maximum predictable thermal effects would result in skin burns and ignition of flammable materials within 20 km of the impact. Actual thermal effects are expected to be limited to a smaller area. Maximum skin effects might be:

Burn Type	Distance, km
Third degree	12
Second degree	14
First degree	20

TABLE 4.4.3-4. Predicted Structural Damage Caused by a Meteorite Strike (crater 2 km in diameter) at a Geologic Repository for Spent Fuel[18]

Distance from Point of Impact, km	Blast-Resistant Reinforced-Concrete Windowless Building	Multistory Building, Brick Apartment House	Wood Frame House	Heavy Steel Frame Industrial (1 Story, Light Walls)	Motorized Vehicles	Forests (400 trees per hectare)
80						
32		D	D	D		
16		D	D	D		G
8		C	B	C	D	F
3	C	A	A	A	A	E
<1.6	A	A	A	A	A	E

Key:

Type A, virtually complete destruction.
Type B, destruction severe enough to need very extensive (perhaps prohibitive) repair.
Type C, would require major repairs before the object or structure could be used for its intended purpose.
Type D, damage would involve minor repairs or even further use without repairs.
Type E, up to 90% of trees down; remainder denuded of branches and leaves.
Type F, about 30% of trees down; remainder have some branches and leaves blown off.
Type G, few trees down; some leaves and branches blown off.

Maximum thermal energy received might be:

Thermal Energy, cal/cm^2	Distance, km
12	19
8	22
5	27
3	35

Effects of these thermal energies can be related to the following ignition energies for some common materials:

Material	Energy, cal/cm^2
Newspaper	6
Tanned leather	30
Charring of wood	10-15
Cotton shirt	13
Wool flannel	16

From this information it is evident that considerable damage from shock waves and heat can be expected for a significant distance from the point of impact of a large meteorite strike.

Comparison of the meteorite impact to a nuclear explosion raises the question of release of repository inventory in the case of repository breach during a nuclear war. It also points up a disparity between estimates of the size of nuclear weapons capable of breaching the repository and calculated sizes of weapons based on the kinetic energy of the meteorite. On the one hand the difference appears large; however, in the case of the meteorite, essentially all of the kinetic energy is given up in deformation and vaporization at ground level.

Clairborne and Gera[19] state,

> The energy released in the impact (meteorite) would be on the order of several megatons of TNT, and the explosion would be similar to a nuclear blast complete with fireball, shock waves, and mushroom cloud. Temperature in the fireball would reach millions of degrees, and most of the meteorite mass would be vaporized together with some of the indigenous rocks. Some more of the geologic materials would be pulverized and thrown in the air, the destiny of the fine ejecta being controlled by the size of the particles and the height reached. Large particles would fall rapidly to the ground, but fine particles (submicron to a few microns) would remain airborne for significant periods. A certain amount of fine dust would be injected into the stratosphere and, in turn, would achieve worldwide distribution. However, the observation of young impact craters shows that by far the greatest part of the ejected material would fall back inside the crater and its immediate vicinity to form the crater rim and fill.

On the other hand their remarks on nuclear warfare suggest that much larger releases of energy from nuclear weapons would not breach the reference repository. As they state,

> Current nuclear weapons are of such size that a surface burst would penetrate a sealed repository no deeper than 500 m. The largest deployed missile is reported to be capable of carrying a 25-megaton warhead. Using the information given by Glasstone, a surface burst of this magnitude would generate a 270 m deep crater with a fracture zone down to about 400 m in a geologic material with the physical properties of dry soil. The crater would be somewhat smaller in salt. Assuming the development of a 50 megaton weapon, the potential crater depth in dry soil would increase to only 340 m and the fracture zone to 500 m. Since the waste horizon will be about 600 m below the surface, the containment would not be breached even for the larger weapon.*

Other calculations made for this report and based on the work of Glasstone[18] suggest that a nuclear device of on the order of 130 megatons of TNT equivalent (air blast) would be required to produce a crater 2 km in diameter and 600 m deep.

Within the reference environment there are 150 persons assumed to be residing within 3.2 km of the repository center, the assumed point of meteor impact. It is presumed that all of these would be killed by the blast and thermal effects. Similarly devastation of biota in the near-field would be complete. If the same size meteor impacted in the metropolitan area of city G in the reference environment, (50 to 80 km away) the death rate based on total fatalities within a 3.2 km radius would be about 25,000 persons.

Radiological Effects. The amount of waste released in the event of a meteorite impact would depend on the amount of waste in an individual repository. In this LWR scenario, the number of repositories depends on the geologic medium in which the repository is constructed. In the reference case, there are eight spent fuel repositories in salt, three in granite, six in shale, of three in basalt. The reason for the difference in numbers of repositories is based on the design thermal loading for the host rock and the degree to which the reference 800 ha underground

*Note that the reference repository is located at a beginning depth of 525 m rather than 600 m.

cavity may be used for waste disposal. (Larger supporting columns are required for salt than for granite. Thus, for a given areal extent, a granite repository of the same overall area could contain a greater amount of waste.)

No account is made of differences in release of waste that may result from a meteorite impacting on different rock in this analysis (some difference may be expected in the aftermath of an impact of a large meteorite between sedimentary and igneous rock). The likely disposal concept actually put in place may employ repositories in several media. There are apparently no engineering reasons for not having the same amount of waste in each repository with the overall area being a variable rather than a constant. At this time, separation of wastes for placement in different repositories is not contemplated, hence, the relative abundance of individual radionuclides will remain the same regardless of the number of repositories among which the waste is distributed. The consequences of a meteorite strike were calculated based on a fractional release of all wastes generated for the 10,000 GWe-Yr scenario. The tabulated consequences may be divided by the number of repositories or the fraction of total waste inventory in a given repository to obtain an estimate of consequences for the repository presumed to be struck.

At a penetration depth of 600 m, the meteorite impact is assumed to disperse 1% of the repository inventory. The amounts of various radionuclides ejected depend on the length of time between repository closure and meteorite impact. This event is characterized for a strike in the year 2050 (assumed time of repository closure and maximum inventory) and for 1000, 100,000 or 1,000,000 years thereafter.

Dispersion of suspended radioactive material from a meteorite impact is assumed to occur by two modes, developed on the basis of nuclear crater test results.[20] Typical cloud formation consists of a central column rising about a doughnut-shaped (torus) base surge, which rolls outward from the crater. It is assumed that one-half of the suspended material is dispersed in the central column and one-half is dispersed in the base cloud. The material in the central cloud is also assumed to be dispersed evenly across the eastern half of the United States and then to move around the world at high altitude. Compared to the base cloud, it would not contribute significantly to local (radius of 80 km) fallout. Large over-pressures in air produced on meteorite impact are assumed to override any local low altitude winds.

For particulates (all but ^{3}H, ^{14}C, ^{85}Kr, and ^{129}I are assumed to be in particulate form) the source term for this accident, 1% of the repository inventory, is multiplied by 0.1 because it is assumed that only 10% of the particulates suspended are of respirable size. The remaining 90% of the material is assumed to fall out immediately back into or near the crater and not contribute to resulting doses to the regional population. For the regional population the source term is also reduced by one-half to account for the distribution of material between central and base clouds.

Based on the source terms given in Table 4.4.3-5 (1% of LWR scenario spent fuel inventory) for a meteorite strike and on the methods described in Appendix B, 70-year accumulated doses and first-year doses to the maximum individual were calculated using the following assumptions and are presented in Tables 4.4.3-6 through 4.4.3-8.

- Suspended material is uniformly distributed in the cylindrical base cloud.
- The maximum individual is exposed to the base cloud concentration for 2 hr (wind speed of ∿1 m/sec).
- The dimensions of the base cloud are an 8000 m dia and a 1200 m height.
- The maximum individual is located 4000 m from the point of meteorite impact.
- Deposition of material occurs for about 2.2 hr (8000 sec) at the standard deposition velocities.

TABLE 4.4.3-5. Radionuclides (in Ci) Released to the Atmosphere from a Repository from Spent Fuel[a] - Breach by Meteorite

Radionuclide	Year 2050	+1,000 Years	+100,000 Years	+1,000,000 Years
^{3}H	1.1×10^{5}			
^{14}C	6.0×10^{2}	5.5×10^{2}	3.5×10^{-3}	
^{60}Co	2.1×10^{4}			
^{85}Kr	2.0×10^{6}			
^{90}Sr	5.0×10^{6}	6.5×10^{-4}		
^{90}Y	5.0×10^{6}	6.5×10^{-4}		
^{99}Tc	2.4×10^{3}	2.4×10^{3}	1.7×10^{3}	9.0×10^{1}
^{125m}Te	1.1×10^{3}			
^{126}Sn	9.0×10^{1}	9.0×10^{1}	4.4×10^{1}	8.5×10^{-2}
^{126}Sb	9.0×10^{1}	9.0×10^{1}	4.4×10^{1}	8.5×10^{-2}
^{126m}Sb	9.0×10^{1}	9.0×10^{1}	4.4×10^{1}	8.5×10^{-2}
^{129}I	6.0×10^{1}	6.0×10^{1}	6.0×10^{1}	6.0×10^{1}
^{137}Cs	7.0×10^{6}	3.9×10^{-3}		
^{154}Eu	2.2×10^{5}			
^{210}Pb	2.7×10^{-4}	4.6×10^{-1}	1.7×10^{2}	6.5×10^{1}
^{210}Bi	2.7×10^{-4}	4.6×10^{-1}	1.7×10^{2}	6.5×10^{1}
^{226}Ra	7.0×10^{-4}	4.5×10^{-1}	1.7×10^{2}	6.5×10^{1}
^{227}Ac	4.2×10^{-3}	7.5×10^{-2}	4.3	5.0
^{229}Th	7.0×10^{-5}	2.5×10^{-2}	7.5×10^{1}	1.8×10^{2}
^{230}Th	7.5×10^{-2}	2.5	1.6×10^{2}	8.5×10^{1}
^{233}Pa	6.5×10^{1}	1.7×10^{2}	2.0×10^{2}	1.5×10^{2}
^{233}U	2.3×10^{-2}	5.5×10^{-1}	7.0×10^{1}	1.6×10^{2}
^{234}U	2.2×10^{2}	3.2×10^{2}	2.6×10^{2}	7.5×10^{1}
^{236}U	4.2×10^{1}	4.4×10^{1}	6.5×10^{1}	9.0×10^{1}
^{237}Np	6.5×10^{1}	1.7×10^{2}	2.0×10^{2}	1.5×10^{2}
^{238}U	2.9×10^{5}	6.0×10^{1}	6.0×10^{1}	6.0×10^{1}
^{238}Pu	2.9×10^{5}	8.5×10^{3}		
^{239}Pu	5.5×10^{4}	5.5×10^{4}	3.3×10^{3}	3.2×10^{-6}
^{239}Np	2.5×10^{3}	2.3×10^{3}	3.2×10^{-1}	
^{240}Pu	8.5×10^{4}	7.5×10^{4}	3.4	
^{241}Pu	3.9×10^{6}	3.0×10^{1}	8.0×10^{-3}	
^{241}Am	6.0×10^{5}	1.6×10^{5}	8.0×10^{-3}	
^{242}Pu	2.9×10^{2}	2.9×10^{2}	2.4×10^{2}	4.7×10^{1}
^{244}Cm	6.0×10^{4}	8.0×10^{-5}		

a. Assuming all wastes are in one repository (representing 379,000 MTHM).

TABLE 4.4.3-6. First-Year Doses to the Maximum Individual for Breach of Spent Fuel Repository in Salt (47,000 MTHM waste capacity) by Meteorite at Various Times After Repository Closure (Rem)

Pathway	Total Body	Thyroid	Lung	Bone
		Breach at 50 Years		
Air submersion	1.6×10^{-2}	1.6×10^{-2}	1.6×10^{-2}	1.6×10^{-2}
External	2.3×10^{3}	2.3×10^{3}	2.3×10^{3}	2.3×10^{3}
Inhalation	1.5×10^{1}	4.4×10^{-3}	1.3×10^{2}	1.9×10^{2}
Ingestion	6.0×10^{3}	3.6×10^{2}	4.8×10^{2}	1.4×10^{4}
Total	8.3×10^{3}	2.7×10^{3}	2.9×10^{3}	1.6×10^{4}
		Breach at 1,000 Years		
Air submersion	1.5×10^{-5}	1.5×10^{-5}	1.5×10^{-5}	1.5×10^{-5}
External	2.4	2.4	2.4	2.4
Inhalation	2.4	1.7×10^{-3}	3.2×10^{2}	4.1×10^{1}
Ingestion	1.2	3.6×10^{2}	7.5×10^{-3}	1.3×10^{1}
Total	6.0	3.6×10^{2}	3.2×10^{2}	5.6×10^{1}
		Breach at 100,000 Years		
Air submersion	4.8×10^{-7}	4.8×10^{-7}	4.8×10^{-7}	4.8×10^{-7}
External	2.4×10^{-1}	2.4×10^{-1}	2.4×10^{-1}	2.4×10^{-1}
Inhalation	4.1×10^{-2}	1.7×10^{-3}	5.2	8.1×10^{-1}
Ingestion	4.1	3.6×10^{2}	6.3×10^{-4}	5.5
Total	4.4	3.6×10^{2}	5.5	6.6
		Breach at 1,000,000 Years		
Air submersion	1.2×10^{-7}	1.2×10^{-7}	1.2×10^{-7}	1.2×10^{-7}
External	1.5×10^{-1}	1.5×10^{-1}	1.5×10^{-1}	1.5×10^{-1}
Inhalation	1.5×10^{-2}	1.6×10^{-3}	1.8	2.5×10^{-1}
Ingestion	2.3	3.4×10^{2}	3.3×10^{-5}	3.1
Total	2.5	3.4×10^{2}	2.0	3.5

NOTE: The maximum individual is assumed to be standing 4000 m from the point of meteorite impact where the time-integrated atmospheric dispersion factor (E/Q) is 1.2×10^{-7}.

TABLE 4.4.3-7. First-Year Dose to the Maximum Individual for Breach of Spent Fuel Repository in Shale (63,000 MTHM waste capacity) at Various Times After Repository Closure (Rem) by Meteorite

Pathway	Total Body	Thyroid	Lung	Bone
		Breach at 50 Years		
Air submersion	2.1×10^{-2}	2.1×10^{-2}	2.1×10^{-2}	2.1×10^{-2}
External	3.1×10^{3}	3.1×10^{3}	3.1×10^{3}	3.1×10^{3}
Inhalation	2.0×10^{1}	6.0×10^{-3}	1.7×10^{3}	2.6×10^{2}
Ingestion	8.0×10^{3}	4.8×10^{2}	6.5×10^{2}	1.9×10^{4}
Total	1.1×10^{4}	3.6×10^{3}	5.5×10^{3}	2.3×10^{4}
		Breach at 1,000 Years		
Air submersion	2.0×10^{-5}	2.0×10^{-5}	2.0×10^{-5}	2.0×10^{-5}
External	3.2	3.2	3.2	3.2
Inhalation	3.3	2.3×10^{-3}	4.3×10^{2}	5.5×10^{1}
Ingestion	1.6	4.8×10^{2}	1.0×10^{-2}	1.8×10^{1}
Total	8.1	4.8×10^{2}	4.3×10^{2}	7.6×10^{2}
		Breach at 100,000 Years		
Air submersion	6.5×10^{-7}	6.5×10^{7}	6.5×10^{-7}	6.5×10^{-7}
External	3.2×10^{-1}	3.2×10^{-1}	3.2×10^{-1}	3.2×10^{-1}
Inhalation	5.5×10^{-2}	2.3×10^{-3}	7.0	1.1
Ingestion	5.5	4.8×10^{2}	8.5×10^{-4}	7.5
Total	5.9	4.8×10^{2}	7.4	8.9
		Breach at 1,000,000 Years		
Air submersion	1.6×10^{-7}	1.6×10^{-7}	1.6×10^{-7}	1.6×10^{-7}
External	2.0×10^{-1}	2.0×10^{-1}	2.0×10^{-1}	2.0×10^{-1}
Inhalation	2.0×10^{-6}	2.2×10^{-3}	2.4	3.4×10^{-1}
Ingestion	3.1	4.6×10^{2}	2.0×10^{-1}	4.4×10^{-1}
Total	3.3	4.6×10^{2}	2.8	9.8×10^{-1}

NOTE: The maximum individual is assumed to be standing 4000 m from the point of meteorite impact where the time-integrated atmospheric dispersion factor (E/Q) is 1.2×10^{-7}.

TABLE 4.4.3-8. First-Year Dose to the Maximum Individual for Breach of Spent Fuel Repository in Granite or Basalt (126,000 MTHM waste capacity) at Various Times After Repository Closure (rem) by Meteorite

Pathway	Total Body	Thyroid	Lung	Bone
		Breach at 50 Years		
Air submersion	4.2×10^{-2}	4.2×10^{-2}	4.2×10^{-2}	4.2×10^{-2}
External	6.2×10^{3}	6.2×10^{3}	6.2×10^{3}	6.2×10^{3}
Inhalation	4.0×10^{1}	1.2×10^{-2}	3.3×10^{3}	5.2×10^{2}
Ingestion	1.6×10^{4}	9.5×10^{2}	1.3×10^{3}	3.8×10^{4}
Total	2.2×10^{4}	7.2×10^{3}	1.1×10^{4}	4.5×10^{4}
		Breach at 1,000 Years		
Air submersion	4.0×10^{-5}	4.0×10^{-5}	4.0×10^{-5}	4.0×10^{-5}
External	6.3	6.3	6.3	6.3
Inhalation	6.5	4.5×10^{-3}	8.5×10^{2}	1.1×10^{2}
Ingestion	3.2	9.5×10^{2}	2.0×10^{-2}	3.5×10^{1}
Total	1.6×10^{1}	9.6×10^{2}	8.6×10^{2}	1.5×10^{2}
		Breach at 100,000 Years		
Air submersion	1.3×10^{-6}	1.3×10^{-6}	1.3×10^{-6}	1.3×10^{-6}
External	6.3×10^{-1}	6.3×10^{-1}	6.3×10^{-1}	6.3×10^{-1}
Inhalation	1.1×10^{-1}	4.5×10^{-3}	1.4×10^{1}	2.2
Ingestion	1.1×10^{1}	9.5×10^{2}	1.7×10^{-3}	1.5×10^{1}
Total	1.2×10^{1}	9.5×10^{2}	1.5×10^{1}	1.8×10^{1}
		Breach at 1,000,000 Years		
Air submersion	3.2×10^{-7}	3.2×10^{-7}	3.2×10^{-7}	3.2×10^{-7}
External	4.0×10^{-1}	4.0×10^{-1}	4.0×10^{-1}	4.0×10^{-1}
Inhalation	4.0×10^{-2}	4.3×10^{-3}	4.8	6.7×10^{-1}
Ingestion	6.2	9.2×10^{2}	4.0×10^{-1}	8.7×10^{-1}
Total	6.6	9.2×10^{2}	5.6	1.9

NOTE: The maximum individual is assumed to be standing 4000 m from the point of meteorite impact where the time-integrated atmospheric dispersion factor (E/Q) is 1.2×10^{-7}.

Doses presented in Table 4.4.3-6 through 4.4.3-9 are directly proportional to the fraction of inventory released; thus, if it were postulated that 10% of the inventory was released, the reported dose would be 10 times higher.

The maximum individual, who is assumed to be at 4 km from point of impact, is believed to have only a small chance of surviving the initial blast of the meteorite. Regardless, doses in the first year following a release of wastes in the year 2050 from one among 8 repositories (salt case) would amount to 8300 rem and would be fatal.

TABLE 4.4.3-9. 70-Year Accumulated Doses to the Maximum Individual from Breach of Spent Fuel Repositories by Meteorite at Various Times after Closure, man-rem

Repository Media	Total Body	Thyroid	Lung	Bone
		Breach at 50 Years		
Salt	3.9×10^{6}	1.6×10^{5}	1.7×10^{5}	1.5×10^{7}
Granite	1.0×10^{7}	4.3×10^{5}	4.5×10^{5}	4.0×10^{7}
Basalt	1.0×10^{7}	4.3×10^{5}	4.5×10^{5}	4.0×10^{7}
Shale	5.1×10^{6}	2.2×10^{5}	2.3×10^{5}	2.0×10^{7}
		Breach at 1,000 Years		
Salt	3.6×10^{2}	1.1×10^{3}	1.0×10^{3}	3.9×10^{3}
Granite	9.5×10^{2}	2.8×10^{3}	2.7×10^{3}	1.0×10^{4}
Basalt	9.5×10^{2}	2.8×10^{3}	2.7×10^{3}	1.0×10^{4}
Shale	4.7×10^{2}	1.4×10^{3}	1.4×10^{3}	5.0×10^{3}
		Breach at 100,000 Years		
Salt	3.3×10^{2}	8.8×10^{2}	3.0×10^{1}	9.4×10^{2}
Granite	8.9×10^{2}	2.3×10^{2}	8.0×10^{1}	2.5×10^{3}
Basalt	8.9×10^{2}	2.3×10^{2}	8.0×10^{1}	2.5×10^{3}
Shale	4.4×10^{2}	1.2×10^{2}	4.0×10^{1}	1.3×10^{3}
		Breach at 1,000,000 Years		
Salt	1.7×10^{2}	8.1×10^{2}	1.5×10^{1}	4.6×10^{2}
Granite	4.5×10^{2}	2.2×10^{3}	4.0×10^{1}	1.2×10^{3}
Basalt	4.5×10^{2}	2.2×10^{3}	4.0×10^{1}	1.2×10^{3}
Shale	2.2×10^{2}	1.1×10^{3}	2.0×10^{1}	6.0×10^{2}

NOTE: The maximum individual is assumed to be standing 4000 m from the point of meteorite impact where the time-integrated atmospheric dispersion factor (E/Q) is 1.2×10^{-7}.

An estimate was made of the number of persons in the reference environment who would be expected to receive at least 500 rem to the total body the first year from a breach in the year 2050. This was done by calculating the ratio of the atmospheric dispersion coefficients at various points of the compass and the distance from the point of contact. The number of persons so exposed amounted to about 30,000. If it is assumed that this dose is received in a short time, it would prove fatal to about one half of the individuals.

Doses to the maximum individual for breaches of a spent fuel repository after 1000 years and beyond are not particularly remarkable in terms of accidental exposure. Doses for a breach by meteorite in the year 3050 range from about 1/3 (salt case) to 3 times the currently applicable occupational exposure limit. Dose as a function of time of repository breach decreases slowly after the first thousand years. For a breach at one million years, the dose would vary from about 1% (salt case) to 100% (granite and basalt cases) of existing occupational dose limits.

Doses to the regional population (2 million persons within 80 km) were calculated based on the radionuclide releases given in Table 4.4.3-5 and the following assumptions:

- Suspended material is uniformly distributed in the cylindrical base cloud.
- The regional population is exposed to the base cloud concentration, which has been reduced by a factor of 10 for 2 hr (windspeed, ~1 m/sec).
- The dimensions of the base cloud are an 8000 m dia and a 1200 m height.
- The toroidal base cloud expands in radius across the 80 km of the reference environment.
- Deposition of material occurs for about 2.2 hr (8000 sec) at standard deposition velocities.
- About 120 days after the accident crops are planted and grown on the contaminated land.
- These crops are contaminated via root uptake and deposition of resuspended material on plant surfaces.

First-year doses and 70-year dose commitments to the regional population are given in Tables 4.4.3-10 and 4.4.3-11 respectively.

TABLE 4.4.3-10. First-Year Dose to the Regional Population for Breach of a Spent Fuel Repository by Meteorite at Various Times After Repository Closure (man-rem)

Repository Media	Total Body	Thyroid	Lung	Bone
		Breach at 50 Years		
Salt	2.1×10^{6}	3.0×10^{3}	1.7×10^{8}	2.8×10^{7}
Granite	5.7×10^{6}	8.0×10^{3}	4.5×10^{8}	7.3×10^{7}
Basalt	5.7×10^{6}	8.0×10^{3}	4.5×10^{8}	3.7×10^{7}
Shale	2.9×10^{6}	4.0×10^{3}	2.3×10^{8}	3.7×10^{7}
		Breach at 1,000 Years		
Salt	3.4×10^{5}	3.7×10^{2}	4.5×10^{7}	5.7×10^{6}
Granite	9.2×10^{5}	9.9×10^{2}	1.2×10^{8}	1.5×10^{7}
Basalt	9.2×10^{5}	9.9×10^{2}	1.2×10^{8}	1.5×10^{7}
Shale	4.6×10^{5}	5.0×10^{2}	6.0×10^{7}	7.5×10^{6}
		Breach at 100,000 Years		
Salt	5.7×10^{3}	3.7×10^{2}	7.5×10^{5}	1.1×10^{5}
Granite	1.5×10^{4}	9.9×10^{2}	2.0×10^{6}	3.0×10^{5}
Basalt	1.5×10^{4}	9.9×10^{2}	2.0×10^{6}	3.0×10^{5}
Shale	7.5×10^{3}	5.0×10^{2}	1.0×10^{6}	1.5×10^{5}
		Breach at 1,000,000 Years		
Salt	2.1×10^{3}	3.6×10^{2}	2.6×10^{5}	3.5×10^{4}
Granite	5.7×10^{3}	9.5×10^{2}	7.0×10^{5}	9.4×10^{4}
Basalt	5.7×10^{3}	9.5×10^{2}	7.0×10^{5}	9.4×10^{4}
Shale	2.8×10^{3}	4.8×10^{2}	3.5×10^{5}	4.7×10^{4}

TABLE 4.4.3-11. 70-Year Accumulated Doses to the Regional Population for Breach of a Spent Fuel Repository by Meteorite at Various Times After Closure (man-rem)

Repository Media	Total Body	Thyroid	Lung	Bone
		Breach at 50 Years		
Salt	6.9×10^{7}	3.1×10^{3}	4.1×10^{8}	1.0×10^{9}
Granite	1.8×10^{8}	8.2×10^{3}	1.1×10^{9}	2.7×10^{9}
Basalt	1.8×10^{8}	8.2×10^{3}	1.1×10^{9}	2.7×10^{9}
Shale	9.1×10^{7}	4.1×10^{3}	5.5×10^{8}	1.4×10^{9}
		Breach at 1,000 Years		
Salt	1.6×10^{7}	4.9×10^{2}	1.1×10^{8}	2.8×10^{8}
Granite	4.2×10^{7}	1.3×10^{3}	3.0×10^{8}	7.5×10^{8}
Basalt	4.2×10^{7}	1.3×10^{3}	3.0×10^{8}	7.5×10^{8}
Shale	2.1×10^{7}	6.5×10^{2}	1.5×10^{8}	3.8×10^{8}
		Breach at 100,000 Years		
Salt	2.8×10^{5}	4.8×10^{2}	1.8×10^{6}	5.3×10^{6}
Granite	7.4×10^{5}	1.3×10^{3}	4.8×10^{6}	1.4×10^{7}
Basalt	7.4×10^{5}	1.3×10^{3}	4.8×10^{6}	1.4×10^{7}
Shale	3.7×10^{5}	6.5×10^{2}	2.4×10^{6}	7.0×10^{6}
		Breach at 1,000,000 Years		
Salt	9.4×10^{4}	4.7×10^{2}	6.3×10^{5}	1.8×10^{6}
Granite	2.5×10^{5}	1.3×10^{3}	1.7×10^{6}	4.7×10^{6}
Basalt	2.5×10^{5}	1.3×10^{3}	1.7×10^{6}	4.7×10^{6}
Shale	1.2×10^{5}	6.5×10^{2}	8.5×10^{5}	2.4×10^{6}

The regional population was assumed to be replaced by a second-generation population at the end of the 70-year dose commitment period; the doses to that population were calculated. Similarly, doses to a third population, whose 70-year dose commitment period would begin 140 years after the repository breach, were calculated. Doses to the second and third generation are presented in Table 4.4.3-12.

Doses to the population of the eastern half of the United States were also calculated. It is assumed that the prevailing winds in the upper atmosphere will move the radionuclides released during the accident in an eastward direction, which will expose about 160 million persons east of the reference site. The 2 million persons in the reference population are excluded. Additional assumptions used in these calculations are as follows:

- All of the respirable material suspended from the meteorite impact would reach the exposed population.
- The exposed population is that in the eastern United States where 80% of the U.S. population resides (taken to be 160 million).

- Depletion by deposition was ignored when calculating average air concentrations at ground level.
- The atmospheric dispersion factor for this population is 8×10^{-3} sec/m^3, as determined from References 21 and 22 based on estimates of ^{85}Kr first-pass dispersion.
- The inhalation dose is based on the chronic breathing rate of 20 m^3/day.
- Dose from ingestion is based on a ground concentration of 2.7×10^{-13} Ci/m^2 per Ci released, which is based on uniform distribution of all material released over the eastern U.S.; an area of 3.8×10^6 km^2.(21)
- All of the material is deposited uniformly.

TABLE 4.4.3-12. 70-Year Dose Commitments to the Regional Population Beginning 70 and 140 Years After Breach of Spent Fuel Repository (year 2050) in Various Geological Media by a Meteorite (man-rem)

Repository Media	Total Body	Thyroid	Lung	Bone
		Second Generation		
Salt	1.1×10^3	5.5×10^1	4.2×10^3	5.6×10^1
Granite	2.8×10^3	1.5×10^2	1.1×10^4	1.5×10^2
Basalt	2.8×10^3	1.5×10^2	1.1×10^4	1.5×10^2
Shale	1.4×10^3	7.4×10^1	5.6×10^3	7.4×10^1
		Third Generation		
Salt	2.1×10^2	1.3×10^1	7.5×10^2	1.3×10^1
Granite	5.5×10^2	3.3×10^1	2.0×10^3	3.3×10^1
Basalt	5.5×10^2	3.3×10^1	2.0×10^3	3.3×10^1
Shale	2.7×10^2	1.7×10^1	1.0×10^3	1.7×10^1

Based on these assumptions, dose factors were calculated relating the maximum individual's dose to the U.S. population dose. Dose factors obtained were 1.3×10^5 (U.S. man-rem)/(rem to the maximum individual) for dose received from direct exposure and ingestion and 8.8×10^4 (U.S. man-rem)/(rem to the maximum individual) for dose received from inhalation. First-year and 70-year dose commitments to the population of the eastern United States outside of the reference environment are presented in Tables 4.4.3-13 and 4.4.3-14 respectively.

The preceding presentation has assumed that the meteorite strike did occur; that is, the incident had a probability of one over the period of interest. The probability of a meteorite striking the surface over the repository and producing a crater 2 km in diameter has been estimated to be 2×10^{-7} over a one-million year period or 2×10^{-13} per year. If risk is taken as probability times consequences, the societal risk of death or serious genetic defect would be less than 4×10^{-3} from the largest dose to the population as presented in Table 4.4.3-11 over one million years. By way of perspective, in the United States the societal risk of death by lightning is about 120 per year, or about 1×10^8 per million years (200 million persons) (probability of 0.6 per million persons).(9) Thus, in this framework, the societal risk from a meteorite breach of a repository is about 3×10^{-11} that from lightning strikes.

TABLE 4.4.3-13. First-Year Dose to the Population of the Eastern United States for Breach of a Spent Fuel Repository by Meteorite at Various Times After Repository Closure (man-rem)

Repository Media	Total Body	Thyroid	Lung	Bone
		Breach at 50 Years		
Salt	1.7×10^{6}	7.5×10^{4}	1.1×10^{8}	1.8×10^{7}
Granite	4.5×10^{6}	2.0×10^{5}	2.8×10^{8}	4.7×10^{7}
Basalt	4.5×10^{6}	2.0×10^{5}	2.8×10^{8}	4.7×10^{7}
Shale	2.3×10^{6}	1.0×10^{5}	1.4×10^{8}	2.3×10^{7}
		Breach at 1,000 Years		
Salt	2.1×10^{5}	2.2×10^{3}	2.8×10^{7}	3.5×10^{6}
Granite	5.7×10^{5}	5.9×10^{3}	7.4×10^{7}	9.4×10^{6}
Basalt	5.7×10^{5}	5.9×10^{3}	7.4×10^{7}	9.4×10^{6}
Shale	2.8×10^{5}	2.9×10^{3}	3.7×10^{7}	4.7×10^{6}
		Breach at 100,000 Years		
Salt	3.7×10^{3}	2.1×10^{3}	4.5×10^{5}	6.9×10^{4}
Granite	9.9×10^{3}	5.5×10^{3}	1.2×10^{6}	1.8×10^{5}
Basalt	9.9×10^{3}	5.5×10^{3}	1.2×10^{6}	1.8×10^{5}
Shale	4.9×10^{3}	2.8×10^{3}	6.0×10^{5}	9.2×10^{4}
		Breach at 1,000,000 Years		
Salt	1.4×10^{3}	2.0×10^{3}	1.6×10^{5}	2.1×10^{4}
Granite	3.8×10^{3}	5.3×10^{3}	4.3×10^{5}	5.7×10^{4}
Basalt	3.8×10^{3}	5.3×10^{3}	4.3×10^{5}	5.7×10^{4}
Shale	1.9×10^{3}	2.7×10^{3}	2.2×10^{5}	2.8×10^{4}

TABLE 4.4.3-14. 70-Year Accumulative Dose to the Population of the Eastern United States for Breach of a Spent Fuel Repository by Meteorite at Various Times After Repository Closure (man-rem)

Repository Media	Total Body	Thyroid	Lung	Bone
		Breach at 50 Years		
Salt	5.6×10^{7}	3.9×10^{5}	2.5×10^{8}	6.9×10^{8}
Granite	1.5×10^{8}	1.0×10^{6}	6.7×10^{8}	1.8×10^{9}
Basalt	1.5×10^{8}	1.0×10^{6}	6.7×10^{8}	1.8×10^{9}
Shale	7.4×10^{7}	5.2×10^{5}	3.3×10^{8}	9.2×10^{8}
		Breach at 1,000 Years		
Salt	1.0×10^{7}	1.7×10^{4}	6.9×10^{7}	1.8×10^{8}
Granite	2.7×10^{7}	4.5×10^{4}	1.8×10^{8}	4.7×10^{8}
Basalt	2.7×10^{7}	4.5×10^{4}	1.8×10^{8}	4.7×10^{8}
Shale	1.3×10^{7}	2.3×10^{4}	9.2×10^{7}	2.3×10^{8}
		Breach at 100,000 Years		
Salt	1.8×10^{5}	1.4×10^{4}	1.1×10^{6}	3.3×10^{6}
Granite	4.8×10^{5}	3.8×10^{4}	3.0×10^{6}	8.7×10^{6}
Basalt	4.8×10^{5}	3.8×10^{4}	3.0×10^{6}	8.7×10^{6}
Shale	2.4×10^{5}	1.9×10^{4}	1.5×10^{6}	4.3×10^{6}
		Breach at 1,000,000 Years		
Salt	6.3×10^{4}	1.4×10^{4}	4.0×10^{5}	1.1×10^{6}
Granite	1.7×10^{5}	3.7×10^{4}	1.1×10^{6}	2.8×10^{6}
Basalt	1.7×10^{5}	3.7×10^{4}	1.1×10^{6}	2.8×10^{6}
Shale	8.5×10^{4}	1.8×10^{4}	5.3×10^{5}	1.4×10^{6}

The dose to the total body for the maximum individual, members of the regional population, and members of the population of the eastern United States are summarized in Table 4.4.3-15.

TABLE 4.4.3-15. Summary of Total-Body Doses to Maximum Individual and Population Groups from Breach of Spent Fuel Repository in Salt by Meteorite

Time Breach After Repository Closure	Maximum Individual, rem	Regional Population, man-rem	Eastern U.S., man-rem
		First-Year Dose	
50 years	8.3×10^{3}	2.1×10^{6}	1.7×10^{6}
1,000 years	6.0	3.4×10^{5}	2.1×10^{5}
100,000 years	4.4	5.7×10^{3}	3.7×10^{3}
1,000,000 years	2.5	2.1×10^{3}	1.4×10^{3}
		70-Year Dose Commitment	
50 years	3.9×10^{6}	6.9×10^{7}	5.6×10^{7}
1,000 years	3.6×10^{2}	1.6×10^{7}	1.0×10^{7}
100,000 years	3.3×10^{2}	2.8×10^{5}	1.8×10^{5}
1,000,000 years	1.7×10^{2}	9.4×10^{4}	6.3×10^{4}

The largest number of health effects from a breach by meteorite impact is calcualted to occur 50 years after repository closure. Based on 100 to 800 health effects per million man-rem among the regional population and the doses from Table 4.4.3-15, the breach of a salt repository by meteorite leads to 7,000 to 60,000 such effects from a 70-year exposure period. The number of health effects calculated for breaches of the repository at 1000, 100,000 and 1,000,000 years after closure are 1600 to 13,000, 28 to 220, and 9 to 72, respectively.

Based on the 1% release rate of ^{3}H, ^{14}C, and ^{85}Kr the 70-year total-body dose commitment to the worldwide population would amount to 1.1×10^{4} man-rem for a breach at 50 years, 9.8×10^{2} man-rem for a breach at 1,000 years, and 2×10^{-2} man-rem for a breach at 100,000 years after closure.

As noted previously, for accidents whose impacts are directly related to the total inventory of a repository, i.e., meteorite accident, the doses calculated are dependent on the quantity of spent fuel in the repository. The quantity of spent fuel stored in a given repository varies, depending on the type of geologic media in which the repsitory is constructed. Overall underground repository area in salt, granite, shale, and basalt is approximately 800 ha (2000 acres). Maintaining the same repository size in each rock media results in different repository capacities for each media because of different thermal criteria for emplacing the spent fuel.

These constraints may make comparisons of radiological effects among repositories in different media confusing. For example, when comparisons are made between calculated doses

resulting from the meteorite strike in various media, the media requiring the largest number of repositories, i.e., lowest thermal loading, seems to have a lower impact. While the radiological impact would be smaller for a repository with lower thermal loading, the probability of a meteorite striking would be higher because of the increase in the number of repositories.

Another approach for comparing radiological impacts of repositories in various geologic media is to normalize the impacts to a common reference point. Table 4.4.3-16 normalizes the radiological impact on the regional population to the quantity of spent fuel resulting from the generation of 1 GWe-year. Based on this comparison, radiological impacts of meteorite accidents are the same for the various geologic media and do not form bases for selection of one geologic media over another.

TABLE 4.4.3-16. 70-Year Total Body Dose Commitment to the Regional Population Normalized to the Quantity of Fuel Spent per GWe Year Based on the Reference 10^4 GWe-yr Scenario - man-rem

Years Since Repository Closure	
50	5.5×10^4
1×10^3	1.3×10^4
1×10^5	2.2×10^2
1×10^6	7.5×10^1

Another approach is to indicate the consequences of a meteorite impact on a model repository whose waste disposal capacity is the same for any media. Seventy-year total body dose from a meteorite breach and release of 1% of repository of a 50,000 MTHM repository is presented in Table 4.4.3-17.

TABLE 4.4.3-17. 70-Year Total Body Dose Commitment to the Regional Population from a Breach of a 50,000 MTHM Repository by Meteorite - man-rem

Years Since Repository Closure	
50	7.0×10^7
1×10^3	1.5×10^7
1×10^5	2.7×10^5
1×10^6	9.0×10^4

The meteorite postulated in this repository breach was assumed to be sufficiently large to penetrate to a depth of 600 m. Meteorites may produce rock fractures to depths on the order of 4 times the crater depth.[23] Thus, a smaller meteorite while not causing a direct release

of radioactive material could open the repository to entry of water. For example a meteorite might produce a crater about 150 m deep and fracture to the 600-m depth. Such an occurrence would be expected to have a somewhat higher probability than that of the 600-m deep crater produced by a meteorite. The radiological consequences of a meteorite producing a fracture breach are believed to be no worse than a faulting and flooding event, which is described in detail in a later section.

Repository Breach by Drilling - (DOE/ET-0028, Accident 7.9). Repository breach by exploratory drilling into the repository from the surface is treated on a "what if" basis because at this time no probability can be assigned to the occurrence of drilling at the repository site.

For this accident, it is assumed that the drilling occurs in the repository area 1000 years after mine closure. It is also assumed that one-fourth of a canister (a reference PWR fuel canister containing 0.37 MTHM) is circulated to the surface with the drilling mud and that the radioactive material is uniformly distributed over 0.5 ha in the top 5 cm of the surface soil. Details of this event are given in Table 7.3.28 of DOE/ET-0028.

Table 4.4.3-18 lists the expected releases to the air from contaminated surface soil (radioactive material concentrated in the top 1 cm of soil) assuming a resuspension rate of 0.011 per year[24] and that one-fourth of the radioactive material in the top 5 cm is available for resuspension. First-year doses and 70-year dose commitments to the maximum individual are presented in Table 4.4.3-19. Seventy-year dose commitments to the population are presented in Table 4.4.3-20. It is assumed that the maximum individual will reside and grow crops for his consumption on the contaminated land. It is also assumed that the maximum individual is exposed, on the average, to the contaminated soil for 12 hr/day. For perspective the resulting annual total-body dose to the maximum individual is about 37 times that nominally received from naturally occurring sources and is on the order of 2-3 times the allowable annual exposure for radiation workers.

TABLE 4.4.3-18. Radionuclides Released to the Atmosphere from Salt Repository Breach by Drilling Accident - Spent Fuel Case

Radionuclide	Release, Ci
^{14}C	2.6×10^{-5}
^{129}I	8.6×10^{-6}
^{126}Sn	1.2×10^{-4}
^{126}Sb	1.2×10^{-4}
^{239}Np	3.4×10^{-3}
^{239}Pu	7.3×10^{-2}
^{240}Pu	1.1×10^{-1}
^{241}Am	2.2×10^{-1}

TABLE 4.4.3-19. Doses to the Maximum Individual From a Salt Repository Breach by Drilling Accident - Spent Fuel Case (rem)

Pathway	Total Body	Thyroid[a]	Lung	Bone
		First-Year Dose		
Air submersion	1.7×10^{-7}	1.7×10^{-7}	1.7×10^{-7}	1.7×10^{-7}
Inhalation	2.8×10^{-2}	1.5×10^{-6}	3.1	4.8×10^{-1}
Contaminated ground[b]	1.3×10^{1}	1.3×10^{1}	1.3×10^{1}	1.3×10^{1}
Total	1.3×10^{1}	1.3×10^{1}	1.6×10^{1}	1.4×10^{1}
		70-Year Dose Commitment		
Air submersion	1.7×10^{-7}	1.7×10^{-7}	1.7×10^{-7}	1.7×10^{-7}
Inhalation	8.6×10^{-1}	1.6×10^{-6}	5.9	1.5×10^{1}
Ingestion[c]	3.3×10^{1}	1.5×10^{1}	1.6×10^{-1}	5.5×10^{2}
Contaminated ground[b]	9.1×10^{2}	9.1×10^{2}	9.1×10^{2}	9.1×10^{2}
Total	9.4×10^{2}	9.2×10^{2}	9.2×10^{1}	1.5×10^{3}

NOTE: The maximum individual is defined as a permanent resident on the 0.5 ha of contaminated land where the time-integrated atmospheric dispersion factor (E/Q) is 1.3×10^{-4} sec/m^3.

a. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).
b. Assumes the radioactive material is uniformly distributed in the top 15 cm of soil.
c. Assumes a 12 hr/day exposure to contaminated soil (radioactive material is assumed to be in top 5 cm of soil).

TABLE 4.4.3-20. 70-Year Doses to the Population[a] from a Salt Repository Breach by Drilling Accident - Spent Fuel Case (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
Air submersion	2.1×10^{-5}	2.1×10^{-5}	2.1×10^{-5}	2.1×10^{-5}
Inhalation	1.1×10^{2}	2.0×10^{-4}	7.3×10^{2}	1.9×10^{3}
Ingestion	6.8×10^{-3}	2.4×10^{-3}	8.9×10^{-7}	1.5×10^{-1}
Contaminated ground	5.5×10^{-3}	5.5×10^{-3}	5.5×10^{-3}	5.5×10^{-3}
Total	1.1×10^{2}	8.1×10^{-3}	7.3×10^{2}	1.9×10^{3}

a. None of the regional population resides on the 0.5 ha of contaminated land.

As Table 4.4.3-19 shows, the 70-year total-body dose to the maximum individual from a repository breach by drilling would be 940 rem compared with 7 rem received from naturally occurring sources. Approximately 95% of this 940 rem is received from direct radiation from the contaminated ground. About 60% of the 70-year 1500 rem dose to the bone is from ingestion of crops grown on the contaminated land.

The 70-year total-body dose to the regional population presented in Table 4.4.3-20 would be 110 man-rem compared with about 1.4×10^7 man-rem received from naturally occurring sources for the same period.

The 70-year total-body dose to the worldwide population would be 4.4×10^{-3} man-rem compared with about 4.5×10^{10} man-rem received from naturally occurring sources.

Radiological effects from a breach of the repository by drilling would probably be limited to doses to a few people (the maximum individual and family) of about 40 to 250 times (total body and bone respectively) the doses received from naturally occurring sources. If it were postulated that the 0.5 ha of contaminated land was occupied by a housing project with about 0.1 ha per lot, five families (probably not more than 20 persons) might be exposed to direct radiation from the contaminated ground, each with a resulting dose of about 40 times that from naturally occurring sources. The impact, if any, on the frequency of health effects of this group at a dose rate of about 4 rem/yr over their lifetime is uncertain.

Although the radiological effects associated with a drilling event as described above may be of most interest, in the case of a repository in salt the land contaminated with radioactive material will also be contaminated with salt brought up in the drilling mud. The minimum drill size that would remove one-fourth of a canister would have a diameter of about 23 cm for a breach of a canister containing BWR fuel and about 50 cm for a canister containing PWR fuel. Taking the thickness of salt above the canister (as backfilled) to be 20 m and ignoring the possibility of other salt strata between the repository and the surface, about 0.85 m^3 and 4 m^3 of salt would be removed for a BWR and PWR penetration respectively. These amounts of salt, if distributed uniformly over the assumed 0.5 ha of land, would represent 0.4 to 1.8 kg of salt per m^2. If ploughed to a depth of 15 cm these quantities of salt would correspond to concentrations of about 0.2 to 0.9%. Salt concentration must be on the order of 0.02 to 0.2 kg/m^2 before a normal mix of plants would be expected. The larger of these values exceeds the amount (0.5%) that can be tolerated by ordinary crops.

Some of the more salt-tolerant plants are found in salt marshes, the ocean intertidal zones, and saline desert areas. Salt-tolerant plants (halophytes) are those species capable of tolerating salt in concentrations of 0.5% or more.[25] Some salt desert plant species tolerate salt concentrations of 6%[26] and sea grasses have been grown under experimental conditions at salinities of 40 to 72%.[27] Normal seawater salinity ranges from 30 to 35%. Some forage grasses and agricultural crops such as sugar beets and cotton can withstand salinities of 1.4% but growth is reduced about 50%.[28] Salinities of 0.4 to 1.8 kg/m^2 of salt would eliminate all but salt-tolerant plants. Some forage plants and agricultural crops could possibly be grown at the calculated concentrations of salt in soil from the drilling accident but only at reduced rates of production.

If exploratory drilling were abandoned but the hole left intact it could provide a means for entry of water into the repository. Because of silting and spalling of the sides of the hole it would not likely remain open to the repository for long. Assuming, however, that the

hole remains open and a stream of water enters the hole, the voids that exist after backfilling the repository could fill with water. Because the placement of spent fuel is designed to preclude occurrence of a criticality event if water became available as a neutron moderator, this intrusion of water would not likely result in a criticality event. At such time as the repository voids are filled, there is no reasonable expectation that radioactive material even if leached from fuel elements could move back up the drill hole 0.5 m in diameter by 600 m deep. Water streaming through the hole could cause dissolution of salt at and near the point of entry into the repository. As the voids fill, the eroding action would be expected to decrease. The possibility that such action would open another aquifer into the repository despite site explorations to preclude the presence of nearby aquifers cannot be ruled out. If that should occur, the consequences would not reasonably exceed those described later in this section for faulting and flooding of the repository.

This study concluded that a breach of repository by inadvertent drilling into spent fuel canisters does not constitute a potential for radiological consequences of significant proportions to society.

Breach of Repository by Fault Fracture and Flooding. This scenario is a combination of improbable events. First a fracture or series of fractures either from the surface or from near an aquifer is assumed to penetrate to the repository. The fractures are also assumed to connect and to permit water to reach the wastes. Two cases are presented, one where a fairly large stream of water penetrates the repository and leaches out radioactive waste and then, following a hypothetical conduit, returns to the surface* to form a stream with a flow of 2.8 m^3/s (100 cfs); the second case presumes water reaches the repository and leaches out radioactive waste, some of which is held up by adsorption on soils outside the repository area before slowly working its way to the biosphere.

It should be noted that these accident scenarios assume an improbable combination of events with very low probabilities of occurrence, that are, in some cases, contrary to the evidence available. For example, it is generally accepted that faulting of thick salt units does not lead to formation of permeable zones and that the plastic behavior of salt tends to heal any opening. Most of the known faults in salt formations confirm this self-healing behavior of halite (salt).[19] Also, massive salt units generally occur in a geologic environment that contains clays, shales and argillaceous units that again tend to deform plastically. Faults in rock material that yields by brittle fracture (granite, basalt, some carbonates) are more likely to form permeable zones of crushed, broken rock than faults in salt. However, even in brittle rocks, a fault zone may, through the grinding and crushing of the material, form a zone of very low to essentially no permeability. It is doubtful that any fault would form a continuously permeable conduit to the repository, even if a fault should occur through the repository to the land surface. Therefore, this accident is analyzed on a "what if" basis.

In the case of spent fuel as a waste, it was assumed that the wastes contained in 1230 PWR canisters and 1320 BWR canisters were affected. It was also assumed that the waste was in

* Zero travel time to the surface stream is assumed.

the form of spheres 1 cm in diameter.* A total of 570 kg of PWR spent fuel and 1320 kg of BWR spent fuel was calculated to leach out over the one-year period.

For dose calculations for spent fuel, leach rates enter the dose calculations so that doses assuming different leach rates may be obtained by multiplying the tabulated dose by the ratio of the assumed leach rate to the leach rate of 1×10^{-5} gm/cm^2-day. (A later analysis for ground-water transport obviates this problem in part by bounding the leaching of all wastes between 1 year and 1000 years.)

Radionuclides released to the R River for this event occurring in the year 2050, and 1000, 100,000 or 1,000,000 years thereafter are given for the once-through fuel cycle option in Table 4.4.3-21.

Seventy-year total body dose commitments were calculated for the maximum individual using the data of Table 4.4.3-21, the methods described in Appendix B, and the following assumptions. For wastes in other than a salt repository it was assumed that aquatic food was taken from and recreational activities occurred near the 2.8 m^3/s stream of water from the repository. Drinking water was assumed to be taken from the R River downstream from the point of contamination entry. Contaminants in farm products and ground contamination doses were determined based on irrigation of land with water from the R River. In the case of a repository in salt it was concluded that the 2.8 m^3/s effluent stream would be so laden with salt that no fresh-water biota would be present and that the maximum individual would derive his aquatic food from the R River and conduct his recreational activities near that river. Population doses were also calculated on the basis of contamination of water in the R River.

Because the 70-year dose commitment to the maximum individual was so large for breach of repository in 2050, particularly for repositories in other than salt, a first-year dose was also calculated and is presented in Table 4.4.3-22. Total body dose to the maximum individual in the first year for a repository in salt was 15 rem. The total body dose to the maximum individual from breaches of a nonsalt repository was 530 rem in the first year.

The doses associated with the breach of a salt repository are three times the permissible annual dose for occupational exposures. Since planned whole-body doses up to 25 rems are reasonably accepted for emergency conditions, it follows that accidental doses up to the same magnitude should not cause major concern.[30] A total-body dose of 530 rem to the maximum individual in the nonsalt repository cases is presumed to be fatal to half of those exposed. It is not likely that a breach of repository in the year 2050 would go unnoticed, and measures would be taken to monitor all water supplies that might even have a remote possibility of being contaminated. Thus, the calculated doses and consequences seem most unlikely to occur in practice.

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* The fuel pellet simulating a combination of PWR and BWR fuels is taken to be a cylinder 1.16 cm in diameter by 1.16 cm long. Since the spent fuel dose calculations were made, it has been determined that spent fuel may be fragmented following irradiation and that the area subject to leaching may be about 5 times that used in the original calculations.[29] This factor has been applied to doses in this Section.

TABLE 4.4.3-21. Radionuclides (in Ci) Released from Breach of Spent Fuel Repository by Faulting and Flooding at Various Times After Closure

Nuclide	Year 2050	+1,000 Years	+100,000 Years	+1,000,000 Years
^{3}H	7.5×10^{1}			
^{14}C	4.3×10^{-1}	3.8×10^{-1}	2.4×10^{-6}	
^{54}Mn	8.2×10^{-4}			
^{55}Fe	1.8×10^{1}			
^{60}Co	1.4×10^{2}			
^{59}Ni	3.9	3.9	1.6	6.8×10^{-4}
^{63}Ni	4.6×10^{2}	4.4×10^{-1}		
^{79}Se	4.5×10^{-1}	4.4×10^{-1}	1.5×10^{-1}	1.1×10^{-5}
^{90}Sr	3.4×10^{4}	4.4×10^{-6}		
^{90}Y	3.4×10^{4}	4.4×10^{-6}		
^{93}Zr	2.1	2.1	2.0	1.3
^{93m}Nb	2.1	2.1	2.0	1.3
^{99}Tc	1.6×10^{1}	1.6×10^{1}	1.2×10^{1}	6.1×10^{-1}
^{106}Rh	3.7			
^{107}Ru	3.7			
^{107}Pd	1.2×10^{-1}	1.2×10^{-1}	1.2×10^{-1}	1.1×10^{-1}
^{123}Sn	2.6×10^{-8}			
^{125}Sb	3.2×10^{1}			
^{125m}Te	7.4			
^{126}Sn	6.0×10^{-1}	6.0×10^{-1}	3.0×10^{-1}	5.9×10^{-4}
^{126m}Sb	6.0×10^{-1}	6.0×10^{-1}	3.0×10^{-1}	5.9×10^{-4}
^{126}Sb	6.0×10^{-1}	6.0×10^{-1}	3.0×10^{-1}	5.9×10^{-4}
^{127m}Te	2.1×10^{-9}			
^{127}Te	2.1×10^{-9}			
^{129}I	4.2×10^{-2}	4.2×10^{-2}	4.2×10^{-2}	4.1×10^{-2}
^{134}Cs	1.4×10^{2}			
^{135}Cs	3.4×10^{-1}	3.4×10^{-1}	3.3×10^{-1}	2.7×10^{-1}
^{137}Cs	4.9×10^{4}	2.6×10^{-5}		
^{137m}Ba	4.7×10^{4}	2.6×10^{-5}		
^{144}Ce	8.5×10^{-1}			
^{144}Pr	8.5×10^{-1}			
^{147}Pm	2.8×10^{2}			
^{151}Sm	1.1×10^{3}	6.9×10^{-1}		
^{154}Eu	1.5×10^{3}			
^{155}Eu	2.6			
^{210}Pb	1.8×10^{-6}	3.1×10^{-3}	1.2	5.7×10^{-1}
^{210}Bi	1.8×10^{-6}	3.1×10^{-3}	1.2	5.7×10^{-1}
^{224}Ra	1.8×10^{-2}	1.8×10^{-5}	2.2×10^{-6}	2.2×10^{-5}
^{226}Ra	4.8×10^{-6}	3.1×10^{-3}	1.1	5.7×10^{-1}
^{227}Ac	2.9×10^{-5}	5.0×10^{-4}	2.9×10^{-2}	3.6×10^{-2}
^{228}Th	1.8×10^{-2}	1.9×10^{-5}	2.2×10^{-6}	2.2×10^{-5}
^{229}Th	4.9×10^{-7}	1.7×10^{-4}	5.1×10^{-1}	1.3
^{230}Th	5.0×10^{-4}	1.7×10^{-2}	1.1	5.7×10^{-1}
^{232}Th	3.5×10^{-10}	1.4×10^{-8}	2.1×10^{-6}	2.2×10^{-5}
^{233}Pa	4.3×10^{-1}	1.2	1.4	1.0
^{232}U	1.7×10^{-2}	1.8×10^{-4}		
^{233}U	1.6×10^{-4}	3.7×10^{-3}	4.8×10^{-1}	1.1
^{234}U	1.5	2.1	1.8	5.2×10^{-1}
^{236}U	2.9×10^{-1}	3.10×10^{-1}	4.5×10^{-1}	6.1×10^{-1}
^{238}U	4.1×10^{-1}	4.1×10^{-1}	4.1×10^{-1}	4.1×10^{-1}
^{237}Np	4.3×10^{-1}	1.2	1.4	1.0
^{239}Np	1.7×10^{1}	1.6×10^{1}	2.2×10^{-3}	
^{238}Pu	2.0×10^{3}	5.9		
^{239}Pu	3.7×10^{2}	3.6×10^{2}	2.3×10^{1}	2.2×10^{-8}
^{240}Pu	5.8×10^{2}	5.2×10^{2}	2.3×10^{-2}	
^{241}Pu	2.6×10^{4}	2.0×10^{-1}	5.3×10^{-5}	
^{242}Pu	2.0	2.0	1.7	3.2×10^{-1}
^{241}Am	3.9×10^{3}	1.1×10^{3}	5.3×10^{-5}	
^{242m}Am	1.1×10^{1}	2.4×10^{-1}		
^{242}Am	1.1×10^{1}	2.4×10^{-1}		
^{243}Am	1.7×10^{1}	1.6×10^{1}	2.2×10^{-3}	
^{242}Cm	9.4	2.0×10^{-1}		
^{244}Cm	4.1×10^{2}	5.3×10^{-7}		
^{245}Cm	2.2×10^{-1}	2.0×10^{-1}	5.3×10^{-5}	

TABLE 4.4.3-22. First-Year Doses (in rem) to Maximum Individual - Repository Breach by Faulting and Flooding at Various Times After Repository Closure

Pathway	Salt Repository				Non-Salt Repository			
	Total Body	Thyroid	Lung	Bone	Total Body	Thyroid	Lung	Bone
Breach in Year 2050								
Aquatic food	1.3×10^{1}	7.5×10^{-5}	1.9	1.4×10^{1}	5.2×10^{2}	3.0×10^{-3}	7.6×10^{1}	5.8×10^{2}
Recreational act.	1.6×10^{-1}	1.6×10^{-1}	1.6×10^{-1}	1.6×10^{-1}	6.3	6.3	6.3	6.3
Drinking water	4.5×10^{-1}	3.5×10^{-5}	6.0×10^{-2}	6.8×10^{-1}	4.5×10^{-1}	3.5×10^{-5}	6.0×10^{-2}	6.3×10^{-1}
Farm products	9.5×10^{-1}	2.4×10^{-4}	8.9×10^{-2}	2.0	9.5×10^{-1}	2.4×10^{-4}	8.9×10^{-2}	2.0
Ground contamination	4.8×10^{-1}	4.8×10^{-1}	4.8×10^{-1}	4.8×10^{-1}	4.8×10^{-1}	4.8×10^{-1}	4.8×10^{-1}	4.8×10^{-1}
Total	1.5×10^{1}	6.4×10^{-1}	2.7	1.7×10^{1}	5.3×10^{2}	6.8	8.3×10^{1}	5.9×10^{2}
Breach 1,000 Years after Repository Closure								
Aquatic food	2.5×10^{-3}	2.1×10^{-5}	1.0×10^{-5}	3.2×10^{-2}	1.0×10^{-1}	8.5×10^{-4}	4.1×10^{-4}	1.3
Recreational act.	1.7×10^{-4}	1.7×10^{-4}	1.7×10^{-4}	1.7×10^{-4}	6.7×10^{-3}	6.7×10^{-3}	6.7×10^{-3}	6.7×10^{-3}
Drinking water	1.7×10^{-4}	3.2×10^{-5}	2.1×10^{-7}	2.8×10^{-3}	1.7×10^{-4}	3.2×10^{-5}	2.1×10^{-7}	2.8×10^{-3}
Farm products	3.0×10^{-4}	2.2×10^{-5}	1.5×10^{-4}	3.1×10^{-3}	3.0×10^{-4}	2.2×10^{-5}	1.5×10^{-4}	3.1×10^{-3}
Ground contamination	2.1×10^{-4}	2.1×10^{-4}	2.1×10^{-4}	2.1×10^{-4}	2.1×10^{-4}	2.1×10^{-4}	2.1×10^{-4}	2.1×10^{-4}
Total	3.4×10^{-3}	4.6×10^{-4}	5.4×10^{-4}	3.8×10^{-2}	1.0×10^{-1}	7.8×10^{-3}	7.5×10^{-3}	1.3
Breach 100,000 Years after Repository Closure								
Aquatic food	4.2×10^{-3}	1.2×10^{-5}	2.2×10^{-6}	5.2×10^{-3}	1.7×10^{-1}	4.8×10^{-4}	8.7×10^{-5}	2.1×10^{-1}
Recreational act.	1.5×10^{-5}	1.5×10^{-5}	1.5×10^{-5}	1.5×10^{-5}	6.1×10^{-4}	6.1×10^{-4}	6.1×10^{-4}	6.1×10^{-4}
Drinking water	7.3×10^{-4}	3.1×10^{-5}	1.2×10^{-7}	1.0×10^{-3}	7.3×10^{-4}	3.1×10^{-5}	1.2×10^{-7}	1.0×10^{-3}
Farm Products	1.6×10^{-3}	2.0×10^{-4}	5.6×10^{-7}	2.3×10^{-3}	1.6×10^{-3}	2.0×10^{-4}	5.6×10^{-7}	2.3×10^{-3}
Ground contamination	4.7×10^{-5}	4.7×10^{-5}	4.7×10^{-5}	4.7×10^{-5}	4.7×10^{-5}	4.7×10^{-5}	4.7×10^{-5}	4.7×10^{-5}
Total	6.6×10^{-3}	3.0×10^{-4}	6.5×10^{-5}	8.6×10^{-3}	1.7×10^{-1}	1.4×10^{-3}	7.4×10^{-4}	2.1×10^{-1}
Breach 1,000,000 Years after Repository Closure								
Aquatic food	2.1×10^{-3}	1.0×10^{-5}	1.8×10^{-6}	2.8×10^{-3}	8.5×10^{-2}	4.2×10^{-4}	7.0×10^{-5}	1.1×10^{-1}
Recreational act.	9.2×10^{-6}	9.2×10^{-6}	9.2×10^{-6}	9.2×10^{-6}	3.7×10^{-4}	3.7×10^{-4}	3.7×10^{-4}	3.7×10^{-4}
Drinking water	3.7×10^{-4}	3.0×10^{-5}	5.6×10^{-8}	5.6×10^{-4}	3.7×10^{-4}	3.0×10^{-5}	5.6×10^{-8}	5.6×10^{-4}
Farm products	8.1×10^{-4}	1.9×10^{-4}	2.4×10^{-7}	1.2×10^{-3}	8.1×10^{-4}	1.9×10^{-4}	2.4×10^{-7}	1.2×10^{-3}
Ground contamination	2.8×10^{-5}	2.8×10^{-5}	2.8×10^{-5}	2.8×10^{-5}	2.8×10^{-5}	2.8×10^{-5}	2.8×10^{-5}	2.8×10^{-5}
Total	3.3×10^{-3}	2.7×10^{-4}	3.9×10^{-5}	4.6×10^{-3}	8.7×10^{-2}	1.0×10^{-3}	4.7×10^{-4}	1.1×10^{-1}

Dose decreases with time rather rapidly in the first 1000 years after repository closure; after that time and to 100,000 years, the dose is rather constant reflecting the presence of radium-226. Radium-226, the daughter of very long-lived uranium-238, is also the reason for the large increase in dose at 1,000,000 years.*

Seventy-year dose commitments to the maximum individual are presented in Table 4.4.3-23. Total body doses to the maximum individual are 200 rem for a salt repository and 2200 rem for a non-salt repository.

70-year total body dose commitments to the regional population are presented in Table 4.4.3-24.

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* It is important to note that the ^{226}Ra and ^{238}U are not manufactured in the course of nuclear power production. The total quantities of the elements were always in some geologic formation, were mined, used in reactors and, except for a few percent that was fissioned into other wastes, are being returned to the earth.

TABLE 4.4.3-23. 70-Year Dose Commitment (in rem) to Maximum Individual from Repository Breach by Faulting and Flooding at Various Times After Repository Closure

Pathway	Salt Repository				Non-Salt Repository			
	Total Body	Thyroid	Lung	Bone	Total Body	Thyroid	Lung	Bone
				Breach in Year 2050				
Aquatic food	4.5×10^{1}	7.5×10^{-5}	3.5	1.4×10^{2}	1.8×10^{3}	3.0×10^{-3}	1.4×10^{2}	5.6×10^{3}
Recreational act.	5.5	5.5	5.5	5.5	2.2×10^{2}	2.2×10^{2}	2.2×10^{2}	2.2×10^{2}
Drinking water	3.5	3.5×10^{-5}	1.1×10^{-1}	1.4×10^{1}	3.5	3.5×10^{-5}	1.1×10^{-1}	1.4×10^{1}
Farm products	1.4×10^{2}	2.6×10^{-3}	2.2	5.6×10^{2}	1.4×10^{2}	2.6×10^{-3}	2.2	5.6×10^{2}
Ground contamination	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Total	2.0×10^{2}	8.0	1.4×10^{1}	7.2×10^{2}	2.2×10^{3}	2.2×10^{2}	3.6×10^{2}	6.4×10^{3}
				Breach 1,000 Years after Repository Closure				
Aquatic food	2.3×10^{-1}	2.1×10^{-5}	1.2×10^{-5}	4.0	9.2	8.5×10^{-4}	5.0×10^{-4}	1.6×10^{2}
Recreational act.	1.1×10^{-2}	1.1×10^{-2}	1.1×10^{-2}	1.1×10^{-2}	4.4×10^{-1}	4.4×10^{-1}	4.4×10^{-1}	4.4×10^{-1}
Drinking water	1.5×10^{-2}	3.2×10^{-5}	2.7×10^{-7}	3.2×10^{-1}	1.5×10^{-2}	3.2×10^{-5}	2.7×10^{-7}	3.2×10^{-1}
Farm products	4.5×10^{-2}	2.5×10^{-3}	4.0×10^{-4}	9.6×10^{-1}	4.5×10^{-2}	2.5×10^{-3}	4.0×10^{-4}	9.6×10^{-1}
Ground contamination	5.2×10^{-4}	5.2×10^{-4}	5.2×10^{-4}	5.2×10^{-4}	5.2×10^{-4}	5.2×10^{-4}	5.2×10^{-4}	5.2×10^{-4}
Total	3.0×10^{-1}	1.4×10^{-2}	1.2×10^{-2}	5.3	9.7	4.4×10^{-1}	4.4×10^{-1}	1.6×10^{2}
				Breach 100,000 Years after Repository Closure				
Aquatic food	2.1×10^{-1}	1.8×10^{-5}	4.0×10^{-6}	3.2×10^{-1}	8.4	7.4×10^{-4}	1.6×10^{-4}	1.3×10^{1}
Recreational act.	1.1×10^{-3}	1.1×10^{-3}	1.1×10^{-3}	1.1×10^{-3}	4.3×10^{-2}	4.3×10^{-2}	4.3×10^{-2}	4.3×10^{-2}
Drinking water	3.6×10^{-2}	4.9×10^{-5}	1.8×10^{-7}	5.6×10^{-2}	3.6×10^{-2}	4.9×10^{-5}	1.8×10^{-7}	5.6×10^{-2}
Farm products	1.2×10^{-1}	2.1×10^{-3}	7.8×10^{-6}	2.1×10^{-1}	1.2×10^{-1}	2.1×10^{-3}	7.8×10^{-6}	2.1×10^{-1}
Ground contamination	2.9×10^{-3}	2.9×10^{-3}	2.9×10^{-3}	2.9×10^{-3}	2.9×10^{-3}	2.9×10^{-3}	2.9×10^{-3}	2.9×10^{-3}
Total	3.7×10^{-1}	6.1×10^{-3}	4.0×10^{-3}	5.0×10^{-1}	8.6	4.9×10^{-2}	4.6×10^{-2}	1.3×10^{1}
				Breach 1,000,000 Years after Repository Closure				
Aquatic food	1.0×10^{-1}	1.6×10^{-5}	3.2×10^{-6}	1.7×10^{-1}	4.2	6.6×10^{-4}	1.3×10^{-4}	6.7
Recreational act.	6.5×10^{-4}	6.5×10^{-4}	6.5×10^{-4}	6.5×10^{-4}	2.6×10^{-2}	2.6×10^{-2}	2.6×10^{-2}	2.6×10^{-2}
Drinking water	1.8×10^{-2}	4.8×10^{-5}	1.0×10^{-7}	2.8×10^{-2}	1.8×10^{-2}	4.8×10^{-5}	1.0×10^{-7}	2.8×10^{-2}
Farm products	6.1×10^{-2}	2.0×10^{-3}	2.4×10^{-6}	1.0×10^{-1}	6.1×10^{-2}	2.0×10^{-3}	2.4×10^{-6}	1.0×10^{-1}
Ground contamination	1.8×10^{-3}	1.8×10^{-3}	1.8×10^{-3}	1.8×10^{-3}	1.8×10^{-3}	1.8×10^{-3}	1.8×10^{-3}	1.8×10^{-3}
Total	1.8×10^{-1}	4.5×10^{-3}	2.5×10^{-3}	3.0×10^{-1}	4.3	3.0×10^{-2}	2.8×10^{-2}	6.8

TABLE 4.4.3-24. 70-Year Dose Commitment (in man-rem) to Population from Repository Breach by Faulting and Flooding at Various Times After Repository Closure

Pathway	Total Body	Thyroid	Lung	Bone
		Breach in Year 2050		
Aquatic food	5.5×10^{5}	1.1	7.2×10^{4}	9.9×10^{5}
Recreational act.	2.2×10^{5}	2.2×10^{5}	2.2×10^{5}	2.2×10^{5}
Drinking water	3.5×10^{6}	3.5×10^{1}	1.1×10^{5}	1.4×10^{7}
Farm products	1.1×10^{8}	2.3×10^{3}	2.8×10^{6}	4.3×10^{8}
Ground contamination	2.5×10^{6}	2.5×10^{6}	2.5×10^{6}	2.5×10^{6}
Total	1.2×10^{8}	2.7×10^{6}	5.7×10^{6}	4.5×10^{8}
		1,000 Years		
Aquatic food	1.3×10^{2}	2.7×10^{-1}	1.4×10^{-1}	2.1×10^{3}
Recreational act.	4.5×10^{2}	4.5×10^{2}	4.5×10^{2}	4.5×10^{2}
Drinking water	1.5×10^{4}	3.2×10^{1}	2.7×10^{-1}	3.2×10^{5}
Farm products	4.8×10^{4}	2.2×10^{3}	3.4×10^{2}	1.0×10^{6}
Ground contamination	2.4×10^{4}	2.4×10^{4}	2.4×10^{4}	2.4×10^{4}
Total	8.8×10^{4}	2.7×10^{4}	2.5×10^{4}	1.3×10^{6}
		100,000 Years		
Aquatic food	7.5×10^{2}	3.0×10^{-1}	8.2×10^{-2}	1.2×10^{3}
Recreational act.	8.5×10^{1}	8.5×10^{1}	8.5×10^{1}	8.5×10^{1}
Drinking water	3.6×10^{4}	5.0×10^{1}	1.8×10^{-1}	5.6×10^{4}
Farm products	1.0×10^{5}	1.9×10^{3}	6.9	1.7×10^{5}
Ground contamination	2.9×10^{3}	2.9×10^{3}	2.9×10^{3}	2.9×10^{3}
Total	1.4×10^{5}	4.9×10^{3}	2.9×10^{3}	2.3×10^{5}
		1,000,000 Years		
Aquatic food	3.8×10^{2}	2.6×10^{-1}	6.6×10^{-2}	5.9×10^{2}
Recreational act.	5.2×10^{1}	5.2×10^{1}	5.2×10^{1}	5.2×10^{1}
Drinking water	1.8×10^{4}	4.8×10^{1}	1.0×10^{-1}	2.8×10^{4}
Farm products	5.1×10^{4}	1.8×10^{3}	2.8	8.9×10^{4}
Ground contamination	1.7×10^{3}	1.7×10^{3}	1.7×10^{3}	1.7×10^{3}
Total	7.1×10^{4}	3.4×10^{3}	1.8×10^{3}	1.2×10^{5}

As noted earlier a breach of repository with surface or groundwater contamination would not likely go unnoticed if it occurred in the year 2050, and measures would be taken to preclude use of the contaminated water. It may be illustrative to examine the effects assuming that the contamination did go unnoticed. With a population total-body dose of 1×10^{8} man-rem and the values of 100 to 800 health effects per million man-rem, the calculated number of health effects attributable to this accident would be on the order of from 10,000 to 80,000 for the 70-year period. The societal risk associated with such an event may be estimated using the overall expected frequency of faulting and surface transport of activity of 2×10^{-13}/yr (DOE/ET-0028, p. 7.3.52). Thus, the calculated societal risk might amount to as much as 1×10^{-7} to 8×10^{-7} deaths or serious genetic defects. The societal risk associated with death by being struck by lightning may provide some perspective for the societal risk from this breach of repository. The risk of death from lightning in the reference population is about 2×10^{6} persons x 0.6 fatalities/1×10^{6} persons/yr or 1.2/yr. Over 70 years a societal risk of 84 is obtained. In other words, society's risk from death by lightning is almost a billion times greater than that from a repository under these conditions. Moreover, at such a small societal risk for the assumptions used, an error of several orders of magnitude increase in the estimated leach rates or probability of occurrence would not result in a large risk to society. The population dose to the regional population from naturally occurring sources would amount to about 1.4×10^{7} man-rem over the same time period.

At 1000 years after repository closure, it is reasonable to assume that no mitigating procedures may be attempted because of lack of awareness that the water had become contaminated. However, at that time and thereafter doses are only on the order of 1% of that from naturally occurring sources.

One of the long-term effects of release of radionuclides to the R River would include the movement of these radionuclides to the ocean, where accumulation in mollusks and other marine foods may occur resulting in another pathway to human exposure. It was assumed that the following dilution factors* were applicable for concentrations of elements in an estuary, e.g., concentration of cobalt nuclides in estuary water would be 0.01 of their concentrations in the R River.

Element	Dilution Factor	Element	Dilution Factor
H	0.5	Sr	0.01
C	0.5	Nb, Zr	0.01
Co	0.01	Sb	0.5
Ni	0.01	Sn	0.5
		I	0.5

* Dilution factors are highly dependent on the specific river system and estuary of interest. The dilution factors presented here were developed for movement of radionuclides from reactor effluent water at the Hanford Project in eastern Washington via the Columbia River to Willipa Bay, WA where oysters are harvested. References: Seymour, A. H., and Lewis, G. B., Radionuclides of Columbia River Origin in Marine Organisms, Sediments and Water Collected from Coastal and Off-Shore Waters of Washington and Oregon, USAEC Rept. UWFI-86, University of Washington, 1964. Toombs, G. L., 1964-65 Lower Columbia River Environmental Radiological Survey in Oregon, Oregon Board of Health, 1966. Hanford Environmental Surveillance Reports for 1966, BNWL-CC-637-12 and earlier reports in same series.

Element	Dilution Factor	Element	Dilution Factor
Cs	0.01	Np	0.01
Sm	0.01	Pu	0.01
Eu	0.01	Am	0.01
U	0.01	Cm	0.01

Salt water bioaccumulation factors were used to estimate the concentration of radionuclides in the edible portion of marine foods.[31] Based on these factors, the releases as apportioned for the numbers of repositories in the various media, and the methods described in Appendix D, 70-year total body doses to the maximum individual from ingestion of 10 kg of mollusk per year were calculated; they are presented in Table 4.4.3-25 for repository breaches at the year 2050 or 1000, 100,000 and 1,000,000 years thereafter.

TABLE 4.4.3-25. 70-Year Dose Commitment (in rem) to the Maximum Individual from Ingestion of Mollusks Following Repository Breach by Faulting and Flooding

Years After Repository Closure	Dose			
	Total Body	Thyroid	Lung	Bone
0	1.2×10^{-2}	2.9×10^{-5}	1.3×10^{-3}	1.6×10^{-1}
1,000	2.5×10^{-3}	2.7×10^{-5}	5.4×10^{-7}	4.2×10^{-2}
100,000	8.2×10^{-2}	2.7×10^{-5}	2.9×10^{-7}	2.2×10^{-1}
1,000,000	4.4×10^{-2}	2.6×10^{-5}	3.3×10^{-9}	1.7×10^{-1}

The largest of these, 8.2×10^{-2} rem/70 years, is about 1% of the dose the individual would have received from naturally occurring sources for the same period and would not add significantly to the maximum individual's 70-year dose commitment.

Doses to the regional population for breach of repository in the year 2050 (as in Table 4.4.3-24) were also calculated for the second- and third-generation population (assuming that the entire population was replaced at 70-year intervals). These doses are presented in Table 4.4.3-26.

TABLE 4.4.3-26. 70-Year Commitment to First Three Generation of Regional Population Following Repository Breach by Faulting and Flooding in the Year 2050

Once-Through Spent Fuel	Man-Rem			
	Total Body	Thyroid	Lung	Bone
Generation 1	1.2×10^{8}	2.7×10^{6}	5.7×10^{6}	4.5×10^{8}
Generation 2	6.5×10^{6}	3.5×10^{5}	3.5×10^{5}	2.5×10^{7}
Generation 3	1.2×10^{6}	7.9×10^{4}	7.9×10^{4}	4.7×10^{6}

The dose per generation is decreased slowly primarily because of the presence of longer lived radionuclides in the food chains. The dose is down to less than that due to naturally occurring sources by the second generation and to about 15% of that by the third generation.

These consequences result if the event takes place, which by reason of a combination of improbable events is not likely to occur. (Note also that in the year 2050, mitigating efforts could reduce doses to essentially zero.)

The second scenario developed for the repository fracture and flooding assumes that radionuclides are leached from the waste and are transported via slowly moving (100 m/yr) ground water through the ground before entering the biosphere (the R River). Detailed dose results are presented in Appendix G.

In this scenario only one migration path length (10 km) was investigated, whereas path lengths could vary from a few hundred meters to a few hundred kilometers. Only one ground water velocity (100 m/yr) was investigated; actual ground-water velocities can vary from essentially zero to over 10,000 m/yr. Perhaps the largest limitation on this scenario is that only one set of sorption equilibrium constants (K_d) was used. These had been measured or estimated for one particular subsoil under one set of conditions at one temperature at the Hanford site in Washington state. Sorption equilibrium constants can vary over several orders of magnitude for a single element; however, data are not available for other complete subsoils. The effect these parameters would have on dose is discussed in Appendix G.

Based on the models and dose calculation methods described in Appendix G and the simplifying assumption that the total waste inventory is all located in one repository, doses were calculated for the maximum individual. Total body doses are presented in Table 4.4.3-27 as a function of time since disposal and for several leach rates ranging from complete leaching of all radionuclides in the repository in one year to a leach rate of 0.0001 of inventory per year.

Table 4.4.3-27 contains data about leaching of all of the radioactive material from the hypothetical repository containing all spent fuel from the LWR scenario producing 10,000 GWe-yr and ending in 2050. It shows that beginning about 100 years after breach of the repository and

TABLE 4.4.3-27. 50-Year* Accumulated Total Body Dose (in rem) to Maximum Individual for Various Leach Rates and Times of Spent Fuel Repository Breach by Fracturing and Ground-Water Intrusion (all waste in one repository)

Years Since Disposal	Year 2050			+1,000 Years			+100,000 Years		
	Leach Rate			Leach Rate			Leach Rate		
	100%/yr	0.1%/yr	0.01%/yr	100%/yr	0.1%/yr	0.01%/yr	100%/yr	0.1%/yr	0.01%/yr
1.1×10^2	2.7×10^2	3.0×10^{-1}	3.0×10^{-2}						
2.2×10^2		4.6							
1.0×10^3	6.0×10^2		6.5×10^{-1}	2.7×10^2	3.1×10^{-1}	3.1×10^{-2}			
2.0×10^3				5.0×10^2	6.0	6.0×10^{-1}			
1.0×10^4	1.2×10^1	1.3		2.5×10^1	3.1	4.7×10^{-1}			
3.4×10^4			2.1×10^{-1}	8.5×10^{-1}	2.8×10^{-1}				
1.1×10^5	1.1	7.0×10^{-1}		1.1			2.0×10^2	1.1×10^{-1}	2.3×10^{-2}
1.4×10^6	4.3×10^2	4.5×10^2	4.2×10^2	4.3×10^2	4.5×10^2	4.5×10^2	4.2×10^2	4.5×10^2	4.1×10^2
5.0×10^6		1.4							

* Dose accumulation was set for 50 instead of 70 years in the computer program for making these calculations. If ingestion rates remained constant for the unaccounted-for 20 years, the total doses might be on the order of double those tabulated.

continuing for about 2000 years, the 50-year accumulated total body doses to the maximum individual are one to three times the presently permitted occupational dose limits. The dose then decreases over several hundred thousand years until about 1.4 million years at which time the dose has increased to about twice the permissible occupational limit, after which it again slowly decreases. Over a time span of repository breaches of 100,000 years the occurrence of the latter dose peak is independent of leach rate or time of occurrence. The dose is due principally to the ^{226}Ra daughter of ^{238}U which has an extremely long half-life but which is not retained in soils as are plutonium and other radionuclides.*

Assuming that only one repository is breached by fracturing and flooding followed by ground-water transport, it may be argued that spent fuel as a waste should be placed in many smaller repositories because if water reaches the repository at any time, and if the water reaches the biosphere as postulated, a dose of about twice the currently applicable occupational limit to people (assuming their habits are similar to those of people today) will result about 1-1/2 million years after breach of the repository. The use of several repositories would more closely simulate the rather dilute concentration of ^{238}U which exists in the earth today (see also footnote page 4.4.61).

Fifty-year accumulated total body doses to the maximum individual were also calculated for the case of leaching all of the radionuclides in one year from repositories in various geologic media and with the event occurring in the year of repository closure (2050), and 1,000 years thereafter.** The results of these calculations are presented in Tables 4.4.3-28 and 4.4.3-29 respectively.

It should be reiterated that the transport of radionuclides from the repository to the biosphere is the same for a given repository since only one set of absorption coefficients is presently available. Thus, the dose is proportional only to the number of repositories, which depends on the geologic medium in which the repository is located.

Where the wastes are distributed among 3 to 8 repositories, depending on geologic media, the dose, assuming breach of only one repository in the year 2050 or 1000 years thereafter, would vary from about 10-70% of the presently permissible occupational limit at up to two thousand years. Then at 1.4 million years on the same basis, doses would range from about 20 to 60% of the present occupational dose limit.

Doses to the regional population were not calculated directly for this scenario. However, taking a ratio of the per capita population total body dose and total body dose to the maximum individual in the previously presented scenario, an estimate of the population dose for this

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* There is some evidence that movement of plutonium does not differ from that of ^{238}U. E. A. Bryant, G. A. Corvan, W. R. Daniels, W. J. Maeck, Oklo, an Experiment in Long Term Geologic Storage, ACS Symposium Series No. 35, Actinides in the Environment, 1976 American Chemical Society.

** This dose simply represents the dose results in Table 4.4.3-27 divided by the ratio of the total waste in the LWR scenario to the waste inventory distributed among the reference repositories, i.e., 8 in salt, 3 in granite, 6 in shale and 3 in basalt.

TABLE 4.4.3-28. 50-Year Accumulated Total-Body Dose (in rem) to Maximum Individual-All Radionuclides Leached Out in One Year-Spent Fuel Repository Breach; Year 2050

Year Since Burial	Salt	Granite	Shale	Basalt
1×10^{2}	3.4×10^{1}	9.0×10^{1}	4.6×10^{1}	4.0×10^{1}
1×10^{3}	7.5×10^{1}	2.0×10^{2}	1.0×10^{2}	2.0×10^{2}
1×10^{4}	1.5	4.1	2.1	4.1
1.1×10^{5}	1.4	3.8×10^{-1}	1.9×10^{-1}	3.8×10^{-1}
1.4×10^{6}	5.5×10^{1}	1.4×10^{2}	7.0×10^{1}	1.4×10^{2}

TABLE 4.4.3-29. 50-Year Accumulated Total-Body Dose (in rem) to Maximum Individual-All Radionuclides Leached Out In One Year-Spent Fuel Repository Breach by Fracturing and Ground-Water Intrusion; 1000 Years After Repository Closure

Years Since Burial	Salt	Granite	Shale	Basalt
1.0×10^{3}	3.4×10^{1}	9.0×10^{1}	4.5×10^{1}	9.0×10^{1}
2.0×10^{3}	6.2×10^{1}	1.7×10^{2}	8.5×10^{1}	1.7×10^{2}
1.0×10^{4}	3.1	8.3	4.1	8.3
3.4×10^{4}	1.1×10^{-1}	2.8×10^{-1}	1.4×10^{-1}	2.8×10^{-1}
1.1×10^{5}	1.4×10^{-1}	3.7×10^{-1}	1.8×10^{-1}	3.7×10^{-1}
1.4×10^{6}	5.4×10^{1}	1.4×10^{2}	7.0×10^{1}	1.4×10^{2}

case may be made. The ratio obtained was rounded to one significant figure, 1/5, i.e., the per capita population dose was approximately one-fifth of the maximum individual dose. Thus, by taking one-fifth of the above doses for the maximum individual and multiplying by 2 million, the total-body dose to the regional population was estimated and the results presented in Table 4.4.3-30 for repository breaches in the year 2050. The doses for a breach 1000 years later were not significantly different; the doses are essentially shifted to people 1000 years in the future.

TABLE 4.4.3-30. Estimate of 50-Year Accumulated Total Body Dose (in man-rem) to the Regional Population-All Radionuclides Leached from the Waste in One Year-Spent Fuel Repository Breached in Year 2050

Years Since Disposal	Salt	Granite	Shale	Basalt
1×10^{2}	1×10^{7}	4×10^{7}	2×10^{7}	4×10^{7}
1×10^{3}	3×10^{7}	8×10^{7}	4×10^{7}	8×10^{7}
1×10^{4}	6×10^{5}	2×10^{6}	8×10^{5}	2×10^{6}
1.1×10^{5}	6×10^{4}	2×10^{5}	8×10^{4}	2×10^{5}
1.4×10^{6}	2×10^{7}	6×10^{7}	3×10^{7}	6×10^{7}

These results may be compared with the 50-year accumulated regional population dose of 1×10^7 man-rem from naturally occurring radioactive sources. In the worst case, at about 1,000 years after disposal, the regional population would receive a combined dose of eight times the dose from naturally occurring sources. At about 1.4 million years after disposal, assuming the region and its population remained unchanged, the combined regional population dose would be about six times the background dose alone. Using the values of 100 to 800 health effects per million man-rem, the above tabulated data suggest a range of from 6,000 to 60,000 of such effects in the regional population. Thus, in a population of 2 million, the incidence of health effects would increase, but the increase does not suggest a catastrophic response to such a repository breach. It should be recalled that this is a "what if" event and that the use of even relatively high probabilities for the event occurrence would result in societal risks that are small by most comparisons.

So long as it is known that a repository exists in a given region, there is little question but that water supplies would be monitored for the presence of radioactive materials following any major earth disturbance. This monitoring should successfully detect the contaminated waste from the 2.8 m^3/s stream used in this scenario. In such an event, it would probably be possible to divert the entering stream or control use of the water downstream until, by confluence with other streams, the concentrations of radionuclides resulted in estimates of acceptable doses to population groups of interest. In the case of groundwater intrusion, it is unlikely that any mitigating measures could be taken unless the groundwater and surface water network of the region was thoroughly monitored for millenia. Such thorough monitoring would seem to be beyond reasonable expectations.

Solution Mining. In this accident a geologic repository in salt is breached by solution mining 1000 years after the repository is closed. Although this accident is typified by solution mining for salt recovery, solution mining is also used for extraction of other resources and for construction of underground storage cavities. This accidental breach of a repository is believed to be conceivable only for an industrialized society with substantially the same technological capabilities as exist today.

Basically, solution mining in domed salt involves drilling a well to the desired level in the resource, inserting a double-walled pipe so that water can be forced down the outer pipe into the salt where it dissolves the salt into a brine and forces the brine back up the center pipe. [32] In stratified salt a more common practice is to place wells about 500 m apart using water pumped into one well to hydrofracture through the salt to the other well. (This method results in obtaining saturated brines more efficiently.) The brine may then be purified and salt recovered by several methods such as the vacuum pan and grainier processes or by solar evaporation of the brine. The life of such solution wells varies markedly, some failing in a few years. For purposes of this accident analysis it is assumed that the well(s) could operate for 50 years before being abandoned because of failure from cave-in and crushing and plugging of piping with debris.

This accident, as in the case of the drilling accident, makes the assumption that repository markers are either no longer evident, are misunderstood, or are ignored. No probabilities are assigned to this event and it is presented only as a hypothetical "what if" accident.

Once the brines are brought to the surface they are analyzed to determine the kinds and amounts of ordinarily encountered impurities such as calcium sulfate, calcium-magnesium carbonate, sulfides, etc., which would govern further processing to purify the salt. Calculations suggest that radioactivity could be determined with off-the-shelf gamma-ray spectrometer apparatus on samples of a few hundred grams at concentrations of waste in salt existing after a few days of drilling operation (as described later) and with certainty by one month of operation.

It is assumed that although the salt stratum of the reference site is about 80 m thick, the salt removed is principally that from backfill, ceiling, pillars and floor where radioactive waste has been placed. In mining the repository, about 33 million tons of salt were removed for waste placement. This represents about one-fourth of the total salt volume in the mined area (it is assumed that the repository has been backfilled completely with salt; actually backfill of about 60% is presently planned). The total salt postulated to the solution mined over 50 years is then about 130 million tons.* (This represents about 10% of the total salt contained in the salt strata bounded by the repository area.) Assuming an equal amount of salt is mined in each of 50 years, the annual production would be about 2.6 million tons. (In 1957 about 24 million tons of salt were produced in the United States.)[32] Such a solution mining operation for salt would exceed the size of those presently in operation in the United States; a very large operation in the United States produces about 0.4 million tons annually and in Europe a very large operation may produce about 1 million tons of salt annually.

Assuming that 100 parts of water (at 20-100°C) by weight can dissolve 36-39 parts of salt, then over a 50-year period a stream flow of 3300 gpm is required. Assuming that an adequate source of water is available, 9 wells each operating at above 370 gpm would be sufficient.

The actual solution chemistry of leached radionuclides moving into the salt brine is open to question at this writing. For simplicity it is assumed that radionuclides leached from spent fuel mix completely with the salt brine and are carried to the surface. Although it may take 1/2 to 1-1/2 years to bring a brine well to production, it is assumed that the brine well produces immediately and continuously for 50 years, at the end of which the entire quantity of salt surrounding the waste would have been mined out. (It is assumed that water flow would follow a course of least resistance and would follow the previously mined carvern boundaries where possible; this maximizes the consequences.)

The reference LWR scenario places a total of 379,000 MTHM of spent fuel in repositories. Eight repositories would be required if spent fuel were to be disposed of in salt. It is assumed that the waste is equally distributed among the 8 repositories so that each repository contains about 47,000 MTHM.

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* Although it is believed that radioanalysis of salt would result in termination of the operation soon after start-up, the scenario is developed based on removal of the repository salt over a 50-year period. Amounts of wastes and salt brought to the surface over shorter periods of time are prorated based on water contact with all wastes by the end of 50 years. Consequences are based on the assumption that the presence of radioactivity goes undetected for one year.

It is assumed that the canistered fuel assemblies have been laid bare and that water contacts the fuel rods directly.* Since all the waste is assumed to be contacted by water in 50 years, the fraction of waste Q contacted by water in one day could be approximated by

$$(50 \times 365)^{-1} Q = 5.5 \times 10^{-5} Q$$

The number of waste-water contact days in the first year would be the sum of

$$(1 + 2 + \ldots 365)\ (5.5 \times 10^{-5})\ Q = 3.7\ Q \text{ days}$$

During any given year, n, the number of waste-water contact days, would be determined from

$$\left[\left(\frac{n-1}{50}\right) 365 + 3.7\right] Q.$$

The reference fuel configuration is composite of dimensions based on the expected mixture of PWR and BWR fuel elements and results in fuel rods of 1.16 cm in dia by 370 cm in length. Each rod contains 319 pellets about 1 cm in length. Since this configuration contains 3.21 assemblies/MTHM and 121 rods/assembly, there would be 388 rods/MTHM. The surface area of each rod is 2022 cm^2. Then there would be $388 \frac{\text{rods}}{\text{MTHM}} \times 2022 \frac{cm^2}{\text{rod}} \times 4.74 \times 10^4$ MTHM = $3.7 \times 10^{10} cm^2$ in total waste.

Experience has shown the fuel pellets are fractured during the irradiation process and that the area of fragments is about 5 times that of the pellet alone. Thus, the total area of the waste is taken to be 1.9×10^{11} cm^2. The leach rate of spent fuel is taken as 1×10^{-5} g/cm^2 -d, and the amount of waste leached into the salt brine the first year would be (3.7d) (1×10^{-5} g/cm^2-d) (1.9×10^{11} cm^2) = 7.0×10^6 g = 7.0 MTHM. In one year 132 million tons/50 or 2.6 million tons of salt will be mined out. This is equivalent to 2.4×10^{12} g of salt. Quantities of individual radionuclides in spent fuel are tabulated in DOE/ET-0028 Sec. 3 on a Ci/MTHM basis. So for ease in developing source terms, the waste removed in solution mining is reduced to units of MTHM/g salt which in this instance results in a concentration of 2.9×10^{-12} MTHM/g salt.

A person consuming a nominal 5 g/day[32] of this salt either as table salt or in other preparations would consume about 1800 g salt/yr, which would infer an ingestion of 5.3×10^{-9} MTHM of wastes (that amounts to about 0.005 gHM).

If it is assumed that about 3% of the 2.4 million MT of salt mined per year is used in table and culinary salt then about 72,000 MT would be used for that purpose. Again, assuming 1800 g/yr per person, then this amount of salt would provide for about 40 million persons. For purposes of this analysis the exposed population is assumed to consist of 40 million persons.

Although it is expected that daily monitoring controls on the salt would bring attention to the presence of contaminated salt, the possible failure of such monitoring was recognized. It may be a week before such failure was recognized by the producers' quality assurance labora-

* This assumption may be plausible if water had entered the repository over the 1000 years following disposal. If water has not entered the repository and it has remained dry, the containers have not corroded away, this assumption may be unduly pessimistic.

tory. That failing, it might take as much as a year before a food processor discovered the contamination. On this series of circumstances it was concluded that a reasonable upper bound on waste entering the food trade would be that in salt produced in one year. Therefore, the consequences of this accident in terms of radiation dose to an exposed population of 40 million persons from ingestion of contaminated salt for one year were calculated. The quantities of radionuclides which contributed significantly to total body dose are listed in Table 4.4.3-31 and doses are given in Table 4.4.3-32.

TABLE 4.4.3-31. Hypothetical Amounts of Radionuclides (in Ci) Ingested with Salt Obtained by Solution Mining from a Spent Fuel Repository in Salt. One-Year Period Beginning in Year 3050

^{129}I	1.7×10^{2}
^{239}Pu	1.5×10^{-6}
^{240}Pu	2.2×10^{-6}
^{241}Am	4.5×10^{-6}
^{243}Am	6.6×10^{-8}

TABLE 4.4.3-32. 70-Year Dose Commitment (in rem) to an Individual from Ingestion of Spent Fuel with 1800 g of Salt - Year 3050

	Total Body	Gi-LLI	Thyroid	Bone
^{129}I	1.2×10^{-3}	7.7×10^{-8}	1.2×10^{-3}	5.6×10^{-7}
^{239}Pu	3.6×10^{-2}	9.9×10^{-2}	---	1.6
^{240}Pu	5.3×10^{-2}	1.5×10^{-1}	---	2.4
^{241}Am	3.0×10^{-1}	3.5×10^{-1}	---	5.2
^{243}Am	4.0×10^{-3}	5.7×10^{-3}	---	7.3×10^{-2}
Total	3.9×10^{-1}	6.1×10^{-1}	1.2×10^{-3}	9.2

The population of 40 million persons 70-year total body dose commitment would amount to 1.6×10^{7} man-rem for such an accident in a spent fuel repository. In terms of an accidental occurrence this dose is negligible in comparison to the total body dose of 2.8×10^{8} man-rem this population would receive over the same time period from naturally occurring sources.

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5.0 ENVIRONMENTAL EFFECTS OF RADIOACTIVE WASTE MANAGEMENT ASSOCIATED WITH AN LWR FUEL REPROCESSING PLANT

5.1 REFERENCE FUEL REPROCESSING PLANT

5.0 ENVIRONMENTAL EFFECTS OF RADIOACTIVE WASTE MANAGEMENT ASSOCIATED WITH AN LWR FUEL REPROCESSING PLANT

In the event that unused uranium and/or plutonium is to be recovered from spent reactor fuel and used in the fabrication of new fuel, facilities will be required for chemical separation of these elements from the spent fuel. The plants in which this separation is carried out are called fuel reprocessing plants (FRP).

In the light-water reactor (LWR) fuel reprocessing options, spent fuel will be transferred to a receiving basin at an FRP where it will be stored until it has been out of the reactor at least 1.5 years before reprocessing. While at the FRP storage basin some radioactive wastes such as gases from failed fuel elements may be generated and require treatment.

At the FRP the spent fuel will be dissolved, and the uranium and plutonium will be separated out. The uranium will be sent to an enrichment plant and, depending on the fuel cycle option chosen, the plutonium will be sent to a mixed-oxide fuel fabrication plant or to storage or will remain in the high level waste. In the FRP, fuel assembly hardware will be removed as radioactive waste; acid dissolution of fuel will produce high-level liquid wastes; and radioactive gaseous effluents will be generated. These and other radioactive wastes such as air filters, failed equipment, and general trash will be treated for volume reduction, immobilized, and prepared for disposal and isolation from the biosphere.

This section deals with the environmental effects from various aspects of radioactive waste management resulting from the reprocessing of spent reactor fuel.

5.1 REFERENCE FUEL REPROCESSING PLANT (Including Spent Fuel Receiving and Storage Basin)

A number of the waste treatment and storage facilities related to a fuel reprocessing plant (FRP) are located within or adjacent to the FRP. These facilities share utilities and heat dissipation systems with the FRP. As a consequence, descriptions of some of the shared operations at the FRP are necessary to assess the environmental effects related to individual waste treatment processes.

Analysis of environmental effects of radioactive waste management does not include analysis of environmental effects of construction and operation of the FRP itself; environmental effects of the construction and operation of the primary production facilities are beyond the scope of this document. However, because presentation of the effects of some aspects of FRP construction and operation simplifies or gives perspective to the assessment of waste management effects, Sections 5.1.1 through 5.1.3 present a cursory evaluation of environmental effects of the reference FRP. Decommissioning of an FRP, however, is included in the scope of waste management and is presented in Section 5.4.

5.1.1 Description of Reference Fuel Reprocessing Plant

The reference FRP is situated on a 2400-ha site in the reference environment. The entire 2400 ha are restricted from public use and are enclosed by posted agricultural type (barbed wire) of fencing. The main facilities are located near the center of the area within a protected (chainlink fence) security area of about 40 ha.

The reference FRP has the capacity to process 2000 MT/yr of uranium or equivalent heavy metal (MTHM) of spent light-water reactor (LWR) fuel. Plant processes are discussed in detail in DOE/ET-0028 Sec. 3.2.3.[1]

The principal features of the FRP that affect radioactive waste management are the process cooling system and the ventilation air cleaning and atmospheric protection system, which are shared by many waste management facilities.

The reference FRP process cooling system is composed of a three-cell mechanical-draft cooling tower with the following characteristics:

Heat dissipation	2×10^9 MJ/yr (75 MW)
Water flow	
Circulating	1500 ℓ/sec at 27 to 38°C
Evaporated	31 ℓ/sec at 38°C
In drift	0.15 ℓ/sec at 38°C
In blowdown	5.4 ℓ/sec at 27°C
Makeup*	36 ℓ/sec at 10°C

About 10 ℓ/sd of water is required for various FRP process uses.

The atmospheric protection system (APS) is designed to remove radioactive materials from the ventilation air and to reduce radioactivity released to the atmosphere. The reference FRP contains one bank of high-efficiency particulate air (HEPA) filters [decontamination factor (DF) = 1×10^3] in each of building and laboratory ventilation systems. Some waste treatment off-gas streams such as the high-level liquid waste (HLLW) solidification vessel and cell ventilation streams are expected to enter these FRP systems. These streams then flow to the reference APS, which is made up of a roughing filter (DF = 10) and a bank of HEPA filters (DF = 1×10^3). Waste treatment streams such as the process off-gas from HLLW solidification pass directly from the facility cleanup to the APS. However, two reference FRP streams bypass the APS and enter the stack directly. These are the excess water vaporizer (~ 2 m^3/sec) and UF_6 process off-gas ($\sim 4 \times 10^{-7}$ m^3/sec).

The reference FRP stack is 110 m high and operates at an air flow of about 120 m^3/sec with a linear velocity of 25 m/sec and a temperature of about 40°C. The air moving up the stack rejects about 25 MJ/sec of sensible heat to the atmosphere. The total heat release for 300 days of FRP operation is 2.0×10^9 MJ. The fuel receiving and storage basin stack is 45 m high and operates at an air flow of 80 m^3/sec and a linear velocity of 15 m/sec.

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* The average temperature of the R River, the assumed source of cooling tower make-up water is approximately 10°C. The average Δt of the tower drift and evaporated water is therefore 29°C and about 17°C for blowdown.

5.1.2 Environmental Effects Related to Construction of the Reference FRP

One method of judging the significance of individual waste management processes is to compare the effect of a given process against that produced by the FRP, of which the process is a part. For example, it is pointless to investigate land use in detail for a process that requires 100 m^2 of space when in an FRP other land commitments amount to about 400,000 m^2 regardless of the existence of the process requirement. Where the effects of the FRP can be shown to be negligible, the same can be inferred for individual waste management processes. As a consequence, certain aspects of FRP construction and operation are evaluated in terms of environmental effects to serve as a basis for evaluating component waste management processes.

5.1.2.1 Resource Commitments

The reference FRP will occupy an area of about 40 ha. Other land uses include an area of about 60 ha cleared for construction; about 32 ha for a two-lane highway, railroad spur, and electrical transmission facilities; and a restricted area of about 2400 ha.

Direct land use impacts associated with construction of the reference FRP are limited to modification of previous uses of the portion of the site occupied by buildings and transportation and transmission corridors. The actual area cleared for construction is expected to include approximately 60 ha. The remaining approximately 2300 ha of the site will be largely undisturbed. Previous uses of this buffer area may be eliminated, however, because of the need to control access. Agricultural uses may be either stopped or allowed to continue under lease, depending on specific site conditions.

Because of the large buffer area surrounding the site of active construction, noise and dust typically associated with construction activities are not expected to affect uses of the adjoining land. Minor soil erosion could occur at site boundaries as existing vegetation is cleared for fence construction but, if properly managed, poses no threat to adjacent land uses.

About 1.8×10^5 m^3 of water will be needed during construction. If this water requirement is distributed evenly over a 4-year construction period, the average withdrawal rate would be about 90 ℓ/min. This withdrawal rate is about 0.001 and 0.02% of the average and record low flows, respectively, of the R River and would be insignificant in terms of other downstream uses. During the construction period wells could also supply the required amount of water without consequence.

Materials committed for construction of the reference FRP are:

Concrete	120,000 m^3
Steel	25,000 MT
Copper	140 MT
Zinc	9 MT
Aluminum	220 MT
Lumber	4,700 m^3

Energy resources committed for construction are:

Propane	1,500 m^3
Diesel fuel	7,600 m^3
Gasoline	9,800 m^3
Electricity	
Peak demand	3,000 kW
Total consumption	740,000 kWh

5.1.2.2 Physical and Chemical Effects

Several aspects of construction activities at the FRP may have an effect on the environment. The information to follow gives an overview of some effects that may be expected during construction of the FRP.

Pollutants Released to Atmosphere. Pollutants released to the atmosphere during the construction of the reference FRP result primarily from combustion of gasoline and diesel fuel in construction machinery, dust from ground clearing operations, and particulate emissions from concrete batching operations. Secondary emissions of nonradiological pollutants will result from combustion of gasoline in automobiles and trucks during traveling of the construction force to and from the site. To analyze these emissions as worst case, all construction activities were considered for the year of maximum activity. Specific emission factors for machinery type are contained in a detailed summary report.(1) Expected construction emissions for all activities completed in 1 year are listed in Table 5.1.2-1.

TABLE 5.1.2.-1. Pollutants Released to Atmosphere During the Period of Maximum Activities

Pollutant	Annual Primary Emissions, MT	Annual Secondary Emissions, MT	Total
Carbon monoxide	2000	2700	4700
Hydrocarbons	84	42	130
Nitrogen oxides	250	250	500
Sulfur oxides	15	9	24
Particulates	810	23	850

The impact of these emissions on the ambient air quality was predicted using an established modeling procedure.(2) Results of that effort(1) indicate that the maximum concentration of particulates off the immediate construction site is 30 $\mu g/m^3$. The maximum areal extent of the impact occurs about 3 km from the site boundary to the southeast, where an increase in particulate concentration of 5 $\mu g/m^3$ is predicted. Particulate concentrations on the construction site, however, were found to exceed 100 $\mu g/m^3$. With a Federal ambient air quality standard of 75 $\mu g/m^3$, control measures will need to be implemented to mitigate this impact.

Maximum predicted sulfur dioxide concentrations would occur on the construction site itself. The annual average concentration of 7 $\mu g/m^3$ is about 10% of the Federal standard of 80 $\mu g/m^3$.

Concentrations of carbon monoxide resulting from construction force traffic and construction equipment emissions were found to be less than ambient air quality standards. Maximum 1-hr concentrations are 12.5 ppm and 9 ppm for traffic and equipment emission, respectively, as compared with the Federal standard of 35 ppm.

Evaluation of hydrocarbon and nitrogen oxides emissions, although predicted in a slightly different manner from other pollutants, predicted no significant impact.

Cooling Tower Impacts. A three-cell mechanical-draft cooling tower will reject 75 MJ/s of waste heat to the atmosphere. Plume rise and drift analyses have been performed and the principal results are presented below.

Plume heights will range from 73 to 310 m above the tower with an annual mean rise of 140 m. Plumes will seldom be visible above 100 m and a mean visible height was determined to be 30 m.

Close to the tower drift will be appreciable. A flux of 1000 kg/m^2-yr represents a water depth of 100 cm acquired through a period of a year and corresponds to a continuous rainfall of 0.01 mm/hr or 70 cm/yr. This value can also be compared with the total annual precipitation at the reference site of about 60 cm. The drift rate used in this calculation is 0.0001 times the circulating water. This value could be reduced by an order of magnitude if currently available drift eliminators were incorporated.

The deposition of 2 cm of water per week close to the cooling tower will necessitate good drainage to eliminate the accumulation of water. During the winter months structures and natural objects in the area will be subjected to ice loads and special precautions may be necessary.

Estimates of biocide (chlorine) deposition caused by drift from the FRP cooling tower are given in Table 5.1.2-2.

TABLE 5.1.2-2. Estimated Flux of Biocide Deposition Resulting from Drift at the FRP Cooling Tower

Downwind Distance, m	Flux, g/m^2-yr			
	Southeast	Northwest	Northeast	Southwest
10	120	120	105	88
50	13	11	7.1	5.4
100	3.4	2.9	2.0	1.5
200	1.4	1.2	0.9	0.7
500	0.2	0.2	0.2	0.1
700	0.1	0.1	0.1	0.1
1000	0.1	0.1	0.1	<0.1

Noise Impacts. Noise caused by construction activities will vary with day-to-day schedules, variations in equipment operations, weather conditions, and other factors. The noisiest phase of work will be during excavation and grading, which will be completed during the first 3 or 4 months of construction. The approximate indication of human response to blasting noise is given in Table 5.1.2-3.

TABLE 5.1.2-3. Approximate Human Reaction to Blasting Noise During Construction of the Reference FRP

Pressure Level of Peak Blast Sound (dB)	Human Response to Noise of Short Duration
110 to 120	Little annoyance, no complaints
120 to 130	Moderate annoyance, some complaints
130 to 140	Severe annoyance, moderate number of complaints
140	Many complaints, may break windows, probably above OSHA limit for impulsive noise exposure

The estimated maximum noise level from excavation activities is 60 dBA (zero dB equivalent to 20 μPa) at the property line. The estimated peak sound pressure levels from explosive blasting of rock is 98 dB at the property line and 110 dB at the project exclusion fence line. The noise produced by explosive blasting is a low-frequency sound, with most of the energy in the 5- to 50-Hz range. This type of impulsive (typically 250 msec rise) low frequency should be felt as much as heard.

Noise levels will be monitored on a random basis to ensure conformance to Occupational Safety and Health Act, Environmental Protection Agency, state, and local regulations.

Construction noise may disturb and displace some birds and mammals. This impact will subside when construction is complete.

Impacts on Geology and Soils. Although clearing, grading, and excavation activities can increase the potential for wind and water erosion, water erosion of disturbed areas should be minimal because of the relatively flat terrain. During heavy rainstorms, however, some gullying may occur on cleared acreage, with accompanying transport of silt and suspended matter in surface water runoff. Runoff containing suspended solids will also occur from roadways, storage areas, and spoils piles during construction. However, with proper soils erosion control programs, it is anticipated that such impacts will be minor and transitory. Soil erosion control measures in the form of drainage ditches will be provided to collect runoff from such areas, thereby minimizing the turbidity of the surface water runoff. Stockpiles of excavation spoils will be graded and shaped for proper drainage.

Effects on Water Use. Construction activities that normally have major effects on water use include dredging, channel diversion, impounding, and shoreline construction. However, none of these activities except shoreline construction will occur at the reference site. Activities that would cause minor effects on water use are aquifer pumping, dust control, drainage ditch digging, solid waste storage on site, land clearing, and excavation on or near the site.

Effects on the Groundwater System. Excavation of pits for the fuel storage basin and other below-grade facilities may interrupt shallow unconfined aquifers on site. Once these pits are sealed, aquifer conditions are expected to return to normal. The finished facilities should present no serious barrier to aquifer flow. Until the pits are sealed, however, temporary dewatering may be necessary.

Construction dewatering will consist of draining localized perched water in the area of the excavation. The perched water and surface runoff from precipitation will be collected in subdrainage trenches and sumps. This water will then be directed to natural drainage channels where check dams and other measures will control erosion and the silt level of the effluent. The check dams will also allow periodic monitoring of the discharge into natural drainage channels. The water level in private water wells off the project site should not be affected.

Any organic solid waste temporarily stored on site may contribute small amounts of pollutants to the shallow aquifer on a long-term basis.

Effects on Surface Water Drainage Patterns. Minor impacts on surface water drainage patterns will occur as a result of site preparation and construction activities. These activities will result in local changes in surface drainage patterns on site. The changes will be permanent, but the effect on regional hydrology should not be discernible. Surface runoff will be collected in trenches and sumps and directed to natural drainage channels where check dams and other measures will control erosion and silt level of the effluents. During periods of high runoff, turbid water from the construction areas might find its way to nearby rivers but the distance from the site to the river, plus the drainage controls to be used on site, make drainage to rivers extremely unlikely.

Upon completion of construction activities, the laydown areas, spoils area, temporary parking areas, and temporary roads and haulways that are not needed for the facility operations will be covered either with topsoil or rock that has been excavated from the fuel receiving area and crushed. The area will then be graded, seeded, and landscaped to be compatible with the original terrain and new grade. These measures will ensure that the overall final drainage patterns adjacent to the facility will be similar to those existing before construction began.

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5.1.3 Ecological Effects Related to Construction of the Reference FRP

Some aspects of site preparation and facility construction may affect the ecology of the surrounding area. The information that follows is provided to form a basis for evaluating the ecological effects of construction activities.

5.1.3.1 Exclusion Area

Within the exclusion area, habitat disruption will be nearly total as the area is converted from its previous use to an industrial complex. All plant and animal species will be affected. The exclusion area for the reference FRP totals 40 ha. Because the facility will most likely be built on arable level ground, the previous land use (agricultural) will change. Agronomic plants will be eliminated concomitant with movement of indigenous wildlife. This includes small mammals, such as mice and gophers, and some bird species, such as pheasant, quail, sparrows, blackbirds, and hawks. Insect populations will also change drastically; some will be completely removed because agricultural crops necessary to support them will not be available. The aquatic ecosystems of extant surface water within the exclusion area will be destroyed.

5.1.3.2 Restricted Area

The restricted area, 2400 ha, will be about sixty times larger than the exclusion area, thus forming the largest area of potential impact. Since most human activity is assumed to be excluded from this area, construction will not directly affect it. Consequently, the effect of construction will be to eliminate the agricultural activities without replacing them with other activities. Although the choice of farming this land would be lost to a few individuals, the impact on regional crop production is judged to be insignificant. The land will thus undergo a transition from the disturbed form of landscape required for agriculture to a natural relatively undisturbed site. Many years of old-field succession should lead to a forest community. However, succession to the original climax deciduous hardwood forest would not be attained during the life of the facility.

Successional processes that extend well beyond the construction phase and the life of the FRP will have a profound effect on the biotic components in the restricted area. During these successional stages, which should last for several hundred years, plant communities typically change from low stature grasses and other herbs, through moderate statured woody species and colonizing tree species, ending at the reference site in an equilibrium wooded condition dominated by hardwoods.

The animals in the area will likewise undergo long-term change. Life forms common in an agricultural landscape will be displaced by those adapted to more stable conditions. The growth of trees and shrubs will provide a considerably more diverse habitat for animal species than that provided by the annual crop rotation. Therefore, shifts in the presence and abundance of species can be anticipated for several years. These types of population shifts will take years to complete and will coincide approximately with the old-field succession. Browsing animals may become more common as shrub and tree species provide food and cover.

In the restricted area some uncommon species may become more abundant, especially in view of the relatively large size of the area. For example, carnivorous animals may be able to survive in the restricted area that could not survive the pressure of an agricultural system. Specific examples might be foxes, coyotes, or bobcats. Although the restricted area may not be large enough to provide all the territory required for such predators, it could provide enough of a sanctuary from persistent pressure and habitat changes to allow survival.

5.1.3.3 Ponds and Ditches

Part of the activity at the construction site will involve drainage ditches. Ephemeral waters in ditches will probably enhance the diversity of species more for plants than for animals. However, an opposite effect is expected if running or standing water is continuously present. Insect and other invertebrate species adapted to moist and aquatic environments will inhabit these areas. If the plant cover is allowed to proliferate sufficiently, vertebrate species might be able to colonize the area; examples include small amphibians or shore birds. Algae and rooted aquatic plant communities would also become established.

5.1.3.4 Effects on Creeks and Other Regional Water Resources

Construction activities can adversely affect stream ecosystems by increasing water temperature, adding silt or debris, directly destroying aquatic habitat, and altering stream flows. Water withdrawal from the R River during the estimated 4-year construction period is 1.8×10^5 m^3. This represents an average use rate of about 90 ℓ/min, or approximately 0.001 and 0.02% of the average and minimum river flow respectively. No perceptible impact on the river ecosystem is to be expected from this small removal of water. Construction activities should have little, if any, impact on regional water resources. No effects on river navigation or regional hydrology are anticipated. Water used for process and domestic purposes during construction should have minimal effects on regional water supplies. Wastes from chemical toilets will be disposed of in compliance with state regulations.

5.1.3.5 Fences

The existence of fences to restrict access to either the exclusion or the restricted area will affect the movement of some animals. The exclusion area, fenced with a high chain-link fence, will prevent all but insects, birds, and small ground-dwelling animals from entrance. The barbed wire fence around the restricted area will probably not affect the movement of large animals. Low fences would ordinarily present no barrier to such animals as deer.

5.1.3.6 Transportation Corridors

The roadways and railroads required for transportation within the restricted areas will have some effect on the plant and animal communities nearby. Mortality from automobile traffic will probably increase and the readily available carcasses may support an increase in scavenger populations. Highways probably present a greater potential than railroads in this respect. Maintenance of rights-of-way will reduce roadside vegetation. Control of roadside vegetation by chemicals rather than by mechanical means may affect nearby surface water biota if the translocation of these materials by runoff is not controlled. Access to roads down the middle

of transmission line corridors will be restricted to discourage public access and eliminate constant perturbations. Roads, parking areas, and laydown and assembly areas will be located away from waterways on level terrain.

5.1.3.7 Increases in Human Activities

One of the greatest pressures on rural landscapes comes from an increase in the numbers of human beings. Increased pressure on game species populations can be expected, depending upon the relative abundance. Nesting success of waterfowl, winter survival of deer, and reproductive activities of raptors and grouse may be disrupted by human presence in the area during critical periods.

5.2 TREATMENT OF RADIOACTIVE WASTES

5.2 TREATMENT OF RADIOACTIVE WASTES

At an FRP a number of radioactive wastes are generated. Some of these wastes require treatment to prevent release to the biosphere while a process is in operation; others require treatment before storage or disposal. This section addresses alternative treatments available for treating these wastes and evaluates the environmental effects related to their use.

5.2.1 Recovery of Volatile Radionuclides from Dissolver and Vessel Off-Gas

Volatile wastes are 1) released when fuel elements are chopped and dissolved during fuel reprocessing or 2) generated in processes used to reduce the volume or combustibility of secondary wastes. Krypton-85, iodine-129, tritium, and carbon-14 are released during fuel preparation and dissolution; ruthenium, oxides of nitrogen, and particulates are released during solidification of by-product solutions; and hydrogen chloride and particulates are released during combustion of solid wastes containing chlorinated hydrocarbons.

Volatile radioisotopes and other off-gas wastes may either be released or recovered, depending on the potential environmental impact. The primary release technologies, dilution and dispersion from tall stacks, are widely used in industry. Recovery and treatment processes vary with the type of waste being handled; more complex systems may combine steps involving concentration, isolation, and immobilization.

Waste management systems for handling volatile radioisotopes pose a common problem. They tend to convert a low-concentration (perhaps insignificant) waste with certainty of escape to the atmosphere to a high-concentration waste with a low probability of escape. Effective treatment technologies must therefore provide reliable physical or chemical systems to immobilize volatile wastes after they are collected.

Technologies available for removing carbon, iodine, and krypton are analyzed to determine their value in keeping exposure as low as reasonably achievable (ALARA).

Tritium is removed from the off-gas stream in both carbon removal and krypton removal processes; however, this removal is only temporary because the tritium is actually released to the atmosphere at a subsequent step (excess water evaporation) in the process. Since the delay time is insignificant compared with its half-life, all the tritium is assumed to be released at the time of release of dissolver off-gas.

5.2.1.1 Removal of Ruthenium and Iodine from Dissolver Off-Gas

For recovery of iodine the reference system consists of a water scrubber to remove NO_x and particulates, a heater to raise the gas temperature above the dew point, a ruthenium adsorber to recover volatile ruthenium that might plate out in the iodine adsorber, a fiberglass filter (HEPA) to remove particulates, a second heater to increase the temperature of the gas to 150°C, and an iodine adsorber to remove volatile iodine.

The reference iodine adsorber uses silver-loaded zeolite to sorb the iodine. Removal of iodine in this manner has been demonstrated at the Karlsruhe Reprocessing Pilot Plant in Germany.

The reference process was selected from several alternatives including caustic scrubbing, mercury nitrate-nitric acid scrubbing, and the Iodex process. The caustic scrubbing system was not considered here because of the low iodine removal efficiency. The mercury nitrate-nitric acid system is ineffective for organic species of iodine because of the slow reaction kinetics for organic iodides. The Iodex scrubbing process using 20 to 22 M HNO_3 was not chosen because long-term capacity and corrosion effects on materials of construction are yet to be determined.

The design volumetric flow is about 0.06 m^3/sec. The treated off-gas is released to the combined atmospheric protection system of the reference FRP and discharged via the 110-m FRP stack along with 120 m^3/sec of air flow. The exit velocity is 25 m/sec.

In the iodine recovery process, the following decontamination factors are obtained with respect to the incoming waste streams: 1×10^5 for particulates, 1×10^4 for volatile ruthenium and 1×10^3 for iodine. Figure 5.2.1-1 shows a flow diagram of the iodine recovery system.

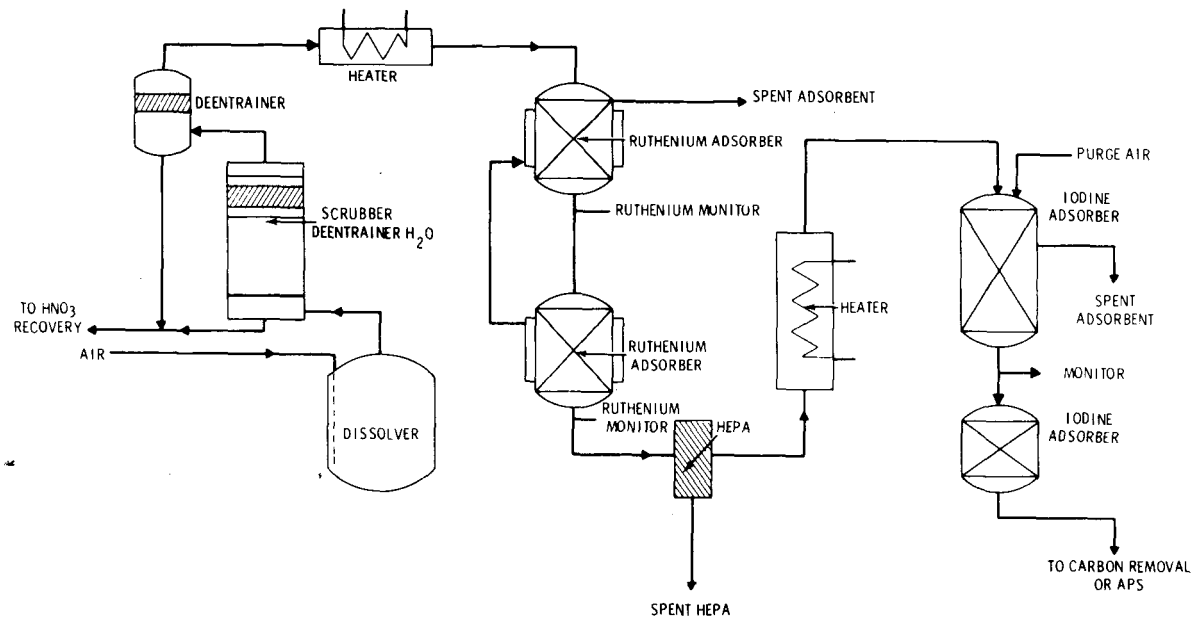

FIGURE 5.2.1-1. Simplified Flow Sheet of Iodine Recovery System

Environmental Effects Related to Facility Construction. Some of the factors relating to site preparation and reference facility construction may have an effect on the environment and the natural resources of the surrounding area. The information that follows provides a basis for evaluating the effect of construction activities.

Resource Commitments. The ruthenium and iodine recovery system will be an integral part of the reference FRP, whose structures will be located within a secured area of about 400,000 m^2. Land use attributable to the recovery system is inconsequential by comparison and in any event would be preempted by construction of the FRP.

Water used during construction is estimated to be 2.7×10^3 m^3. Withdrawal of this amount of water from the R River (described in the reference environment in Appendix A), with an average flow of 1.0×10^7 m^3/day, is judged to be insignificant with respect to other downstream uses. During the construction period, wells could also supply the required amount of water without environmental consequence.

Materials committed for construction of the ruthenium and iodine recovery system are:

Steel	270 MT
Copper	3 MT
Lumber	50 m^3
Concrete	1200 m^3

Energy resources committed for construction are:

Propane	27 m^3
Diesel fuel	260 m^3
Gasoline	170 m^3
Electricity	
Peak demand	200 kW
Total consumption	130,000 kWh

These quantities represent an additional 2 to 3% of the amounts required for construction of the reference FRP.

Manpower requirements for construction of the ruthenium and iodine recovery system amount to 230,000 man-hr, which will likely be integrated with labor schedules for the FRP.

No additional transportation requirements for the ruthenium and iodine recovery system have been identified beyond those for the FRP. No other site-specific requirements have been identified.

Physical and Chemical Effects. Effects on air quality from construction of the ruthenium and iodine recovery system will be an indistinguishable fraction of those resulting from construction of the reference FRP (Section 5.1.2). Similarly, effects on water quality will be indistinguishable.

Ecological Effects. There will be no construction impacts for the ruthenium and iodine recovery system apart from those of the reference FRP. Land area requirements are included with those of the FRP. Water used during the 4-year construction period of the entire FRP is approximately 1.8×10^5 m^3 and will come from the R River at the reference site. This amounts to less than the 0.02% of the river at low flow (Appendix A) and will not have an impact on the river biota. Since water used during construction of the ruthenium and iodine recovery system is only a small percentage ($\sim$2%) of that required for the entire FRP, no separately identifiable ecological impacts are anticipated.

A common system will probably be constructed to supply water to all facilities within the FRP complex. Procedures will be required to keep disruption of current patterns and disturbance of the river bottom to a minimum during construction of the intake for this system.

Environmental Effects Related to Facility Operation. Some of the factors relating to facility operation may have an effect on the environment and the natural resources of the surrounding area. The information that follows provides a basis for evaluating the effect of process operation.

Resource Commitments. Resources required during planned operation of the ruthenium and iodine recovery system are given in Table 5.2.1-1.

TABLE 5.2.1-1. Utilities and Materials Required for Operating the Ruthenium and Iodine Recovery System

Resource	Average Annual Use
Electricity	53 MWh
Silica gel	0.5 m^3
Silver zeolite	6.6 m^3
Manpower (routine)	2.5 man-yr

No cooling water is required for heat removal in this process.

Process Effluents. The amounts of radioactive materials that reach the biosphere after leaving the ruthenium and iodine recovery system and passing through the reference FRP atmospheric protection system (APS) are shown in Table 5.2.1-2. The radionuclides listed are those that will contribute at least 1% to the total dose to any organ from any pathway to man or that are otherwise of interest.

TABLE 5.2.1-2. Radionuclides Released to the Biosphere After Ruthenium and Iodine Recovery System Treatment of the Dissolver Off-Gas (Ci/yr)

Radionuclide	U Recycle with Pu in SHLW or PuO_2 Stored	U and Pu Recycle
^{3}H*	6.5×10^{5}	6.5×10^{5}
^{14}C	1.2×10^{3}	1.2×10^{3}
^{85}Kr	1.8×10^{7}	1.7×10^{7}
^{90}Sr	1.4×10^{-6}	1.3×10^{-6}
^{106}Ru	5.1	5.7
^{129}I	6.6×10^{-2}	7.0×10^{-2}
^{137}Cs	2.0×10^{-6}	2.1×10^{-6}
^{234}U	--	6.8×10^{-3}
^{236}U	6.4×10^{-3}	5.2×10^{-3}
^{238}U	6.4×10^{-3}	6.4×10^{-3}
^{238}Pu	1.2×10^{-4}	2.2×10^{-4}
^{239}Pu	1.2×10^{-5}	1.4×10^{-5}
^{240}Pu	1.8×10^{-5}	2.9×10^{-5}
^{241}Pu	4.4×10^{-3}	7.2×10^{-3}

* ^{3}H is included in this waste stream for simplicity of calculation. While ^{3}H is removed from the dissolver off-gas it ultimately leaves the FRP via the excess water vaporizer which empties directly into the FRP stack.

The radionuclides entrained in air are derived from process off-gas. The total air flow through the process is estimated to be 0.06 m^3/sec or about 0.1% of the total flow of air through the FRP-APS. No radioactive material will be released to the biosphere via liquid effluent streams.

During normal operation of the ruthenium and iodine recovery system no nonradioactive materials will be released to the atmosphere or ground.

Physical, Chemical, and Thermal Effects. With no release of nonradioactive materials to the atmosphere and a contribution of about 0.07% of the heat released by the FRP, no effects on the atmosphere are expected from operation of the ruthenium and iodine recovery system.

There will be no discharge from this process of heated effluents to surface waters.

There is no direct ground disposal of nonradioactive liquid or solid wastes from the ruthenium and iodine recovery system. All liquid and solid waste disposal for the system is part of the overall FRP operation.

Radiological Effects. Doses to individuals in the vicinity of the ruthenium and iodine recovery system were calculated based on the releases of radionuclides listed in Table 5.2.1-2; exposure pathways, demography, and other parameters described for the reference environment in Appendix A; and mathematical models relating dose to man from radionuclide releases (Appendix B). For planned operation of the ruthenium and iodine recovery system, the only exposure pathway to man is via airborne effluents; there are no releases to ground or water.

The annual doses to individuals whose habits tend to maximize their dose ("maximum individual") are shown in Table 5.2.1-3. For perspective, the dose to the total body of an individual from naturally occurring radioactive sources averages about 0.1 rem/yr.

The combined dose from gaseous effluents to the population living within an 80-km radius of the plant was calculated using the projected year 2000 population data given for the reference environment (Appendix A). Table 5.2.1-4 summarizes the annual doses received by this population. The annual total-body population dose from naturally occurring sources to the approximately 2 million persons living within an 80-km radius of the plant in the year 2000 would be about 200,000 man-rem compared with the value of about 320 man-rem from process sources given in Table 5.2.1-4.

The annual total-body dose to the work force associated with the ruthenium and iodine recovery system was estimated based on permissible exposure limits and experience of operating plants. The annual occupational dose was calculated to be 2 man-rem. Table 5.2.1-5 summarizes the annual total-body dose to the work force and the general population from process and naturally occurring sources in the year 2000.

TABLE 5.2.1-3. Annual Doses to Maximum Individual from Dissolver Off-Gas After Treatment by the Ruthenium and Iodine Recovery System (rem)[a]

Pathway	Skin	Total Body	Thyroid (child)[b]	Thyroid[c]	Lung	Bone
		U Recycle with Pu in SHLW or PuO_2 Stored				
Air submersion	1.3×10^{-2}	1.3×10^{-4}	1.3×10^{-4}	1.3×10^{-4}	1.3×10^{-4}	1.3×10^{-4}
Inhalation		3.4×10^{-4}		3.4×10^{-4}	4.0×10^{-4}	8.4×10^{-6}
Ingestion		2.2×10^{-3}	1.4×10^{-3}	2.4×10^{-3}	2.2×10^{-3}	1.1×10^{-3}
Total	1.3×10^{-2}	2.7×10^{-3}	1.5×10^{-3}	2.9×10^{-3}	2.7×10^{-3}	1.2×10^{-3}
		U and Pu Recycle				
Air submersion	1.2×10^{-2}	1.2×10^{-4}	1.2×10^{-4}	1.2×10^{-4}	1.2×10^{-4}	1.2×10^{-4}
Inhalation		3.4×10^{-4}		3.4×10^{-4}	4.1×10^{-4}	7.9×10^{-6}
Ingestion		2.2×10^{-3}	1.4×10^{-3}	2.4×10^{-3}	2.2×10^{-3}	1.0×10^{-3}
Total	1.2×10^{-2}	2.7×10^{-3}	1.5×10^{-3}	2.9×10^{-3}	2.7×10^{-3}	1.1×10^{-3}

Note: The maximum individual is defined as a permanent resident at a location with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 1.5×10^{-8} sec/m^3 2800 m southeast of the stack.

a. After 30 years of release and accumulation in the environment.

b. Thyroid dose is calculated for a 1-year-old child breathing air containing radioactive effluents and consuming 1 ℓ of milk per day from cows grazing 7 months/yr at the site boundary. Inhalation dose is <2% of total dose.

c. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

TABLE 5.2.1-4. Annual Doses to Population (within 80 km) from Dissolver Off-Gas After Treatment by the Ruthenium and Iodine Recovery System (man-rem)[a]

Pathway	Total Body	Thyroid	Lung	Bone
	U Recycle with Pu in SHLW or PuO_2 Stored			
Air submersion	3.1×10^{1}	3.1×10^{1}	3.1×10^{1}	3.1×10^{1}
Inhalation	8.0×10^{1}	8.0×10^{1}	9.3×10^{1}	2.0
Ingestion	2.1×10^{2}	2.2×10^{2}	2.1×10^{2}	1.2×10^{2}
Total	3.2×10^{2}	3.3×10^{2}	3.4×10^{2}	1.5×10^{2}
	U and Pu Recycle			
Air submersion	2.9×10^{1}	2.9×10^{1}	2.9×10^{1}	2.9×10^{1}
Inhalation	8.0×10^{1}	8.0×10^{1}	9.5×10^{1}	1.8
Ingestion	2.1×10^{2}	2.2×10^{2}	2.1×10^{2}	1.2×10^{2}
Total	3.2×10^{2}	3.3×10^{2}	3.4×10^{2}	1.5×10^{2}

a. After 30 years of release and accumulation in the environment.

TABLE 5.2.1-5. Summary of Annual Total-Body Doses Received from the Dissolver Off-Gas from the Ruthenium and Iodine Recovery System and Naturally Occurring Sources in the Year 2000

	Man-rem
Ruthenium and iodine recovery system	
Process work force (30 yr)	2
Population (within 80 km)	320
Naturally occurring sources	
Population (within 80 km)	200,000

The 70-year doses to the maximum individual and to the population within 80 km of the facility are given in Tables 5.2.1-6 and 5.2.1-7 respectively. A summary of the 70-year total-body doses to the work force and the population is given in Table 5.2.1-8. For comparison, the dose to the same population from naturally occurring sources over the 70-year period amounts to about 14,000,000 man-rem, which may be compared with 11,000 man-rem received from the treated off-gases released by the FRP.

TABLE 5.2.1-6. 70-Year Doses to Maximum Individual from Dissolver Off-Gas After Treatment by the Ruthenium and Iodine Recovery System (rem)

Pathway	Skin	Total Body	Thyroid[a]	Lung	Bone
		U Recycle with Pu in SHLW or PuO_2 Stored			
Air submersion	3.8×10^{-1}	4.0×10^{-3}	4.0×10^{-3}	4.0×10^{-3}	4.0×10^{-3}
Inhalation		1.0×10^{-2}	1.0×10^{-2}	1.2×10^{-2}	2.9×10^{-4}
Ingestion		7.1×10^{-2}	8.1×10^{-2}	7.1×10^{-2}	4.1×10^{-2}
Total	3.8×10^{-1}	8.5×10^{-2}	9.5×10^{-1}	8.7×10^{-2}	4.5×10^{-2}
		U and Pu Recycle			
Air submersion	3.5×10^{-1}	3.7×10^{-3}	3.7×10^{-3}	3.7×10^{-3}	3.7×10^{-3}
Inhalation		1.0×10^{-2}	1.0×10^{-2}	1.3×10^{-2}	3.0×10^{-4}
Ingestion		7.0×10^{-2}	8.1×10^{-2}	7.0×10^{-2}	3.8×10^{-2}
Total	3.5×10^{-1}	8.4×10^{-2}	9.4×10^{-2}	8.7×10^{-2}	4.2×10^{-2}

Note: The maximum individual is defined as a permanent resident at a location with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 1.5×10^{-8} sec/m^3 2800 m southeast of the stack.

a. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

TABLE 5.2.1-7. 70-Year Doses to Population (within 80 km) from Dissolver Off-Gas After Treatment by the Ruthenium and Iodine Recovery System (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
	U Recycle with Pu in SHLW or PuO_2 Stored			
Air submersion	9.2×10^{2}	9.2×10^{2}	9.2×10^{2}	9.2×10^{2}
Inhalation	2.6×10^{3}	2.6×10^{3}	2.6×10^{3}	6.1×10^{1}
Ingestion	7.6×10^{3}	8.6×10^{3}	7.6×10^{3}	5.9×10^{3}
Total	1.1×10^{4}	1.2×10^{4}	1.1×10^{4}	6.9×10^{3}
	U and Pu Recycle			
Air submersion	8.7×10^{2}	8.7×10^{2}	8.7×10^{2}	8.7×10^{2}
Inhalation	2.3×10^{3}	2.4×10^{3}	3.0×10^{3}	7.1×10^{1}
Ingestion	6.7×10^{3}	7.8×10^{3}	6.7×10^{3}	4.3×10^{3}
Total	9.9×10^{4}	1.1×10^{4}	1.1×10^{4}	5.2×10^{3}

TABLE 5.2.1-8. Summary of 70-Year Total-Body Doses Received from the Dissolver Off-Gas from the Ruthenium and Iodine Recovery System and Naturally Occurring Sources in the Year 2000

	Man-rem
Ruthenium and iodine recovery system	
Process work force (30 yr)	60
Population (within 80 km)	9,900
Naturally occurring sources	
Population (within 80 km)	14,000,000

"Health effects" for regional populations are discussed at the plant level where several processes within the plant are combined. In general, doses at the individual process level are too small for meaningful discussion of health effects. In this report, 100 to 800 health effects are postulated to occur in the exposed population per million man-rem.

Table 5.2.1-9 summarizes doses to the worldwide population (assumed to be 6.4×10^9 persons in the year 2000) for two cases--dose for the 30th year of plant operation and the accumulated dose over 70 years, both of which include accumulation in the environment from 30 years of operation. These doses are from the release of ^3H, ^{14}C, and ^{85}Kr, based on values in Table 5.2.1-2, also included is the dose from naturally occurring sources.

TABLE 5.2.1-9. Doses to Worldwide Population from Dissolver Off-Gas After Treatment by the Ruthenium and Iodine Recovery System and Naturally Occurring Sources (man-rem)

Source	30th Year Dose	70-Year Accumulated Dose
U Recycle with Pu in SHLW or PuO_2 Stored		
^3H	4.4×10^3	1.5×10^5
^{14}C	8.7×10^4	4.8×10^6
^{85}Kr	7.3×10^3	2.5×10^5
Total	9.9×10^4	5.2×10^6
U and Pu Recycle		
^3H	4.4×10^3	1.5×10^5
^{14}C	7.9×10^4	4.4×10^6
^{85}Kr	6.9×10^3	2.3×10^5
Total	9.0×10^4	4.8×10^6
Naturally occurring sources	6.4×10^8	4.5×10^{10}

Ecological Effects. No adverse impacts are expected from routine operation of the ruthenium and iodine recovery system. Nonradioactive chemicals that are potentially harmful to terrestrial plants and animals will not be released to the environment.

There is no requirement for surface water for this process. There will be no direct discharge of liquid effluents from the facility to surface waters.

Environmental Effects Related to Postulated Accidents. Minor accidents and process upsets associated with the ruthenium and iodine recovery system have not been described individually; rather, the downtime of the system for various reasons was postulated from operational experience with related systems. The resultant releases were estimated and are included in the planned annual releases discussed previously.

There are several accidents thought to have releases of radioactive material somewhat larger than those from the minor accidents. These are classified as moderate accidents and are listed below.

Accident Number	Description
4.9.3	Process shutdown while dissolver is operating
4.4.4	Iodine canister absorbent spill
4.9.5	Ruthenium canister adsorbent spill during replacement

Of these accidents, process shutdown while dissolver is operating (Accident 4.9.3) was judged to be more severe and was taken as representative of the set. For this accident it was assumed that all volatile isotopes were vented to the FRP stack because of recovery system failure. The failure involved the entire system, and carbon and krypton were released along with ruthenium and iodine. The venting occurred over a 30-day period with a frequency of occurrence of once every 10 years. The radioactive material associated with such an event is given in Table 5.2.1-10.

The 70-year dose commitment to the maximum individual was calculated and is presented in Table 5.2.1-11. Numerically, the largest of these dose values is less than the variation in dose the individual would have received from naturally occurring sources during the 70-year period. The dose via the ingestion pathway is not included because it is assumed that following an accident, edible produce could be purchased or other action taken if warranted to preclude human consumption.

During the month the recovery system will be inoperative, about 10 g of NO_x will also be released. The average concentration of NO_x at this location will be 2.2×10^{-4} $\mu g/m^3$. No effect is expected from this concentration, however, since it is several orders of magnitude below the EPA standard of 100 $\mu g/m^3$.

No serious accidents could be identified within the design basis of the facility. Nondesign basis accidents were not considered.

TABLE 5.2.1-10. Radionuclides Released to the Atmosphere from Failure of the Ruthenium and Iodine Recovery System (Ci)

Radionuclide	U Recycle with Pu in SHLW or PuO_2 Stored	U and Pu Recycle
^{3}H	5.8×10^{4}	5.8×10^{4}
^{14}C	1.2×10^{2}	1.2×10^{2}
^{85}Kr	1.5×10^{6}	1.4×10^{6}
^{90}Sr	1.1×10^{-4}	1.0×10^{-4}
^{106}Ru	5.6×10^{-1}	6.3×10^{-1}
^{129}I	5.4	5.7
^{137}Cs	1.5×10^{-4}	1.5×10^{-4}
^{239}Pu	4.8×10^{-7}	5.9×10^{-7}

TABLE 5.2.1-11. 70-Year Dose Commitment to the Maximum Individual Resulting from Failure of the Ruthenium and Iodine Recovery System (rem)

Pathway	Skin	Total Body	Thyroid	Lung	Bone
	U Recycle with Pu in SHLW or PuO_2 Stored				
Air submersion	2.8×10^{-2}	2.9×10^{-4}	2.9×10^{-4}	2.9×10^{-4}	2.9×10^{-4}
Inhalation		1.3×10^{-3}	6.0×10^{-3}	1.6×10^{-3}	3.5×10^{-5}
Total	2.8×10^{-2}	1.6×10^{-3}	6.3×10^{-3}	1.9×10^{-3}	3.3×10^{-4}
	U and Pu Recycle				
Air submersion	2.7×10^{-2}	2.8×10^{-4}	2.8×10^{-4}	2.8×10^{-4}	2.8×10^{-4}
Inhalation		1.3×10^{-3}	6.3×10^{-3}	1.6×10^{-3}	3.7×10^{-5}
Total	2.7×10^{-2}	1.6×10^{-3}	6.6×10^{-3}	1.9×10^{-3}	3.2×10^{-4}

5.2.1.2 Removal of Ruthenium, Iodine, and Carbon from Dissolver Off-Gas

Carbon-14 is produced during the operation of nuclear power reactors as an activation product by the reaction between neutrons and the minor components nitrogen, carbon-13, and oxygen. In spent fuel elements the major source of carbon is the approximately 25 ppm of nitrogen originally present in the fuel.

For the carbon recovery process, it is assumed that the dissolver off-gas has passed through the reference ruthenium and iodine recovery system. The resulting treated off-gases can then be sent to the APS or routed through the carbon recovery facility to remove carbon, generally present in the form of carbon dioxide, prior to being discharged via the APS to the FRP stack. Figure 5.2.1-2 shows a flow diagram of the carbon recovery system.

The carbon recovery facility requires that oxides of nitrogen and water vapor first be removed from the off-gas stream for efficient recovery of carbon dioxide. Carbon dioxide is then removed from the off-gas by adsorption on molecular sieves followed by desorption and

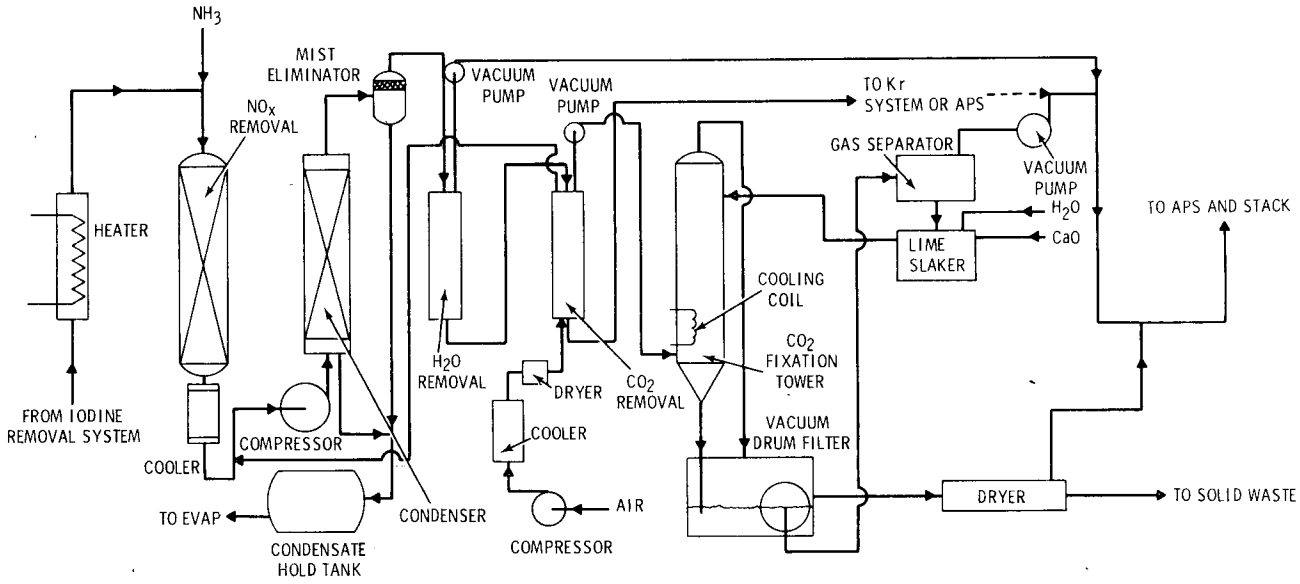

FIGURE 5.2.1-2. Flow Diagram of the Carbon Recovery System

capture by a slurry of calcium oxide, which forms $CaCO_3$. The slurry is dewatered and placed in storage as a solid. There is no FRP operating experience for the removal of carbon from off-gas streams. However, similar flowsheets for recovery of carbon dioxide are well proven in the chemical industry. Caustic scrubbing and fluorocarbon adsorption have been suggested as alternatives.

The carbon recovery facility is designed to treat about 0.06 m^3/sec of off-gas received from the ruthenium and iodine recovery system. The resulting treated off-gas joins 120 m^3/sec of air released to the atmosphere via the 110-m FRP stack at a linear velocity of 25 m/sec.

The decontamination factor applicable to the carbon removal system is 1×10^2 for carbon.

Environmental Effects Related to Facility Construction. Some of the factors relating to site preparation and reference facility construction may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of construction activities.

Resource Commitments. The ruthenium, iodine, and carbon recovery system will be an integral part of the reference FRP, whose structures will occupy about 40 ha. Land use attributable to the recovery system is inconsequential by comparison and in any event would be preempted by construction of the FRP.

Water used during construction is estimated to be 4.6×10^3 m^3. Withdrawal of this amount of water from the R River, with an average flow is 1.0×10^7 m^3/day, is judged to be insignificant with respect to other downstream uses. During the construction period, wells could also supply the required amount of water required without environmental consequence.

Materials committed for construction of the ruthenium, iodine, and carbon recovery system are:

Steel	440 MT
Copper	4.6 MT
Lumber	70 m^3
Concrete	1800 m^3

Energy resources committed for construction are:

Propane	46 m^3
Diesel fuel	450 m^3
Gasoline	290 m^3
Electricity	
Peak demand	350 kW
Total consumption	220,000 kWh

These quantities represent an addition of about 3% of the amounts required for construction of the reference FRP.

Manpower requirements for the construction of the ruthenium, iodine, and carbon recovery system amount to 390,000 man-hr, which will likely be integrated with labor schedules for the FRP.

No additional transportation requirements for the ruthenium, iodine, and carbon recovery system have been identified beyond those for the FRP. No other site-specific requirements have been identified.

Physical and Chemical Effects. Effects on air quality from construction of the recovery system will be an indistinguishable fraction of those resulting from construction of the reference FRP (Section 5.1.2). Similarly, effects on water quality will be indistinguishable.

Ecological Effects. There will be no construction impacts for the ruthenium, iodine, and carbon recovery system apart from those of the reference FRP. Land area requirements are included with those of the FRP. Water used during the 4-year construction period of the entire FRP is approximately 1.8×10^5 m^3 and will come from the R River at the reference site. This amounts to less than the 0.02% of the river at low flow (Appendix A) and will not have an impact on the river biota. Since the water used during construction of the ruthenium, iodine, and carbon recovery system is only a small percentage ($\sim$3%) of that required for the entire FRP, no separately identifiable ecological impacts are anticipated.

A common system will probably be constructed to supply water to all facilities within the FRP complex. Procedures will be required to keep disruption of current patterns and disturbance of the river bottom to a minimum during the construction of the intake for this system.

Environmental Effects Related to Facility Operation. Some of the factors relating to facility operation may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of operation.

Resource Commitments. Resources required during planned operation of the ruthenium, iodine, and carbon recovery system are given in Table 5.2.1-12.

The commitment of the amount of water given in Table 5.2.1-12 is insignificant compared with that expected to be routinely required for the reference FRP (makeup water, 9.3×10^5 m^3/yr). The commitment of the other tabulated resources is also considered to be insignificant.

TABLE 5.2.1-12. Utilities and Materials Required for Operating the Ruthenium, Iodine, and Carbon Recovery System

Resource	Average Annual Use
Electricity	350 MWh
Water	
Evaporated	470 m^3
Drift	2.3 m^3
Blowdown	82 m^3
Total makeup	550 m^3
CaO	1.4 MT
Silica gel	0.5 m^3
Silver zeolite	8.8 m^3
Ammonia	22 MT
Manpower (routine)	3600 man-hr

Process Effluents. The amounts of radioactive materials that reach the biosphere after leaving the ruthenium, iodine, and carbon recovery system and passing through the reference FRP-APS are shown in Table 5.2.1-13. The radionuclides listed are those that will contribute at least 1% to the total dose to any organ from any pathway to man or that are otherwise of interest.

The radionuclides entrained in air are derived from process off-gas. The total air flow through the process is estimated to be 0.06 m^3/sec or about 0.05% of the total flow of air through the FRP-APS. No radioactive material will be released to the biosphere via liquid effluent streams.

During normal operation of the ruthenium, iodine, and carbon recovery system no nonradioactive materials will be released to the atmosphere or ground. About 82 m^3/yr (4×10^{-3} ℓ/sec) of cooling tower blowdown will be released to the R River. Temperature of this water will, on the average, have been elevated 17°C.

Physical, Chemical, and Thermal Effects. With no release of nonradioactive materials to the atmosphere and a heat contribution of 1.1×10^6 MJ over 300 days of operation (which is about 0.1 MJ/sec or 100 kW), no effects on the atmosphere are expected from operation of the ruthenium, iodine, and carbon recovery system

TABLE 5.2.1-13. Radionuclides Released to the Biosphere After Ruthenium, Iodine, and Carbon Recovery System Treatment of the Dissolver Off-Gas (Ci/yr)

Radionuclide	U Recycle with Pu in SHLW or PuO_2 Stored	U and Pu Recycle
^{3}H*	6.5×10^{5}	6.5×10^{5}
^{14}C	1.2×10^{1}	1.1×10^{1}
^{85}Kr	1.8×10^{7}	1.7×10^{7}
^{90}Sr	1.4×10^{-6}	1.3×10^{-6}
^{106}Pu	5.1	5.7
^{129}I	6.5×10^{-2}	6.9×10^{-2}
^{137}Cs	1.8×10^{-6}	1.1×10^{-6}
^{232}U	2.2×10^{-4}	2.4×10^{-4}
^{234}U	7.2×10^{-4}	6.8×10^{-3}
^{236}U	6.4×10^{-3}	5.2×10^{-3}
^{238}U	6.4×10^{-3}	6.4×10^{-3}
^{238}Pu	1.2×10^{-4}	2.2×10^{-4}
^{239}Pu	1.2×10^{-5}	1.4×10^{-5}
^{240}Pu	1.8×10^{-5}	2.9×10^{-5}
^{241}Pu	4.3×10^{-3}	7.2×10^{-3}

The return of 82 m^3/yr of water heated to 17°C above ambient will have an imperceptible effect on the thermal plume resulting from release of blowdown and once-through cooling water from the reference FRP.

There is no direct ground disposal of nonradioactive liquid or solid wastes from the ruthenium, iodine, and carbon recovery system. All liquid and solid waste disposal for the process is part of the overall FRP operation.

Radiological Effects. Doses to individuals in the vicinity of the ruthenium, iodine, and carbon recovery system were calculated based on the releases of radionuclides as listed in Table 5.2.1-13; exposure pathways, demography, and other parameters described in Appendix A; and mathematical models relating dose to man from radionuclide releases (Appendix B). For planned operation of the recovery system, the only exposure pathway for radionuclides to man is via airborne effluents; there are no releases to ground or water.

The annual doses to individuals whose habits tend to maximize their dose ("maximum individual") are shown in Table 5.2.1-14. For perspective, the dose to the total body of an individual from naturally occurring radioactive sources averages about 0.1 rem/yr.

* See note Table 5.2.1-2.

TABLE 5.2.1-14. Annual Doses to Maximum Individual from Dissolver Off-Gas After Treatment by the Ruthenium, Iodine, and Carbon Recovery System (rem)[a]

Pathway	Skin	Total Body	Thyroid (child)[b]	Thyroid[c]	Lung	Bone
		U Recycle with Pu in SHLW or PuO_2 Stored				
Air submersion	1.3×10^{-2}	1.3×10^{-4}	1.3×10^{-4}	1.3×10^{-4}	1.3×10^{-4}	1.3×10^{-4}
Inhalation		3.4×10^{-4}		4.0×10^{-4}	3.7×10^{-4}	1.1×10^{-6}
Ingestion		2.0×10^{-3}	1.1×10^{-8}	2.0×10^{-3}	2.1×10^{-3}	1.2×10^{-5}
Total	1.3×10^{-2}	2.5×10^{-3}	1.3×10^{-4}	2.5×10^{-3}	2.6×10^{-3}	1.4×10^{-4}
		U and Pu Recycle				
Air submersion	1.2×10^{-2}	1.2×10^{-4}	1.2×10^{-4}	1.2×10^{-4}	1.2×10^{-4}	1.2×10^{-4}
Inhalation		3.4×10^{-4}		3.4×10^{-4}	4.0×10^{-4}	1.4×10^{-6}
Ingestion		2.0×10^{-3}	1.1×10^{-3}	2.1×10^{-3}	2.0×10^{-3}	1.1×10^{-5}
Total	1.2×10^{-2}	2.5×10^{-3}	1.2×10^{-3}	2.6×10^{-3}	2.5×10^{-3}	1.3×10^{-4}

Note: The maximum individual is defined as a permanent resident at a location with the highest annual average dispersion factor ($\bar{\chi}/Q'$) of 1.5×10^{-8} sec/m^3 2800 m southeast of the stack.

a. After 30 years of release and accumulation in the environment.
b. Thyroid dose is calculated for a 1-year-old child breathing air containing radioactive effluents and consuming 1 ℓ of milk per day from cows grazing 7 months/yr at the site boundary. Inhalation dose is <2% of total dose.
c. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

The combined dose from gaseous effluents to the population living within an 80-km radius of the plant was calculated using the projected year 2000 population data given in the reference environment (Appendix A). Table 5.2.1-15 summarizes the annual doses received by this population. The annual total-body population dose from naturally occurring sources to the approximately 2 million persons living within an 80-km radius of the plant in the year 2000 would be about 200,000 man-rem compared with the value of about 290 man-rem from process sources given in Table 5.2.1-15.

TABLE 5.2.1-15. Annual Doses to Population (within 80 km) from Dissolver Off-Gas After Treatment by the Ruthenium, Iodine, and Carbon Recovery System (man-rem)[a]

Pathway	Total Body	Thyroid	Lung	Bone
	U Recycle with Pu in SHLW or PuO_2 Stored			
Air submersion	3.1×10^{1}	3.1×10^{1}	3.1×10^{1}	3.1×10^{1}
Inhalation	7.9×10^{1}	8.0×10^{1}	4.2×10^{1}	2.6×10^{-1}
Ingestion	1.8×10^{2}	2.0×10^{2}	1.8×10^{2}	1.3
Total	2.9×10^{2}	3.1×10^{2}	3.0×10^{2}	3.3×10^{1}
	U and Pu Recycle			
Air submersion	2.9×10^{1}	2.9×10^{1}	2.9×10^{1}	2.9×10^{1}
Inhalation	7.9×10^{1}	8.0×10^{1}	9.4×10^{1}	3.2×10^{-1}
Ingestion	1.8×10^{2}	2.0×10^{2}	1.8×10^{2}	1.2
Total	2.9×10^{2}	3.1×10^{2}	3.0×10^{2}	3.1×10^{1}

a. After 30 years of release and accumulation in the environment.

The annual total-body dose to the work force associated with the ruthenium, iodine, and carbon recovery system was estimated based on permissible exposure limits and experience of operating plants. The annual occupational dose was calculated to be 2 man-rem. Table 5.2.1-16 summarizes the annual total-body dose to the work force and the general population from process and naturally occurring sources in the year 2000.

TABLE 5.2.1-16. Summary of Annual Total-Body Doses Received from Dissolver Off-Gas and from the Ruthenium, Iodine, and Carbon Recovery System and Naturally Occurring Sources in the Year 2000

	Man-rem
Ruthenium, iodine, and carbon recovery system	
Process work force (30th yr)	2
Population (within 80 km)	290
Naturally occurring sources	
Population (within 80 km)	200,000

The 70-year doses to the maximum individual and to the population within 80 km of the facility are given in Tables 5.2.1-17 and 5.2.1-18 respectively. A summary of the 70-year total-body doses to the work force and the population is given in Table 5.2.1-19. For comparison, the dose to the same population from naturally occurring sources over the 70-year period amounts to about 14,000,000 man-rem, which may be compared with 9,200 man-rem received from the treated off-gases released by the FRP.

TABLE 5.2.1-17. 70-Year Doses to Maximum Individual from Dissolver Off-Gas After Treatment by the Ruthenium, Iodine, and Carbon Recovery System (rem)

Pathway	Skin	Total Body	Thyroid[a]	Lung	Bone
	U Recycle with Pu in SHLW or PuO_2 Stored				
Air submersion	3.8×10^{-1}	4.0×10^{-3}	4.0×10^{-3}	4.0×10^{-3}	4.0×10^{-3}
Inhalation		1.0×10^{-2}	1.0×10^{-2}	1.2×10^{-2}	7.3×10^{-5}
Ingestion		6.2×10^{-2}	7.3×10^{-2}	6.2×10^{-2}	4.2×10^{-4}
Total	3.8×10^{-1}	7.6×10^{-2}	8.7×10^{-2}	7.8×10^{-2}	4.5×10^{-3}
	U and Pu Recycle				
Air submersion	3.5×10^{-1}	3.7×10^{-3}	3.7×10^{-3}	3.7×10^{-3}	3.7×10^{-3}
Inhalation		1.0×10^{-2}	1.0×10^{-2}	1.3×10^{-2}	1.1×10^{-4}
Ingestion		6.2×10^{-2}	7.3×10^{-2}	6.2×10^{-2}	3.9×10^{-4}
Total	3.5×10^{-1}	7.6×10^{-2}	8.7×10^{-2}	7.9×10^{-2}	4.2×10^{-3}

Note: The maximum individual is defined as a permanent resident at a location with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 1.5×10^{-8} sec/m^3 2800 m southeast of the stack.

a. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

TABLE 5.2.1-18. 70-Year Doses to Population (within 80 km) from Dissolver Off-Gas After Treatment by the Ruthenium, Iodine, and Carbon Recovery System (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
	U Recycle with Pu in SHLW or PuO_2 Stored			
Air submersion	9.2×10^2	9.2×10^2	9.2×10^2	9.2×10^2
Inhalation	2.4×10^3	2.4×10^3	2.9×10^3	1.7×10^1
Ingestion	5.9×10^3	6.9×10^3	5.9×10^3	4.8×10^1
Total	9.2×10^3	1.0×10^4	9.7×10^3	9.9×10^2
	U and Pu Recycle			
Air submersion	8.7×10^2	8.7×10^2	8.7×10^2	8.7×10^2
Inhalation	2.4×10^3	2.4×10^3	3.0×10^3	2.5×10^1
Ingestion	5.9×10^3	7.0×10^3	5.9×10^3	4.4×10^1
Total	9.2×10^3	1.0×10^4	9.8×10^3	9.4×10^2

TABLE 5.2.1-19. Summary of 70-Year Total-Body Doses from Dissolver Off-Gas and from the Ruthenium, Iodine, and Carbon Recovery System and Naturally Occurring Sources in the Year 2000

	Man-rem
Ruthenium, iodine, and carbon recovery system	
Process work force (30 yr)	60
Population (within 80 km)	9,200
Naturally occurring sources	
Population (within 80 km)	14,000,000

"Health effects" for regional populations are discussed at the plant level where several processes within the plant are combined. In general, doses at the individual process level are too small for a meaningful discussion of health effects. In this report, 100 to 800 health effects are postulated to occur in the exposed population per million man-rem.

Table 5.2.1-20 summarizes doses to the worldwide population (assumed to be 6.4×10^9 persons in the year 2000) for two cases--dose for the 30th year of plant operation and the accumulated dose over 70 years, both of which include accumulation in the environment from 30 years of operation. These doses are from the release of ^3H, ^{14}C, and ^{85}Kr, based on values in Table 5.2.1-13; also included is the dose from naturally occurring sources.

Ecological Effects. No materials toxic to plants and animals are released to the environment via the gaseous effluents released from the ruthenium, iodine, and carbon recovery system. The recovery system produces about 2600 kg of $CaCO_3$ containing 2.0 kg of ^{14}C, which in the reference scenario will be disposed of in a deep geologic repository.

TABLE 5.2.1-20. Total-Body Doses to Worldwide Population from Dissolver Off-Gas After Treatment by the Ruthenium, Iodine, and Carbon Recovery System and Naturally Occurring Sources (man-rem)

Source	30th Year Dose	70-Year Accumulated Dose
U Recycle with Pu in SHLW or PuO_2 Stored		
^{3}H	4.4×10^{3}	1.5×10^{5}
^{14}C	8.7×10^{2}	4.8×10^{4}
^{85}Kr	7.3×10^{3}	2.5×10^{5}
Total	1.2×10^{4}	4.5×10^{5}
U and Pu Recycle		
^{3}H	4.4×10^{3}	1.5×10^{5}
^{14}C	7.9×10^{2}	4.4×10^{4}
^{85}Kr	6.8×10^{3}	2.3×10^{5}
Total	1.2×10^{4}	4.3×10^{5}
Naturally occurring sources	6.4×10^{8}	4.5×10^{10}

Water use, to be supplied from the R River, is 550 m^3 per year. The maximum rate of withdrawal of river water during periods of low flow is less than 0.05% of the river flow, which will have an insignificant impact on the river aquatic system. There will be no direct discharge of liquid effluents from the facility to surface waters.

Environmental Effects Related to Postulated Accidents. Minor accidents and process upsets associated with the ruthenium, iodine, and carbon recovery system have not been described individually; rather, the downtime of the system for various reasons was postulated from operational experience with related systems. The resultant releases were estimated and are included in the planned annual releases discussed previously.

There are several accidents thought to have releases of radioactive material somewhat larger than those from minor accidents. These are classified as moderate accidents and are listed below.

Accident Number	Description
4.9.3	Process shutdown while dissolver is operating
4.9.4	Iodine canister absorbent spill
4.9.5	Ruthenium canister adsorbent spill during replacement

Of these accidents, process shutdown while dissolver is operating (Accident 4.9.3) was judged to be most severe and was taken as representative of the set. For this accident it was assumed that all volatile isotopes were vented to the FRP stack because of recovery system failure. The failure involved the entire system, and krypton was released along with ruthenium, iodine, and carbon. The venting occurred over a 30-day period with a frequency of occurrence of once every 10 years. The radioactive material associated with such an event is given in Table 5.2.1-21.

TABLE 5.2.1-21. Radionuclides Released to the Atmosphere from Failure of the Ruthenium, Iodine, and Carbon Recovery System (Ci)

Radionuclide	U Recycle with Pu in SHLW or PuO_2 Stored	U and Pu Recycle
^{3}H	5.8×10^{4}	5.8×10^{4}
^{14}C	1.2×10^{2}	1.2×10^{2}
^{85}Kr	1.5×10^{6}	1.4×10^{6}
^{90}Sr	1.1×10^{-4}	1.0×10^{-4}
^{106}Ru	5.6×10^{-1}	6.3×10^{-1}
^{129}I	5.4	5.7
^{137}Cs	1.5×10^{-4}	1.5×10^{-4}
^{239}Pu	4.8×10^{-7}	5.9×10^{-7}

The 70-year dose commitment to the maximum individual was calculated and is presented in Table 5.2.1-22. Numerically, the largest of these dose values is less than the variation in dose that the individual would have received from naturally occurring sources during the 70-year period. The dose via the ingestion pathway is not included because it is assumed that following an accident, edible produce could be purchased or other action taken if warranted to preclude human consumption.

TABLE 5.2.1-22. 70-Year Dose Commitment to the Maximum Individual Resulting from Failure of the Ruthenium, Iodine, and Carbon Recovery System (rem)

Pathway	Skin	Total Body	Thyroid	Lung	Bone
	U Recycle with Pu in SHLW or PuO_2 Stored				
Air submersion	2.8×10^{-2}	2.9×10^{-4}	2.9×10^{-4}	2.9×10^{-4}	2.9×10^{-4}
Inhalation		1.3×10^{-3}	6.0×10^{-3}	1.6×10^{-3}	3.5×10^{-5}
Total	2.8×10^{-2}	1.6×10^{-3}	6.3×10^{-3}	1.9×10^{-3}	3.3×10^{-4}
	U and Pu Recycle				
Air submersion	2.7×10^{-2}	2.8×10^{-4}	2.8×10^{-4}	2.8×10^{-4}	2.8×10^{-4}
Inhalation		1.3×10^{-3}	6.3×10^{-3}	1.6×10^{-3}	3.7×10^{-5}
Total	2.7×10^{-2}	1.6×10^{-3}	6.6×10^{-3}	1.9×10^{-3}	3.2×10^{-4}

During the month the recovery system will be inoperative, about 10 g of NO_x will also be released. The average concentration of NO_x at this location will be 2.2×10^{-4} $\mu g/m^3$. No effect is expected from this concentration, however, since it is several orders of magnitude below the EPA standard of 100 $\mu g/m^3$.

No serious accidents could be identified within the design basis of the facility. Non-design basis accidents were not considered.

5.2.1.3 Removal of Ruthenium, Iodine, and Krypton from Dissolver Off-Gas

Of the radioactive noble gases formed by nuclear fission (krypton and xenon), only ^{85}Kr has a half-life sufficiently long to be present at the time of fuel reprocessing. Most of the krypton in the fuel is released during shearing and dissolution and is removed by the off-gas stream at low concentrations. (Krypton-85 constitutes ∿6% of all krypton isotopes present, and krypton is ∿0.04% of the total off-gas.) The major radiation from ^{85}Kr is beta particles of 0.65 MeV; ^{85}Kr decays with a half-life of 10.7 years.

Collection of ^{85}Kr by cryogenic distillation and storage in pressurized cylinders are considered to be currently available technologies. Other methods that could be used at a commercial reprocessing plant but require further development include ^{85}Kr collection by liquid fluorocarbon absorption and storage by zeolite encapsulation. Additional collection and storage techniques have been considered, but their application to the process flow stream anticipated at a commercial facility is questionable.

The reference krypton recovery facility requires that the oxides of nitrogen, water vapor, and carbon dioxide first be removed from the off-gas stream for efficient krypton recovery. Carbon dioxide is desorbed from the molecular sieve and vented to the FRP stack,* and the rare gases are sent to the krypton recovery facility. The inflow stream consists primarily of air with very small amounts of NO_x and water. The oxygen is removed in a catalytic recombiner with hydrogen supplied by an electrolytic generator. The gas is then refrigerated to remove additional water and enters the cryogenic absorption, stripping distillation, and recovery system. Figure 5.2.1-3 shows a process flow diagram for the removal of krypton. No previous waste management technology exists except for dispersal of krypton to the atmosphere. Absorption by liquid fluorocarbons has been offered commercially but has not been demonstrated in an FRP. The cryogenic process was selected based on non-radioactive pilot scale demonstration at the Allied Chemical Plant in Idaho.

Although the theoretical efficiency of the reference krypton recovery facility suggests a decontamination factor of more than 10, the potential for process upsets precludes use of a higher factor with confidence. No significant quantities of other radionuclides are removed in this process. The krypton recovery facility is designed to treat 0.06 m^3/sec of off-gas received from the iodine recovery facility. The facility is incorporated as an integral part of the reference FRP. The effluent stream is joined by about 120 m^3/sec of air released via the 110-m stack at a linear velocity of 25 m/sec.

Environmental Effects Related to Facility Construction. Some of the factors relating to site preparation and reference facility construction may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of construction activities.

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* In practice carbon dioxide would not be released but would be recovered to remove ^{14}C. Because of the need to remove carbon dioxide for efficient krypton recovery, removal of ^{85}Kr and ^{14}C could be achieved for essentially the cost of ^{85}Kr recovery alone.

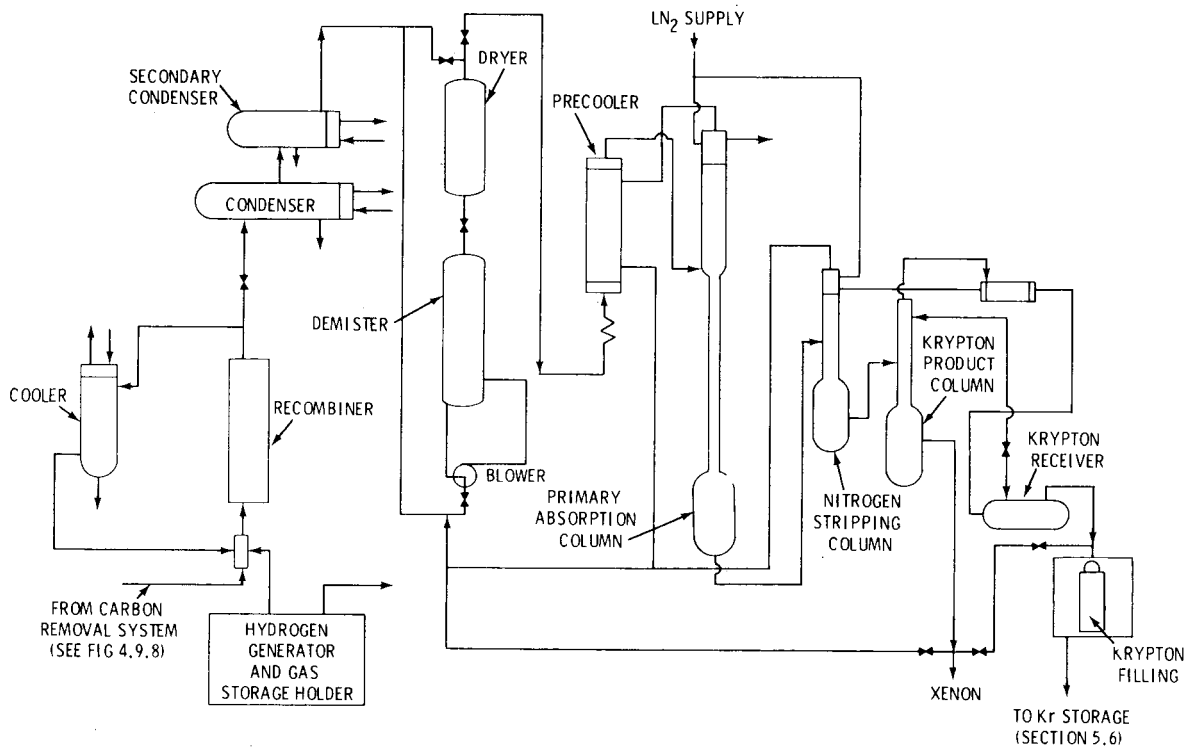

FIGURE 5.2.1-3. Flow Diagram for the Krypton Recovery System

Resource Commitments. The Ruthenium, iodine, and krypton recovery system will be an integral part of the reference FRP, whose structures will be located in a secured area of about 40 ha. Land use attributable to the recovery system is inconsequential by comparison and in any event would be preempted by construction of the FRP.

Water used during construction is estimated to be 6.9×10^3 m^3. Withdrawal of this amount of water from the R River, with an average flow of 1.0×10^7 m^3/day, is judged to be insignificant with respect to other downstream uses. During the construction period, wells could also supply the required amount of water without environmental consequence.

Materials committed for construction of the ruthenium, iodine, and krypton recovery system are:

Steel	700 MT
Copper	6.3 MT
Lumber	100 m^3
Concrete	2600 m^3

Energy resources committed for construction are:

Propane	69 m^3
Diesel fuel	680 m^3
Gasoline	440 m^3
Electricity	
Peak demand	500 kW
Total consumption	330,000 kWh

These quantities represent an additional 2 to 4% of the amounts required for construction of the reference FRP.

Manpower requirements for construction of the ruthenium, iodine, and krypton recovery system amount to 590,000 man-hr, which will likely be integrated with labor schedules for the FRP.

No additional transportation requirements for the recovery system have been identified beyond those for the FRP. No other site-specific requirements have been identified.

Physical and Chemical Effects. Effects on air quality from construction of the ruthenium, iodine, and krypton recovery system will be an indistinguishable fraction of those resulting from construction of the reference FRP (Section 5.1.2). Similarly, effects on water quality will be indistinguishable.

Ecological Effects. There will be no construction impacts for the ruthenium, iodine, and krypton recovery system apart from those of the FRP. Land area requirements are included in those of the FRP. Water used during the 4-year construction period of the entire FRP is approximately 1.8×10^5 m^3 and will come from the R River at the reference site. This amounts to less than the 0.02% of the river at low flow and will not have an impact on the river biota. Since the water used during construction of the recovery system is only a small percentage ($\sim$4%) of that required for the entire FRP, no separately identifiable ecological impacts are anticipated.

A common system will probably be constructed to supply water to all facilities within the FRP complex. Procedures will be required to keep disruption of current patterns and disturbance of the river bottom to a minimum during the construction of the intake for this system.

Environmental Effects Related to Facility Operation. Some of the factors relating to facility operation may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of operation.

Resource Commitments. Resources required during planned operation of the ruthenium, iodine, and krypton recovery system are given in Table 5.2.1-23.

The commitment of the amount of water given in Table 5.2.1-23 is insignificant compared with that expected to be routinely required for the reference FRP (makeup water, 1.1×10^6 m^3/yr). The commitment of the other tabulated resources is also considered to be insignificant.

TABLE 5.2.1-23. Utilities and Materials Required for Operating the Ruthenium, Iodine, and Krypton Recovery System

Resource	Average Annual Use
Electricity	1000 mWh
Water	
Evaporated	3500 m^3
Drift	17 m^3
Blowdown	600 m^3
Total makeup	4100 m^3
Silica gel	0.5 m^3
Liquid nitrogen	400 MT
Hydrogen	66 MT
Silver zeolite	8.8 m^3
Gas cylinders	145
Manpower (routine)	10 man-yr

Process Effluents. The amounts of radioactive materials that reach the biosphere after leaving the ruthenium, iodine, and krypton recovery system and passing through the reference FRP-APS are shown in Table 5.2.1-24. The radionuclides listed are those that will contribute at least 1% to the total dose to an organ from any pathway to man or that are otherwise of interest.

The radionuclides entrained in air are derived from process off-gas. The total air flow through the process is estimated to be 0.06 m^3/sec or about 0.05% of the total flow of air through the FRP-APS. No radioactive material will be released to the biosphere via liquid effluent streams.

TABLE 5.2.1-24. Radionuclides Released to the Biosphere After Ruthenium, Iodine, and Krypton Recovery System Treatment of the Dissolver Off-Gas (Ci/yr)

Radionuclide	U Recycle with Pu in SHLW or PuO_2 Stored	U and Pu Recycle
^{3}H	6.5×10^{5}	6.5×10^{5}
^{14}C	1.2×10^{3}	1.1×10^{3}
^{85}Kr	1.8×10^{6}	1.9×10^{6}
^{90}Sr	1.4×10^{-6}	1.3×10^{-6}
^{106}Ru	5.1	5.7
^{129}I	6.6×10^{-2}	7.0×10^{-2}
^{137}Cs	2.0×10^{-6}	2.1×10^{-6}
^{234}U		6.8×10^{-3}
^{236}U	6.4×10^{-3}	5.2×10^{-3}
^{238}U	6.4×10^{-3}	6.4×10^{-3}
^{238}Pu	1.2×10^{-4}	2.2×10^{-4}
^{239}Pu	1.2×10^{-5}	1.4×10^{-5}
^{240}Pu	1.8×10^{-5}	2.9×10^{-5}
^{241}Pu	4.4×10^{-2}	7.2×10^{-3}

Nonradioactive materials released to the biosphere via the 110-m FRP stack are as follows:

Gases	Quantity Released, MT/yr
Oxygen	720
Hydrogen	0.8
Nitrogen	1200

About 600 m^3/yr of cooling tower blowdown will be released to the R River (average annual flow of 3.9×10^9 m^3). Temperature of this water will, on the average, have been elevated 17°C. This process is expected to contribute about 17 m^3/yr of drift from the FRP cooling tower.

About 8×10^6 MJ of heat will be released annually (300 days operation) to the atmosphere from the cooling tower. This corresponds to a rate of about 300 kW or 300 kJ/s. Operation of the recovery system results in release to the biosphere of 3×10^5 MJ kW of waste heat via the plant stack.

Physical, Chemical, and Thermal Effects. Atmospheric effects resulting from operation of the ruthenium, iodine, and krypton recovery system at the FRP include air quality impacts resulting from release of nonradioactive pollutants and waste heat.

Annual average and maximum ground level concentrations of pollutants released from the recovery system at the FRP were computed using dispersion factors ($\overline{\chi}/Q'$) derived from data presented for the reference environment (Appendix A). These concentrations are listed in Table 5.2.1-25. No Federal air quality standards exist for these pollutants since they are constituents of the atmosphere. Their gaseous concentration in unpolluted dry air is given in the far right column of Table 5.2.1-25. Ground level concentrations of gases released during operation of the ruthenium, iodine, and krypton recovery system will be a small percentage of the atmospheric concentrations of naturally occurring gases.

With a contribution of 8×10^6 MJ of heat to the 1.9×10^9 MJ of heat released by the FRP no effects to the atmosphere are expected to result from operation of the ruthenium, iodine, and krypton recovery system.

TABLE 5.2.1-25. Ground Level Concentrations[a] of Gases Released Following Treatment of Dissolver Off-Gas in the Ruthenium, Iodine, and Krypton Recovery System and Normal Concentrations of These Gases in Air ($\mu g/m^3$)

Pollutant	Maximum	Average	Normal
Oxygen	4.9×10^{-1}	3.3×10^{-1}	2.7×10^8
Hydrogen	1.0×10^{-3}	$<1.0 \times 10^{-3}$	4.1×10^1
Nitrogen	8.9×10^1	4.6×10^{-1}	9.0×10^8

a. At FRP fence line, 2800 m from the FRP stack.

The return of 600 m^3/yr of water heated to 17°C above ambient will have an imperceptible effect on the thermal plume resulting from release of blowdown and once-through water from the reference FRP.

There are no direct releases of nonradioactive liquid or solid wastes to surface or ground waters from the ruthenium, iodine, and krypton recovery system. All liquid and solid waste disposal for the facility is part of the overall FRP operation.

Radiological Effects. Doses to individuals in the vicinity of the ruthenium, iodine, and krypton recovery system were calculated based on the releases of radionuclides listed in Table 5.2.1-24; pathways, demography, and other parameters described in Appendix A; and mathematical models relating dose to man from radionuclide releases (Appendix B). For planned operation of the recovery system the only exposure pathway for radionuclides to man is via airborne effluents; there are no releases to ground or water.

The annual doses to individuals whose habits tend to maximize their dose ("maximum individual") are shown in Table 5.2.1-26. For perspective, the dose to an individual from naturally occurring radioactive sources averages about 0.1 rem/yr.

TABLE 5.2.1-26. Annual Doses to Maximum Individual from Dissolver Off-Gas After Treatment by the Ruthenium, Iodine, and Krypton Recovery System (rem)(a)

Pathway	Total Body	Thyroid (child)(b)	Thyroid(c)	Lung	Bone
	U Recycle with Pu in SHLW or PuO_2 Stored				
Air submersion	1.3×10^{-5}	1.3×10^{-5}	1.3×10^{-5}	1.3×10^{-5}	1.3×10^{-5}
Inhalation	3.4×10^{-4}		3.4×10^{-4}	4.0×10^{-4}	8.4×10^{-6}
Ingestion	2.2×10^{-3}	1.4×10^{-3}	2.4×10^{-3}	2.2×10^{-3}	1.1×10^{-3}
Total	2.6×10^{-3}	1.4×10^{-3}	2.8×10^{-3}	2.6×10^{-3}	1.1×10^{-3}
	U and Pu Recycle				
Air submersion	1.2×10^{-5}	1.2×10^{-5}	1.2×10^{-5}	1.2×10^{-5}	1.2×10^{-5}
Inhalation	3.4×10^{-4}		3.4×10^{-4}	4.1×10^{-4}	7.9×10^{-6}
Ingestion	2.2×10^{-3}	1.4×10^{-3}	2.4×10^{-3}	2.2×10^{-3}	1.0×10^{-3}
Total	2.6×10^{-3}	1.4×10^{-3}	2.8×10^{-3}	2.6×10^{-3}	1.0×10^{-3}

Note: The maximum individual is defined as a permanent resident at a location with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 1.5×10^{-8} sec/m^3 2800 m southeast of the stack.

a. After 30 years of release and accumulation in the environment.
b. Thyroid dose is calculated for a 1-year-old child breathing air containing radioactive effluents and consuming 1 ℓ of milk per day from cows grazing 7 months/yr at the site boundary. Inhalation dose is <2% of total dose.
c. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

The combined dose from gaseous effluents to the population living within an 80-km radius of the plant was calculated using the projected year 2000 population data given for the reference environment (Appendix A). Table 5.2.1-27 summarizes the annual doses received by this population. The annual total-body population dose from naturally occurring sources to the

TABLE 5.2.1-27. Annual Doses to Population (within 80 km) from Dissolver Off-Gas After Treatment by the Ruthenium, Iodine, and Krypton Recovery System (man-rem)[a]

Pathway	Total Body	Thyroid	Lung	Bone
	U Recycle with Pu in SHLW or PuO_2 Stored			
Air submersion	3.1	3.1	3.1	3.1
Inhalation	8.0×10^{1}	8.0×10^{1}	9.3×10^{1}	2.0
Ingestion	2.1×10^{2}	2.2×10^{2}	2.1×10^{2}	1.3×10^{2}
Total	2.9×10^{2}	3.0×10^{2}	3.1×10^{2}	1.3×10^{2}
	U and Pu Recycle			
Air submersion	2.9	2.9	2.9	2.9
Inhalation	8.1×10^{1}	8.0×10^{1}	9.5×10^{1}	1.8
Ingestion	2.1×10^{2}	2.2×10^{2}	2.1×10^{2}	1.2×10^{2}
Total	2.9×10^{2}	3.0×10^{2}	3.1×10^{2}	1.2×10^{2}

a. After 30 years of release and accumulation in the environment.

approximately 2 million persons living within an 80-km radius of the plant in the year 2000 would be about 200,000 man-rem compared with the value of about 290 man-rem from process sources given in Table 5.2.1-28.

The annual total-body dose to the work force associated with the ruthenium, iodine, and krypton recovery system was estimated based on permissible exposure limits and experience of operating plants. The annual occupational dose was calculated to be 20 man-rem. Table 5.2.1-28 summarizes the annual total-body dose to the work force and the general population from process and naturally occurring sources in the year 2000.

TABLE 5.2.1-28. Summary of Annual Total-Body Doses Received from Treated Dissolver Off-Gas and the Ruthenium, Iodine, and Krypton Recovery System and Naturally Occurring Sources in the Year 2000

	Man-rem
Ruthenium, iodine, and krypton recovery system	
Process work force (30 yr)	20
Population (within 80 km)	290
Naturally occurring sources	
Population (within 80 km)	200,000

The 70-year doses to the maximum individual and to the population within 80 km of the facility are given in Tables 5.2.1-29 and 5.2.1-30 respectively. A summary of the 70-year total-body doses to the work force and the population is given in Table 5.2.1-31. For comparison, the dose to the same population from naturally occurring sources over the 70-year period amounts to about 14,000,000 man-rem, which may be compared with 9,100 man-rem received from the treated off-gases released by the FRP.

TABLE 5.2.1-29. 70-Year Doses to Maximum Individual from Dissolver Off-Gas After Treatment by the Ruthenium, Iodine, and Krypton Recovery System (rem)

Pathway	Total Body	Thyroid[a]	Lung	Bone
	U Recycle with Pu in SHLW or PuO_2 Stored			
Air submersion	4.0×10^{-4}	4.0×10^{-4}	4.0×10^{-4}	4.0×10^{-4}
Inhalation	1.0×10^{-2}	1.0×10^{-2}	1.2×10^{-2}	2.9×10^{-4}
Ingestion	7.1×10^{-2}	8.1×10^{-2}	7.1×10^{-2}	4.1×10^{-2}
Total	8.1×10^{-2}	9.1×10^{-2}	8.3×10^{-2}	4.1×10^{-2}
	U and Pu Recycle			
Air submersion	3.7×10^{-4}	3.7×10^{-4}	3.7×10^{-4}	3.7×10^{-4}
Inhalation	1.0×10^{-2}	1.0×10^{-2}	1.3×10^{-2}	3.0×10^{-4}
Ingestion	7.0×10^{-2}	8.1×10^{-2}	7.0×10^{-2}	3.8×10^{-2}
Total	8.0×10^{-2}	9.1×10^{-2}	8.3×10^{-2}	3.9×10^{-2}

Note: The maximum individual is defined as a permanent resident at a location with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 1.5×10^{-8} sec/m^3 2800 m southeast of the stack.

a. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

TABLE 5.2.1-30. 70-Year Doses to Population (within 80 km) from Dissolver Off-Gas After Treatment by the Ruthenium, Iodine, and Krypton Recovery System (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
	U Recycle with Pu in SHLW or PuO_2 Stored			
Air submersion	9.2×10^{1}	9.2×10^{1}	9.2×10^{1}	9.2×10^{1}
Inhalation	2.4×10^{3}	2.4×10^{3}	2.9×10^{3}	6.8×10^{1}
Ingestion	6.8×10^{3}	7.8×10^{3}	6.8×10^{3}	4.7×10^{3}
Total	9.2×10^{3}	1.0×10^{4}	9.7×10^{3}	4.8×10^{3}
	U and Pu Recycle			
Air submersion	8.7×10^{1}	8.7×10^{1}	8.7×10^{1}	8.7×10^{1}
Inhalation	2.4×10^{3}	2.4×10^{3}	3.0×10^{3}	7.1×10^{1}
Ingestion	6.7×10^{3}	7.8×10^{3}	6.7×10^{3}	4.3×10^{3}
Total	9.1×10^{3}	1.0×10^{4}	9.7×10^{3}	4.5×10^{3}

TABLE 5.2.1-31. Summary of 70-Year Total-Body Doses Received from the Ruthenium, Iodine, and Krypton Recovery System and Naturally Occurring Sources in the Year 2000

	Man-rem
Ruthenium, iodine, and krypton recovery system	
Process work force (30 yr)	600
Population (within 80 km)	9,100
Naturally occurring sources	
Population (within 80 km)	14,000,000

Table 5.2.1-32 summarizes doses to the worldwide population (assumed to be 6.4×10^9 persons in the year 2000) for two cases--dose for the 30th year of plant operation and the accumulated dose over 70 years, both of which include accumulation in the environment from 30 years of operation. These doses are from the release of ^3H, ^{14}C, and ^{85}Kr, based on values in Table 5.2.1-24, and from naturally occurring sources.

TABLE 5.2.1-32. Total-Body Doses to Worldwide Population from Radionuclides Released by the Ruthenium, Iodine, and Krypton Recovery System and Naturally Occurring Sources (man-rem)

Source	30th Year Dose	70-Year Accumulated Dose
U Recycle with Pu in SHLW or PuO_2 Stored		
^3H	4.4×10^3	1.5×10^5
^{14}C	8.7×10^4	4.8×10^6
^{85}Kr	7.3×10^2	2.5×10^4
Total	9.1×10^4	5.0×10^6
U and Pu Recycle		
^3H	4.4×10^3	1.5×10^5
^{14}C	7.9×10^4	4.4×10^6
^{85}Kr	6.9×10^2	2.3×10^4
Total	8.3×10^4	4.6×10^6
Naturally occurring sources	6.4×10^8	4.5×10^{10}

"Health effects" for regional populations are discussed at the plant level where several processes within the plant are combined. In general, doses at the individual process level are too small for a meaningful discussion of health effects. In this report, 100 to 800 health effects are postulated to occur in the exposed population per million man-rem.

Ecological Effects. The effects of routine operation of the ruthenium, iodine, and krypton recovery system on the terrestrial and aquatic ecosystems will be negligible. Nonradioactive gaseous discharges will contain 3 ppm CO_2 and traces of NO_x and N_2O. After discharge from the FRP-APS, these concentrations will be reduced by a factor of 1×10^6 due to dispersion, far below the toxic level to plants and animals.

The water requirements for the facility are about 4.1×10^3 m^3/yr, or less than 0.003 and 0.05% of the average and low flows of the R River respectively.

Cooling water released from the recovery system to the R River will be about 600 m^3/yr at a temperature of 27°C. This release will have no effect on the river biota. No chemicals will be released in this effluent stream.

Environmental Effects Related to Postulated Accidents. Minor accidents and process upsets associated with the ruthenium, iodine, and krypton recovery system have not been described individually; rather, the downtime of the system for various reasons was postulated from operational experience with related systems. The resultant releases were estimated and included in the planned annual releases discussed previously.

There were several accidents thought to have releases of radioactive material somewhat larger than those from minor accidents. These are classified as moderate accidents and are listed below.

Accident Number	Description
4.9.3	Process shutdown while dissolver is operating
4.9.4	Iodine canister absorbent spill
4.9.5	Ruthenium canister adsorbent spill during replacement

Of these accidents, process shutdown while dissolver is operating (Accident 4.9.3) was judged to be most severe and was taken as representative of the set. For this accident all volatile isotopes were assumed to be vented to the FRP stack because of recovery system failure. The failure involved the entire system and carbon and krypton were released along with ruthenium and iodine. The venting occurred over a 30-day period with a frequency of occurrence of once every 10 years. The radioactive material associated with such an event is given in Table 5.2.1-33.

TABLE 5.2.1-33. Radionuclides Released to the Atmosphere from Failure of the Ruthenium, Iodine, and Krypton Recovery System (Ci)

Radionuclide	U Recycle with Pu in SHLW or PuO_2 Stored	U and Pu Recycle
^{3}H	5.8×10^{4}	5.8×10^{4}
^{14}C	1.2×10^{2}	1.2×10^{2}
^{85}Kr	1.5×10^{6}	1.4×10^{6}
^{90}Sr	1.1×10^{-4}	1.0×10^{-4}
^{106}Ru	5.6×10^{-1}	6.3×10^{-1}
^{129}I	5.4	5.7
^{137}Cs	1.5×10^{-4}	1.5×10^{-4}
^{239}Pu	4.8×10^{-7}	5.9×10^{-7}

The 70-year dose commitment to the maximum individual was calculated and is presented in Table 5.2.1-34. Numerically, the largest of these dose values is less than the variation in dose the individual would have received from naturally occurring sources during the 70-year period. The dose via the ingestion pathway is not included because it is assumed that following an accident, edible produce could be purchased or other action taken if warranted to preclude human consumption.

TABLE 5.2.1-34. 70-Year Dose Commitment to the Maximum Individual Resulting from Failure of the Ruthenium, Iodine, and Krypton Recovery System (rem)

Pathway	Skin	Total Body	Thyroid	Lung	Bone
	U Recycle with Pu in SHLW or PuO_2 Stored				
Air submersion	2.8×10^{-2}	2.9×10^{-4}	2.9×10^{-4}	2.9×10^{-4}	2.9×10^{-4}
Inhalation		1.3×10^{-3}	6.0×10^{-3}	1.6×10^{-3}	3.5×10^{-5}
Total	2.8×10^{-2}	1.6×10^{-3}	6.3×10^{-3}	1.9×10^{-3}	3.3×10^{-4}
	U and Pu Recycle				
Air submersion	2.7×10^{-2}	2.8×10^{-4}	2.8×10^{-4}	2.8×10^{-4}	2.8×10^{-4}
Inhalation		1.3×10^{-3}	6.3×10^{-3}	1.6×10^{-3}	3.7×10^{-5}
Total	2.7×10^{-2}	1.6×10^{-3}	6.6×10^{-3}	1.9×10^{-3}	3.2×10^{-4}

During the month the recovery system will be inoperative, about 10 g of NO_x will also be released. The average concentration of NO_x at this location will be 2.2×10^{-4} $\mu g/m^3$. No effect is expected from this concentration, however, since it is several orders of magnitude below the EPA standard of 100 $\mu g/m^3$.

No serious accidents were postulated within the design basis of the facility. Non-design basis accidents were not considered.

5.2.1.4 Removal of Ruthenium, Iodine, Carbon, and Krypton from Dissolver Off-Gas

In place of the off-gas treatment systems for recovering either ruthenium, iodine, and carbon or ruthenium, iodine, and krypton, discussed above, an integrated off-gas recovery system is possible. This system would also be an integral part of the reference FRP. In this system, the decontamination factors for individual radionuclides are: carbon, 1×10^2; krypton, 1.0×10^1; iodine, 1×10^3; volatile ruthenium, 1×10^4; and particulates, 1×10^5.

The volume of dissolver off-gas processed is 0.06 m^3/sec, which is added to the 120 m^3/sec of air released from the FRP to the atmosphere via the 110-m stack at a linear velocity of 25 m/sec.

Environmental Effects Related to Facility Construction. Some of the factors relating to site preparation and reference facility construction may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of construction activities.

Resource Commitments. The ruthenium, iodine, carbon, and krypton recovery system will be an integral part of the reference FRP, whose structures will be located in the FRP secured area of about 40 ha. Land use attributable to the recovery system is inconsequential by comparison and in any event would be preempted by construction of the FRP.

Water used during construction is estimated to be 6.8×10^3 m^3. Withdrawal of this amount of water from the R River, with an average flow of 1.0×10^7 m^3/day, is judged to be insignificant with respect to other downstream uses. During the construction period, wells can probably supply the required amount of water without consequence.

Materials committed for construction of the ruthenium, iodine, carbon, and krypton recovery system are:

Steel	660 MT
Copper	6.4 MT
Lumber	90 m^3
Concrete	2600 m^3

These quantities are judged to be insignificant in terms of resource use.

Energy resources committed for construction are:

Propane	64 m^3
Diesel fuel	660 m^3
Gasoline	440 m^3
Electricity	
Peak demand	500 kW
Total consumption	330,000 kWh

These quantities represent an additional 3 to 5% of the amounts required for construction of the reference FRP.

Manpower requirements for construction of the ruthenium, iodine, carbon, and krypton recovery system will amount to 590,000 man-hr, which will likely be integrated with labor schedules for the FRP.

No additional transportation requirements for the recovery system have been identified beyond those for the FRP. No other site-specific requirements have been identified.

Physical and Chemical Effects. Effects on air quality from construction of the ruthenium, iodine, carbon, and krypton recovery system will be an indistinguishable fraction of those resulting from construction of the reference FRP (Section 5.1.2). Similarly, effects on water quality will be indistinguishable.

Ecological Effects. There will be no construction impacts for the ruthenium, iodine, carbon, and krypton recovery system apart from those of the FRP. Land area requirements are included in those of the FRP. Water used during the 4-year construction period of the entire FRP is approximately 1.8×10^5 m^3 and will come from the R River at the reference site. This amounts to less than the 0.02% of the river at low flow and will not have an impact on the river biota. Since the construction water used for the recovery system is only a small percentage ($\sim$5%) of that required for the entire FRP, no separately identifiable ecological impacts are anticipated.

A common system will probably be constructed to supply water to all facilities within the FRP complex. Procedures will be required to keep disruption of current patterns and disturbance of the river bottom to a minimum during the construction of the intake for this system.

Environmental Effects Related to Facility Operation. Some of the factors relating to facility operation may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of facility operation.

Resource Commitments. Resources required during planned operation of the ruthenium, iodine, carbon, and krypton recovery system are given in Table 5.2.1-35.

TABLE 5.2.1-35. Utilities and Materials Required for Operating the Ruthenium, Iodine, Carbon, and Krypton Recovery System

Resource	Average Annual Use
Electricity	1300 MWh
Water	
Withdrawn (contribution to cooling tower makeup)	4100
Returned (contribution from cooling tower blowdown)	600
CaO	1.4 MT
Silica gel	0.5 m^3
Liquid nitrogen	400 MT
Silver zeolite	8.8 m^3
Hydrogen generator	66 MT
Gas cylinders	145
Ammonia	22 MT
Manpower (routine)	12 man-yr

The commitment of this amount of water is insignificant compared with that expected to be routinely required for the reference FRP (makeup water, 1.1 x 10^6 m^3/yr). The commitment of the other tabulated resources is considered to be insignificant.

Process Effluents. The amounts of radioactive materials that reach the biosphere after leaving the ruthenium, iodine, carbon, and krypton recovery system and passing through the FRP-APS are shown in Table 5.2.1-36. The radionuclides listed are those that will contribute at least 1% to the total dose to a given organ from any pathway to man or that are otherwise of interest.

The radionuclides are entrained in air derived from process off-gas. The total air flow through the process is estimated to be 0.06 m^3/sec or about 0.05% of the total flow of air through the FRP-APS. No radioactive material will be released to the biosphere via liquid waste streams.

Nonradioactive materials released to the biosphere via the FRP-APS are as follows:

Gases	Quantity Released, MT/yr
Oxygen	720
Hydrogen	0.8
Nitrogen	1200

TABLE 5.2.1-36. Radionuclides Released to the Biosphere After Ruthenium, Iodine, Carbon, and Krypton Recovery System Treatment of the Dissolver Off-Gas (Ci/yr)

Radionuclide	U Recycle with Pu in SHLW or PuO_2 Stored	U and Pu Recycle
^{3}H	6.5×10^{5}	6.5×10^{5}
^{14}C	1.2×10^{1}	1.1×10^{1}
^{85}Kr	1.8×10^{6}	1.7×10^{6}
^{90}Sr	1.4×10^{-6}	1.3×10^{-6}
^{106}Ru	5.1	--
^{129}I	6.6×10^{2}	7.0×10^{-2}
^{137}Cs	2.0×10^{-6}	2.1×10^{-6}
^{232}U	2.2×10^{-4}	2.4×10^{-4}
^{234}U	7.2×10^{-4}	6.8×10^{-3}
^{236}U	--	5.2×10^{-3}
^{238}U	6.4×10^{-3}	6.4×10^{-3}
^{238}Pu	1.2×10^{-4}	2.2×10^{-4}
^{239}Pu	1.2×10^{-5}	1.4×10^{-5}
^{240}Pu	1.8×10^{-5}	2.9×10^{-5}
^{241}Pu	4.4×10^{-3}	7.2×10^{-3}

The ruthenium, iodine, carbon, and krypton recovery system contributes about 0.02 ℓ/sec of water to the FRP cooling tower blowdown discharge during 300 days per year. The total annual heat rejected to the atmosphere from this process is 8×10^{6} MJ. The process requires the diversion of about 4.1×10^{3} m^3 of cooling water annually, of which 600 m^3 is returned to receiving water bodies as part of the cooling tower blowdown. Drift is estimated to be about 17 m^3/yr.

There is no direct disposal of nonradioactive liquid or solid wastes to the ground from the recovery process. All liquid and solid waste disposal for the process is part of the overall FRP operation.

Physical, Chemical, and Thermal Effects. Atmospheric effects resulting from the ruthenium, iodine, carbon, and krypton recovery system at the FRP include air quality impacts from releases of nonradioactive pollutants and waste heat.

Annual average and maximum ground level concentrations of pollutants released from the recovery system at the FRP were computed using dispersion factors ($\overline{\chi}/Q'$) derived from data presented for the reference environment (Appendix A). These concentrations are listed in Table 5.2.1-37. No Federal air quality standards exist for these pollutants since they are constituents of the atmosphere. Their gaseous concentrations in unpolluted air are given in the far right column of Table 5.2.1-37.

TABLE 5.2.1-37. Ground Level Concentrations[a] of Gases Released Following Treatment of Dissolver Off-Gases in the Ruthenium, Iodine, Carbon, and Krypton Recovery System and Normal Concentrations of these Gases in Air ($\mu g/m^3$)

Pollutant	Maximum	Average	Normal
Oxygen	4.9×10^{-1}	3.3×10^{-1}	2.7×10^{8}
Hydrogen	1.0×10^{-3}	$<1.0 \times 10^{-3}$	4.1×10^{1}
Nitrogen	8.9×10^{-1}	4.6×10^{-1}	9.0×10^{8}

a. At FRP fence line, 2800 m from the FRP stack.

Ground level concentrations of gases released during operation of the ruthenium, iodine, carbon, and krypton recovery system will be a small percentage of the atmospheric concentrations in naturally occurring gases.

Heat (8×10^{6} MJ/yr) released to the biosphere by the recovery system amounts to approximately 0.5% of that released by the FRP cooling system. The resulting impact of heat released by this process is insignificant.

There are no direct releases of nonradioactive liquid or solid wastes to surface or ground waters from the ruthenium, iodine, carbon, and krypton recovery system. All liquid and solid waste disposal for the system is part of the overall FRP operation.

Radiological Effects. Doses to individuals in the vicinity of the ruthenium, iodine, carbon, and krypton recovery system were calculated based on the releases of radionuclides listed in Table 5.2.1-36; pathways, demography, and other parameters described in Appendix A; and mathematical models relating dose to man from radionuclide releases (Appendix B). For planned operation of the recovery system the only exposure pathway for radionuclides to man is via airborne effluents; there are no releases to ground or water.

The annual doses to individuals whose habits tend to maximize their dose ("maximum individual") are shown in Table 5.2.1-38. For perspective, the dose to an individual from naturally occurring radioactive sources averages about 0.1 rem/yr.

The combined dose from gaseous effluents to the population living within an 80-km radius of the plant was calculated using the projected year 2000 population data given for the reference environment (Appendix A). Table 5.2.1-39 summarizes the annual doses received by this population. The annual total-body population dose from naturally occurring sources to the approximately 2 million persons living within an 80-km radius of the plant in the year 2000 would be about 200,000 man-rem compared with the value of about 260 man-rem from Table 5.2.1-39.

The annual total-body dose to the work force associated with the ruthenium, iodine, carbon, and krypton recovery system was estimated based on permissible exposure limits and experience of operating plants. The annual occupational dose was calculated to be 20 man-rem. Table 5.2.1-40 summarizes the annual total-body dose to the work force and the general population from process and naturally occurring sources in the year 2000.

TABLE 5.2.1-38. Annual Doses to Maximum Individual from Dissolver Off-Gas After Treatment by the Ruthenium, Iodine, Carbon, and Krypton Recovery System (rem)[a]

Pathway	Total Body	Thyroid (child)[b]	Thyroid[c]	Lung	Bone
	U Recycle with Pu in SHLW or PuO_2 Stored				
Air submersion	1.3×10^{-5}	1.3×10^{-5}	1.3×10^{-5}	1.3×10^{-5}	1.3×10^{-5}
Inhalation	3.4×10^{-4}		3.4×10^{-4}	4.0×10^{-4}	1.1×10^{-6}
Ingestion	2.0×10^{-3}	1.1×10^{-3}	2.1×10^{-3}	2.0×10^{-3}	1.2×10^{-5}
Total	2.4×10^{-3}	1.1×10^{-3}	2.5×10^{-3}	2.4×10^{-3}	2.6×10^{-5}
	U and Pu Recycle				
Air submersion	1.2×10^{-5}	1.2×10^{-5}	1.2×10^{-5}	1.2×10^{-5}	1.2×10^{-5}
Inhalation	3.4×10^{-4}		3.4×10^{-4}	4.0×10^{-4}	1.4×10^{-6}
Ingestion	2.0×10^{-3}	1.1×10^{-3}	2.1×10^{-3}	2.0×10^{-3}	1.1×10^{-5}
Total	2.4×10^{-3}	1.1×10^{-3}	2.5×10^{-3}	2.4×10^{-3}	2.4×10^{-5}

Note: The maximum individual is defined as a permanent resident at a location with the highest annual average dispersion factor (χ/Q') of 1.5×10^{-8} sec/m^3 2800 m southeast of the stack.

a. After 30 years of release and accumulation in the environment.
b. Thyroid dose is calculated for a 1-year-old child breathing air containing radioactive effluents and consuming 1 ℓ of milk per day from cows grazing 7 months/yr at the site boundary. Inhalation dose is <2% of total dose.
c. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

TABLE 5.2.1-39. Annual Doses to Population (within 80 km) from Dissolver Off-Gas After Treatment by the Ruthenium, Iodine, Carbon, and Krypton Recovery System (man-rem)[a]

Pathway	Total Body	Thyroid	Lung	Bone
	U Recycle with Pu in SHLW or PuO_2 Stored			
Air submersion	3.1	3.1	3.1	3.1
Inhalation	7.9×10^{1}	8.0×10^{1}	9.2×10^{1}	2.6×10^{-1}
Ingestion	1.8×10^{2}	2.0×10^{2}	1.8×10^{2}	1.3
Total	2.6×10^{2}	2.8×10^{2}	2.7×10^{2}	4.7
	U and Pu Recycle			
Air submersion	2.9	2.9	2.9	2.9
Inhalation	7.9×10^{1}	8.0×10^{1}	9.4×10^{1}	3.2×10^{-1}
Ingestion	1.8×10^{2}	2.0×10^{2}	1.8×10^{2}	1.2
Total	2.6×10^{2}	2.8×10^{2}	2.8×10^{2}	4.4

a. After 30 years of release and accumulation in the environment.

TABLE 5.2.1-40. Summary of Annual Total-Body Doses Received from Treated Dissolver Off-Gas and the Ruthenium, Iodine, Carbon, and Krypton Recovery System and Naturally Occurring Sources in the Year 2000

	Man-rem
Ruthenium, iodine, carbon, and krypton recovery system	
Process work force (30 yr)	20
Population (within 80 km)	260
Naturally occurring sources	
Population (within 80 km)	200,000

The 70-year doses to the maximum individual and to the population within 80 km of the facility are given in Tables 5.2.1-41 and 5.2.1-42 respectively. A summary of the 70-year total-body doses to the work force and the population is given in Table 5.2.1-43. For comparison, the dose to the same population from naturally occurring sources over the 70-year period amounts to about 14,000,000 man-rem, which may be compared with 8300 man-rem received from the treated off-gases released by the FRP.

TABLE 5.2.1-41. 70-Year Dose to Maximum Individual from Dissolver Off-Gas After Treatment by the Ruthenium, Iodine, Carbon, and Krypton Recovery System (rem)

Pathway	Total Body	Thyroid[a]	Lung	Bone
	U Recycle with Pu in SHLW or PuO_2 Stored			
Air submersion	4.0×10^{-4}	4.0×10^{-4}	4.0×10^{-4}	4.0×10^{-4}
Inhalation	1.0×10^{-2}	1.0×10^{-2}	1.2×10^{-2}	7.3×10^{-5}
Ingestion	6.2×10^{-2}	7.3×10^{-2}	6.2×10^{-2}	4.2×10^{-4}
Total	7.2×10^{-2}	8.3×10^{-2}	7.4×10^{-2}	8.9×10^{-4}
	U and Pu Recycle			
Air submersion	3.7×10^{-4}	3.7×10^{-4}	3.7×10^{-4}	3.7×10^{-4}
Inhalation	1.0×10^{-2}	1.0×10^{-2}	1.1×10^{-2}	1.1×10^{-4}
Ingestion	6.2×10^{-2}	7.3×10^{-2}	6.2×10^{-2}	3.9×10^{-4}
Total	7.2×10^{-2}	8.3×10^{-2}	7.3×10^{-2}	8.7×10^{-4}

Note: The maximum individual is defined as a permanent resident at a location with the highest annual average dispersion factor ($\bar{\chi}/Q'$) of 1.5×10^{-8} sec/m^3 2800 m southeast of the stack.

a. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

TABLE 5.2.1-42. 70-Year Doses to Population (within 80 km) from Dissolver Off-Gas After Treatment by the Ruthenium, Iodine, Carbon, and Krypton Recovery System (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
	U Recycle with Pu in SHLW or PuO_2 Stored			
Air submersion	9.2×10^{1}	9.2×10^{1}	9.2×10^{1}	9.2×10^{1}
Inhalation	2.4×10^{3}	2.4×10^{3}	2.9×10^{3}	1.7×10^{1}
Ingestion	5.9×10^{3}	6.9×10^{3}	5.9×10^{3}	4.8×10^{1}
Total	8.3×10^{3}	9.3×10^{3}	8.8×10^{3}	1.6×10^{2}
	U and Pu Recycle			
Air submersion	8.7×10^{1}	8.7×10^{1}	8.7×10^{1}	8.7×10^{1}
Inhalation	2.4×10^{3}	2.4×10^{3}	3.0×10^{3}	2.5×10^{1}
Ingestion	5.9×10^{3}	7.0×10^{3}	5.9×10^{3}	4.4×10^{1}
Total	8.3×10^{3}	9.4×10^{3}	8.9×10^{3}	1.6×10^{2}

TABLE 5.2.1-43. Summary of 70-Year Total Body Doses Received from Treated Dissolver Off-Gas and the Ruthenium, Iodine, Carbon, and Krypton Recovery System and Naturally Occurring Sources in the Year 2000

	Man-rem
Ruthenium, iodine, carbon and krypton recovery system	
Process work force (30 yr)	600
Population (within 80 km)	8,300
Naturally occurring sources	
Population (within 80 km)	14,000,000

"Health effects" for regional populations are discussed at the plant level where several processes within the plant are combined. In general, doses at the individual process level are too small for a meaningful discussion of health effects. In this report, 100 to 800 health effects are posulated to occur in the exposed population per million man-rem.

Table 5.2.1-44 summarizes doses to the worldwide population (assumed to be 6.4×10^9 persons in the year 2000) for two cases--dose for the 30th year of plant operation and the accumulated dose over 70 years, both of which include accumulation in the environment from 30 years of operation. These doses are from the release of ^3H, ^{14}C, and ^{85}Kr, based on values in Table 5.2.1-36, also included are the doses from naturally occurring sources.

TABLE 5.2.1-44. Total-Body Doses to Worldwide Population from Dissolver Off-Gas After Treatment by the Ruthenium, Iodine, Carbon, and Krypton Recovery System and Naturally Occurring Sources (man-rem)

Source	30th Year Dose	70-Year Accumulated Dose
U Recycle with Pu in SHLW or PuO_2 Stored		
^3H	4.4×10^3	1.5×10^5
^{14}C	8.7×10^2	4.8×10^4
^{85}Kr	7.3×10^2	2.5×10^4
Total	6.0×10^3	2.2×10^5
U and Pu Recycle		
^3H	4.4×10^3	1.5×10^5
^{14}C	7.9×10^2	4.4×10^4
^{85}Kr	6.9×10^2	2.3×10^4
Total	5.9×10^3	2.2×10^5
Naturally occurring sources	6.4×10^8	4.5×10^{10}

Ecological Effects. The effects of routine operation of the ruthenium, iodine, carbon, and krypton recovery system on the terrestrial and aquatic ecosystems will be negligible. Non-radioactive gaseous discharges will contain 3 ppm CO_2 and traces of NO_x and N_2O. After discharge from the atmospheric protection system, these concentrations will be reduced by a factor of 10^6, far below the toxic level to plants and animals.

The water requirements for the facility are about 0.16 ℓ/sec, or less than 0.003 and 0.05% of the average and low flows of the R River.

Cooling water released from the recovery system to the R River will be about 0.023 ℓ/sec at a temperature of 27°C. This release will have no effect on the river biota. No chemicals will be released in this effluent stream.

Environmental Effects Related to Postulated Accidents. Minor accidents and process upsets associated with the ruthenium, iodine, carbon, and krypton recovery system have not been described individually; rather, the downtime of the system for various reasons was postulated from operational experience with related systems. The resultant releases were estimated and included in the planned annual releases discussed previously.

There are several accidents thought to have releases of radioactive material larger than those from minor accidents. These are classified as moderate accidents and are listed below.

Accident Number	Description
4.9.3	Process shutdown while dissolver is operating
4.9.4	Iodine canister absorbent spill
4.9.5	Ruthenium canister adsorbent spill during replacement

Of these accidents, process shutdown while dissolver is operating (Accident 4.9.3) was judged to be most severe and was taken as representative of the set. For this accident all volatile isotopes were assumed to be vented to the FRP stack because of recovery system failure. The failure involved the entire system and carbon and krypton were released along with ruthenium and iodine. The venting occurred over a 30-day period with a frequency of occurrence of once every 10 years. The radioactive material associated with such an event is given in Table 5.2.1-45.

The 70-year dose commitment to the maximum individual was calculated and is presented in Table 5.2.1-46. Numerically, the largest of these dose values is less than the variation in dose the individual would have received from naturally occurring sources during the 70-year period. The dose via the ingestion pathway is not included because it is assumed that following an accident, edible produce could be purchased or other action taken if warranted to preclude human consumption.

During the month the recovery system will be inoperative, about 10 g of NO_x will also be released. The average concentration of NO_x at this location will be 2.2×10^{-4} μg/m^3. No effect is expected from this concentration, however, since it is several orders of magnitude below the EPA standard of 100 μg/m^3.

No serious accidents were postulated within the design basis of the facility. Non-design basis accidents were not considered.

TABLE 5.2.1-45. Radionuclides Released to the Atmosphere from Failure of the Ruthenium, Iodine, Carbon, and Krypton Recovery System (Ci)

Radionuclide	U Recycle with Pu in SHLW or PuO_2 Stored	U and Pu Recycle
^{3}H	5.8×10^{4}	5.8×10^{4}
^{14}C	1.2×10^{2}	1.2×10^{2}
^{85}Kr	1.5×10^{6}	1.4×10^{6}
^{90}Sr	1.1×10^{-4}	1.0×10^{-4}
^{106}Ru	5.6×10^{-1}	6.3×10^{-1}
^{129}I	5.4	5.7
^{137}Cs	1.5×10^{-4}	1.5×10^{-4}
^{239}Pu	4.8×10^{-7}	5.9×10^{-7}

TABLE 5.2.1-46. 70-Year Dose Commitment to the Maximum Individual Resulting from Failure of the Ruthenium, Iodine, Carbon, and Krypton Recovery System (rem)

Pathway	Skin	Total Body	Thyroid	Lung	Bone
	U Recycle with Pu in SHLW or PuO_2 Stored				
Air submersion	2.8×10^{-2}	2.9×10^{-4}	2.9×10^{-4}	2.9×10^{-4}	2.9×10^{-4}
Inhalation		1.3×10^{-3}	6.0×10^{-3}	1.6×10^{-3}	3.5×10^{-5}
Total	2.8×10^{-2}	1.6×10^{-3}	6.3×10^{-3}	1.9×10^{-3}	3.3×10^{-4}
	U and Pu Recycle				
Air submersion	2.7×10^{-2}	2.8×10^{-4}	2.8×10^{-4}	2.8×10^{-4}	2.8×10^{-4}
Inhalation		1.3×10^{-3}	6.3×10^{-3}	1.6×10^{-3}	3.7×10^{-5}
Total	2.7×10^{-2}	1.6×10^{-3}	6.6×10^{-3}	1.9×10^{-3}	3.2×10^{-4}

5.2.1.5 No Treatment of Dissolver Off-Gas

This section presents the radiological effects to be expected from operating the reference FRP without treatment of dissolver off-gas. These results should provide the reader with a basis for comparing the efficacy of the off-gas treatments described in previous sections.

Process Effluents. The amounts of radioactive materials that reach the biosphere after leaving the dissolver off-gas system and passing through the FRP-APS are shown in Table 5.2.1-47. The radionuclides listed are those that will contribute at least 1% to the total dose to an organ from any pathway to man or that are otherwise of interest.

The radionuclides are entrained in air derived from the process off-gas. The total air flow through the process is estimated to be 0.06 m^3/sec or about 0.05% of the total flow of air through the FRP-APS. No radioactive material will be released to the biosphere via liquid waste streams.

TABLE 5.2.1-47. Radionuclides Released to the Biosphere from Untreated Dissolver Off-Gas (Ci/yr)

Radionuclide	U Recycle with Pu in SHLW or PuO_2 Stored	U and Pu Recycle
^{3}H	6.5×10^{5}	6.5×10^{5}
^{14}C	1.2×10^{3}	1.1×10^{3}
^{85}Kr	1.8×10^{7}	1.7×10^{7}
^{90}Sr	2.6×10^{-3}	2.4×10^{-3}
^{106}Ru	3.4×10^{4}	3.8×10^{4}
^{129}I	6.6×10^{1}	7.0×10^{1}
^{137}Cs	3.7×10^{-3}	3.7×10^{-3}
^{239}Pu	2.3×10^{-5}	2.9×10^{-5}

Radiological Effects. Doses to individuals in the environs of the dissolver off-gas facility were calculated based on the releases of radionuclides as listed in Table 5.2.1-47; pathways, demography, and other parameters described in Appendix A; and mathematical models relating dose to man from radionuclide releases (Appendix B). For planned operation of the dissolver off-gas facility the only pathway for radionuclides to man is via airborne effluents; there are no releases to ground or water.

The annual doses to individuals whose habits tend to maximize their dose ("maximum individual") are shown in Table 5.2.1-48. For perspective, the dose to an individual from naturally occurring radioactive sources averages about 0.1 rem/yr.

TABLE 5.2.1-48. Annual Doses to Maximum Individual from Release of Untreated Dissolver Off-Gas (rem)[a]

Pathway	Total Body	Thyroid (child)[b]	Thyroid[c]	Lung	Bone
	U Recycle with Pu in SHLW or PuO_2 Stored				
Air submersion	1.4×10^{-4}	1.4×10^{-4}	1.4×10^{-4}	1.4×10^{-4}	1.4×10^{-4}
Inhalation	9.1×10^{-4}		1.7×10^{-3}	3.0×10^{-1}	4.5×10^{-3}
Ingestion	2.5×10^{-3}	2.2×10^{-3}	1.5×10^{-1}	2.2×10^{-3}	2.0×10^{-3}
Total	3.6×10^{-3}	2.3×10^{-3}	1.5×10^{-1}	3.0×10^{-1}	6.6×10^{-3}
	U and Pu Recycle				
Air submersion	1.4×10^{-4}	1.4×10^{-4}	1.4×10^{-4}	1.4×10^{-4}	1.4×10^{-4}
Inhalation	9.8×10^{-4}		1.7×10^{-3}	3.3×10^{-1}	5.1×10^{-3}
Ingestion	2.5×10^{-3}	2.2×10^{-3}	1.6×10^{-1}	2.2×10^{-3}	2.0×10^{-3}
Total	3.6×10^{-3}	2.3×10^{-3}	1.6×10^{-1}	3.3×10^{-1}	7.2×10^{-3}

Note: The maximum individual is defined as a permanent resident at a location with the highest annual average dispersion factor (χ/Q') of 1.5×10^{-8} sec/m^3 2800 m southeast of the stack.

a. After 30 years of release and accumulation in the environment.
b. Thyroid dose is calculated for a 1-year-old child breathing air containing radioactive effluents and consuming 1 ℓ of milk per day from cows grazing 7 months/yr at the site boundary. Inhalation dose is <2% of total dose.
c. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

The combined dose from gaseous effluents to the population living within an 80-km radius of the plant was calculated using the projected year 2000 population data given in the reference environment (Appendix A). Table 5.2.1-49 summarizes the annual doses received by this population. The annual total-body population dose from naturally occurring sources to the approximately 2 million persons living within an 80-km radius of the plant in the year 2000 would be about 200,000 man-rem compared with about 480 man-rem received from release of untreated off-gas as given in Table 5.2.1-49.

TABLE 5.2.1-49. Annual Doses to Population (within 80 km) from Release of Untreated Dissolver Off-Gas (man-rem)(a)

Pathway	Total Body	Thyroid	Lung	Bone
	U Recycle with Pu in SHLW or PuO_2 Stored			
Air submersion	3.4×10^{1}	3.4×10^{1}	3.4×10^{1}	3.4×10^{1}
Inhalation	2.1×10^{2}	3.9×10^{2}	7.0×10^{4}	1.1×10^{3}
Ingestion	2.4×10^{2}	1.5×10^{4}	2.1×10^{2}	2.1×10^{2}
Total	4.8×10^{2}	1.5×10^{4}	7.0×10^{4}	1.3×10^{3}
	U and Pu Recycle			
Air submersion	3.2×10^{1}	3.2×10^{1}	3.2×10^{1}	3.2×10^{1}
Inhalation	2.3×10^{2}	4.1×10^{2}	7.8×10^{4}	1.2×10^{3}
Ingestion	2.4×10^{2}	1.6×10^{4}	2.1×10^{2}	2.1×10^{2}
Total	5.0×10^{2}	1.6×10^{4}	7.8×10^{4}	1.4×10^{3}

a. After 30 years of release and accumulation in the environment.

The annual total-body dose to the work force associated with the dissolver off-gas facility was estimated based on permissible exposure limits and experience of operating plants. The annual occupational dose was calculated to be 2 man-rem. Table 5.2.1-50 summarizes the annual total-body dose to the work force and the general population from process and naturally occurring sources in the year 2000.

TABLE 5.2.1-50. Summary of Annual Total-Body Doses Received from Release of Untreated Dissolver Off-Gas and Naturally Occurring Sources in the Year 2000

	Man-rem
Dissolver off-gas facility	
Process work force (30 yr)	2
Population (within 80 km)	480
Naturally occurring sources	
Population (within 80 km)	200,000

The 70-year doses to the maximum individual and to the population within 80-km of the facility are given in Tables 5.2.1-51 and 5.2.1-52 respectively. A summary of the 70-year total-body doses to the work force and the population is given in Table 5.2.1-53. For comparison, the dose to the same population from naturally occurring sources over the 70-year period amounts to about 14,000,000 man-rem, which may be compared with 16,000 man-rem received from the release of untreated off-gas.

TABLE 5.2.1-51. 70-Year Dose to Maximum Individual from Release of Untreated Dissolver Off-Gas (rem)

Pathway	Total Body	Thyroid[a]	Lung	Bone
	U Recycle with Pu in SHLW or PuO_2 Stored			
Air submersion	4.3×10^{-3}	4.3×10^{-3}	4.3×10^{-3}	4.3×10^{-3}
Inhalation	2.7×10^{-2}	5.3×10^{-2}	1.1×10^{1}	1.4×10^{-1}
Ingestion	8.7×10^{-2}	1.0×10^{1}	7.1×10^{-2}	7.0×10^{-2}
Total	1.2×10^{-1}	1.0×10^{1}	1.1×10^{1}	2.1×10^{-1}
	U and Pu Recycle			
Air submersion	4.1×10^{-3}	4.1×10^{-3}	4.1×10^{-3}	4.1×10^{-3}
Inhalation	2.9×10^{-2}	5.6×10^{-2}	1.2×10^{1}	1.5×10^{-1}
Ingestion	8.7×10^{-2}	1.1×10^{1}	7.0×10^{-2}	7.0×10^{-2}
Total	1.2×10^{-1}	1.1×10^{1}	1.2×10^{1}	2.2×10^{-1}

Note: The maximum individual is defined as a permanent resident at a location with the highest annual average dispersion factor ($\bar{\chi}/Q'$) of 1.5×10^{-8} sec/m^3 2800 m southeast of the stack.

a. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

TABLE 5.2.1-52. 70-Year Doses to Population (within 80 km) from Release of Untreated Dissolver Off-Gas (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
	U Recycle with Pu in SHLW or PuO_2 Stored			
Air submersion	1.0×10^{3}	1.0×10^{3}	1.0×10^{3}	1.0×10^{3}
Inhalation	6.4×10^{3}	1.2×10^{4}	2.5×10^{6}	3.2×10^{4}
Ingestion	8.4×10^{3}	1.0×10^{6}	6.8×10^{3}	7.5×10^{3}
Total	1.6×10^{4}	1.0×10^{6}	2.5×10^{6}	4.1×10^{4}
	U and Pu Recycle			
Air submersion	9.6×10^{2}	9.6×10^{2}	9.6×10^{2}	9.6×10^{2}
Inhalation	6.8×10^{3}	3.5×10^{4}	2.8×10^{6}	1.3×10^{4}
Ingestion	8.5×10^{3}	1.1×10^{6}	6.7×10^{3}	7.4×10^{3}
Total	1.6×10^{4}	1.1×10^{6}	2.8×10^{6}	2.1×10^{4}

TABLE 5.2.1-53. Summary of 70-Year Total-Body Doses Received from Release of Untreated Dissolver Off-Gas and Naturally Occurring Sources in the Year 2000 (man-rem)

	Man-rem
Dissolver off-gas facility	
Process work force (30 yr)	60
Population (within 80 km)	16,000
Naturally occurring sources	
Population (within 80 km)	14,000,000

Table 5.2.1-54 summarizes doses to the worldwide population (assumed to be 6.4×10^9 persons in the year 2000) for two cases--dose for the 30th year of plant operation and accumulated dose over 70 years, both of which include accumulation in the environment from 30 years of operation. These doses are from the release of ^{3}H, ^{14}C, and ^{85}Kr, based on values in Table 5.2.1-47; also included are doses from naturally occurring sources.

TABLE 5.2.1-54. Doses to Worldwide Population from Release of Untreated Dissolver Off-Gas and Naturally Occurring Sources (man-rem)

Source	30th Year Dose	70-Year Accumulated Dose
U Recycle with Pu in SHLW PuO_2 Stored		
^{3}H	4.4×10^3	1.5×10^5
^{14}C	8.7×10^4	4.8×10^6
^{85}Kr	7.3×10^3	2.5×10^5
Total	9.9×10^4	5.2×10^6
U and Pu Recycle		
^{3}H	4.4×10^3	1.5×10^5
^{14}C	7.9×10^4	4.4×10^6
^{85}Kr	6.9×10^3	2.3×10^5
Total	9.0×10^4	4.8×10^6
Naturally occurring sources	6.4×10^8	4.5×10^{10}

"Health effects" for regional populations are discussed at the plant level where several processes within the plant are combined. In this report, 100 to 800 health effects are postulated to occur in the exposed population per million man-rem. Two to twenty health effects in the regional population and 10 to 80 in the worldwide population might result from untreated dissolver off-gas.

Environmental Effects Related to Postulated Accidents. Without treatment of dissolver off-gas, all radionuclides are continuously released to the atmosphere. This release is larger than any accident postulated within the design basis of the dissolver off-gas facility. Therefore, no accidents are described for operation of the facility in this manner.

5.2.1.6 Comparison of Environmental Effects Among Dissolver Off-Gas Treatment Alternatives

Quantities of radioactive materials released and doses to individuals and population groups following application of several reference dissolver off-gas treatments are presented in Tables 5.2.1-55 and 5.2.1-56 respectively.

TABLE 5.2.1-55. Radionuclides Released to Biosphere Following Application of Dissolver Off-Gas Treatment Alternatives (Ci/yr)

Radionuclide	No Treatment	Ru and I Removal	Ru, I, and C Removal	Ru, I, and Kr Removal	Ru, I, C, and Kr Removal
^{3}H	6.5×10^{5}	6.5×10^{5}	6.5×10^{5}	6.5×10^{5}	6.5×10^{5}
^{14}C	1.1×10^{3}	1.1×10^{3}	1.1×10^{-1}	1.1×10^{3}	1.1×10^{-1}
^{85}Kr	1.7×10^{7}	1.7×10^{7}	1.7×10^{7}	1.7×10^{6}	1.7×10^{6}
^{90}Sr	2.4×10^{-3}	1.3×10^{-6}	1.3×10^{-6}	1.3×10^{-6}	1.3×10^{-6}
^{106}Ru	3.8×10^{4}	5.7	5.7	5.7	5.7
^{129}I	7.0×10^{1}	7.0×10^{-2}	7.0×10^{-2}	7.0×10^{-2}	7.0×10^{-2}
^{137}Cs	3.7×10^{-3}	2.1×10^{-6}	2.0×10^{-6}	2.1×10^{-6}	2.1×10^{-6}
^{239}Pu	2.9×10^{-5}	1.4×10^{-5}	1.4×10^{-5}	1.4×10^{-5}	1.4×10^{-5}

TABLE 5.2.1-56. Annual Doses to Individuals and Population Groups from Gaseous Effluents Released After Dissolver Off-Gas Treatment(a)

	No Treatment	Ru and I Removal	Ru, I, and C Removal	Ru, I, and Kr Removal	Ru, I, C, and Kr Removal
Dose to Maximum Individual, rem					
Total body	3.6×10^{-3}	2.7×10^{-3}	2.5×10^{-3}	2.6×10^{-3}	2.4×10^{-3}
Thyroid	1.6×10^{-1}	2.9×10^{-3}	2.6×10^{-3}	2.8×10^{-3}	2.5×10^{-3}
Lung	3.3×10^{-3}	2.7×10^{-3}	2.5×10^{-3}	2.6×10^{-3}	2.4×10^{-3}
Bone	7.2×10^{-3}	1.1×10^{-3}	1.3×10^{-4}	1.0×10^{-3}	2.6×10^{-5}
Skin	1.3×10^{-2}	1.3×10^{-2}	1.2×10^{-2}	1.3×10^{-3}	1.3×10^{-3}
(Total-body dose from naturally occurring sources for same period, 0.1 rem)					
Dose to regional Population, 2×10^{6} Persons, man-rem					
Total body	5.0×10^{2}	3.2×10^{2}	2.9×10^{2}	2.9×10^{2}	2.6×10^{2}
Thyroid	1.6×10^{4}	3.3×10^{2}	3.1×10^{2}	3.0×10^{2}	2.8×10^{2}
Lung	7.8×10^{2}	3.4×10^{2}	3.0×10^{2}	3.1×10^{2}	2.7×10^{2}
Bone	1.4×10^{2}	1.5×10^{2}	3.3×10^{1}	1.2×10^{2}	4.7
(Total-body dose from naturally occurring sources for same period, 2×10^{5} man-rem)					
Total-Body Dose to Worldwide Population, 6.4×10^{9} Persons, man-rem					
^{3}H		4.4×10^{3}	4.4×10^{3}	4.4×10^{3}	4.4×10^{3}
^{14}C	7.9×10^{4}	7.9×10^{4}	7.9×10^{2}	7.9×10^{4}	7.9×10^{2}
^{85}Kr	6.9×10^{3}	6.9×10^{3}	6.9×10^{3}	6.9×10^{2}	6.9×10^{2}
Total	9.0×10^{4}	9.0×10^{4}	1.2×10^{4}	8.3×10^{4}	5.9×10^{3}
(Dose to worldwide population from natural sources, 6×10^{8} man-rem)					
Dose to Process Work Force, man-rem					
Total body	2	2	2	20	20

a. After 30 years of plant operation and accumulation of radionuclides in the environment.

Release of dissolver off-gas without treatment results in a calculated total-body dose of 3.6×10^{-3} rem/yr to the maximum individual. Since this dose is less than the nominal variation in dose at a given location from naturally occurring sources reduction may be unwarranted for the maximum individual. The dose to the thyroid was calculated to be 1.6×10^{-1} rem/yr, which is over twice the annual dose from naturally occurring sources and warrants reduction. The doses to lung, bone, and skin of 3.3×10^{-3}, 7.2×10^{-3}, and 1.3×10^{-2} rem/yr, respectively, when taken alone, probably do not warrant reduction for the maximum individual. Although the dose to skin is larger by a factor of about 4 than the dose to total body, the permissible dose to skin for occupational exposure is sixfold higher than that for total body,[1] thereby making the two doses roughly equivalent in relation to occupational limits.

Addition of the ruthenium and iodine removal system reduces the thyroid dose of the maximum individual to 2.9×10^{-3} rem/yr, which probably does not warrant further reduction for the maximum individual. Doses to other organs are reduced at most by 10%, which is not significant.

Various aspects of construction and operation of the dissolver off-gas alternative systems are summarized in Tables 5.2.1-57 and 5.2.1-58 respectively. Resource costs of implementing the ruthenium and iodine recovery system are believed to be insignificant. Dollar costs of the various dissolver off-gas alternatives are shown in Table 5.2.1-59. Environmental effects were substantially invariant in terms of significance between dissolver off-gas treatment alternatives.

TABLE 5.2.1-57. Summary of Resources Committed for Facility Construction of Dissolver Off-gas Treatment Systems

Resource	Ru and I Removal	Ru, I, and C Removal	Ru, I, and Kr Removal	Ru, I, C, and Kr Removal
Water, m^3	2.7×10^3	1.9×10^3	4.2×10^3	6.8×10^3
Materials				
Concrete, m^3	1.2×10^3	1.8×10^3	2.6×10^3	2.6×10^3
Steel, MT	2.7×10^2	4.4×10^2	7.0×10^2	6.6×10^2
Copper, MT	3.0	4.5	6.3	6.4
Lumber, m^3	5.0×10^1	7.0×10^1	1.0×10^2	9.0×10^1
Energy				
Propane, m^3	2.7×10^1	4.6×10^1	6.9×10^1	6.4×10^1
Diesel fuel, m^3	2.6×10^2	4.5×10^2	6.8×10^2	6.6×10^2
Gasoline, m^3	1.7×10^2	2.9×10^2	4.4×10^2	4.4×10^2
Electricity, kWh	1.3×10^5	2.2×10^5	3.3×10^5	3.3×10^5
Manpower, man-hr	2.3×10^5	3.9×10^5	5.9×10^5	5.9×10^5

Note: No significant differences were identified between reprocessing modes.
a. This system requires prior removal of carbon dioxide which results in resource commitments substantially the same as the combined system. Differences in values are within the level of uncertainty of requirements.

Although doses to individual organs and the total body after addition of the ruthenium and iodine removal system were judged acceptable in terms of dose to the maximum individual, a brief description of the effects of the other alternative treatment systems is given below.

TABLE 5.2.1-58. Summary of Nonradiological Aspects of Facility Operation of Dissolver Off-Gas Treatment Alternatives

	Ru and I Removal	Ru, I, and C Removal	Ru, I, and Kr Removal	Ru, I, C, and Kr Removal
Manpower, man-hr/yr	2.0×10^3	4.0×10^3	1.0×10^4	1.0×10^4
Water consumed, m^3/yr	0	5.5×10^2	4.0×10^3	4.0×10^3
Operation				
Silica gel, m^3/yr	5.0×10^{-1}	5.0×10^{-1}	5.0×10^{-1}	5.0×10^{-1}
Ag zeolite, m^3/yr	6.6	6.6	6.6	6.6
Steam, MT/yr	3.0×10^2	3.0×10^2	3.0×10^2	3.0×10^2
CaO, MT/yr		1.4		1.4
Ammonia, MT/yr		2.0×10^1		2.0×10^1
Liquid nitrogen, MT/yr			4.0×10^2	4.0×10^2
H_2 generation, MT/yr			6.6×10^1	6.6×10^1
Gas cylinders, no./yr			1.4×10^2	1.4×10^2
Electricity, kWh/yr	5.0×10^4	3.5×10^5	1.0×10^6	1.3×10^6
Heat released to atmosphere, kJ/s	0	40	310	310

Note: No radioactive material was released to water or ground. No significant ecological impacts were identified for any of the processes. No significant differences in terms of routine operation between reprocessing modes were identified.

TABLE 5.2.1-59. Summary of Costs of Dissolver Off-Gas Treatment Alternatives in Mid-1976 Dollars (DOE/ET-0028, Section 4.9)

	Ru and I Removal	Ru, I, and C Removal	Ru, I, and Kr Removal	Ru, I, C, and Kr Removal
Construction costs	8,400,000	13,900,000	25,000,000	26,000,000
Owner's cost	2,600,000	4,100,000	8,000,000	8,000,000
Total facility costs	11,000,000	18,000,000	33,000,000	34,000,000
Annual operating and maintenance costs	660,000	770,000	1,740,000	1,850,000
Total unit cost (per unit material processed), per kgHM	1.70	2.70	5.10	5.20

Removal of ^{14}C in addition to ruthenium and iodine reduces the total-body dose by 10%, which is not significant. The regional population total-body dose is similarly reduced by about 10%. The dose to bone is reduced by a factor of about 6. The total-body dose to the population is 290 man-rem. If applicable, the $1000 per man-rem criteria for dose reduction used in estimating cost effectiveness of dose reduction suggests that the cost of the removal

process should not exceed about $0.3 million. The incremental cost of the carbon removal system is about $7 million, which by use of that criteria does not justify addition of the carbon removal system.

On the other hand in a combined removal system for ruthenium, iodine, carbon and krypton the cost of carbon removal becomes insignificant by comparison and its removal could be recommended in the spirit of prudent radiation protection practice and ALAP principles, particularly if reprocessing becomes commonplace worldwide.

Carbon-14 is the major contributor to worldwide dose. Releases from reprocessing plants throughout the world would add to the pool of ^{14}C and to the exposure of the world population. For the reference FRP the removal of ^{14}C would reduce the annual dose to the world population from 9.0×10^4 man-rem to 1.2×10^4 man-rem. The annual dose to the world population from naturally occurring radioactive sources is on the order of 600 million man-rem. In the same units, 600.1 million man-rem is obtained without the carbon recovery system in place and 600.01 million man-rem with it in place. It is concluded that addition of a carbon recovery system to the reference FRP dissolver off-gas treatment system is not necessary for protection of the worldwide population.

If it is assumed that a maximum of 10 reference FRPs are operated in this country and an additional 20 in the rest of the world, the total addition to worldwide dose would be on the order of 3 million man-rem/yr. This is an addition of one half of 1% of the 600 million man-rem/yr, or about the same as the nominal variation in annual dose received from naturally occurring sources.

Without ^{14}C removal, ^{85}Kr contributes about 6% to the total-body dose of 9.0×10^4 man-rem. In terms of total-body dose it is concluded that removal of krypton is unnecessary to protect the maximum individual, regional population, or the worldwide population. The doses calculated for ^{85}Kr were based on the accumulation for the life of the plant. This amounts to about 85% of the total equilibrium quantity that could be reached at a constant annual release.

Exposure to krypton results in a dose to skin on the order of 80 times that of the whole body. Thus the dose to skin of the worldwide population may be about 4.5×10^5 man-rem. The significance of dose in man-rem to skin is uncertain. However, the permissible occupational exposure limit for skin is six times that for the total body, which would place the worldwide dose to skin at about 7×10^4 man-rem for a quasi "total-body equivalent dose".

The Environmental Protection Agency has promulgated Environmental Standards for the Uranium Fuel Cycle.[2] Part of these standards is as follows:

> Subpart B—Environmental Standards for the Uranium Fuel Cycle
>
> § 190.10 Standards for normal operations.
>
> Operations covered by this Subpart shall be conducted in such a manner as to provide reasonable assurance that:

(a) The annual dose equivalent does not exceed 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to any other organ of any member of the public as the result of exposures to planned discharges of radioactive materials, radon and its daughters excepted, to the general environment from uranium fuel cycle operations and to radiation from these operations.
(b) The total quantity of radioactive materials entering the general environment from the entire uranium fuel cycle, per gigawatt-year of electrical energy produced by the fuel cycle, contains less than 50,000 curies of krypton-85, 5 millicuries of iodine-129, and 0.5 millicuries combined of plutonium-239 and other alpha-emitting transuranic radionuclides with half-lives greater than one year.

§ 190.11 Variances for unusual operations.

§ 190.12 Effective date.

(a) The standards in § 190.10(a) shall be effective December 1, 1979, except that for doses arising from operations associated with the milling of uranium ore the effective date shall be December 1, 1980.
(b) The standards in § 190.10(b) shall be effective December 1, 1979, except that the standards for krypton-85 and iodine-129 shall be effective January 1, 1983, for any such radioactive materials generated by the fission process after these dates.

(FR Doc.77-399 Filed 1-12-77; 8:45 am)

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(1) "Organ" means any human organ exclusive of the dermis, the epidermis, or the cornea.

With the ruthenium and iodine recovery system in place, annual doses to any member of the public from exposure to dissolver off-gas from the reference FRP are less than the stated standards. Releases of ^{129}I and alpha-emitting radionuclides are also within these standards.

The reference FRP represents about 50 GWe-yr, from which the standard suggests a permissible release of ^{85}Kr of 2.5×10^{6} Ci/yr. For the 30-year life of the plant a release of 7.5×10^{7} Ci is obtained. (Reactors release a small quantity of ^{85}Kr by comparison and it is ignored.) Without the reference krypton removal system the reference FRP would release about 5.4×10^{8} Ci over 30 years, which exceeds the standard about sevenfold.

If ^{85}Kr is removed and stored in gas cylinders, it will leak from the cylinders at an estimated rate of 0.1% per year. After 50 years of storage in these cylinders, the remaining krypton ($\sim$4%) will be released. If the releases as a result of moderate accidents are also taken into account an additional 5×10^{7} Ci of ^{85}Kr would be released to the atmosphere over a 30-year period. As a result the calculated total release over a 30-year plant operating period and a 50-year storage period would amount to about 8.7×10^{7} Ci of ^{85}Kr. The EPA standard for the 30-year plant life amounts to 7.5×10^{7} Ci of ^{85}Kr. Thus even with addition of the krypton recovery system the EPA standard is exceeded by a small amount in this scenario (additional storage of about two years would bring the release to within limits).

For the individual living in the vicinity of the FRP (which is assumed to contain the krypton storage facility) for the 30-year plant operating period and for 40 years thereafter, a total dose to skin of 5.8×10^{-2} rem is obtained. Without krypton recovery the total dose

would amount to 4×10^{-1} rem. A reduction of such a low dose by a factor of 7 at a cost of about $30 million for the recovery system and about $210 million for the storage facility, appears to be required by regulation but without justification in terms of dose to the skin of the maximum individual.

5.2.1.7 Vessel Off-Gas Treatment

The vessel off-gas system in the FRP is designed to remove particulates, iodine, and oxides of nitrogen from the FRP spent fuel storage basin process vent and from all process vessels within the FRP, excluding the fuel shear and dissolver off-gas system, the UF_6 off-gas system, and the excess water vaporizer.

The vessel off-gas treatment system consists of a water scrubber for particulate removal, a heater to raise the gas temperature above the dew point, a packaged fiberglass high-efficiency filter for particulate removal, a second heater to increase the temperature of the gas to 150°C, an iodine adsorber for recovery of volatile iodine, a third heater to increase the gas temperature to 350°C, a NO_x removal system, and a cooler to reduce the temperature of the gas to 35°C before release to the FRP atmospheric protection system. Figure 5.2.1-4 shows a flow diagram of the vessel off-gas treatment system.

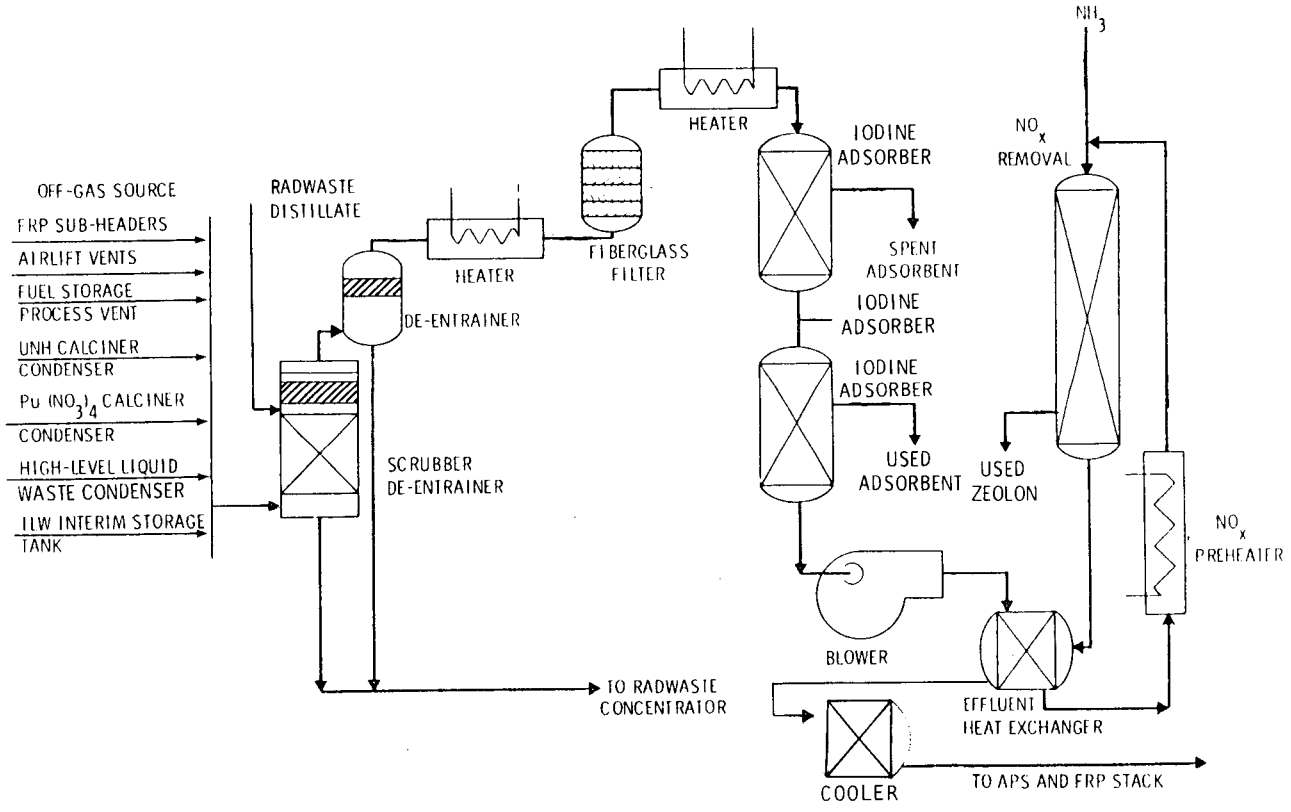

FIGURE 5.2.1-4. Flow Diagram of the Vessel Off-Gas Treatment System

Catalytic reduction of nitrogen oxides was selected as the reference process after review of several alternatives. Release without recovery was not considered a viable alternative. Aqueous scrubbing technology is used in part, but efficiencies above 70% are seldom obtained. The nonselective gas-phase catalytic reduction was tested by the Atlantic Richfield Hanford Company and American Cyanamid, who report that about 90% abatement of 1% NO_x can be obtained in air. Thus it appeared to be the most efficient alternative.

The vessel off-gas facility is designed to treat 140 m^3/min of off-gas from cask venting, leaking fuel assemblies, and other areas with high potential for release of gaseous fission products in the fuel storage basin. In addition, off-gases from various vessels within the FRP are collected in subheaders for treatment.

Major pieces of equipment (Figure 5.2.1-4) include the scrubber de-entrainer, heaters, a packaged filter, the iodine adsorber cartridge, the NO_x reactor, an effluent heat exchanger, and a cooler. Most of the particulates are removed in the scrubber de-entrainer, while a second de-entrainer removes water particles from the off-gas. The gas is heated and passed through a large packaged filter containing fiberglass to remove additional particulates. The gas is then passed through a second heater and through the silver zeolite beds, designed to remove iodine. The gas is further heated to increase the temperature to 350°C, ammonia is added, and the gas is passed through a heated bed of synthetic mordenite to provide catalytic reduction of the oxides of nitrogen. Finally the treated gas is passed through a heat exchanger to conserve energy and through a cooler to reduce the temperature to 35°C before release to the APS and the FRP stack.

Environmental Effects Related to Facility Construction. Some of the factors relating to site preparation and reference facility construction may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of construction activities.

Resource Commitments. This process facility will be an integral part of the reference FRP, whose structures will be located within a 40 ha secured area for the FRP. Land use attributable to the recovery system is inconsequential by comparison and in any event would be preempted by construction of the FRP.

Water used during construction is estimated to be 8×10^3 m^3. Withdrawal of this amount of water from the R River, with an average flow of 1.0×10^7 m^3/day, is judged to be insignificant with respect to other downstream uses. During the construction period, wells can probably supply the amount of water without environmental consequence.

Materials committed for construction of the iodine and particulate recovery system are:

Steel	500 MT
Copper	2.7 MT
Lumber	95 m^3
Concrete	2500 m^3

These quantities are judged to be insignificant in terms of resource use.

Energy resources committed for construction are:

Propane	76 m^3
Diesel fuel	760 m^3
Gasoline	490 m^3
Electricity	
Peak demand	300 kW
Total consumption	380,000 kWh

These quantities represent an additional 2 to 3% of the amount required for construction of the reference FRP.

Manpower requirements for the construction of the iodine and particulate recovery system amount to 662,000 man-hr, which will likely be integrated with labor schedules for the FRP.

No additional transportation requirements for the iodine and particulate recovery system have been identified beyond those for the FRP. No other site-specific requirements have been identified.

Physical and Chemical Effects. The effects on air quality from construction of the iodine and particulate recovery system will be an indistinguishable fraction of the impacts resulting from construction of the FRP (discussed in Section 5.1.2).

The use of a small amount of land within the FRP restricted area for the recovery system will have no additional impact on local land use.

Ecological Effects. There will be no construction impacts from the iodine and particulate recovery system apart from those of the FRP. Land area required is about 2000 m^2 and is included in land requirements for the FRP. Water used during the 4-year construction period of the entire FRP is approximately 1.8×10^5 m^3 and will come from the R River at the reference site. This amounts to less than the 0.02% of the river at low flow (Appendix A) and will not have an impact on the river biota. Since water used for the construction of the iodine and particulate recovery system is only a fraction of that required for the entire FRP, no separately identifiable ecological impacts are anticipated.

A common system will probably be constructed to supply water to all facilities within the FRP complex. Procedures will be required to keep disruption of current patterns and disturbance of the river bottom to a minimum during the construction of the intake for this system.

Environmental Effects Related to Facility Operation. Some of the factors relating to facility operation may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of operation.

Resource Commitments. Resources required during planned operation of the iodine and particulate recovery system are given in Table 5.2.1-60.

Process Effluents. The amounts of radioactive material that reach the biosphere after leaving the iodine and particulate recovery system and passing through the FRP-APS are shown in Table 5.2.1-61. The radionuclides listed include those that will contribute at least 1% to the total dose to an given organ from any pathway to man, or that are otherwise of interest.

TABLE 5.2.1-60. Utilities and Materials Required for Operating the Iodine and Particulate Recovery System

Resource	Average Annual Use
Zeolite	1.3×10^{1} m^3
NH_3	2.2×10^{-1} MT
Water, Consumed	1.2×10^{4} m^3
Electricity	2.3×10^{6} kWh
Manpower	5 man-yr

TABLE 5.2.1-61. Radionuclides Released to the Biosphere After Iodine and Particulate Treatment of the Vessel Off-Gas (Ci/yr)

Radionuclide	U Recycle with Pu in SHLW or PuO_2 Stored	U and Pu Recycle
^{3}H	8.4×10^{2}	8.4×10^{2}
^{85}Kr	1.8×10^{1}	1.7×10^{1}
^{90}Sr	1.3×10^{-6}	1.2×10^{-6}
^{106}Ru	1.7	1.9
^{129}I	3.3×10^{-4}	3.5×10^{-4}
^{137}Cs	1.8×10^{-6}	1.9×10^{-6}
^{239}Pu	5.8×10^{-9}	7.2×10^{-9}

The radionuclides entrained in air are derived from vessel storage ventilation. No radioactive material will be released to the biosphere via liquid waste streams.

The annual releases of nonradioactive material to the atmosphere are air - 9.4×10^{4} MT, N_2O - 0.002 MT, NO_x - 2.5×10^{-4} MT and H_2O - 1.9×10^{3} MT. The total amount of heat released over a 300 day operating period would amount to 2.5×10^{7} MJ.

There are no direct releases of nonradioactive liquid or solid wastes to surface or ground waters from the iodine and particulate recovery system. All liquid and solid waste disposal for the system is part of the overall FRP operation.

Physical, Chemical, and Thermal Effects. The consumptive use of about 7000 m^3 of process water required annually can be obtained from internal FRP water recovery and recycle operations and consequently does not have an impact on local water supplies. The annual cooling tower water requirement of 1.2×10^{4} m^3 is small compared to the 3.9×10^{9} m^3 average annual flow of the R River and is not expected to have any effect on other river uses.

Radiological Effects. Doses to individuals in the vicinity of the iodine and particulate recovery system were calculated based on the releases of radionuclides listed in Table 5.2.1-61; pathways, demography, and other parameters described in Appendix A; and mathematical models relating dose to man from radionuclide releases (Appendix B). For planned operation of the recovery system the only exposure pathway for radionuclides to man is via airborne effluents; there are no releases to ground or water.

The annual doses to individuals whose habits tend to maximize their dose ("maximum individual") are shown in Table 5.2.1-62. For comparison, the dose to an individual from naturally occurring radioactive sources averages about 0.1 rem/yr.

TABLE 5.2.1-62. Annual Doses to Maximum Individual from Vessel Off-Gas After Treatment by the Iodine and Particulate Recovery System (rem)[a]

Pathway	Total Body	Thyroid (child)[b]	Thyroid[c]	Lung	Bone
	U Recycle with Pu in SHLW or PuO_2 Stored				
Air submersion	7.2×10^{-10}	7.2×10^{-10}	7.2×10^{-10}	7.2×10^{-10}	7.2×10^{-10}
Innalation	4.7×10^{-7}		4.7×10^{-7}	1.5×10^{-5}	2.3×10^{-7}
Ingestion	2.5×10^{-6}	1.5×10^{-6}	3.3×10^{-6}	2.5×10^{-6}	3.9×10^{-8}
Total	3.0×10^{-6}	1.5×10^{-6}	3.8×10^{-6}	1.8×10^{-5}	2.7×10^{-7}
	U and Pu Recycle				
Air submersion	7.8×10^{-10}	7.8×10^{-10}	7.8×10^{-10}	7.8×10^{-10}	7.8×10^{-10}
Inhalation	4.7×10^{-7}		4.5×10^{-7}	1.7×10^{-5}	2.5×10^{-7}
Ingestion	2.5×10^{-6}	1.5×10^{-6}	3.3×10^{-6}	2.5×10^{-6}	4.3×10^{-8}
Total	3.0×10^{-6}	1.5×10^{-6}	3.8×10^{-6}	2.7×10^{-6}	2.9×10^{-7}

Note: The maximum individual is defined as a permanent resident at a location with the highest annual average dispersion factor ($\bar{\chi}/Q'$) of 1.5×10^{-8} sec/m^3 2800 m southeast of the stack.

a. After 30 years of release and accumulation in the environment.
b. Thyroid dose is calculated for a 1-year-old child breathing air containing radioactive effluents and consuming 1 ℓ of milk per day from cows grazing 7 months/yr at the site boundary. Inhalation dose is <2% of total dose.
c. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

The combined dose (man-rem) from gaseous effluents to the population living within an 80-km radius of the plant was calculated using the projected year 2000 population data given in the reference environment. Table 5.2.1-63 summarizes the annual doses received by this population. The annual total-body population dose from naturally occurring sources to the approximately 2 million persons living within an 80-km radius of the plant in the year 2000 would be about 200,000 man-rem compared with the value of about 0.3 man-rem from process sources as given in Table 5.2.1-63.

TABLE 5.2.1-63. Annual Doses to Population (within 80 km) from Vessel Off-Gas After Treatment by the Iodine and Particulate Recovery System (man-rem)(a)

Pathway	Total Body	Thyroid	Lung	Bone
	U Recycle with Pu in SHLW or PuO_2 Stored			
Air submersion	1.7×10^{-4}	1.7×10^{-4}	1.7×10^{-4}	1.7×10^{-4}
Inhalation	1.1×10^{-1}	1.0×10^{-1}	3.6	5.2×10^{-2}
Ingestion	2.3×10^{-1}	3.1×10^{-1}	2.3×10^{-1}	3.7×10^{-3}
Total	3.4×10^{-1}	4.1×10^{-1}	3.8	5.3×10^{-2}
	U and Pu Recycle			
Air submersion	1.8×10^{-4}	1.8×10^{-4}	1.8×10^{-4}	1.8×10^{-4}
Inhalation	1.1×10^{-1}	1.0×10^{-1}	4.0	5.9×10^{-2}
Ingestion	2.3×10^{-1}	3.1×10^{-1}	2.3×10^{-1}	4.1×10^{-3}
Total	3.4×10^{-1}	4.1×10^{-1}	4.2	6.3×10^{-2}

a. After 30 years of release and accumulation in the environment.

The annual total-body dose to the work force associated with iodine and particulate recovery system was estimated based on permissible exposure limits and experience of operating plants. The annual occupational dose was calculated to be 2 man-rem. Table 5.2.1-64 summarizes the annual total-body dose to the work force and the general population from process and naturally occurring sources in the year 2000.

TABLE 5.2.1-64. Summary of Annual Total-Body Doses Received from Vessel Off-Gas and the Iodine and Particulate Recovery System and Naturally Occurring Sources in the Year 2000

	Man-rem
Iodine and particulate recovery system	
Process work force (30 yr)	2
Population (within 80 km)	0.3
Naturally occurring sources	
Population (within 80 km)	200,000

The 70-year doses to the maximum individual and to the population within 80 km of the facility are given in Tables 5.2.1-65 and 5.2.1-66 respectively. A summary of accumulated total-body doses to the work force and the population is given in Table 5.2.1-67. For comparison, the dose to the same population from naturally occurring sources is also given for the 70-year period.

"Health effects" are discussed at the plant level where several processes within the plant are combined. In general, doses at the individual process level are too small for a meaningful discussion of health effects. In this report, 100 to 800 health effects are postulated to occur in the exposed population per million man-rem.

TABLE 5.2.1-65. 70-Year Doses to Maximum Individual from Vessel Off-Gas After Treatment by the Iodine and Particulate Recovery System (rem)

Pathway	Total Body	Thyroid[a]	Lung	Bone
	U Recycle with Pu in SHLW or PuO_2 Stored			
Air submersion	2.2×10^{-8}	2.2×10^{-8}	2.2×10^{-8}	2.2×10^{-8}
Inhalation	1.4×10^{-5}	1.3×10^{-5}	5.5×10^{-5}	6.8×10^{-6}
Ingestion	8.1×10^{-5}	1.3×10^{-4}	8.1×10^{-5}	1.3×10^{-6}
Total	1.0×10^{-4}	1.4×10^{-4}	1.0×10^{-4}	5.6×10^{-5}
	U and Pu Recycle			
Air submersion	2.3×10^{-8}	2.3×10^{-8}	2.3×10^{-8}	2.3×10^{-8}
Inhalation	1.4×10^{-5}	1.3×10^{-5}	6.2×10^{-4}	7.6×10^{-6}
Ingestion	8.1×10^{-5}	1.4×10^{-4}	8.1×10^{-5}	1.4×10^{-6}
Total	9.5×10^{-5}	1.5×10^{-4}	7.0×10^{-4}	8.0×10^{-6}

Note: The maximum individual is defined as a permanent resident at a location with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 1.5×10^{-8} sec/m^3 2800 m southeast of the stack.

a. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

TABLE 5.2.1-66. 70-Year Doses to Population from Vessel Off-Gas After Treatment by the Iodine and Particulate Recovery System (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
	U Recycle with Pu in SHLW or PuO_2 Stored			
Air submersion	5.0×10^{-3}	5.0×10^{-3}	5.0×10^{-3}	5.0×10^{-3}
Inhalation	3.3	3.1	1.3×10^{2}	1.6
Ingestion	7.6	1.3×10^{1}	7.6	1.2×10^{-1}
Total	1.1×10^{1}	1.6×10^{1}	1.4×10^{2}	1.7
	U and Pu Recycle			
Air submersion	5.5×10^{-3}	5.5×10^{-3}	5.5×10^{-3}	5.5×10^{-3}
Inhalation	3.3	3.1	1.4×10^{-2}	1.8
Ingestion	7.6	1.3×10^{1}	7.6	1.3×10^{-1}
Total	1.1×10^{1}	1.6×10^{1}	1.4×10^{2}	1.9

TABLE 5.2.1-67. Summary of 70-Year Total-Body Doses Received from the Iodine and Particulate Recovery System and Naturally Occurring Sources in the Year 2000

	Man-rem
Iodine and particulate recovery system	
Process work force (30 yr)	60
Population (within 80 km)	11
Naturally occurring sources	
Population (within 80 km)	14,000,000

Ecological Effects. No adverse impacts are expected from routine operation of the iodine and particulate recovery system. Nonradioactive chemicals that are potentially harmful to terrestrial plants and animals will not be released in the environment.

Daily water use, to be supplied from the R River, is about 33 m^3. The maximum rate of withdrawal of river water during low flow periods is less than 0.005% of the river flow and will have an insignificant impact on the river aquatic system. There will be a discharge of about 5 m^3/d of cooling tower blowdown to the R River. This effluent will have a Δt of approximately 17°C and is not expected to have a measurable effect on the river ecosystem due to the high dilution by the river.

Environmental Effects Related to Postulated Accidents. Minor accidents and process upset associated with the iodine and particulate recovery system have not been described individually; rather, the downtime of the system for various reasons was postulated from operational experience with related systems. The resultant releases were estimated and included in the planned annual releases.

More severe accidents have not been considered; however, the radiological effects of no iodine or particulate treatment are addressed in detail in Section 5.2.1.8.

5.2.1.8 No Treatment of Vessel Off-Gas

This section presents a description of radiological effects to be expected from operating the reference FRP without treatment of vessel off-gas. In this case vessel off-gas goes directly to the FRP-APS. These results are presented to give the reader a basis for judging the efficacy of the off-gas treatment presented in Section 5.2.1.7.

Radioactive Process Effluents. The amounts of radioactive materials that reach the biosphere after leaving the vessel off-gas system and passing through the model FRP-APS are shown in Table 5.2.1-68. The radionuclides listed are those that will contribute at least 1% to the total dose to a given organ from any pathway to man or that are otherwise of interest.

The radioactive material entrained in air is derived from vessel off-gas. The total air flow through the process is estimated to be 2.3 m^3/sec or about 2% of the total flow of air through the FRP-APS.

Radiological Effects. Doses to individuals in the environs of the vessel off-gas facility were calculated based on the releases of radionuclides listed in Table 5.2.1-68; pathways, demography, and other parameters described in Appendix A; and mathematical models relating dose to man from radionuclide releases (Appendix B). For planned operation of the vessel off-gas facility, the only pathway for radionuclides to man is via airborne effluents; there are no releases to ground or water.

The annual doses to individuals whose habits tend to maximize their dose ("maximum individual") are shown in Table 5.2.1-69. For perspective, the dose to an individual from naturally occurring radioactive sources averages about 0.1 rem/yr.

TABLE 5.2.1-68. Radionuclides Released to the Atmosphere from the Untreated Vessel Off-Gas (Ci/yr)

Radionuclide	U Recycle with Pu in SHLW or PuO_2 Stored	U and Pu Recycle
^{3}H	8.4×10^{2}	8.4×10^{2}
^{85}Kr	1.8×10^{1}	1.7×10^{1}
^{90}Sr	1.3×10^{-3}	1.2×10^{-3}
^{106}Ru	1.7×10^{-1}	1.9×10^{-1}
^{129}I	3.3×10^{-1}	3.5×10^{-1}
^{137}Cs	1.8×10^{-3}	1.9×10^{-3}
^{238}Pu	6.2×10^{-5}	1.1×10^{-4}
^{239}Pu	5.8×10^{-6}	7.2×10^{-6}
^{240}Pu	9.0×10^{-6}	1.5×10^{-5}
^{241}Pu	2.2×10^{-3}	3.6×10^{-3}
^{244}Cm	2.4×10^{-5}	1.4×10^{-4}

TABLE 5.2.1-69. Annual Doses to Maximum Individual from the Release of Untreated Vessel Off-Gas (rem)[a]

Pathway	Total Body	Thyroid (child)[b]	Thyroid[c]	Lung	Bone
	U Recycle with Pu in SHLW or PuO_2 Stored				
Air submersion	6.1×10^{-9}	6.1×10^{-9}	6.1×10^{-9}	6.1×10^{-9}	6.1×10^{-9}
Inhalation	7.4×10^{-7}		7.0×10^{-6}	1.5×10^{-4}	2.3×10^{-6}
Ingestion	3.5×10^{-6}	5.4×10^{-6}	7.5×10^{-4}	2.5×10^{-6}	9.2×10^{-7}
Total	4.2×10^{-6}	5.4×10^{-6}	7.6×10^{-4}	1.5×10^{-4}	3.2×10^{-6}
	U and Pu Recycle				
Air submersion	6.7×10^{-9}	6.7×10^{-9}	6.7×10^{-9}	6.7×10^{-9}	6.7×10^{-9}
Inhalation	7.7×10^{-7}		7.4×10^{-6}	1.7×10^{-4}	2.6×10^{-6}
Ingestion	3.6×10^{-6}	5.7×10^{-6}	8.0×10^{-4}	2.5×10^{-6}	1.0×10^{-6}
Total	4.4×10^{-6}	5.7×10^{-6}	8.1×10^{-4}	1.7×10^{-4}	3.6×10^{-6}

Note: The maximum individual is defined as a permanent resident at a location with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 1.5×10^{-8} sec/m^3 2800 m southeast of the stack.

a. After 30 years of release and accumulation in the environment.
b. Thyroid dose is calculated for a 1-year-old child breathing air containing radioactive effluents and consuming 1 ℓ of milk per day from cows grazing 7 months/yr at the site boundary. Inhalation dose is <2% of total dose.
c. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

The dose of interest from the vessel off-gas waste stream is that to the thyroid, since it is roughly 1000 times greater than the dose to other organs. The annual dose to the thyroid of the maximum individual from untreated vessel off-gas is 8.1×10^{-4} rem, which is less than one-fifth of the nominal variation in dose at a given location from naturally occurring sources.

The combined dose from gaseous effluents to the population living within an 80-km radius of the plant was calculated using the projected year 2000 population data given in the reference environment section (Appendix A). Table 5.2.1-70 summarizes the annual doses received by this population. The annual total-body population dose from naturally occurring sources to the approximately 2 million persons living within an 80-km radius of the plant in the year 2000 would be about 200,000 man-rem compared with the value of about 0.5 man-rem given in Table 5.2.1-70.

TABLE 5.2.1-70. Annual Doses to Population from the Release of Untreated Vessel Off-Gas (man-rem)[a]

Pathway	Total Body	Thyroid	Lung	Bone
	U Recycle with Pu in SHLW or PuO_2 Stored			
Air submersion	1.4×10^{-3}	1.4×10^{-3}	1.4×10^{-3}	1.4×10^{-3}
Inhalation	1.7×10^{-1}	1.6	3.5×10^{1}	5.4×10^{-1}
Ingestion	3.3×10^{-1}	7.5×10^{1}	2.3×10^{-1}	8.9×10^{-2}
Total	5.0×10^{-1}	7.7×10^{1}	3.5×10^{1}	6.3×10^{-1}
	U and Pu Recycle			
Air submersion	1.6×10^{-3}	1.6×10^{-3}	1.6×10^{-3}	1.6×10^{-3}
Inhalation	1.8×10^{-1}	1.7	3.9×10^{1}	6.1×10^{-1}
Ingestion	3.4×10^{-1}	7.9×10^{1}	9.6×10^{-2}	2.3×10^{-1}
Total	5.2×10^{-1}	8.1×10^{1}	3.9×10^{1}	8.4×10^{-1}

a. After 30 years of release and accumulation in the environment.

The 70-year doses to the maximum individual and to the population within 80 km of the facility are given in Tables 5.2.1-71 and 5.2.1-72 respectively. For comparison, the population dose to the same population from naturally occurring sources over the 70-year period amounts to about 14,000,000 man-rem compared with 19 man-rem received from untreated vessel off-gas.

Ecological Effects. Environmental concentrations of radioactive materials will be several orders of magnitude below those believed to cause observable effects in terrestrial biota.

Environmental Effects Related to Postulated Accidents. Without treatment of vessel off-gas, all radionuclides are continuously released to the atmosphere. This release is larger than any accident postulated within the design basis of the vessel off-gas facility. Therefore, the doses given in Tables 5.2.1-69 through 5.2.1-72 are larger than those that would result from any accident scenario for the facility.

TABLE 5.2.1-71. 70-Year Doses to Maximum Individual from the Release of Untreated Vessel Off-Gas (rem)

Pathway	Total Body	Thyroid[a]	Lung	Bone
	U Recycle with Pu in SHLW or PuO_2 Stored			
Air submersion	1.8×10^{-7}	1.8×10^{-7}	1.8×10^{-7}	1.8×10^{-7}
Inhalation	2.3×10^{-5}	2.3×10^{-4}	5.4×10^{-3}	9.1×10^{-5}
Ingestion	1.6×10^{-4}	5.2×10^{-2}	8.1×10^{-5}	6.9×10^{-5}
Total	1.6×10^{-4}	5.2×10^{-2}	5.5×10^{-3}	1.6×10^{-4}
	U and Pu Recycle			
Air submersion	2.0×10^{-7}	2.0×10^{-7}	2.0×10^{-7}	2.0×10^{-7}
Inhalation	2.6×10^{-5}	2.4×10^{-4}	6.1×10^{-3}	1.2×10^{-4}
Ingestion	1.6×10^{-4}	5.5×10^{-2}	8.1×10^{-5}	6.9×10^{-5}
Total	1.9×10^{-4}	5.5×10^{-2}	6.9×10^{-3}	8.1×10^{-5}

Note: The maximum individual is defined as a permanent resident at a location with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 1.5×10^{-8} sec/m^3 2800 m southeast of the stack.

a. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

TABLE 5.2.1-72. 70-Year Doses to Population from the Release of Untreated Vessel Off-Gas (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
	U Recycle with Pu in SHLW or PuO_2 Stored			
Air submersion	4.2×10^{-2}	4.2×10^{-2}	4.2×10^{-2}	4.2×10^{-2}
Inhalation	5.5	5.3×10^{1}	1.3×10^{3}	2.1×10^{1}
Ingestion	1.5×10^{1}	5.1×10^{3}	7.6	6.4
Total	2.1×10^{1}	5.1×10^{3}	1.3×10^{3}	2.7×10^{1}
	U and Pu Recycle			
Air submersion	4.7×10^{-2}	4.7×10^{-2}	4.7×10^{-2}	4.7×10^{-2}
Inhalation	6.0	5.6×10^{1}	1.4×10^{3}	2.8×10^{1}
Ingestion	1.5×10^{1}	5.4×10^{3}	7.6	6.5
Total	2.1×10^{1}	5.4×10^{3}	1.4×10^{3}	3.5×10^{1}

5.2.1.9 Comparison of Environmental Effects Among Alternatives

The decision to treat vessel off-gas for removal of iodine rests primarily with the reduction in dose to the individual's thyroid. Doses to other organs are sufficiently small, $<1 \times 10^{-5}$ rem/yr to be neglected. The annual dose to the thyroid of the maximum individual from exposure to untreated vessel off-gas amounts to 8.1×10^{-4} rem. The annual dose to this individual with the reference treatment process in place (DF of 1×10^{3} for iodine and 10 for particulates) amounts to 3.8×10^{-6} rem.

The principal sources of thyroid exposure are the release of dissolver off-gas and vessel off-gas to the atmosphere. With the reference treatment for removal of ruthenium and iodine from dissolver off-gas in place, the annual dose to the thyroid for the maximum individual is 2.9×10^{-3} rem. The addition of 8.1×10^{-4} rem from untreated vessel off-gas results in a total dose to the maximum individual that is still only on the order of the annual variation in dose from naturally occurring sources. It is concluded that the addition of the reference vessel off-gas treatment to affect a 20% reduction in the already small dose to the thyroid is not warranted.

REFERENCES FOR SECTION 5.2.1

1. Report of the International Commission on Radiological Protection. ICRP Publication 2, International Commission on Radiological Protection, London, 1959.

2. U.S. Code of Federal Regulations, Title 40, Part 190 in Federal Register Vol. 42, No. 9, Thursday, January 13, 1977.

5.2.2 Solidification of High-Level Liquid Waste (DOE/ET-0028 Sec. 4.1)

High-level liquid waste (HLLW) is defined in Appendix F, Part 50, Chapter 10, Code of Federal Regulations (CFR), as the aqueous wastes resulting from the operation of the first cycle solvent extraction system, or equivalent, and the concentrated wastes from subsequent extraction cycles, or equivalent, in a facility for processing irradiated reactor fuels. This regulation requires that HLLW be converted to a stable, dry solid within five years after reprocessing and transferred to a Federal repository in sealed containers no later than ten years after reprocessing.

Two processes considered for solidification of HLLW were calcination and vitrification. Calcination of HLLW produces a dry powder composed mainly of oxides of the various HLLW constituents. When placed in a deep, dry geologic isolation facility, this material is expected to remain in place indefinitely (regardless of the integrity of its original container). Vitrification of HLLW produces a dry, solid semimonolithic form (although some fracturing is expected). When placed in a deep geologic isolation facility in the absence of water, it too would be expected to remain in place indefinitely.

5.2.2.1 Calcination (DOE/ET-0028 Sec. 4.1.2)

The first engineering-scale operational facility for the solidification of liquid radioactive wastes was the Waste Calcining Facility (WCF), which began calcining wastes from the Idaho Chemical Processing Plant in 1963. Although these wastes were generally factors of 10 to 100 less radioactive than commercial HLLW is expected to be, the successful operation of the WCF demonstrates the feasibility of solidifying radioactive waste on a routine basis. The WCF product is a granular free-flowing powder that is being stored onsite in vented stainless steel bins.

The WCF uses a continuous fluidized-bed calciner. A batch-operated fluidized-bed calciner was designed and built for operation in the Midwest Fuel Recycle Plant (MFRP), a 1-MTU/day commercial fuel reprocessing plant constructed at Morris, Illinois, by the General Electric Company. Startup of the MFRP has been postponed indefinitely but apparently not for reasons associated with waste treatment.

A batch calcine process, the Potcal process, was developed at Oak Ridge National Laboratory (ORNL) specifically for the solidification of commercial HLLW and demonstrated at Pacific Northwest Laboratory (operated by Battelle Memorial Institute) on a fully radioactive basis in the Waste Solidification Engineering Prototypes Program (1966 to 1970). Other calciners developed for use with vitrification processes, can also stop at a calcine, although not developed for that purpose.

The calcines produced by all of the calciners have many properties in common, differing mainly in particle size and bulk density. Some common properties of the calcine that affect process design and other considerations include thermal conductivity, leachability, and volatiles content. The thermal conductivity of calcine is generally two to three times lower than that of consolidated products. Thus, because of the high heat generation in solidified high-level waste (SHLW), the storage of calcine requires small-diameter bins or cans or special heat removal features. Up to 20 to 25% of the constituents of a typical commercial HLW calcine

produced by the Potcal process dissolve readily on contact with water. The volatiles content consists mainly of residual nitrates that are not completely decomposed at average calciner temperatures (350 to 550°C). The problem of volatiles in the calcine was obviated with the WCF product by venting the storage facility. To prevent sealed canisters of calcine from pressurizing, an additional processing step at a temperature of 700°C to achieve complete nitrate decomposition can also be used. Therefore, in the following descriptions of HLLW calcining processes a "bakeout" of the loaded calcine canisters at 700°C is assumed.

Fluidized-Bed Calcination. Fluidized-bed calcination was chosen as the reference calcination process for this report based primarily on its successful use at Idaho National Engineering Laboratory (INEL). It was developed at INEL from 1952 to 1959. A demonstration-plant-scale facility for solidifying aluminum nitrate wastes was constructed and began "hot" operation in 1963. Figure 5.2.2-1 is a schematic drawing of the fluidized-bed calcination process.

Fluidized-bed calcination is basically a continuous evaporation process for converting HLLW and intermediate-level liquid waste (ILLW) to a blend of powder and granular materials. Concentrates from the evaporation of low-level liquid wastes and spent solvents can also be processed in the fluidized bed.

Feed is transferred by air or steam jet to the feed preparation system in the calcining facility; the feed is prepared (chemical additives and mixing of HLLW and ILLW) in a batch process and fed by a combination airlift and gravity system to the calciner. The feed is atomized by air through spray nozzles located on the calciner vessel.

The primary mechanism for solidification is the evaporation of atomized liquid droplets on the fluidized-bed particles; a portion of the atomized liquid also evaporates to a dry solid before striking the surface of a bed particle. Process heat is provided by in-bed combustion of kerosene, and the bed temperature can be easily maintained at any temperature in the range of 500 to 600°C.

The final product form consists of a mixture of granules and powder ranging from 0.05 to 0.5 mm. Calcined product density is in the range of 2.0 to 2.4 g/cm^3; specific volume is nominally 40 ℓ/MTU when processing combines HLLW and ILLW. The thermal conductivity of simulated commercial waste calcined solids is in the range of 0.2 to 0.3 W/m-°C. Although the leach rate of fluidized-bed calcine produced from typical commercial HLW waste compositions has not been determined, as much as 20-25% of the cesium and strontium were dissolved in less than one week.

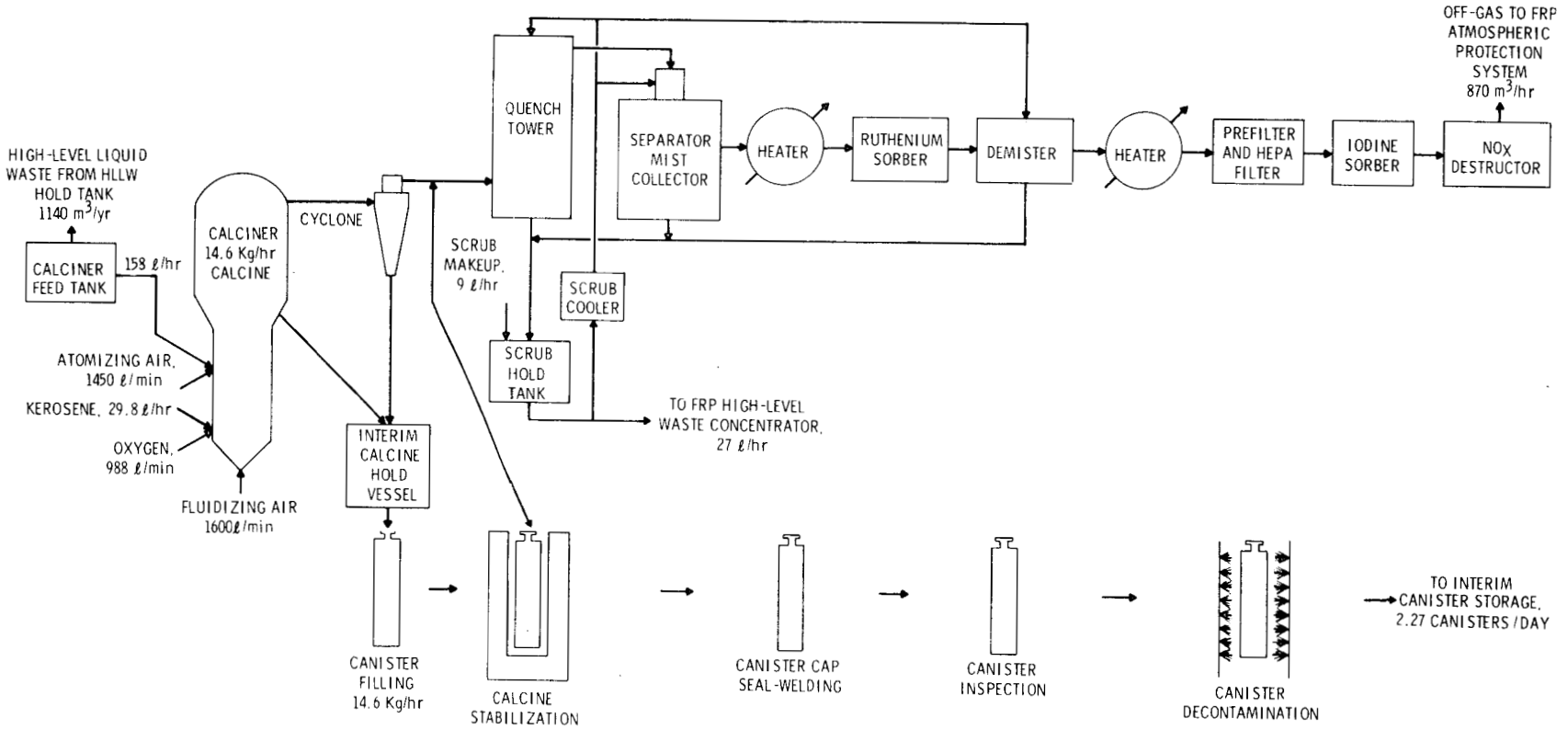

FIGURE 5.2.2-1. Fluidized-Bed Calcination Process

Reference Calcination Facility Description. The reference calcination facility will occupy about 7400 m^2 of space within the reference FRP. The relationship of the facility to the FRP is shown in Figure 5.2.2-2. About 20 individuals are expected to be required for planned operation and about 9 individuals for maintenance. Construction of the facility will likely coincide with construction of the reference FRP.

The calcination facility will share the ventilation systems, water supply and cooling facilities, utilities, and services of the FRP. Water requirements for calcination facilities are related primarily to process cooling and amount to about 0.1 ℓ/sec or about 0.2% of the reference FRP cooling system requirements. Cooling water increases in temperature by about 17°C. Some of the heat is released as cooling tower blowdown to the surface stream in the reference environment. Other process water will amount to about 0.2 ℓ/sec and will be routed to the FRP acid recovery and cleanup system for removal of radioactive material and eventual release to the atmosphere.

Air flow requirements include about 0.1 m^3/sec for process off-gas, vessel ventilation, and cell ventilation, which are released via the reference FRP atmospheric protection system (APS). The process off-gas stream passes through decontamination processes that have a total particulate decontamination factor (DF)* of 4 x 10^{10} before passing to the FRP-APS. The air and water vapor are released along with about 120 m^3/sec of air from the FRP via the APS 110-m stack.

At planned capacity, the calcination facility will convert about 3800 ℓ/day of HLLW to about 160 ℓ/day of calcine sealed in canisters 3 m long and 0.2 m in diameter. The stated capacity of 300 operating days per year is compatible with the amount of HLLW produced by the 2000-MTHM/yr reference FRP.

Environmental Effects Related to Facility Construction. Some of the factors related to site preparation and calcination facility construction may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of construction activities.

Resource Commitments. The reference HLLW calcination facility including the calcination cell, operating area, interim waste canister, water storage facility and canister shipping facility will occupy about 7400 m^2. The FRP, of which the calcination facility is assumed to be an integral part, will occupy about 400,000 m^2. The area committed to a reprocessing plant (restricted area of 2400 ha) will include an area for a solidification facility, whether or not the waste treatment facility is built. As a consequence, a separate analysis of land use attributable to the calcination facility was not made.

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* Except for ruthenium, for which a DF of 2 x 10^7 applies.

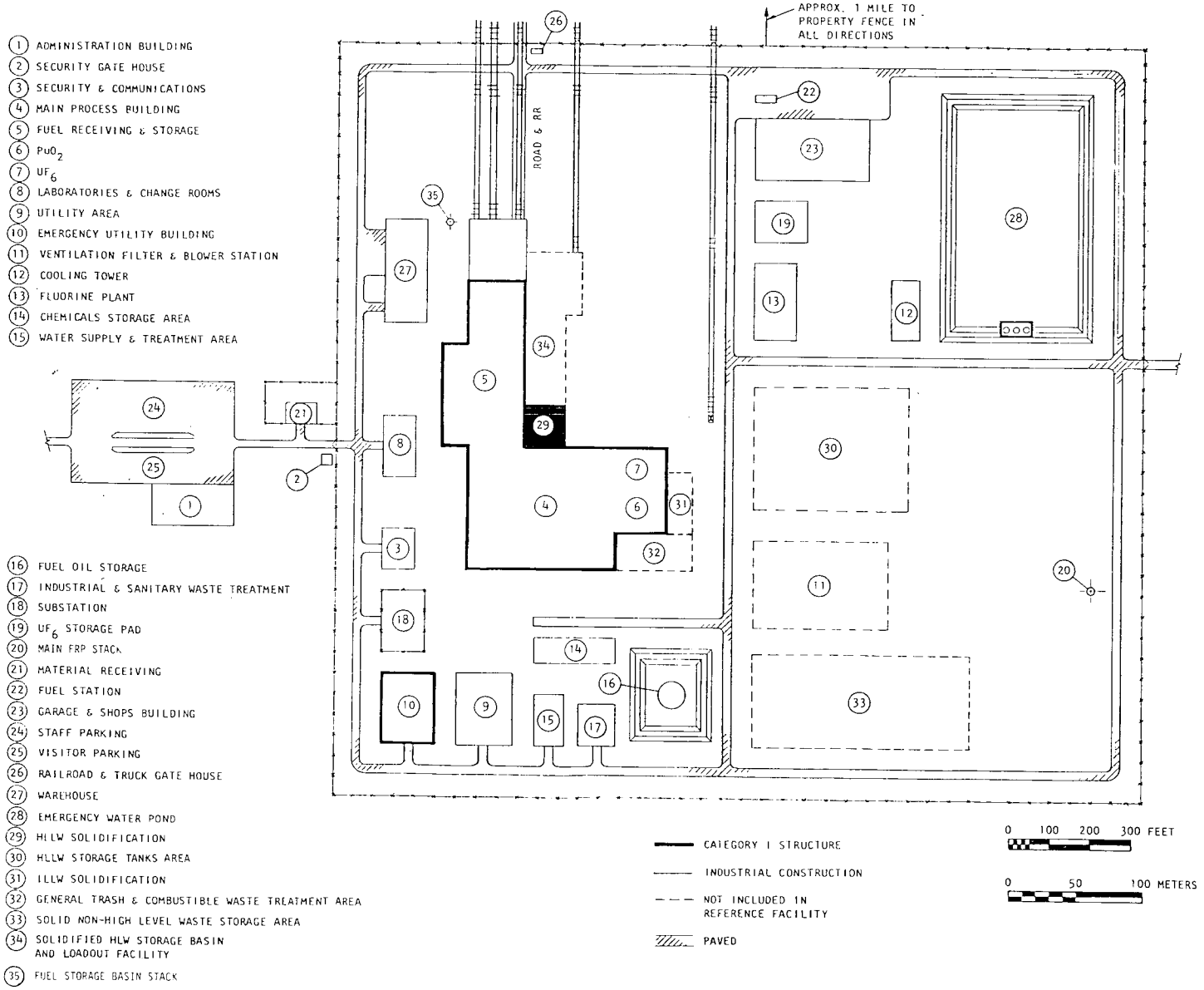

FIGURE 5.2.2-2. Location of the Reference Calcination Facility at the FRP

Water used during the construction period will be about 2.3×10^4 m^3.

Construction materials committed to the calcination facility are:

Concrete	6100 m^3
Steel	1800 MT
Copper	18 MT
Zinc	2 MT
Lumber	330 m^3

Energy resources used during construction will be:

Propane	227 m^3
Diesel fuel	2,000 m^3
Gasoline	1,400 m^3
Electricity	
Peak demand	50 kW
Total consumption	1,000,000 kWh

Manpower requirements for construction of the calcination facility will amount to about 1.8 million man-hr, which will likely be integrated with labor schedules for the FRP. No special requirements for transportation or storage of hazardous materials have been identified beyond those for the FRP.

Physical and Chemical Effects. Releases from construction of the calcination facility consist mainly of liquids used in facility cleanup and washdown, exhaust emissions to the atmosphere from traffic and equipment, heat, and sanitary wastes. None of these waste sources were identified as having significant impact or effects on environmental quality.

The 2.3×10^4 m^3 of water required during construction are expected to come from several sources, some treated and some untreated. However, for purposes of this analysis, the water was assumed to come from the R River of the reference environment. Less than 10% of the water was assumed to be committed for use in construction material; the rest will be used for several purposes including but not limited to concrete wetting and washdown, dust control and soils stabilization, and sanitary use. Sanitary wastes will be treated before release to the environment. No drain or surface water releases containing toxic substances were identified, and no perceptible environmental impact from releases noted is projected.

Ecological Effects. Ecological effects from construction of the reference calcination facility are, for the most part, indistinguishable from those associated with the FRP. About 2.3×10^4 m^3 of water, to be drawn from the R River of the reference environment, will be required during construction. If one assumes a 250-day construction period, the water use rate is 92 m^3/day. This amounts to less than 0.001% of the annual average river flow of 1.1×10^1 m^3/day. Withdrawal of this proportion of the river flow and the associated loss of any entrained organisms will have an imperceptible effect on the river's ecosystem.

The noise and activity associated with the construction of the calcination facility may be disruptive to nearby birds and animals. This impact is judged to be small and will become inconsequential as the local animal populations become accustomed to these changes and as construction activity subsides.

Environmental Effects Related to Facility Operation. Some of the factors relating to operation of the calcination facility may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of facility operation.

Resource Commitments. Resources required during planned operation of the calcination facility are listed in Table 5.2.2-1.

Process Effluents. The amounts of radioactive material reaching the atmosphere after leaving the calcination facility and passing through the FRP-APS are given in Table 5.2.2-2. The radionuclides listed are those that will contribute at least 1% to the total dose for any given organ from any pathway to man or that are otherwise of interest.

The radioactive material entrained in air is derived from process and vessel off-gas and cell ventilation air. The total volume of air and water vapor is estimated at 0.2 m^3/sec or about 0.2% of the air flow through the FRP-APS.

TABLE 5.2.2-1. Utilities and Materials Required for Operation of the Calcination Facility

Resource	Average Annual Use
Electricity	5.0×10^3 MWh
Water	2.9×10^3 m^3
Stainless steel	1.1×10^2 MT
Kerosene	2.2×10^2 m^3
Oxygen	4.3×10^5 m^3
NH_3	2.1×10^5 m^3
HNO_3	3.3×10^1 m^3
Detergent	1×10^2 kg
Silver Zeolite	6.4×10^1 kg
Manpower	
Routine	4×10^4 man-hr
Maintenance	2×10^4 man-hr

There will be no planned releases of radioactive materials to the biosphere via liquid waste streams.

TABLE 5.2.2-2. Radionuclides Released to the Atmosphere from the Calcination Facility via the FRP-APS (Ci/yr)

Radionuclide	U Recycle with Pu in SHLW	U Recycle with PuO_2 Stored	U and Pu Recycle
^{3}H	6.7×10^{4}	6.7×10^{4}	6.7×10^{4}
^{90}Sr	3.2×10^{-7}	3.2×10^{-7}	3.0×10^{-7}
^{106}Ru	1.7×10^{-3}	1.7×10^{-3}	1.9×10^{-3}
^{129}I	3.2×10^{-4}	3.2×10^{-4}	3.2×10^{-4}
^{137}Cs	4.6×10^{-7}	4.6×10^{-7}	4.6×10^{-7}
^{238}Pu	1.6×10^{-8}		
^{239}Pu	1.5×10^{-9}	7.2×10^{-12}	9.0×10^{-12}
^{240}Pu	2.3×10^{-9}		
^{241}Am	1.8×10^{-9}	1.8×10^{-9}	3.5×10^{-9}
^{244}Cm	5.9×10^{-9}	5.9×10^{-9}	3.6×10^{-8}

Quantities of nonradioactive materials released to the atmosphere via the FRP-APS are presented in Table 5.2.2-3.*

Heat released to the biosphere from the calcination process comes from process cooling and ventilation air. Equipment or processes that require cooling include the calciner feed tank, canister storage rack, welding and inspection station, calciner off-gas condenser, calcine condensate tank, NO_x destructor, off-gas cooler, and welder. Cooling water requirements are about 0.11 ℓ/sec. The temperature of the cooling tower evaporation and drift is increased by 28°C and the blowdown by 170°C. The cooling water passes through the FRP cooling system (about 0.017 ℓ/sec is used for tower makeup) and emerges at the R River at about 17°C above ambient river water temperature. During summer and at the record low flow of the R River of 6200 ℓ/sec, a release of 0.017 ℓ/sec of water at 17°C Δt from the calcination facility plus the 5.4 ℓ/sec from the FRP cooling system would cause the 0.6°C Δt isotherm in the R River to occupy less than 130 m^2.

TABLE 5.2.2-3. Nonradioactive Materials Released to the Atmosphere from the Calcination Facility via the FRP-APS

Material	Quantity Released, MT/yr
H_2O	2.5×10^{3}
CO_x	8.8×10^{2}
NH_3	4.6×10^{1}
N_2	6.6×10^{3}
O_2	1.9×10^{3}

* It is understood that kerosene is burned in this process, and although CO and CO_2 have been identified as effluents, other pollutants including hydrocarbons could be emitted. Such emissions have not been quantified at this writing.

Physical, Chemical, and Thermal Effects. Atmospheric effects of operating the calcination facility include impacts on air quality resulting from release of sensible heat, emission of nonradioactive pollutants, and emissions from vehicles used by the operating force.

Annual average and maximum ambient ground level concentrations of pollutants emitted by the calcination facility at the FRP were computed using $\overline{\chi}/Q'$ values developed from stack effluent parameters and the table of average joint frequency distribution, as listed in the reference environment. These concentrations are given in Table 5.2.2-4.

TABLE 5.2.2-4. Ground Level Concentrations of Pollutants[a] Released by the Calcination Facility at the FRP ($\mu g/m^3$)

Pollutant	Maximum	Average
NH_3 (ammonia)	0.07	0.03
H_2O (water vapor)	65	27
N_2	300	125
CO_x	40	17
O_2	85	35

a. At FRP fence line, 2800 m from the FRP stack.

Although no Federal ambient air quality standards exist for ammonia (NH_3), a threshold limit value can be used as a standard. Currently an occupational exposure of 18,000 μg NH_3/m^3 is considered an inhalation hazard.[1] Even the expected maximum concentration is many orders of magnitude below this value, and the release of NH_3 in these amounts is expected to be without environmental consequence.

Most of the 6.0×10^6 MJ of waste heat from the calcination facility is rejected to the environment over a 300 day period via the FRP cooling system.

Radiological Effects. Doses to individuals in the vicinity of the calcination facility were calculated based on the releases of radionuclides as listed in Table 5.2.2-2; pathways, demography, and other parameters described in Appendix A; and mathematical models relating radionuclide doses to man (Appendix B). For planned operation of the calcination facility the only exposure pathway for radionuclides to man is via airborne effluents; there are no releases to ground or water.

The annual doses to individuals whose habits tend to maximize their dose ("maximum individual") are shown in Table 5.2.2-5. For perspective the dose to an individual from naturally occurring radioactive sources averages about 0.1 rem/yr.

The combined dose from gaseous effluents to the population living within an 80-km radius of the plant was calculated using the projected year 2000 population data given in the reference environment. Table 5.2.2-6 summarizes the annual doses received by this population.

The annual population dose from naturally occurring sources to the approximately 2 million persons living within an 80-km radius of the plant in the year 2000 would be about 200,000 man-rem compared with the highest value from the calcination facility of about 30 man-rem, as indicated in Table 5.2.2-6.

The annual total-body dose to the work force associated with the calcination facility was estimated based on permissible exposure limits and experience of operating plants. The annual occupational dose was calculated to be about 50 man-rem. Table 5.2.2-7 summarizes the annual total-body dose to the work force and the general public from the calcination facility and from naturally occurring sources in the year 2000. Differences between uranium and plutonium recycle and uranium recycle with plutonium as a waste were not sufficient to cause a difference in the process work force dose estimate.

The dose to both the maximum individual and to the regional population is essentially the same for either recycle mode. This effect is due to tritium, which is the controlling factor and is substantially invariant between the operating modes of uranium and plutonium recycle and uranium recycle with plutonium as a waste. Although the amount of plutonium could be about 200 times greater in effluents where plutonium is included in the solid waste, the total amount of plutonium released is not large enough to change the resulting dose.

TABLE 5.2.2-5. Annual Doses to Maximum Individual from Gaseous Effluents Released by the Calcination Facility (rem)[a]

Pathway	Total Body	Thyroid (child)[b]	Thyroid[c]	Lung	Bone
	U Recycle with Pu in SHLW or PuO_2 Stored				
Air submersion	7.4×10^{-13}	7.4×10^{-13}	7.4×10^{-13}	7.4×10^{-13}	7.4×10^{-13}
Inhalation	3.5×10^{-5}		3.5×10^{-5}	3.5×10^{-5}	2.4×10^{-10}
Ingestion	2.0×10^{-4}	1.2×10^{-4}	2.1×10^{-4}	2.0×10^{-4}	7.9×10^{-9}
Total	2.4×10^{-4}	1.2×10^{-4}	2.5×10^{-4}	2.4×10^{-4}	8.1×10^{-9}
	U and Pu Recycle				
Air submersion	8.2×10^{-13}	7.4×10^{-13}	8.2×10^{-13}	8.2×10^{-13}	8.2×10^{-13}
Inhalation	3.5×10^{-5}		3.5×10^{-5}	3.5×10^{-5}	2.6×10^{-10}
Ingestion	2.4×10^{-4}	1.2×10^{-4}	2.1×10^{-4}	2.0×10^{-4}	8.4×10^{-9}
Total	2.8×10^{-4}	1.2×10^{-4}	2.4×10^{-4}	2.4×10^{-4}	8.7×10^{-9}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the highest annual average dispersion factor ($\bar{\chi}/Q'$) of 1.5×10^{-8} sec/m^3.

a. After 30 years of release and accumulation in the environment.
b. Thyroid dose is calculated for a 1-year-old child breathing air containing radioactive effluents and consuming 1 ℓ of milk per day from cows grazing 7 months/yr at the site boundary. Inhalation dose is <2% of total dose.
c. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

TABLE 5.2.2-6. Annual Doses to Population (within 80 km) from Gaseous Effluents Released by the Calcination Facility (man-rem)[a]

Pathway	Total Body	Thyroid	Lung	Bone
	U Recycle with Pu in SHLW or PuO_2 Stored			
Air submersion	1.7×10^{-7}	1.7×10^{-7}	1.7×10^{-7}	1.7×10^{-7}
Inhalation	8.2	8.2	8.2	5.5×10^{-5}
Ingestion	1.9×10^{1}	2.0×10^{1}	1.9×10^{1}	7.0×10^{-4}
Total	2.7×10^{1}	2.8×10^{1}	2.7×10^{1}	7.6×10^{-4}
	U and Pu Recycle			
Air submersion	1.9×10^{-7}	1.9×10^{-7}	1.9×10^{-7}	1.9×10^{-7}
Inhalation	8.2	8.2	8.2	6.1×10^{-5}
Ingestion	1.9×10^{1}	2.0×10^{1}	1.9×10^{1}	7.4×10^{-4}
Total	2.7×10^{1}	2.8×10^{1}	2.7×10^{1}	8.0×10^{-4}

a. After 30 years of release and accumulation in the environment.

TABLE 5.2.2-7. Summary of Annual Total-Body Doses Received from Operation of the Calcination Facility and Naturally Occurring Sources in the Year 2000

	Man-rem
Calcination facility	
Process work force	70
Population (within 80 km)	30
Naturally occurring sources	
Population (within 80 km)	200,000

Integrated 70-year doses to the maximum individual were calculated and are presented in Table 5.2.2-8. Integrated 70-year doses to the population are presented in Table 5.2.2-9. A summary of 70-year total-body dose is presented in Table 5.2.2-10. The dose for the process work force is determined only for the 30-year period of plant operation.

Total-body dose to the worldwide population is limited to that received from the release of 6.7×10^{4} Ci of ^{3}H; no ^{14}C or ^{85}Kr are released during the calcination process. The worldwide population dose for the 30th year of plant operation was calculated to be 4.6×10^{2} man-rem, and the 70-year accumulated dose from 30 years of plant operation was calculated to be 1.6×10^{4} man-rem. The dose to this population from naturally occurring radioactive sources for these two periods would be about 6×10^{8} and 4×10^{10} man-rem respectively.

"Health effects" are discussed at the plant level where several processes within the plant are combined. In general, doses at the individual process level are too small for a meaningful discussion of health effects. In this report, 100 to 800 health effects are postulated to occur in the exposed population per million man-rem to the total body. Two to twenty health effects might occur in the worldwide population over a 70-year period from this process.

TABLE 5.2.2-8. 70-Year Doses to Maximum Individual from Gaseous Effluents Released by the Calcination Facility (rem)

Pathway	Total Body	Thyroid[a]	Lung	Bone
U Recycle with Pu in SHLW Waste or PuO_2 Stored				
Air submersion	2.2×10^{-11}	2.2×10^{-11}	2.2×10^{-11}	2.2×10^{-11}
Inhalation	1.1×10^{-3}	1.1×10^{-3}	1.1×10^{-3}	1.2×10^{-8}
Ingestion	6.4×10^{-3}	6.9×10^{-3}	6.4×10^{-3}	2.4×10^{-7}
Total	7.5×10^{-3}	8.0×10^{-3}	7.5×10^{-3}	2.5×10^{-7}
U and Pu Recycle				
Air submersion	2.4×10^{-11}	2.4×10^{-11}	2.4×10^{-11}	2.4×10^{-11}
Inhalation	1.1×10^{-3}	1.1×10^{-3}	1.1×10^{-3}	1.1×10^{-8}
Ingestion	6.4×10^{-3}	7.0×10^{-3}	6.4×10^{-3}	2.6×10^{-7}
Total	7.5×10^{-3}	8.1×10^{-3}	7.5×10^{-3}	2.7×10^{-7}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the highest annual average dispersion factor ($\bar{\chi}/Q'$) of 1.5×10^{-8} sec/m^3.

a. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green vegetables (growing season, 4 months/yr).

TABLE 5.2.2-9. 70-Year Doses to Population (within 80 km) from Gaseous Effluents Released by the Calcination Facility (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
U Recycle with Pu in SHLW or PuO_2 Stored				
Air submersion	5.2×10^{-6}	5.2×10^{-6}	5.2×10^{-6}	5.2×10^{-6}
Inhalation	2.5×10^{2}	2.5×10^{2}	2.5×10^{2}	2.9×10^{-3}
Ingestion	6.1×10^{2}	6.6×10^{2}	6.1×10^{2}	2.4×10^{-2}
Total	8.6×10^{2}	9.1×10^{2}	8.6×10^{2}	2.7×10^{-2}
U and Pu Recycle				
Air submersion	5.7×10^{-6}	5.7×10^{-6}	5.7×10^{-6}	5.7×10^{-6}
Inhalation	2.5×10^{2}	2.5×10^{2}	2.5×10^{2}	2.5×10^{-3}
Ingestion	6.1×10^{2}	6.6×10^{2}	6.1×10^{2}	2.5×10^{-2}
Total	8.6×10^{2}	9.1×10^{2}	8.6×10^{2}	2.8×10^{-2}

TABLE 5.2.2-10. Summary of 70-Year Total-Body Doses Received from Operation of the Calcination Facility and Naturally Occurring Sources in the Year 2000

	Man-rem
Calcination facility	
Process work force (30 yr)	2,100
Population (within 80 km)	860
Naturally occurring sources	
Population (within 80 km)	14,000,000

Ecological Effects. During planned operation, the calcination facility will release about 0.017 ℓ/sec of water at a Δt of 17°C to the R River. This water will be diluted by factors of about 370,000 and 7,300,000 at minimum and average river flows respectively. The surface area bounded by the 0.6°C isotherm in the thermal plume will be less than 130 m^2 during low flow. The introduction of this amount of heated water will have no discernible effects on the river biota. Design criteria call for no chemical release in the aqueous effluents. Any discharge of nonradioactive pollutants is expected to be slight and to have no adverse effect on the river ecosystem.

Concentrations of chemicals contained in air released via the reference FRP stack are calculated at the point of maximum $\bar{\chi}/Q'$ (about 2800 m southeast of the stack). These concentrations are at least three orders of magnitude below the relevant standard for breathing air. Deposition and/or uptake and effect on terrestrial biota at these concentrations would be inconsequential.

The dose to man from radioactive effluents is described in the section on process effluents. In the absence of releases of radioactive material to water, only the pathway of airborne pollutants to the terrestrial food web need be considered. The quantities of radioactive materials deposited on vegetation will be in the range of 0.02 fCi/g; even with bioaccumulation factors of several orders of magnitude, the resulting doses to higher animals would not likely exceed those specified for the maximum individual. Since terrestrial biota have not been shown to be more radiosensitive than man and since the dose to man is numerically insignificant compared with the annual fluctuation in radiation dose at a given location from naturally occurring radionuclides, it is concluded that radioactive effluents from the reference calcination facility will have no effect on biota in the plant environs.

Effects Related to Postulated Accidents. Several minor accidents or other events associated with waste solidification by calcination that would be expected to lead to releases of radioactive material have been identified. Scenarios for these accidents are provided in DOE/ET-0028.[2] The accidents are listed below.

Accident Number	Description
4.1.11	Hydrogen explosion in feed tank
4.1.12	HLLW feed system leakage
4.1.13	Canister spill due to overfilling (calcine) or other process irregularity
4.1.14	Overheating of calciner equipment due to plugging
4.1.15	Canister and retort failure during melting operation

Based on anticipated releases of these minor accidents and as weighted by their expected frequency of occurrence, an average annual release of 2.2×10^{-4} g of calcine to the FRP-APS is postulated. Table 5.2.2-11 gives the estimated quantities of radionuclides released to the atmosphere.

Annual doses and 70-year dose commitments were calculated for the maximum individual and the regional population. These doses were calculated using average annual dispersion factors. In no case was the dose to the maximum individual greater than 1×10^{-6} rem/yr and was most often several orders of magnitude less.

Of the minor accidents, Accident 4.1.13 (canister spill dose due to overfilling) was judged to cause the largest release of radioactive material. This accident, with a postulated frequency of about 0.01 per year, would release 2.1 kg of calcine to the process cell. Of this material, 70% is expected to reach the cell filters (HEPA filters with a particulate DF of 1×10^{6}), thus causing a release over a 1-hr period of 1.5×10^{-3} g to the FRP-APS (whose additional filtration results in a particulate DF of 1×10^{4}).

While Accident 4.1.13 was considered to have the largest release, an expected frequency of once per 100 years makes its occurrence unlikely during the 30-year life of the plant. Albeit the largest resulting dose was 6×10^{-6} rem to lung. For perspective, the annual fluctuations in the dose to lung from naturally occurring sources are on the order of 5×10^{-3} rem.

TABLE 5.2.2-11. Releases of Radionuclides to the Atmosphere from Minor Accidents in the Calcination Facility (Ci)

Radionuclide	U Recycle with Pu in SHLW	U Recycle with PuO_2 Stored	U and Pu Recycle
^{90}Sr	2.7×10^{-8}	2.7×10^{-8}	2.5×10^{-8}
^{95}Nb	3.2×10^{-9}	3.2×10^{-9}	3.2×10^{-9}
^{106}Ru	7.1×10^{-8}	7.1×10^{-8}	7.9×10^{-8}
^{125m}Te	9.2×10^{-10}	9.2×10^{-10}	1.0×10^{-10}
^{127m}Te	1.8×10^{-10}	1.8×10^{-10}	1.8×10^{-10}
^{134}Cs	5.0×10^{-8}	5.0×10^{-8}	5.0×10^{-8}
^{137}Cs	3.8×10^{-8}	3.8×10^{-8}	3.9×10^{-8}
^{144}Ce	1.0×10^{-7}	1.0×10^{-7}	1.0×10^{-7}
^{154}Eu	2.3×10^{-9}	2.3×10^{-9}	2.5×10^{-9}
^{238}Pu	1.3×10^{-9}	6.5×10^{-12}	
^{239}Pu	1.2×10^{-10}	6.1×10^{-13}	7.6×10^{-13}
^{240}Pu	1.9×10^{-10}		
^{241}Pu	4.2×10^{-8}		
^{241}Am	1.5×10^{-10}	1.5×10^{-10}	3.0×10^{-10}
^{242}Cm	1.5×10^{-9}	1.5×10^{-9}	4.1×10^{-9}
^{244}Cm	5.0×10^{-10}	5.0×10^{-10}	3.0×10^{-9}

There are several accidents thought to involve larger releases of radioactive material. These are classed as moderate accidents and are listed below.

Accident Number	Description
4.1.16	Feed solution backup in air line or contamination spread to occupied areas
4.1.17	Off-gas absorber failure
4.1.18	Process off-gas cleanup system failure
4.1.19	Off-gas blower failure
4.1.20	Failure of cell exhaust filters

Of these accidents, Accident 4.1.18 (process off-gas cleanup system failure) was judged to be the most severe and was taken as representative of the set. For this accident, 10 g of calcine was assumed to be released to the FRP-APS during a 30-min period with a postulated frequency of 0.2 per year. The radioactive materials released in such an event are listed in Table 5.2.2-12. The calculated 70-year dose commitment to the maximum individual is presented in Table 5.2.2-13. Numerically, the largest of these dose values is less than 5% of the dose the individual would have received from naturally occurring sources. Accidents that would lead to more serious consequences were not identified for the calcination process.

TABLE 5.2.2-12. Releases of Radionuclides to the Atmosphere from Moderate Accidents in the Calcination Facility (Ci)

Radionuclide	U Recycle with Pu in SHLW	U Recycle with PuO_2 Stored	U and Pu Recycle
^{90}Sr	1.2×10^{-3}	1.2×10^{-3}	1.2×10^{-3}
^{95}Nb	1.4×10^{-4}	1.4×10^{-4}	1.4×10^{-4}
^{106}Ru	3.2×10^{-3}	3.2×10^{-3}	3.6×10^{-3}
^{125m}Te	4.1×10^{-5}	4.1×10^{-5}	4.5×10^{-5}
^{127m}Te	7.9×10^{-6}	7.9×10^{-6}	8.1×10^{-6}
^{134}Cs	2.3×10^{-3}	2.3×10^{-3}	2.3×10^{-3}
^{137}Cs	1.7×10^{-3}	1.7×10^{-3}	1.8×10^{-3}
^{144}Ce	4.7×10^{-3}	4.7×10^{-3}	4.5×10^{-3}
^{154}Eu	1.0×10^{-4}	1.0×10^{-4}	1.2×10^{-4}
^{238}Pu	5.9×10^{-5}	3.0×10^{-7}	
^{239}Pu	5.5×10^{-6}	2.8×10^{-8}	3.4×10^{-8}
^{240}Pu	8.5×10^{-6}		
^{241}Pu	1.9×10^{-3}		
^{241}Am	7.0×10^{-6}	7.0×10^{-6}	1.3×10^{-5}
^{242}Cm	6.6×10^{-5}	6.6×10^{-5}	1.9×10^{-4}
^{244}Cm	2.3×10^{-5}	2.3×10^{-5}	1.3×10^{-4}

TABLE 5.2.2-13. 70-Year Dose Commitment to the Maximum Individual from a Moderate Accident in the Calcination Facility (rem)

Organ	U Recycle with Pu in SHLW	U Recycle with PuO_2 Stored	U and Pu Recycle
Total body	3×10^{-4}	1×10^{-4}	2×10^{-4}
Thyroid	6×10^{-7}	6×10^{-7}	7×10^{-7}
Lung	2×10^{-3}	1×10^{-3}	3×10^{-3}
Bone	4×10^{-3}	8×10^{-4}	2×10^{-3}
Skin	2×10^{-7}	2×10^{-7}	2×10^{-7}

5.2.2.2 Vitrification (DOE/ET-0028 Sec. 4.1.1)

Several HLLW vitrification processes are being developed for installation at reprocessing plants in various countries. Among these are spray calcination and continuous melting in Germany; rotary kiln calcination and continuous melting in France; the HARVEST process in Great Britain; fluidized-bed calcination and continuous melting in the USSR; spray calcination and in-can melting and fluidized-bed or direct-liquid-fed continuous melting in the United States. The vitrification process selected for reference in this report is spray calcination and in-can melting, the U.S. vitrification process that was identified in ERDA 76-43 as being most fully developed.

In-can melting is a batch process for vitrifying HLLW. The storage canister is placed in a multizone furnace and coupled directly to a HLLW calciner. The HLLW is pumped to an internal-mixing pneumatic atomizing nozzle in the top of the heated (700°C wall temperature) spray calciner barrel. The atomizer droplets (nominally <80 μm in diameter) are flash dried and calcined as they fall through the hot barrel. The finely divided powdery product is separated from the off-gas by sintered stainless steel filters. Glass-forming frit is fed to the canister at a rate proportional to the calcine production rate, and the blend is melted at 1000 to 1100°C in the canister. As the melt level rises, the furnace zones below the level are turned off and cooling is started to remove heat generated by the waste. The off-gas from the melting is vented through the calciner off-gas system. The canister of glass is cooled, sealed, cleaned of surface contamination, and inspected. The process arrangement is shown schematically in Figure 5.2.2-3. The final product consists of borosilicate glass containing about one part HLLW oxides and two parts glass-forming additives by weight — a stable product having low leachability. Most waste oxides are accommodated in the glass structure, but a few occur as separate phases that are dispersed in the glass. Typical characteristics of the final product are shown in Table 5.2.2-14.

Reference Vitrification Facility Description. The reference vitrification facility will be located in essentially the same space in the FRP as the calcination facility, which is shown in Figure 5.2.2-2. The vitrification facility will occupy about 7400 m^2 of space within the reference FRP. About 20 individuals are expected to be required for planned operation and about 9 individuals for maintenance. Construction of the facility will probably coincide with construction of the reference FRP.

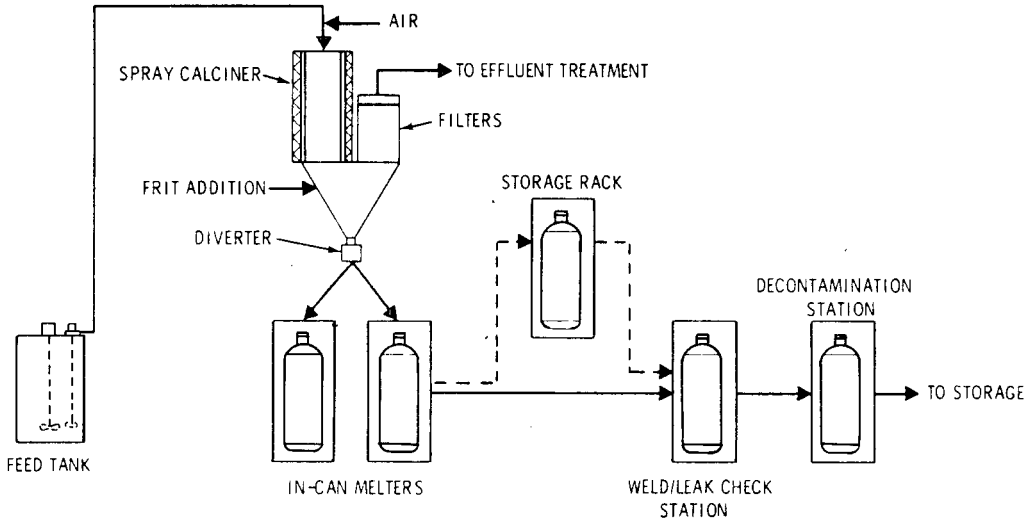

FIGURE 5.2.2-3. Spray Calciner and In-Can Melting Process

TABLE 5.2.2-14. Borosilicate Glass Characteristics[a]

Characteristics	
Composition	
SiO_2	25-40 wt%
B_2O_3	10-15 wt%
Alkali metal oxides	5-10 wt%
ZnO	0-20 wt%
Waste oxides	20-35 wt%
Typical volume	60-80 ℓ/MTU
Density	3.0-3.6 g/cm^3
Thermal conductivity	0.9-1.3 W/m-°C
Leach rate	10^{-4} to 10^{-7} g/cm^2-day

a. Processing temperature, 1000 to 1400°C.

The vitrification facility will share the ventilation systems, water supply, cooling facilities, utilities, and services of the FRP. Water requirements for the vitrification facility are related mainly to process cooling and amount to about 0.1 ℓ/sec or about 0.2% of the FRP cooling system requirements. Cooling water, in the form of blowdown, increased in temperature by about 17°C, is assumed to be routed via the FRP cooling tower system to the surface stream in the reference environment. Other process water (about 0.2 ℓ/sec) will be routed to the FRP acid recovery and cleanup system for removal of radioactive material and eventual release to the atmosphere.

Air flow requirements include about 0.02 m^3/sec for process off-gas, about 0.006 m^3/sec for vessel ventilation, and about 4 m^3/sec for cell ventilation. This air is released via the FRP-APS. About 5 m^3/sec of air is required for facility ventilation. The process off-gas

stream passes through decontamination processes having a total particulate DF of 4×10^{10}* before passing to the APS. The APS has filters that provide for an additional DF of 1×10^{4} for particles. This filtered air is released along with about 120 m^3/sec of air from the FRP-APS via the 110-m stack.

At planned operating capacity, the vitrification facility will convert about 3800 ℓ/day of HLLW to about 390 ℓ/day of glass sealed in canisters 3 m long and 0.3 m in diameter. The stated capacity is compatible with the amount of HLLW produced by the 2000-MTHM/yr reference FRP.

Environmental Effects Related to Facility Construction. Some of the factors relating to site preparation and vitrification facility construction may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of construction activities.

Resource Commitments. The reference HLLW vitrification facility including the vitrification cell, operating area, and other services will occupy about 7400 m^2. The FRP, of which the vitrification facility is assumed to be an integral part, will occupy about 400,000 m^2. The area committed to a reprocessing plant (restricted area of 2400 ha) will include an area for a solidification facility, whether or not such a waste treatment facility is built. Consequently, a separate analysis of land use attributable solely to the vitrification facility was not made.

Water used during construction will be about 1.7×10^{7} ℓ.

Construction materials committed to the vitrification facility are:

Concrete	6100 m^3
Steel	1700 MT
Copper	18 MT
Zinc	0.9 MT
Lumber	330 m^3

Energy resources used during construction will be:

Propane	150 m^3
Diesel fuel	1,500 m^3
Gasoline	980 m^3
Electricity	
Peak demand	40 kW
Total consumption	750,000 kWh

Manpower requirements for construction of the vitrification facility amount to 1.3 million man-hr, which will likely be integrated with labor schedules for the FRP.

No special requirements for transportation or storage of hazardous materials have been identified beyond those for the FRP.

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* Except for ruthenium, for which a DF of 1×10^{6} applies.

Physical and Chemical Effects. Releases from construction of the vitrification facility consist mainly of liquids used in facility cleanup and washdown, exhaust emission to the atmosphere from traffic and equipment, heat, and sanitary wastes. None of these waste sources were identified as having significant impact or effects on environmental quality.

The 4.3×10^3 m^3 of water required annually are, assuming a 4-year construction period, expected to come from the R River of the reference environment. Less than 10% of the water was assumed to be committed for use in construction material; the rest will be used for several purposes including but not limited to concrete wetting and washdown, dust control and soils stabilization, and sanitary use. Sanitary wastes will be treated before release to the environment. No drain or surface water releases containing toxic substances were identified, and no perceptible environmental impact from the releases is projected.

Ecological Effects. The ecological effects from construction of the reference vitrification facility are, for the most part, indistinguishable from those associated with the FRP. About 1.7×10^4 m^3 of water, to be drawn from the R River of the reference environment, will be required during construction. If one assumes as a worst case a 250-day construction period, the water use rate is 68 m^3/day. This amounts to less than 0.001% of the average river flow of 1.1×10^7 m^3/day. Withdrawal of this proportion of the river flow and the associated loss of any entrained organisms is expected to have an imperceptible effect on the river's ecosystem.

The noise and activity associated with the construction of the vitrification facility may be disruptive to nearby birds and animals. This impact is judged to be small and will become inconsequential as the local animal populations become accustomed to these changes and as the construction activity subsides.

Environmental Effects Related to Facility Operation. Some of the factors relating to operation of the vitrification facility may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of facility operation.

Resource Commitments. Resources required during planned operation of the vitrification facility are listed in Table 5.2.2-15.

Process Effluents. The amounts of radioactive material reaching the biosphere after leaving the vitrification facility and passing through the FRP-APS are shown in Table 5.2.2-16. The radionuclides listed are those that will contribute at least 1% to the total dose for any given organ from any pathway or that are otherwise of interest. Contributions to the source terms presented in Table 5.2.2-16 from releases during minor accidents were always less than 0.001% of the routine release and therefore do not add measurably to the radioactive effluent release.

TABLE 5.2.2-15. Utilities and Materials Required for Operation of the Vitrification Facility

Resource	Average Annual Use
Electricity	4.3×10^3 MWh
Water	2.9×10^3 m^3
Compressed air	1×10^6 m^3
Frit	2.5×10^2 MT
Stainless steel for canisters	2.2×10^2 MT
Caustic (19 M)	8 m^3
Nitric acid (12.2 M)	1.2×10^1 m^3
Argon	1.7×10^3 m^3
Helium Sources	7.5×10^2
Detergent	2.3×15^1
Ammonia	1.2×10^2 MT
Steam	6×10^2 MT
Manpower	
Routine	20 man-yr
Maintenance	9 man-yr

TABLE 5.2.2-16. Radionuclides Released to the Atmosphere from the Vitrification Facility via the FRP-APS (Ci/yr)

Radionuclide	U Recycle with Pu in SHLW	U Recycle with PuO_2 Stored	U and Pu Recycle
^{3}H	6.7×10^{4}	6.7×10^{4}	6.7×10^{4}
^{90}Sr	3.2×10^{-7}	3.2×10^{-7}	3.0×10^{-7}
^{106}Ru	3.4×10^{-2}	3.4×10^{-2}	3.8×10^{-2}
^{129}I	3.3×10^{-4}	3.3×10^{-4}	3.5×10^{-4}
^{137}Cs	4.6×10^{-7}	4.6×10^{-7}	4.6×10^{-7}
^{238}Pu	1.6×10^{-8}		
^{239}Pu	1.5×10^{-9}	7.2×10^{-12}	9×10^{-12}
^{241}Pu	5.0×10^{-7}		
^{244}Cm			3.6×10^{-8}

The radioactive material entrained in air is derived from process and vessel off-gas and cell ventilation air. The process off-gas contains about one-half of the radioactive material and is released at the rate of about 0.003 m^3/sec. About one-sixth of the radioactive material is in vessel ventilation air and is released at a rate of about 0.006 m^3/sec. Cell ventilation air accounts for about one-third of the radioactive material and is released at a rate of about 4 m^3/sec. The total volume of air including facility ventilation is estimated at 9 m^3/sec or about 8% of the air flow through the FRP-APS.

No radioactive materials will be released to the biosphere via liquid waste streams. About 0.2 ℓ/sec of process water is used. This is recycled through the FRP acid recovery system for the recovery of wastes which are then rerouted to HLLW solidification for treatment. The remaining liquid is released as water vapor to the APS stack and the atmosphere. This process water derives from canister decontamination, cell and equipment decontamination, calcine off-gas condensate, ruthenium scrubber regeneration solution, and miscellaneous sources.

Nonradioactive materials released to the atmosphere via the FRP-APS are presented in Table 5.2.2-17. No significant differences in release of nonradioactive material are expected between the uranium and plutonium recycle and uranium-only recycle modes.

TABLE 5.2.2-17. Nonradioactive Materials Released to the Atmosphere from the Vitrification Facility Via the FRP-APS

Material	Quantity Released, MT/yr
H_2O	2.5×10^{3}
NO_x	7.7×10^{-1}
NH_3	1.0×10^{1}
N_2	5.5×10^{1}

Heat released to the biosphere from the vitrification process comes from process cooling and ventilation air. Equipment or processes that require cooling include the calciner feed tank, canister storage rack, welding and inspection station, calciner off-gas condenser, calcine condensate tank, NO_x destructor off-gas cooler, and welder. Cooling water requirements are about 0.1 ℓ/sec. The temperature of the cooling tower drift and evaporation is 38°C and that of the blowdown is 27°C and the average make up water temperature is 10°C. These temperatures correspond to average Δt's of 28°C and 17°C respectively. This increase in temperature corresponds to an annual heat load of about 6×10^{6} MJ kW. The cooling water passes through the FRP cooling system (about 36 ℓ/sec are used for tower makeup) and emerges at the R River at about 17°C above average ambient river water temperature. During summer and at the record low flow of the R River of 6200 ℓ/sec, releases of 0.02 ℓ/sec of water at 17°C Δt from the vitrification facility and the 5.4 ℓ/sec from the FRP cooling system would result in the 0.6°C Δt isotherm in the R River to occupy less than 130 m^2.

The total annual heat rejection of 6.0×10^{6} MJ is primarily through the FRP cooling tower. Of this about 15% is rejected via the FRP stack. At a maximum, the vitrification facility adds about 1% to the FRP heat rejection.

Physical, Chemical, and Thermal Effects. Atmospheric effects of operating the vitrification facility include impacts on air quality resulting from release of sensible heat, emission of nonradiological pollutants, and emissions from vehicles used by the operating force.

Annual average and maximum ambient ground level concentrations of pollutants emitted by the vitrification facility at the FRP were computed using $\overline{\chi}/Q'$ values developed from stack effluent parameters and the table of average joint frequency distribution, as listed in the reference environment. These concentrations are given in Table 5.2.2-18.

TABLE 5.2.2-18. Ground Level Concentrations of Pollutants[a] Released by the Vitrification Facility at the FRP ($\mu g/m^3$)

Pollutant	Maximum	Average
NO_2	0.04	0.02
NH_3 (ammonia)	0.4	0.18
H_2O (water vapor)	120	48
N_2	2.5	1.0

a. At FRP fence line, 2800 m from FRP stack.

Regarding the pollutants listed in Table 5.2.2-18, Federal ambient air quality standards currently exist only for NO_2. For this pollutant a standard of 100 $\mu g/m^3$, computed as an annual arithmetic mean, can be used. Thus, neither estimated ground level ambient air concentrations at the fence line nor maximum exposure exceed present Federal standards.

Although no Federal ambient air quality standards exist for ammonia (NH_3), a threshold limit value can be used as a standard. Currently an occupational exposure of 18,000 $\mu g/m^3$ is considered an inhalation hazard.[1] Even the expected maximum concentration is many orders of magnitude below this value, and the release of NH_3 in these amounts is expected to be without consequence.

Radiological Effects from Operation. Doses to individuals in the vicinity of the vitrification facility were calculated based on the releases of radionuclides as listed in Table 5.2.2-16; pathways, demography, and other parameters described in Appendix A; and mathematical models relating radionuclide doses to man (Appendix B). For planned operation of the vitrification facility the only exposure pathway for radionuclides to man is via airborne effluents; there are no releases to ground or water.

The annual doses to individuals whose habits tend to maximize their dose ("maximum individual") are shown in Table 5.2.2-19. For perspective, the total-body dose to an individual from naturally occurring radioactive sources averages about 0.1 rem/yr.

The combined dose from gaseous effluents to the population living within an 80-km radius of the plant was calculated using the projected year 2000 population data given in the reference environment. Table 5.2.2-20 summarizes the annual doses received by this population. The annual population dose from naturally occurring sources to the approximately 2 million persons living within an 80-km radius of the plant in the year 2000 would be about 200,000 man-rem compared with the highest value from the vitrification facility of about 30 man-rem as indicated in Table 5.2.2-20.

The annual total-body dose to the work force associated with the vitrification facility was estimated based on permissible exposure limits and experience of operating plants. The annual occupational total-body dose was calculated to be 70 man-rem.

Table 5.2.2-21 summarizes the annual total-body dose to the work force and the general public from the vitrification facility and from naturally occurring sources in the year 2000.

Differences between uranium and plutonium recycle and uranium recycle with plutonium as a waste are not sufficient to cause a significant difference in the process work force dose estimate.

TABLE 5.2.2-19. Annual Doses to Maximum Individual from Gaseous Effluents Released by the Vitrification Facility (rem)(a)

Pathway	Total Body	Thyroid (child)(b)	Thyroid(c)	Lung	Bone
	U Recycle with Pu in SHLW or PuO_2 Stored				
Air submersion	1.2×10^{-11}	1.2×10^{-11}	1.2×10^{-11}	1.2×10^{-11}	1.2×10^{-11}
Inhalation	3.5×10^{-5}		3.5×10^{-5}	3.6×10^{-5}	4.5×10^{-9}
Ingestion	2.0×10^{-4}	1.2×10^{-4}	2.1×10^{-4}	2.0×10^{-4}	8.7×10^{-9}
Total	2.4×10^{-4}	1.2×10^{-4}	2.5×10^{-4}	2.4×10^{-4}	1.3×10^{-8}
	U and Pu Recycle				
Air submersion	1.3×10^{-11}	1.3×10^{-11}	1.3×10^{-11}	1.3×10^{-11}	1.3×10^{-11}
Inhalation	3.5×10^{-5}		3.5×10^{-5}	3.6×10^{-5}	5.0×10^{-9}
Ingestion	2.0×10^{-4}	1.2×10^{-4}	2.1×10^{-4}	2.0×10^{-4}	9.2×10^{-9}
Total	2.4×10^{-4}	1.2×10^{-4}	2.5×10^{-4}	2.4×10^{-4}	1.4×10^{-8}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 1.5×10^{-8} sec/m^3.

a. After 30 years of release and accumulation in the environment.
b. Thyroid dose is calculated for a 1-year-old child breathing air containing radioactive effluents and consuming 1 ℓ of milk per day from cows grazing 7 months/yr at the site boundary. Inhalation dose is <2% of total dose.
c. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

TABLE 5.2.2-20. Annual Doses to Population (within 80 km) from Gaseous Effluents Released by the Vitrification Facility (man-rem)(a)

Pathway	Total Body	Thyroid	Lung	Bone
	U Recycle with Pu in SHLW or PuO_2 Stored			
Air submersion	2.8×10^{-6}	2.8×10^{-6}	2.8×10^{-6}	2.8×10^{-6}
Inhalation	8.2	8.2	8.3	1.0×10^{-3}
Ingestion	1.9×10^{1}	2.0×10^{1}	1.9×10^{1}	7.7×10^{-4}
Total	2.7×10^{1}	2.8×10^{1}	2.7×10^{1}	1.8×10^{-3}
	U and Pu Recycle			
Air submersion	3.1×10^{-6}	3.1×10^{-6}	3.1×10^{-6}	3.1×10^{-6}
Inhalation	8.2	8.2	8.3	1.2×10^{-3}
Ingestion	1.9×10^{1}	2.0×10^{1}	1.9×10^{1}	8.2×10^{-4}
Total	2.7×10^{1}	2.8×10^{1}	2.7×10^{1}	2.0×10^{-3}

a. After 30 years of release and accumulation in the environment.

TABLE 5.2.2-21. Summary of Annual Total-Body Doses Received from Operation of the Vitrification Facility and Naturally Occurring Sources in the Year 2000

	Man-rem
Vitrification facility	
Process work force (30 yr)	70
Population (within 80 km)	27
Naturally occurring sources	
Population (within 80 km)	200,000

The dose to both the maximum individual and to the regional population is essentially the same for either recycle mode. This effect is due to tritium, which is the controlling factor and is invariant in either of the waste recycle modes. Although the amount of plutonium isotopes could be expected to be 200 times greater in effluents where solidification includes plutonium as a waste, the total amount of plutonium is inadequate to change the resulting dose.

Integrated 70-year doses to the maximum individual were calculated and are presented in Table 5.2.2-22. Integrated 70-year doses to the population are presented in Table 5.2.2-23. A summary of 70-year total-body doses is presented in Table 5.2.2-24. The dose for the process work force is determined only for the 30-year period of plant operation.

TABLE 5.2.2-22. 70-Year Doses to Maximum Individual from Gaseous Effluents Released by the Vitrification Facility (rem)

Pathway	Total Body	Thyroid[a]	Lung	Bone
U Recycle with Pu in SHLW Waste or PuO_2 Stored				
Air submersion	3.5×10^{-10}	3.5×10^{-10}	3.5×10^{-10}	3.5×10^{-10}
Inhalation	1.1×10^{-3}	1.1×10^{-3}	1.1×10^{-3}	1.4×10^{-7}
Ingestion	6.4×10^{-3}	6.9×10^{-3}	6.4×10^{-3}	2.6×10^{-7}
Total	7.5×10^{-3}	8.0×10^{-3}	7.5×10^{-3}	4.0×10^{-7}
U and Pu Recycle				
Air submersion	4.0×10^{-10}	4.0×10^{-10}	4.0×10^{-10}	4.0×10^{-10}
Inhalation	1.1×10^{-3}	1.1×10^{-3}	1.1×10^{-3}	1.5×10^{-7}
Ingestion	6.4×10^{-3}	7.0×10^{-3}	6.4×10^{-3}	2.8×10^{-7}
Total	7.5×10^{-3}	8.1×10^{-3}	7.5×10^{-3}	4.3×10^{-7}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 1.5×10^{-8} sec/m^3.

a. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green vegetables (growing season, 4 months/yr).

TABLE 5.2.2-23. 70-Year Doses to Population from Gaseous Effluents Released by the Vitrification Facility (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
	U Recycle with Pu in SHLW or PuO_2 Stored			
Air submersion	8.3×10^{-5}	8.3×10^{-5}	8.3×10^{-5}	8.3×10^{-5}
Inhalation	2.5×10^{2}	2.5×10^{2}	2.5×10^{2}	3.3×10^{-2}
Ingestion	6.1×10^{2}	6.6×10^{2}	6.1×10^{2}	2.6×10^{-2}
Total	8.6×10^{2}	9.1×10^{2}	8.6×10^{2}	5.9×10^{-2}
	U and Pu Recycle			
Air submersion	9.2×10^{-5}	9.2×10^{-5}	9.2×10^{-5}	9.2×10^{-5}
Inhalation	2.5×10^{2}	2.5×10^{2}	2.5×10^{2}	3.6×10^{-2}
Ingestion	6.1×10^{2}	6.6×10^{2}	6.1×10^{2}	2.7×10^{-2}
Total	8.6×10^{2}	9.1×10^{2}	8.6×10^{2}	6.3×10^{-2}

TABLE 5.2.2-24. Summary of 70-Year Total-Body Doses from Operation of the Vitrification Facility and Naturally Occurring Sources in the Year 2000

	Man-rem
Vitrification facility	
Process work force (30 yr)	1,500
Population (within 80 km)	860
Naturally occurring sources	
Population (within 80 km)	14,000,000

Total-body dose to the worldwide population is limited to that received from the release of 6.7×10^{4} Ci of ^{3}H; no ^{14}C or ^{85}Kr are released during the vitrification process. The worldwide population dose for the 30th year of plant operation was calculated to be 4.6×10^{2} man-rem, and the 70-year accumulated dose from 30 years of plant operation was calculated to be 1.6×10^{4} man-rem. The dose to this population from naturally occurring radioactive sources for these two periods would be about 6×10^{8} and 4×10^{10} man-rem respectively.

"Health effects" are discussed at the plant level where several processes within the plant are combined. In this report, 100 to 800 health effects are postulated to occur in the exposed population per million man-rem to the total body. As in the case of solidification by calcination, two to twenty health effects might occur in the worldwide population from this process.

Ecological Effects. During planned operation, the vitrification facility will release about 0.02 ℓ/sec of water at a Δt of 17°C to the R River. This water will be diluted by factors of about 57,000 and 1,100,000 at minimum and average river flows respectively. The area bounded by the 0.6°C isotherm in the thermal plume would be less than 130 m^2 during low flow. The introduction of this amount of heated water will have no discernible effects on the river biota. Design criteria call for no chemical release in the aqueous effluents.

Concentrations of chemicals contained in air released via the reference FRP stack are calculated at the point of maximum $\overline{\chi}/Q'$ (about 2800 m southeast of the stack). These concentrations are at least three orders of magnitude below the relevant standards for breathing air. Deposition and/or uptake and effect on terrestrial biota at these concentrations would be inconsequential.

The dose to man from radioactive effluents is described in the section on process effluents. In the absence of releases of radioactive material to water, only the pathway of airborne pollutants to the terrestrial food web need be considered. The quantities of radioactive materials deposited on vegetation will be in the range of 0.02 fCi/g; even with bioaccumulation factors of several orders of magnitude, the resulting doses to higher animals would not likely exceed those specified for the maximum individual. Since terrestrial biota have not been shown to be more radiosensitive than man and since the dose to man is numerically insignificant compared with annual fluctuation in radiation dose from naturally occurring radionuclides, it is concluded that radioactive effluents from the reference vitrification facility will have no effect on biota in the plant environs.

Environmental Effects Related to Postulated Accidents. Several minor accidents or other events associated with waste solidification by vitrification that would be expected to lead to releases of radioactive material have been identified. Scenarios for these accidents are provided in DOE/ET-0028.[2] The accidents are listed below.

Accident Number	Description
4.1.1	Hydrogen explosion in feed tank
4.1.2	HLLW feed system leakage
4.1.3	Calcine spill from calcine handling equipment due to process irregularity
4.1.4	Sintered metal filter failure
4.1.5	Calcine overheating in canister

Based on anticipated releases of these minor accidents weighted by their expected frequency of occurrence, an average annual release of 1.2×10^{-5} g of calcine to the FRP-APS is postulated. Table 5.2.2-25 gives the estimated quantities of radionuclides released to the atmosphere.

Annual doses and 70-year dose commitments were calculated for the maximum individual and the regional population. In no case was the dose to the maximum individual greater than 1×10^{-6} rem/yr and was most often several orders of magnitude less.

Several accidents were thought to release amounts of radioactive materials larger than those released from minor accidents. These were classed as moderate accidents and are listed below.

Accident Number	Description
4.1.6	Feed solution backup in air line or contamination spread to occupied zone
4.1.7	Calciner pressurization due to malfunction of fuel ignition system
4.1.8	Failure of off-gas filter or scrubber
4.1.9	Loss of off-gas system flow
4.1.10	Failure of cell exhaust filters

TABLE 5.2.2-25. Releases of Radionuclides to the Atmosphere from Minor Accidents in the Vitrification Facility (Ci)

Radionuclide	U Recycle with Pu in SHLW	U Recycle with PuO_2 Stored	U and Pu Recycle
^{90}Sr	1.5×10^{-9}	1.5×10^{-9}	1.4×10^{-9}
^{95}Nb	1.7×10^{-10}	1.7×10^{-10}	1.7×10^{-10}
^{106}Ru	3.9×10^{-9}	3.9×10^{-9}	4.3×10^{-9}
^{125m}Te	5.0×10^{-11}	5.0×10^{-11}	5.5×10^{-11}
^{127m}Te	9.6×10^{-12}	9.6×10^{-12}	9.8×10^{-12}
^{134}Cs	2.7×10^{-9}	2.7×10^{-9}	2.7×10^{-9}
^{137}Cs	2.1×10^{-9}	2.1×10^{-9}	2.1×10^{-9}
^{144}Ce	5.7×10^{-9}	5.7×10^{-9}	5.5×10^{-9}
^{144}Pr			5.5×10^{-9}
^{154}Eu	1.2×10^{-10}	1.2×10^{-10}	1.4×10^{-10}
^{238}Pu	7.2×10^{-11}	3.6×10^{-13}	
^{239}Pu	6.7×10^{-12}	3.3×10^{-13}	4.1×10^{-14}
^{240}Pu	1.0×10^{-11}		
^{241}Am	8.4×10^{-12}	8.4×10^{-12}	1.6×10^{-11}
^{242}Cm	2.5×10^{-13}	8.0×10^{-11}	2.2×10^{-10}
^{244}Cm	8.0×10^{-11}	2.7×10^{-11}	1.6×10^{-10}

Of these moderate accidents, Accident 4.1.8 (process off-gas cleanup system failure) was judged to be most severe and was taken as representative of the set. This accident was also postulated for the calcination facility (Section 5.2.2.1); releases and consequences are presented in Tables 5.2.2-12 and 5.2.2-13.

In addition several non-design basis accidents were identified, e.g., calciner rupture and calciner damaged due to overheating. As discussed in DOE/ET-0028,[2] these kinds of accidents, have the potential for substantially larger releases; however, specific design features make occurrence of these accidents virtually impossible.

5.2.2.3 Comparison of Environmental Effects Between Alternatives

In terms of resource commitments, construction of the calcination facility would require 35% more water, 200% more zinc and propane, 35% more diesel fuel, 40% more gasoline, and 33% more electricity than that required for construction of the vitrification facility. No significant differences exist in chemical, thermal, or ecological effects related to construction of either solidification facility. Although the resource commitments do not appear significant in either case, the vitrification process could allow for some saving of these resources.

During operation about twice as much stainless steel would be required for canisters to contain vitrified HLW as that required for calcined HLW. This amount implies that an additional 10 kg of chromium per MTHM processed and 5 kg of nickel per MTHM processed would be required in the vitrification process. Vitrification would require 250 MT of frit per year, which is about 0.04% of the U.S. production and is not considered an important resource commitment.

In terms of nonradioactive effluents the calcination process would add about 900 MT of CO/CO_2 to the atmosphere whereas no release of these components was identified for the vitrification process.

During routine operation there is little difference between radiological impacts anticipated from the calcination facility and those anticipated from the vitrification facility. Tritium releases are the same for both processes and as a consequence there is no significant difference in radiological impact.

Radioactive source terms were developed for minor accidents for both processes. In both cases no significant addition to the dose from routine releases resulted. Moderate accidents for both processes were characterized by the same representative accident; thus, the moderate accident cannot be used as a basis for comparison. No severe accidents were postulated for either process.

Based on the findings of environmental analysis of the two processes, a numerical advantage among some commitments and effects is found for the vitrification process. Since none of the effects found are judged to warrant mitigation, this numerical advantage is not considered to be a determining factor in the selection of either process.

From an environmental point of view the choice between calcination and vitrification depends on which product will present less potential for adverse environmental effects in the event of an accident during transportation, at an interim storage facility, during placement in a deep geologic repository, or as a result of unexpected events after placement in geologic storage.

The principal difference between calcined waste and vitrified waste is the physical form of the product. Calcine is a free-flowing powder having a bimodal particle size distribution centering roughly on 20 μm and 200 μm depending on process parameters. Vitrified waste is essentially a monolithic solid (which may be fractured). In the event of a canister rupture the potential for dispersal of HLW is judged to be substantially greater for calcined waste than for vitrified waste. Because of the substantially greater surface area associated with the particles of calcined waste in the event of contact with water, leaching would be expected to proceed at a substantially greater rate than for vitrified waste.

Data presented in Tables 5.2.2-26 through 5.2.2-29 permit a tabular comparison of HLLW solidification by calcination and vitrification. These tables highlight effects from construction and operation of these facilities. There were no significant differences as a result of reprocessing mode.

TABLE 5.2.2-26. Comparison of Facility Construction

Resource Commitments	Calcination	Vitrification
Man-hours	1.8×10^6	1.3×10^6
Land, m^2	7.4×10^3	7.4×10^3
Water, m^3	2.3×10^4	1.7×10^4
Materials		
Concrete, m^3	6.1×10^3	6.1×10^3
Steel, MT	1.8×10^3	1.7×10^3
Copper, MT	1.8×10^1	1.8×10^1
Zinc, MT	2	9×10^{-1}
Lumber, m^3	3.3×10^2	3.3×10^2
Energy		
Propane, m^3	2.3×10^2	1.5×10^2
Diesel fuel, m^3	2.0×10^3	1.5×10^3
Gasoline, m^3	1.4×10^3	9.8×10^2
Electricity, kWh	1.0×10^6	7.5×10^5

TABLE 5.2.2-27. Comparison of Nonradiological Aspects of Facility Operation

	Calcination	Vitrification
Water consumed, m^3/yr	2.9×10^3	2.9×10^3
Man-yr/yr	2.9×10^1	2.9×10^1
Materials		
Kerosene	2.2×10^2	
Stainless steel, MT/yr	1.1×10^2	2.2×10^2
Chromium (in stainless steel), MT/yr	2×10^1	4×10^1
Nickel (in stainless steel), MT/yr	9	1.8×10^1
Compressed air, m^3/yr	4.0×10^6	6.0×10^6
Oxygen, m^3/yr	4.3×10^5	
Ammonia, m^3/yr	2.1×10^5	5.4×10^4
Nitric acid, m^3/yr	6.0×10^1	1.2×10^1
Argon, m^3/yr	--	1.7×10^3
Detergent, MT/yr		2.3×10^{-1}
Helium Sources	1.0×10^{-1}	7.5×10^2
Glass Frit, MT/yr		2.5×10^2
Silver Zeolite	6.4×10^{-2}	
Electricity, kWh	5×10^6	4.3×10^6
Nonradioactive effluents to atmosphere, MT/yr		
H_2O	2.5×10^3	2.5×10^3
NO_x	0	7.7×10^{-1}
CO_x	8.8×10^2	0
NH_3	4.6×10^1	1.0×10^1
N_2	6.6×10^3	5.5×10^1
O_2	1.9×10^3	
Heat released to atmosphere, MJ	6.0×10^6	6.0×10^2

Note: No significant ecological effects were identified for either process.

TABLE 5.2.2-28. Comparison of Radiological Aspects of Operation

	Calcination	Vitrification
Principal Radionuclides Released to the Atmosphere, Ci/yr[a]		
^{3}H	6.7×10^{4}	6.7×10^{4}
^{90}Sr	3.0×10^{-7}	3.0×10^{-7}
^{106}Ru	1.9×10^{-3}	3.8×10^{-2}
^{129}I	3.2×10^{-4}	3.5×10^{-4}
^{137}Cs	4.6×10^{-7}	4.6×10^{-7}
^{239}Pu	9.0×10^{-12}	9.0×10^{-12}
^{244}Cm	3.6×10^{-8}	3.6×10^{-8}
Dose to Maximum Individual with a 70-Year Residency, rem[b]		
Total body	7.5×10^{-3}	7.5×10^{-3}
Thyroid	8.1×10^{-3}	8.1×10^{-3}
Lung	7.5×10^{-3}	7.5×10^{-3}
Bone	2.7×10^{-7}	4.3×10^{-7}
(Dose from naturally occurring sources for same period, 7.0 rem)		
Dose to Regional Population (2,000,000 persons) with a 70-Year Residency, man-rem[b]		
Total body	8.6×10^{2}	8.6×10^{2}
Thyroid	9.1×10^{2}	9.1×10^{2}
Lung	8.6×10^{2}	8.6×10^{2}
Bone	2.8×10^{-2}	6.3×10^{-2}
(Dose from naturally occurring sources for same period, $\sim 1.4 \times 10^{7}$ man-rem)		
Dose to Process Work Force (30-year plant life), man-rem		
Total body	2.1×10^{3}	1.5×10^{3}
(Minor accident doses negligible for either case)		
70-Year Maximum Individual Dose from Most Severe Accident, man-rem		
Total body	3×10^{-4}	3×10^{-4}

a. No radioactive materials were released from either process to water or ground.
b. After 30 years of plant operation.

TABLE 5.2.2-29. Comparison of Facility Costs in Mid-1976 Dollars

	Calcination	Vitrification
Construction cost	50,000,000	36,000,000
Owner's cost	15,000,000	11,000,000
Total capital cost	65,000,000	47,000,000
Operation and maintenance	6,200,000	6,000,000
Total unit cost	11.00/kgHM	8.90/kgHM

REFERENCES FOR SECTION 5.2.2

1. American Conference of Governmental Industrial Hygienists, Threshold Limit Values for Current Year (1976), Cincinnati, OH, 1976.

2. Technology for Commercial Radioactive Waste Management, DOE/ET-0028, Energy Research and Development Administration, Washington, DC, in press.

5.2.3 Fuel Residues (DOE/ET-0028, Section 4.2)

Fuel bundle residues are generated in the course of reprocessing LWR fuels when fuel bundles are sheared into short (5 to 13 cm) lengths and leached with hot nitric acid. The residues, which are a high-volume waste, include short lengths of Zircaloy fuel cladding (hulls), fuel bundle support rods, poison rods, massive end fittings, fuel support grids, assorted springs, and spacer elements.

The materials and amounts depend partly upon the fuel fabricator. The materials generally used include Zircaloy, 304 stainless steel, and Inconel-718 in the weight ratios of about 24:4:1. The acid-leached fuel cladding sections will contain about 0.05% of the original fuel. Cladding hulls will contain sufficient long-lived α-emitting radionuclides and β-γ emitters to require special handling and storage considerations. In addition, zirconium, the chief alloying element in Zircaloy, is pyrophoric when finely divided.

The radioactive material associated with fuel bundle residues includes the activation products of Zircaloy, stainless steel, and Inconel as well as fission products and transuranic radionuclides from undissolved fuel. The radioactive material is located on the surface and in the surface oxide, and it is uniformly distributed throughout the metal. The uniformly distributed activity comes from activation of the alloying elements and from diffusion of fission-produced tritium.

The hulls treatment facility is part of the FRP, as noted by the shaded area in Figure 5.2.3-1. The alternative treatment processes selected for consideration include 1) mechanical compaction, 2) compaction by melting, and 3) packaging without compaction. Mechanical compaction and compaction by melting are considered technically feasible although demonstration of these processes is incomplete.[1] Packaging without treatment is the simplest method to implement and is essentially a commercial practice.

5.2.3.1 Mechanical Compaction (DOE/ET-0028, Section 4.2.2)

Mechanical compaction is a treatment concept for fuel bundle residues in which hulls are separated from the fuel assembly hardware and Zircaloy fines, compacted to 70-80% of theoretical density, and packaged in stainless steel canisters (0.76 m in diameter by 3 m) for shipment to interim storage or to a repository. The Zircaloy fines are deactivated by oxidation and packaged in canisters with the fuel assembly hardware. Compaction of unirradiated Zircaloy has been studied extensively; however, experience with irradiated hulls is limited. Compaction of the hulls can be accomplished by hydraulic press, high-energy rate compaction, extrusion, swaging, roll flattening, and press flattening. Although none of these options has been evaluated with irradiated hulls, hydraulic press compaction was selected as the only alternative technically feasible at present.

The steps involved in the fuel bundle residue compaction concept are shown in Figure 5.2.3-2. The process is an integral part of fuel dissolution at the FRP. The daily process capacity of the fuel bundle residue compaction facility is about 2.6 m^3 of uncompacted fuel residue, which corresponds to the daily output of the reference 2000-MTHM/yr FRP.

The facility for the fuel bundle residue compaction process is controlled from an operating gallery behind concrete shielding walls equipped with shielding windows and manipulators.

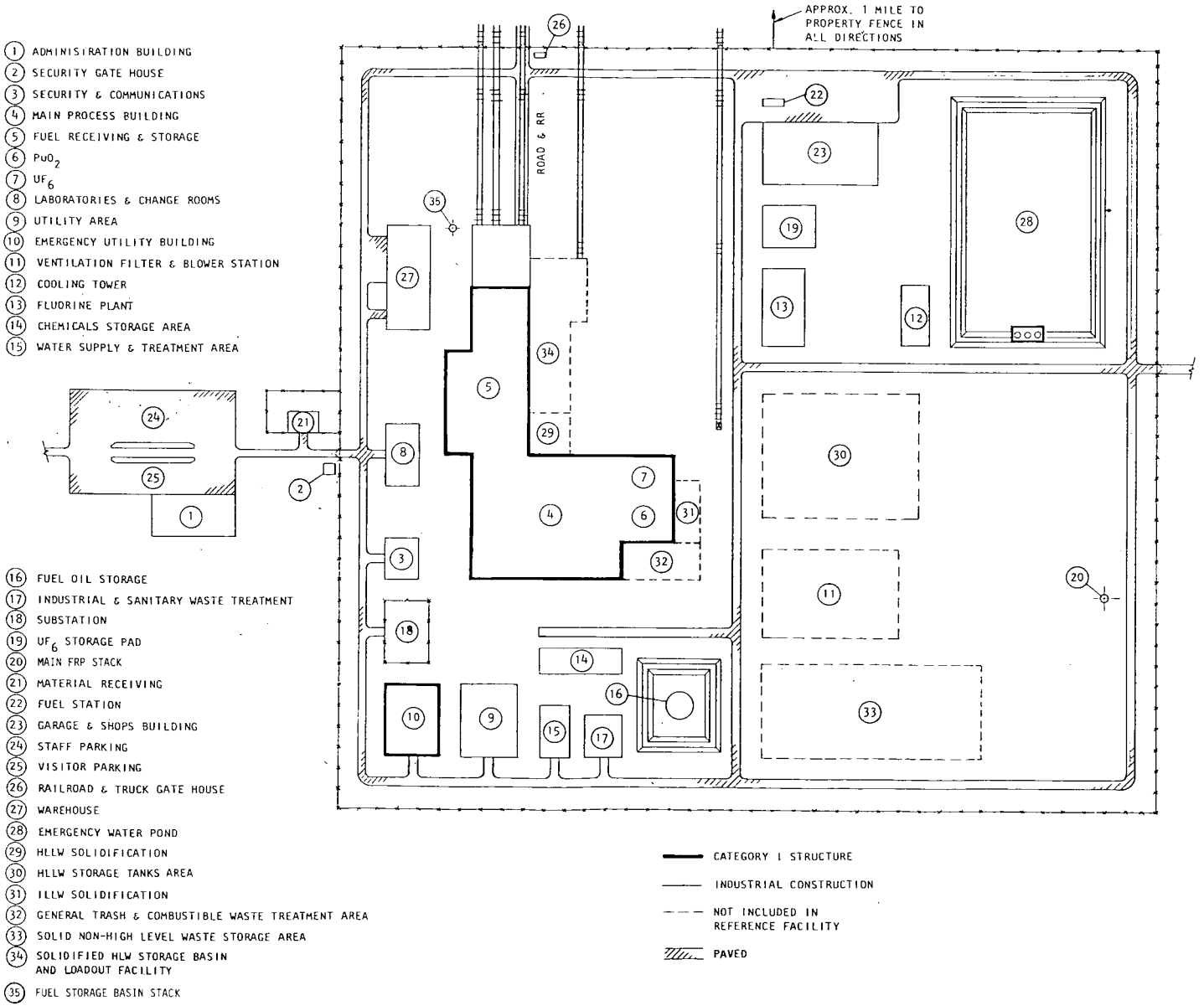

FIGURE 5.2.3-1. Approximate Location of the Fuel Residue Treatment Facility at the FRP

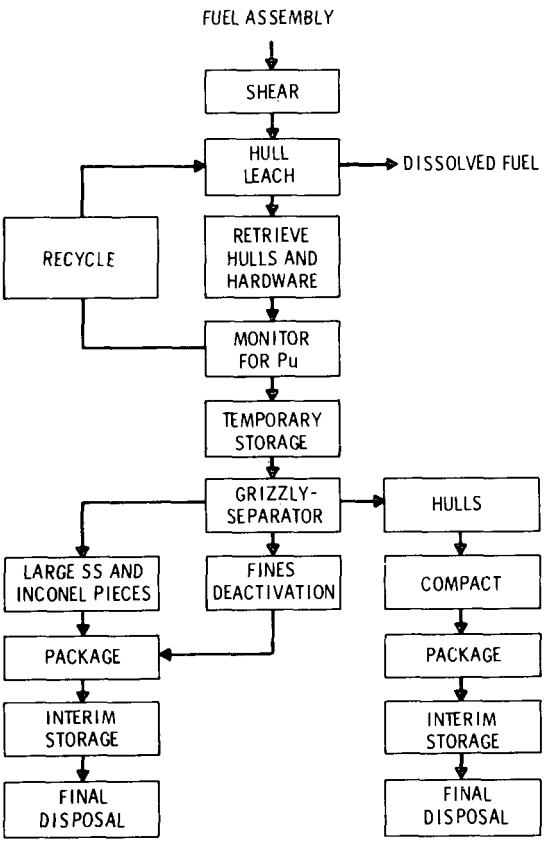

FIGURE 5.2.3-2. Flow Diagram for Mechanical Compaction

Environmental Effects Related to Facility Construction. Some of the factors relating to site preparation and reference facility construction may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of construction activities.

Resource Commitments. The fuel bundle residue compaction facility will be located in the main process building of the reference FRP and will require an area of about 450 m^2. This land requirement will have little effect on the size of the overall main process building and consequently on the area committed for the FRP. A separate analysis of land use attributable to the fuel bundle residue compaction process is therefore not meaningful.

Materials committed for construction of the fuel bundle residue compaction facility are:

Water	4400 m^3
Steel	620 MT
Copper	5 MT
Zinc	0.5 MT
Concrete	2300 m^3
Lumber	140 m^3

Energy resources committed for construction are:

Propane	42 m^3
Diesel fuel	420 m^3
Gasoline	290 m^3
Electricity	
Peak demand	320 kW
Total consumption	210,000 kWh

The schedule for engineering, procurement, and construction of the facility is included in the overall schedule for the FRP.

The field labor force required for the construction of the facility is estimated to be 180 man-yr.

The staff concludes that no special requirements or limitations for siting or construction of the facility are warranted.

Physical and Chemical Effects. The diversion of about 4400 m^3 of water over the period of construction of the fuel bundle residue compaction facility is unlikely to have any impact on local water supplies. This small amount of water could easily be drawn from the R River, with an annual average flow of 1.0×10^7 m^3/day, without affecting other downstream uses.

The use of about 450 m^2 of land for the fuel bundle residue compaction facility will have no significant impact on local land use. Moreover, environmental effects of the facility construction related to land cannot be separated from the effects of the overall FRP construction.

Ecological Effects. The fuel bundle residue compaction facility is an integral part of the FRP and will have no ecological impacts from construction beyond those of the FRP.

The facility will occupy approximately 450 m^2 of land, including the compaction cell, operating gallery, and cask loading station. This amount of land within an industrial complex has no ecological significance.

There will be no human or animal displacement other than that associated with the FRP. In addition, destruction and modification of vegetation will be indistinguishable from that of the FRP.

Water required for facility construction (about 4400 m^3) will be supplied by the R River at the reference site. If an 18-month construction period is assumed, the daily consumption rate will be 7.3 m^3 or less than 0.001% of the river low flow. Removal of this small fraction of the river flow will have no measurable effect on the river ecosystem.

Environmental Effects Related to Planned Operation. Some of the factors relating to facility operation may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of operation.

Resource Commitments. Commitment of resources during operation will include water as press pump and oil coolant, argon for the compacting and welding operation, hydraulic oil for operating the presses, stainless steel casks and canisters for storing the compacted residues, and miscellaneous other equipment items needing periodic replacement.

Materials required during planned operation of the fuel residue compaction facility are listed in Table 5.2.3-1.

TABLE 5.2.3-1. Utilities and Materials Required for Operating the Fuel Bundle Residue Compaction Facility

Resource	Average Annual Use
Water	
Cooling (evaporation, drift, blowdown)	590 m^3 (cooling tower makeup)
Process	10 m^3
Materials	
Argon	40,000 m^3
Helium	4,000 m^3
Waste canisters (0.8 m in diameter by 3 m long)	282
Energy	
Electricity	312,000 kWh
Manpower	17 man-yr

Electricity will be needed to operate various motors and the welding equipment. The use of energy for space ventilation, heating, and air conditioning is included in the total use of the main process building.

The compaction operation (including maintenance and radiation monitoring) is expected to require 17 man-yr/yr (assuming two shifts per day). Supervision is considered part of the total FRP overhead.

Process Effluents. The amounts of radioactive materials that reach the biosphere after leaving the compaction operation and passing through the FRP-APS are shown in Table 5.2.3-2. The radionuclides listed are those that will contribute at least 1% to the total dose for any organ from any pathway.

The radionuclides entrained in air are derived from process ventilation. No radioactive materials will be released to the biosphere via liquid effluent streams.

The compaction process produces a total of 1.2×10^6 MJ of waste heat for 250 days operation per year. This heat will be rejected principally to the atmosphere via the FRP cooling tower.

About 4×10^4 m^3 of argon will be released to the atmosphere annually.

All liquid and solid waste disposal for the process is part of the overall FRP operation.

Physical, Chemical, and Thermal Effects. Atmospheric impacts from operation of the fuel bundle residue compaction facility would be limited to any incremental increase in the impacts of waste heat rejection. These impacts consist of an insignificant addition to any occurrences of fogging from the cooling tower and an insignificant increase in cooling tower drift (2 m^3/yr). This facility's contribution to cooling tower blowdown will be about 86 m^3/yr. Its contribution to makeup water requirements will be 590 m^3/yr, which is insignificant compared with about

TABLE 5.2.3-2. Radionuclides Released to the Biosphere from the Fuel Bundle Residue Compaction Facility (Ci/yr)

Radionuclide	U Recycle, Pu in SHLW or PuO_2 Stored	U and Pu Recycle
^{3}H	6.3×10^{-8}	6.3×10^{-8}
^{14}C	1.1×10^{-10}	1.1×10^{-10}
^{60}Co	4.1×10^{-6}	4.1×10^{-6}
^{90}Sr	3.2×10^{-8}	3.1×10^{-8}
^{95}Zr	8.2×10^{-8}	8.2×10^{-8}
^{106}Ru	8.5×10^{-8}	9.5×10^{-8}
^{125m}Te	1.1×10^{-8}	1.1×10^{-8}
^{127m}Te	2.1×10^{-10}	2.2×10^{-10}
^{134}Cs	6.0×10^{-8}	6.0×10^{-8}
^{137}Cs	4.6×10^{-8}	4.6×10^{-8}
^{144}Ce	1.2×10^{-7}	1.2×10^{-7}
^{238}Pu	1.6×10^{-9}	2.8×10^{-9}
^{239}Pu	1.4×10^{-10}	1.8×10^{-10}
^{240}Pu	2.2×10^{-10}	3.6×10^{-10}
^{241}Pu	5.5×10^{-8}	9.0×10^{-8}
^{241}Am	1.8×10^{-10}	3.6×10^{-10}
^{242}Am	1.8×10^{-9}	5.0×10^{-9}
^{244}Am	6.0×10^{-10}	3.6×10^{-9}

1.1×10^{6} m^3/yr of makeup water required for the FRP. Through evaporation and drift this process will consume about 600 m^3/yr of water, which is not significant when compared with about 9.8×10^{5} m^3/yr evaporated from the FRP.

The energy released in this process is not large enough to have any effect on the local microclimate.

Radiological Effects. Doses to individuals in the vicinity of the fuel bundle residue compaction facility were calculated based on the releases of radionuclides listed in Table 5.2.3-2; exposure pathways, demography, and other parameters described for the reference environment (Appendix A); and mathematical models relating dose to man from radionuclide releases (Appendix B). For planned operation of the compaction facility, the only exposure pathway to man is via airborne effluents; there are no releases to ground or water.

The annual doses to individuals whose habits tend to maximize their dose ("maximum individual") are shown in Table 5.2.3-3. For comparison, the dose to an individual from naturally occurring radioactive sources averages about 0.1 rem/yr.

The combined dose from gaseous effluents to the population living within an 80-km radius of the plant was calculated using the projected year 2000 population data given in the reference environment. Table 5.2.3-4 summarizes the annual doses received by this population.

TABLE 5.2.3-3. Annual Doses to Maximum Individual from Gaseous Effluents Released by the Fuel Bundle Residue Compaction Facility (rem)[a]

Pathway	Total Body	Thyroid (child)[b]	Thyroid[c]	Lung	Bone
	U Recycle, Pu in SHLW or PuO_2 Stored				
Air submersion	3.9×10^{-14}	3.9×10^{-14}	3.9×10^{-14}	3.9×10^{-14}	3.9×10^{-14}
Inhalation	2.4×10^{-13}		1.9×10^{-14}	2.7×10^{-10}	1.5×10^{-12}
Ingestion	5.7×10^{-13}	1.3×10^{-16}	4.0×10^{-16}	2.4×10^{-14}	1.1×10^{-12}
Total	8.5×10^{-13}	3.9×10^{-14}	5.8×10^{-14}	2.7×10^{-10}	2.6×10^{-12}
	U and Pu Recycle				
Air submersion	3.9×10^{-14}	3.9×10^{-14}	3.9×10^{-14}	3.9×10^{-14}	3.9×10^{-14}
Inhalation	3.0×10^{-13}		1.9×10^{-14}	2.7×10^{-10}	2.6×10^{-12}
Ingestion	5.6×10^{-13}	1.3×10^{-16}	4.0×10^{-16}	2.3×10^{-14}	1.2×10^{-12}
Total	5.5×10^{-12}	3.9×10^{-14}	4.9×10^{-13}	1.8×10^{-11}	5.9×10^{-12}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the highest annual average dispersion factor ($\bar{\chi}/Q'$) of 1.5×10^{-8} sec/m^3.

a. After 30 years of release and accumulation in the environment.
b. Thyroid dose is calculated for a 1-year-old child breathing air containing radioactive effluents and consuming 1 ℓ of milk per day from cows grazing 7 months/yr at the site boundary. Inhalation dose is <2% of total dose.
c. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

TABLE 5.2.3-4. Annual Doses to Population (within 80 km) from Gaseous Effluents Released by the Fuel Bundle Residue Compaction Facility (man-rem)[a]

Pathway	Total Body	Thyroid	Lung	Bone
	U Recycle, Pu in SHLW or PuO_2 Stored			
Air submersion	9.1×10^{-9}	9.1×10^{-9}	9.1×10^{-9}	9.1×10^{-9}
Inhalation	5.6×10^{-8}	4.4×10^{-9}	6.2×10^{-5}	3.5×10^{-7}
Ingestion	5.4×10^{-8}	4.0×10^{-11}	2.5×10^{-9}	1.0×10^{-7}
Total	1.0×10^{-7}	1.3×10^{-8}	6.2×10^{-5}	4.5×10^{-7}
	U and Pu Recycle			
Air submersion	9.1×10^{-9}	9.1×10^{-9}	9.1×10^{-9}	9.1×10^{-9}
Inhalation	7.0×10^{-8}	4.4×10^{-9}	6.3×10^{-5}	6.2×10^{-7}
Ingestion	5.4×10^{-8}	4.0×10^{-11}	2.5×10^{-9}	1.0×10^{-7}
Total	1.3×10^{-7}	1.3×10^{-8}	6.3×10^{-5}	7.2×10^{-7}

a. After 30 years of release and accumulation in the environment.

The annual total-body population dose from naturally occurring sources to the approximately 2 million persons living within an 80-km radius of the plant in the year 2000 would be about 200,000 man-rem compared with the value of about 1.0×10^{-7} man-rem received from process sources as given in Table 5.2.3-4.

The annual total-body dose to the work force associated with the fuel bundle residue compaction facility was estimated based on permissible exposure limits and experience of operating plants. The annual occupational dose was calculated to be 20 man-rem. Table 5.2.3-5 summarizes the annual total-body dose to the work force and the general public from process and naturally occurring sources in the year 2000.

TABLE 5.2.3-5. Summary of Annual Total-Body Doses Received from Operation of the Fuel Bundle Residue Compaction Facility and Naturally Occurring Sources in the Year 2000

	Man-rem
Fuel bundle residue compaction facility	
Process work force (30 yr)	20
Population (within 80 km)	<0.001
Naturally occurring sources	
Population (within 80 km)	200,000

The 70-year doses to the maximum individual and to the population within 80 km of the facility are given in Tables 5.2.3-6 and 5.2.3-7 respectively. A summary of the 70-year total-body doses to the work force and the population is given in Table 5.2.3-8. For comparison, the dose to the same population from naturally occurring sources over the 70-year period amounts to about 14,000,000 man-rem compared with <0.001 man-rem received from radionuclides released by the compaction facility.

TABLE 5.2.3-6. 70-Year Doses to Maximum Individual from Gaseous Effluents Released by the Fuel Bundle Residue Compaction Facility (rem)

Pathway	Total Body	Thyroid[a]	Lung	Bone
	U Recycle, Pu in SHLW or PuO_2 Stored			
Air submersion	1.2×10^{-12}	1.2×10^{-12}	1.2×10^{-12}	1.2×10^{-12}
Inhalation	4.1×10^{-11}	5.7×10^{-13}	1.5×10^{-9}	5.8×10^{-10}
Ingestion	2.1×10^{-10}	1.3×10^{-14}	2.3×10^{-12}	8.7×10^{-10}
Total	2.5×10^{-10}	1.8×10^{-12}	1.5×10^{-9}	1.5×10^{-9}
	U and Pu Recycle			
Air submersion	1.2×10^{-12}	1.2×10^{-12}	1.2×10^{-12}	1.2×10^{-12}
Inhalation	6.7×10^{-11}	5.7×10^{-13}	1.8×10^{-9}	1.1×10^{-9}
Ingestion	2.1×10^{-10}	1.3×10^{-14}	2.3×10^{-12}	8.4×10^{-10}
Total	2.8×10^{-10}	1.8×10^{-12}	1.8×10^{-9}	1.9×10^{-9}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the highest annual average dispersion factor ($\bar{\chi}/Q'$) of 1.5×10^{-8} sec/m^3.

a. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/ yr).

TABLE 5.2.3-7. 70-Year Doses to Population (within 80 km) from Gaseous Effluents Released by the Fuel Bundle Residue Compaction Facility (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
	U Recycle, Pu in SHLW or PuO_2 Stored			
Air submersion	2.7×10^{-7}	2.7×10^{-7}	2.7×10^{-7}	2.7×10^{-7}
Inhalation	9.5×10^{-6}	1.3×10^{-7}	3.6×10^{-4}	1.4×10^{-4}
Ingestion	1.9×10^{-5}	1.3×10^{-9}	2.5×10^{-7}	7.7×10^{-5}
Total	2.9×10^{-5}	4.0×10^{-7}	3.6×10^{-4}	2.2×10^{-4}
	U and Pu Recycle			
Air submersion	2.7×10^{-7}	2.7×10^{-7}	2.7×10^{-7}	2.7×10^{-7}
Inhalation	1.6×10^{-5}	1.3×10^{-7}	4.3×10^{-4}	2.6×10^{-4}
Ingestion	1.9×10^{-5}	1.3×10^{-9}	2.5×10^{-7}	7.5×10^{-5}
Total	3.5×10^{-5}	4.0×10^{-7}	4.3×10^{-4}	3.4×10^{-4}

TABLE 5.2.3-8. Summary of 70-Year Total-Body Doses Received from Operation of the Fuel Bundle Residue Compaction Facility and Naturally Occurring Sources in the Year 2000

	Man-rem
Fuel bundle residue compaction facility	
Process work force (30 yr)	600
Population (within 80 km)	<0.001
Naturally occurring sources	
Population (within 80 km)	14,000,000

Total-body dose to the worldwide population results from the annual release of 6.3×10^{-8} Ci of ^{3}H and 1.1×10^{-10} Ci of ^{14}C. The dose for the 30th year of operation was calculated to be 8.4×10^{-9} man-rem, and the 70-year accumulated dose from 30 years of plant operation was calculated to be 4.5×10^{-7} man-rem. The dose to this population from naturally occurring sources for these two periods would be about 6×10^{8} and 4×10^{10} man-rem respectively.

"Health effects" for regional populations are discussed at the plant level where several processes within the plant are combined. In general, doses at the individual process level are too small for a meaningful discussion of health effects. In this report, 100 to 800 health effects are postulated to result in the exposed population per million man-rem.

Ecological Effects. The routine operation of the compaction facility will have little impact on the ecology of nearby land and surface waters.

The only gaseous effluents expected to be released during normal operation will be about 66 MT/yr of argon and 0.13 MT/yr of helium, which will be released through the FRP atmospheric protection system (APS). This release compares with 6×10^{4} MT/yr of naturally occurring argon and 3.5 MT/yr of naturally occurring helium in air passed through the FRP-APS. Oil and other process liquids, generated at the rate of 950 ℓ/yr, will be handled according to acceptable

treatment and disposal practices and will not be released to the environment in an uncontrolled fashion. The noise produced by facility operation may have a slight impact on local bird and animal populations, but these impacts will be indistinguishable from the overall effects of the FRP complex. The annual atmospheric heat release of about 1.2×10^6 MJ represents less than 0.05% of that released by the FRP and will not be ecologically significant.

Process water requirements will be about 0.03 ℓ/sec for the estimated 250 days that the facility will operate annually. This requirement is less than 0.01% at the low flow of the R River near the reference site. No impacts to the river biota will result from this rate of water withdrawal.

Environmental Effects Related to Postulated Accidents. One minor accident associated with compaction of fuel bundle residue was identified that would be expected to lead to releases of radioactive material. The scenario for this accident is provided in DOE/ET-0028.[2] The accident is identified as follows:

Accident Number	Description
4.2.2	Zirconium fines fire

Based on the anticipated releases of this minor accident weighed by the expected frequency of occurrence, an average annual burning of 2 kg of zirconium fines was postulated. The estimated quantities of radionuclides released to the atmosphere are presented in Table 5.2.3-9.

TABLE 5.2.3-9. Releases of Radionuclides to the Atmosphere from a Minor Accident in the Fuel Bundle Residue Compaction Facility (Ci/yr)

Radionuclide	U Recycle, Pu in SHLW or PuO_2 Stored	U and Pu Recycle
^{3}H	4.8×10^{-1}	4.8×10^{-1}
^{14}C	4.6×10^{-7}	4.6×10^{-7}
^{60}Co	7.6×10^{-8}	7.6×10^{-8}
^{90}Sr	2.5×10^{-8}	2.3×10^{-8}
^{95}Zr	6.2×10^{-8}	6.2×10^{-8}
^{106}Ru	6.5×10^{-8}	7.2×10^{-8}
^{134}Cs	4.6×10^{-8}	4.6×10^{-8}
^{137}Cs	3.5×10^{-8}	3.5×10^{-8}
^{144}Ce	9.5×10^{-8}	9.1×10^{-8}
^{238}Pu	1.2×10^{-9}	2.1×10^{-9}
^{239}Pu	1.1×10^{-10}	1.4×10^{-10}
^{240}Pu	1.7×10^{-10}	2.8×10^{-10}
^{241}Pu	4.2×10^{-8}	6.8×10^{-8}
^{241}Am	1.4×10^{-10}	2.7×10^{-10}
^{242}Cm	1.3×10^{-9}	3.8×10^{-9}
^{244}Cm	4.6×10^{-10}	2.7×10^{-9}

An annual dose was calculated for the maximum individual and the regional population. Seventy-year dose commitments were also calculated for these two groups. In no case were the resulting maximum individual doses greater than 1.6×10^{-9} rem/yr and most often were several orders of magnitude less. As a consequence, dose from this accident was considered to be negligible and thus does not constitute a radiological effect. Although insignificant, the dose from this accident resulted in a total-body dose to the maximum individual of about 1.6×10^{-9} rem/yr, which is about 300 times larger than the corresponding dose from routine releases.

There were no accidents identified which would release radioactive materials in amounts larger than those of the postulated accident. Non-design basis accidents were not considered.

The most plausible accident that could occur in the facility would be a fire or explosion of the zirconium fines in the grizzly or compactor. The nonradiological materials created by this event would be contained within the facility and not released to the environment.

5.2.3.2 Melting (DOE/ET-0028 Sec. 4.2.3)

The reference fuel bundle residue melting concept uses the Inductoslag melting process developed by the U.S. Bureau of Mines Metallurgical Research Center in Albany, Oregon. Figure 5.2.3-3 shows schematically the principles of operation for the Inductoslag melter, the key feature in the process. Before melting, the sheared cladding hulls are segregated from the stainless steel end fittings and other fuel element hardware and from the Zircaloy fines on a combination vibratory grizzly-separator. The ingots from the melter are sealed into stainless steel containers; the Zircaloy fines are deactivated by oxidation to eliminate pyrophoric hazards and are packaged with the stainless steel components without the melting step. This melting concept has been demonstrated successfully in making ingots 10 cm in diameter from simulated fuel bundle residues. Alternative cold crucible methods have been evaluated in studies that resulted in selection of Inductoslag melting.

A flow diagram for the fuel bundle residue melting process is shown in Figure 5.2.3-4. The process is an integral part of fuel dissolution at the FRP. The daily process capacity of the facility is about 2.6 m^3 of uncompacted fuel residue, which corresponds to the daily output of the reference 2000-MTHM/yr FRP. The facility is designed to produce six ingots per day, with dimensions of 0.23 m in diameter by 1.3 m long.

Environmental Effects Related to Facility Construction. Some of the factors relating to site preparation and reference facility construction may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of construction activities.

Resource Commitments. The fuel bundle residue melting facility will be located in the main process building of the FRP and occupy an area of about 580 m^2. This land requirement will have little effect on the size of the overall main process building and consequently on the area committed for the FRP. A separate analysis of land use attributable to the fuel bundle residue melting process is therefore not meaningful.

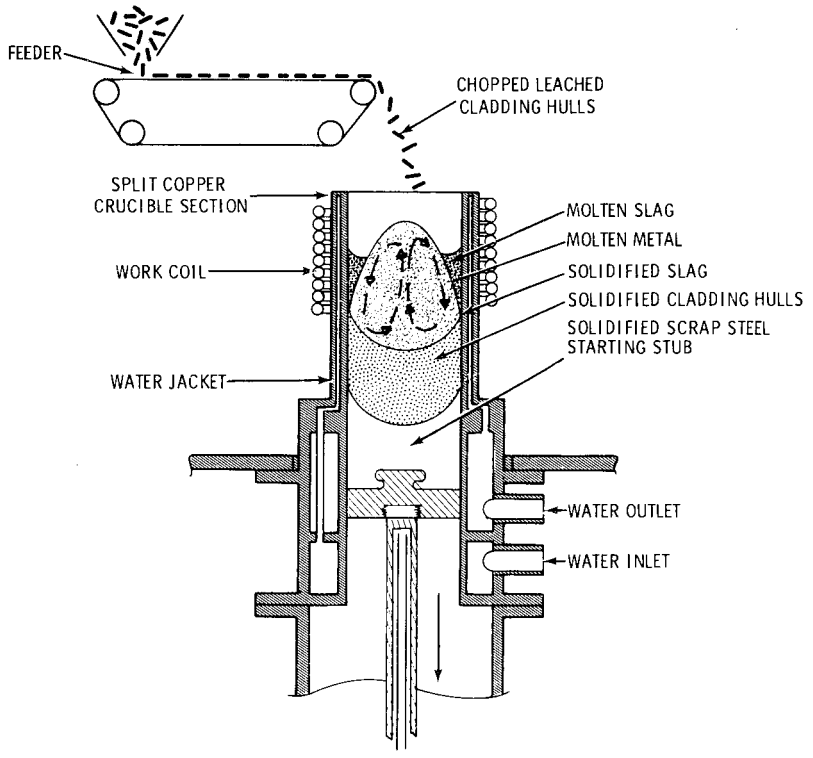

FIGURE 5.2.3-3. Inductoslag Melting Process

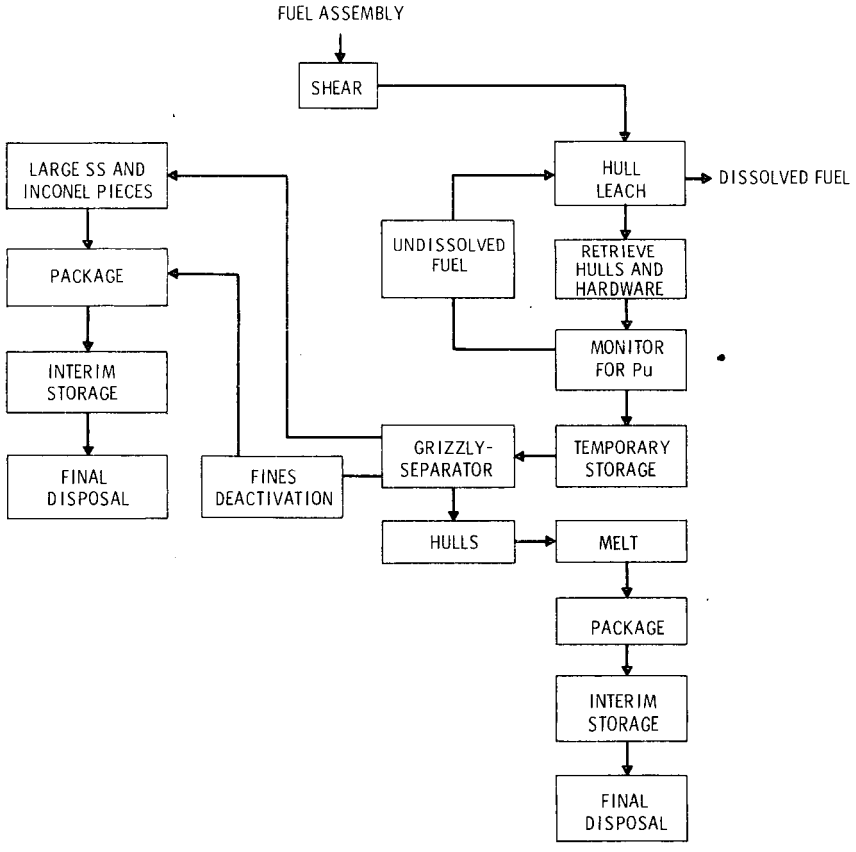

FIGURE 5.2.3-4. Flow Diagram for Fuel Residue Melting Process

Materials committed for construction of the fuel bundle residue melting process facility are:

Water	8400 m^3
Steel	580 MT
Copper	15 MT
Zinc	0.9 MT
Concrete	2220 m^3
Lumber	142 m^3

Energy resources committed for construction are:

Propane	60 m^3
Diesel fuel	720 m^3
Gasoline	360 m^3
Electricity	
Peak demand	430 kW
Total consumption	280,000 kWh

The schedule for engineering, procurement, and construction of the facility is included in the overall schedule for the FRP. The field labor force required for the construction of the facility is estimated at 240 man-yr.

It is concluded that no special requirements or limitations for siting or construction of the facility are warranted.

Physical and Chemical Effects. Effects on air quality will be an indistinguishable portion of those resulting from construction of the FRP.

The diversion of about 8.4×10^3 m^3 of water for the construction of the fuel bundle residue melting facility will not affect local water supplies. This amount of water could be withdrawn from the R River without impact on downstream uses. Over the period of construction it could also be supplied by wells on site.

The use of about 580 m^2 of land for the fuel bundle residue melting facility is not expected to have any impact on local land use. Moreover, environmental effects of the facility construction related to land and water cannot be separated from the effects of the overall FRP construction.

Ecological Effects. Construction impacts of the fuel bundle residue melting facility are a small part of those of the FRP (of which it is an integral part). Therefore, these effects will be indistinguishable from the overall ecological effects of the FRP complex.

The melting facility will occupy less than 0.5% of the 40-ha FRP secured area. Disturbance and modification of vegetation and displacement of birds and animals will be indistinguishable from the construction impacts on the FRP.

Total estimated water use during construction is 8.4×10^3 m^3 and will be supplied from the R River at the reference site. For an estimated construction period of 18 months, the average daily water use will be about 15 m^3 or less than 0.001% of the average river flow. Removal of this small amount of water will have an imperceptible effect on the river ecosystem.

Environmental Effects Related to Facility Operation. Some of the factors relating to facility operation may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of operation.

Resource Commitments. Commitment of resources during operation will include the use of water as a crucible coolant, vacuum pump oil, helium or argon for the crucible atmosphere, calcium fluoride as flux material, slag as crucible lining, stainless steel casks and canisters for storing the ingots, and miscellaneous equipment items needing periodic replacement.

Resources used during facility operation (assuming three 8-hr shifts per day, 5 days per week) are listed in Table 5.2.3-10. Electricity will be used to heat the furnaces and to operate various motors. The use of energy for space ventilation, heating, and air conditioning is included in the total use of the FRP main process building.

TABLE 5.2.3-10. Materials and Resources Required During Operation of the Fuel Bundle Residue Melting Facility

Resource	Average Annual Use
Water	
Cooling (evaporation and drift)	4.8×10^3 m^3
Materials	
Argon	1×10^4 m^3
Helium	3.0×10^3 m^3
Steel	7.3×10^1 MT
Calcium Fluoride	3.2 MT
Waste canisters (0.8 m in diameter by 3 m long)	1.9×10^2
Oil	0.7 m^3
Energy	
Electricity	3×10^6 kWh
Manpower	1.9×10^1 man-yr

The melting operation is expected to require six men per shift or 18 man-yr/yr (assuming three 8-hr shifts per day for operation and maintenance). In addition, about 1 man-yr/yr is required for radiation monitoring. Supervisory personnel are considered part of the total FRP overhead.

Process Effluents. The amounts of radioactive materials that reach the biosphere after leaving the fuel bundle residue melting facility and passing through the reference FRP-APS are shown in Table 5.2.3-11. The radionuclides listed are those that will contribute at least 1% to the total dose to any given organ from any pathway to man.

The radionuclides entrained in air are derived from process off-gas. No radioactive material will be released to the biosphere via liquid effluent streams.

TABLE 5.2.3-11. Radionuclides Released to the Biosphere from the Fuel Bundle Residue Melting Facility (Ci/yr)

Radionuclide	U Recycle, Pu in SHLW or PuO_2 Stored	U and Pu Recycle
^{3}H	1.3×10^{5}	1.3×10^{5}
^{14}C	1.1×10^{-10}	1.1×10^{-10}
^{60}Co	4.1×10^{-6}	4.1×10^{-6}
^{90}Sr	3.2×10^{-8}	3.1×10^{-8}
^{95}Zr	8.2×10^{-8}	8.2×10^{-8}
^{137}Cs	4.6×10^{-8}	4.6×10^{-8}
^{144}Ce	1.2×10^{-7}	1.2×10^{-7}
^{238}Pu	1.6×10^{-9}	2.8×10^{-9}
^{239}Pu	1.4×10^{-10}	1.8×10^{-10}
^{240}Pu	2.2×10^{-10}	3.6×10^{-10}
^{241}Pu	5.5×10^{-8}	9.0×10^{-8}
^{241}Am	1.8×10^{-10}	3.6×10^{-10}
^{242}Cm	1.8×10^{-9}	5.0×10^{-9}
^{244}Cm	6.0×10^{-10}	3.6×10^{-9}

The melting process produces a total of 1×10^{7} MJ of waste heat for 250 days of operation per year; this represents less than 1% of the total heat rejected by the FRP. The waste heat will be rejected through the FRP cooling tower. Assuming 250 days/yr operation of this facility and a heat generation rate of 500 kJ/sec, 720 m^3/yr of blowdown water at a Δt of 17°C will be released. The fuel bundle residue melting facility will be required to contribute about 5×10^{3} m^3/yr to the cooling tower makeup water. About 4×10^{3} m^3/yr of water will be lost to evaporation and drift.

About 1×10^{4} m^3 of argon and 3×10^{3} m^3 of helium are released to the atmosphere annually.

No nonradioactive effluents will be released to land.

Physical, Chemical, and Thermal Effects. Impacts on the atmosphere from waste heat rejected by the fuel bundle residue melting facility will be small (about 1%) when compared with impacts for the entire FRP. These impacts include fogging at the outfall or from the cooling tower, drift impact from the cooling tower, and heat island effects onsite.

There are no direct releases of nonradioactive liquid or solid wastes to land or to surface or groundwaters from the fuel bundle residue melting facility; therefore, no effects are expected. Rejection of heat and blowdown from the facility are not expected to have any significant effects on the environment.

Radiological Effects

Doses to individuals in the vicinity of the fuel bundle residue melting facility were calculated based on the releases of radionuclides listed in Table 5.2.3-11; exposure pathways, demography, and other parameters described for the reference environment (Appendix A); and mathematical models relating dose to man from radionuclide releases (Appendix B). For planned operation of the fuel bundle residue melting facility the only exposure pathway to man is via airborne effluents; there are no releases to ground or water.

The annual doses to individuals whose habits tend to maximize their dose ("maximum individual") are shown in Table 5.2.3-12. For comparison, the dose to an individual from naturally occurring radioactive sources averages about 0.1 rem/yr.

TABLE 5.2.3-12. Annual Doses to Maximum Individual from Gaseous Effluents Released by the Fuel Bundle Residue Melting Facility (rem)(a)

Pathway	Total Body	Thyroid (child)(b)	Thyroid(c)	Lung	Bone
		U Recycle, Pu in SHLW or PuO_2 Stored			
Air submersion	3.9×10^{-14}		3.9×10^{-14}	3.9×10^{-14}	3.9×10^{-14}
Inhalation	6.6×10^{-5}		6.6×10^{-5}	6.6×10^{-5}	1.5×10^{-12}
Ingestion	3.9×10^{-4}	2.2×10^{-4}	3.9×10^{-4}	3.9×10^{-4}	1.1×10^{-12}
Total	4.6×10^{-4}	2.2×10^{-4}	4.6×10^{-4}	4.6×10^{-4}	2.6×10^{-12}
		U and Pu Recycle			
Air submersion	3.9×10^{-14}		3.9×10^{-14}	3.9×10^{-14}	3.9×10^{-14}
Inhalation	6.6×10^{-5}		6.6×10^{-5}	6.6×10^{-5}	2.6×10^{-12}
Ingestion	3.9×10^{-4}	2.2×10^{-4}	3.9×10^{-4}	3.9×10^{-4}	1.1×10^{-12}
Total	4.6×10^{-4}	2.2×10^{-4}	4.6×10^{-4}	4.6×10^{-4}	3.7×10^{-12}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the highest annual average dispersion factor ($\bar{\chi}/Q'$) of 1.5×10^{-8} sec/m^3.

a. After 30 years of release and accumulation in the environment.
b. Thyroid dose is calculated for a 1-year-old child breathing air containing radioactive effluents and consuming 1 ℓ of milk per day from cows grazing 7 months/yr at the site boundary. Inhalation dose is <2% of total dose.
c. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

The combined dose (man-rem) from gaseous effluents to the population living within an 80-km radius of the plant was calculated using the projected year 2000 population data given in the reference environment. Table 5.2.3-13 summarizes the annual doses received by this population. The annual total-body population dose from naturally occurring sources to the approximately 2 million persons living within an 80-km radius of the plant in the year 2000 would be about 200,000 man-rem compared with the value of about 51 man-rem from process sources given in Table 5.2.3-13. The annual total-body dose to the work force associated with the melting facility was estimated based on permissible exposure limits and experience of operating

TABLE 5.2.3-13. Annual Doses to Population (within 80 km) from Gaseous Effluents Released by the Fuel Bundle Residue Melting Facility (man-rem)(a)

Pathway	Total Body	Thyroid	Lung	Bone
	U Recycle, Pu in SHLW or PuO_2 Stored			
Air submersion	9.1×10^{-9}	9.1×10^{-9}	9.1×10^{-9}	9.1×10^{-9}
Inhalation	1.5×10^{1}	1.5×10^{1}	1.5×10^{1}	3.5×10^{-7}
Ingestion	3.6×10^{1}	3.6×10^{1}	3.6×10^{1}	9.7×10^{-8}
Total	5.1×10^{1}	5.1×10^{1}	5.1×10^{1}	4.5×10^{-7}
	U and Pu Recycle			
Air submersion	9.1×10^{-9}	9.1×10^{-9}	9.1×10^{-9}	9.1×10^{-9}
Inhalation	1.5×10^{1}	1.5×10^{1}	1.5×10^{1}	6.2×10^{-7}
Ingestion	3.6×10^{1}	3.6×10^{1}	3.6×10^{1}	9.5×10^{-7}
Total	5.1×10^{1}	5.1×10^{1}	5.1×10^{1}	6.3×10^{-7}

a. After 30 years of release and accumulation in the environment.

plants. The annual occupational dose was calculated to be 50 man-rem. Table 5.2.3-14 summarizes the annual total-body dose to the work force and the general public from process and naturally occurring sources in the year 2000.

TABLE 5.2.3-14. Summary of Annual Total-Body Doses Received from Operation of the Fuel Bundle Residue Melting Facility and Naturally Occurring Sources in the Year 2000

	Man-rem
Fuel bundle residue melting facility	
Process work force (30 yr)	50
Population (within 80 km)	51
Naturally occurring sources	
Population (within 80 km)	200,000

The 70-year doses to the maximum individual and to the population within 80 km of the facility are given in Tables 5.2.3-15 and 5.2.3-16 respectively. A summary of the 70-year total-body doses to the work force and the population is given in Table 5.2.3-17. For comparison, the population dose from naturally occurring sources over the 70-year period amounts to about 14,000,000 man-rem compared with 1700 man-rem received from the reference facility.

Total-body dose to the worldwide population results from the annual release of 1.3×10^{5} Ci of ^{3}H and 1.1×10^{-10} Ci of ^{14}C. The dose for the 30th year of operation was calculated to be 8.9×10^{2} man-rem, and the 70-year accumulated dose from 30 years of plant operation was calculated to be 3.1×1.0^{-4} man-rem. The dose to this population from naturally occurring sources for these two periods would be about 6×10^{8} and 4×10^{10} man-rem respectively.

TABLE 5.2.3-15. 70-Year Doses to Maximum Individual from Gaseous Effluents Released by the Fuel Bundle Residue Melting Facility (rem)

Pathway	Total Body	Thyroid[a]	Lung	Bone
	U Recycle, Pu in SHLW or PuO_2 Stored			
Air submersion	1.2×10^{-12}	1.2×10^{-12}	1.2×10^{-12}	1.2×10^{-12}
Inhalation	2.0×10^{-3}	2.0×10^{-3}	2.0×10^{-3}	5.8×10^{-10}
Ingestion	1.2×10^{-2}	1.2×10^{-2}	1.2×10^{-2}	8.6×10^{-10}
Total	1.4×10^{-2}	1.4×10^{-2}	1.4×10^{-2}	1.4×10^{-9}
	U and Pu Recycle			
Air submersion	1.2×10^{-12}	1.2×10^{-12}	1.2×10^{-12}	1.2×10^{-12}
Inhalation	2.0×10^{-3}	2.0×10^{-3}	2.0×10^{-3}	1.1×10^{-9}
Ingestion	1.2×10^{-2}	1.2×10^{-2}	1.2×10^{-2}	8.4×10^{-10}
Total	1.4×10^{-2}	1.4×10^{-2}	1.4×10^{-2}	1.9×10^{-9}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the highest annual average dispersion factor ($\bar{\chi}/Q'$) of 1.5×10^{-8} sec/m^3.

a. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

TABLE 5.2.3-16. 70-Year Doses to Population (within 80 km) from Gaseous Effluents Released by the Fuel Bundle Residue Melting Facility (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
	U Recycle, Pu in SHLW or PuO_2 Stored			
Air submersion	2.7×10^{-7}	2.7×10^{-7}	2.7×10^{-7}	2.7×10^{-7}
Inhalation	4.6×10^{2}	4.6×10^{2}	4.6×10^{2}	1.4×10^{-4}
Ingestion	1.2×10^{3}	1.2×10^{3}	1.2×10^{3}	7.6×10^{-5}
Total	1.7×10^{3}	1.7×10^{3}	1.7×10^{3}	2.2×10^{-4}
	U and Pu Recycle			
Air submersion	2.7×10^{-7}	2.7×10^{-7}	2.7×10^{-7}	2.7×10^{-7}
Inhalation	4.6×10^{2}	4.6×10^{2}	4.6×10^{2}	2.6×10^{-4}
Ingestion	1.2×10^{3}	1.2×10^{3}	1.2×10^{3}	7.4×10^{-5}
Total	1.7×10^{3}	1.7×10^{3}	1.7×10^{3}	3.3×10^{-4}

TABLE 5.2.3-17. Summary of 70-Year Total-Body Doses Received from Operation of the Fuel Bundle Residue Melting Facility and Naturally Occurring Sources in the Year 2000

	Man-rem
Fuel bundle residue melting facility	
Process work force (30 yr)	1,500
Population (within 80 km)	1,700
Naturally occurring sources	
Population (within 80 km)	14,000,000

"Health effects" for the regional population are discussed at the plant level where several processes within the plant are combined. In general, doses at the individual process level are too small for a meaningful discussion of health effects. In this report, 100 to 800 health effects are postulated to occur in the exposed population per million man-rem.

Ecological Effects. Ecological effects of routine operation of the fuel bundle residue melting facility are expected to be of little consequence. With the exception of argon and helium, there are no environmental releases of nonradioactive gases during routine operation. Argon and helium will be used at the rate of 19 MT and 0.5 MT, respectively, and will be exhausted to the atmosphere via the FRP-APS. Release of these gases will not present an environmental problem.

Calcium fluoride will be used in the facility at the rate of 3200 kg/yr. None of this material will be released to the environment during normal facility operation. An approximate 60-day supply of calcium fluoride will be stored at the facility, and five to six truck or rail shipments to the plant will be required annually. Fluorides are toxic to terrestrial and aquatic plants and animals at concentrations of 1 to 2 ppm;[3] however, because calcium fluoride has a low solubility (less than 0.2%) in water, its accidental release to the environment during transport to or storage at the plant does not present an ecological hazard.

The fuel bundle residue melting facility uses about 5×10^3 m^3/day of water in a closed circuit cooling system. Heat will be removed from this cooling water in the FRP cooling towers; about 2% of the cooling water volume will be lost through evaporation and tower blowdown. Makeup water requirements for the facility cooling system will be about 19 m^3/day. This volume of water can easily be supplied from either groundwater or from the R River near the reference site without affecting the environment. The melting facility will contribute about 2.9 m^3/day to FRP tower blowdown, which will be released to the environment at an average Δt of 17°C. This minor release of heat will have no measurable effect on the nearby terrestrial or aquatic ecosystems.

The only other liquid waste to be released from the facility is 57 ℓ/month of vacuum pump oil. Procedures would be required to ensure that disposal of this oil in the environment will produce no adverse effects.

No ecological impacts from noise or human disturbance beyond those associated with the FRP will result from operation of the melting facility.

Environmental Effects Related to Postulated Accidents. One minor accident associated with the fuel bundle residue melting facility was identified which would be expected to lead to releases of radioactive material. (This accident and its consequences are the same as those described for compaction treatment in Section 5.2.3.1.) The scenario for this accident is provided in DOE/ET-0028[2] and the accident is listed below:

Accident Number	Description
4.2.2	Zirconium fines fire

Based on the anticipated releases of this minor accident weighted by its expected frequency of occurrence, an average annual release from burning 2 kg of zirconium is postulated. The estimated quantities of radionuclides released to the atmosphere are presented in Table 5.2.3-18.

TABLE 5.2.3-18. Releases of Radionuclides to the Atmosphere from a Minor Accident in the Fuel Bundle Residue Melting Facility (Ci)

Radionuclide	U Recycle, Pu in SHLW or PuO_2 Stored	U and Pu Recycle
^{3}H	4.8×10^{-1}	4.8×10^{-1}
^{14}C	4.6×10^{-7}	4.6×10^{-7}
^{60}Co	7.6×10^{-8}	7.6×10^{-8}
^{90}Sr	2.5×10^{-8}	2.3×10^{-8}
^{95}Zr	6.2×10^{-8}	6.2×10^{-8}
^{106}Ru	6.5×10^{-8}	7.2×10^{-8}
^{134}Cs	4.6×10^{-8}	4.6×10^{-8}
^{137}Cs	3.5×10^{-8}	3.5×10^{-8}
^{144}Ce	9.5×10^{-8}	9.1×10^{-8}
^{238}Pu	1.2×10^{-9}	2.1×10^{-9}
^{239}Pu	1.1×10^{-10}	1.4×10^{-10}
^{240}Pu	1.7×10^{-10}	2.8×10^{-10}
^{241}Pu	4.2×10^{-8}	6.8×10^{-8}
^{241}Am	1.4×10^{-10}	2.7×10^{-10}
^{242}Cm	1.3×10^{-9}	3.8×10^{-9}
^{244}Cm	4.6×10^{-10}	2.7×10^{-9}

Annual doses were calculated for these releases for the maximum individual and the regional population. Seventy-year dose commitments for each group were also calculated using average dispersion factors. In no case was the resulting dose greater than 1.6×10^{-9} rem for any individual dose and most often was several orders of magnitude less. As a consequence, doses from these accidents were considered to not constitute a radiological effect. Although insignificant, the dose from this accident resulted in a total-body dose to the maximum individual of about 1.6×10^{-9} rem/yr, which is about 300 times larger than the corresponding dose from routine releases.

No accidents thought to involve larger releases of radioactive material were identified. No non-design basis accidents were considered.

Materials released by plausible accidents, such as fire resulting from ignition of zirconium fines in the grizzly or failure of the water cooling jacket around the crucible, would be contained within the furnace cell and reduced to acceptable concentrations by the FRP-APS before discharge to the environment. No adverse ecological impacts are expected from these kinds of accidents.

5.2.3.3 Packaging Without Compaction (DOE/ET-0028 Sec. 4.2.1)

Packaging without compaction is a treatment concept in which the fuel bundle residue is monitored for residual fuel, dried, and sealed without compaction in stainless steel canisters for shipment to interim storage or to a repository. Sand is placed in the canisters to fill the void spaces and reduce the possibility of ignition of Zircaloy fines in the fuel residue. Past commercial practice has been to simply bury the drums containing the residue. Alternatives within the packaging without compaction concept provide variations in methods used to deactivate the fines before packaging. The concept selected here represents a simple approach to the packaging of the fuel residue.

The flow diagram for fuel bundle residue packaging without compaction, Figure 5.2.3-5, shows the steps involved in the process. The process is an integral part of fuel dissolution at the FRP. The daily process capacity is about 2.6 m^3 of uncompacted fuel residue, which corresponds to the daily output of the reference 2000-MTHM/yr FRP.

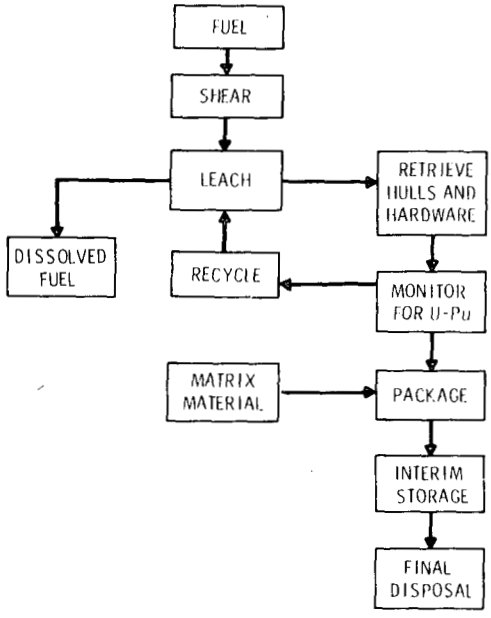

FIGURE 5.2.3-5. Flow Diagram for Fuel Bundle Residue Packaging Without Compaction

The facility for packaging without compaction is controlled and operated from an operating gallery located behind concrete shielding walls fitted with shielding windows and manipulators.

Environmental Effects Related to Facility Construction. Some of the factors relating to site preparation and reference facility construction may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of construction activities.

Resource Commitments. The facility for fuel bundle residue packaging without compaction will be located in the main process building of the FRP and will require an area of about 540 m^2. This land requirement would have little effect on the size of the overall main process building and consequently on the area committed for the FRP. A separate analysis of land use attributable to this facility is therefore not meaningful.

Materials committed for construction of the fuel bundle residue packaging without compaction facility are:

Water	4400 m^3
Steel	590 MT
Copper	5.0 MT
Zinc	1 MT
Concrete	2000 m^3
Lumber	140 m^3

Energy resources committed for construction are:

Propane	42 m^3
Diesel fuel	341 m^3
Gasoline	250 m^3
Electricity	
Peak demand	270 kW
Total consumption	180,000 kWh

The schedule for engineering, procurement, and construction of the facility is included in the overall schedule for the FRP.

The field work force required for the construction of the facility is estimated at 150 man-yr.

No special requirements or limitations for siting or construction appear warranted.

Physical and Chemical Effects. Effects on air quality, water quality, and land use from construction of the packaging facility will be an indistinguishable portion of the effects of construction of the FRP (Section 5.1.2).

Ecological Effects. The ecological effects of the construction of the fuel bundle residue packaging without compaction facility will be indistinguishable from the FRP, of which it is an integral part. The land occupied by the facility will be less the 0.3% of the 40 ha within the secured area of the FRP. Destruction and modification of vegetation and displacement of animals because of noise, dust, excavation, and other construction impacts will not exceed those for the overall FRP complex. No roads, railroads, or power transmission lines in addition to those needed for the FRP will be required.

Water used during the construction period is small, about 4×10^3 m^3. Although no construction time is specified, if one assumes an 18-month construction period, the average daily water use will be about 73 m^3/day, or less than 0.001% of the average flow of the R River. Removal of this fraction of the river flow will not adversely affect the river biota. However, because of the small amount of water required, it will likely be obtained from onsite wells.

Environmental Effects Related to Planned Operation. Some of the factors relating to facility operation may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of operation.

Resource Commitments. Commitment of resources during operation will include argon for the welding operation, helium to flush the storage canisters, sand as inert material to reduce the phyrophoric hazard of fines, stainless steel casks and canisters to store the residues, and miscellaneous equipment items needing periodic replacement.

Resources required during planned operation of the fuel bundle residue packaging without compaction facility, assuming two 8-hr shifts per day 5 days/week, are listed below.

Argon	7×10^3 m^3
Helium	7×10^2 m^3
Sand	650 MT
Waste canisters (0.8 m in diameter by 3 m long)	480
Electricity	25,000 kWh
Manpower	8.0 man-yr

Electricity will be needed to operate various motors and the welding equipment. The use of energy for space ventilation, heating, and air conditioning is included in the total use of the main process building.

Operation and maintenance of the packaging without compaction facility is expected to require 6 man-yr/yr, assuming two shifts per day. In addition, about 1.0 man-yr/yr of radiation monitoring and 1.0 man-yr/yr of maintenance will be required. Supervisory personnel are considered part of the FRP overhead.

Process Effluents. The amounts of radioactive materials that reach the biosphere after leaving the packaging facility and passing through the FRP-APS are shown in Table 5.2.3-19. The radionuclides listed are those that will contribute at least 1% to the total dose for a given organ from any pathway or that are otherwise of interest.

The radionuclides entrained in air are derived from process ventilation. No radioactive material will be released to the biosphere via liquid effluent streams.

About 12 MT of argon and 0.1 MT of helium will be released annually via the FRP stack.

Physical, Chemical, and Thermal Effects. The operation of this facility will produce no significant air quality effects. The release of 12 MT/yr of argon compares with 6×10^4 MT/yr of naturally occurring argon in air passed through the FRP. Similarly, 0.1 MT/yr of helium compares with 3.5 MT/yr released with air.

TABLE 5.2.3-19. Radionuclides Released to the Biosphere from the Fuel Bundle Residue Packaging Without Compaction Facility (Ci/yr)

Radionuclide	U Recycle, Pu in SHLW or PuO_2 Stored	U and Pu Recycle
^{3}H	6.3×10^{-8}	6.3×10^{-8}
^{14}C	1.1×10^{-10}	1.1×10^{-10}
^{54}Mn	2.0×10^{-7}	2.0×10^{-7}
^{55}Fe	4.1×10^{-6}	4.1×10^{-6}
^{60}Co	4.1×10^{-6}	4.1×10^{-6}
^{63}Ni	4.0×10^{-7}	4.0×10^{-7}
^{90}Sr	3.2×10^{-8}	3.1×10^{-8}
^{95}Nb	2.0×10^{-7}	2.0×10^{-7}
^{95}Zr	8.2×10^{-8}	8.2×10^{-8}
^{106}Ru	8.5×10^{-8}	9.5×10^{-8}
^{125m}Te	1.1×10^{-8}	1.1×10^{-8}
^{134}Cs	6.0×10^{-8}	6.0×10^{-8}
^{137}Cs	4.6×10^{-8}	4.6×10^{-8}
^{144}Ce	1.2×10^{-7}	1.2×10^{-7}
^{238}Pu	1.6×10^{-9}	2.8×10^{-9}
^{239}Pu	1.4×10^{-10}	1.8×10^{-10}
^{240}Pu	2.2×10^{-10}	3.6×10^{-10}
^{241}Pu	5.5×10^{-8}	9.0×10^{-8}
^{241}Am	1.8×10^{-10}	3.6×10^{-10}
^{242}Cm	1.8×10^{-9}	5.0×10^{-9}
^{244}Cm	6.0×10^{-10}	3.6×10^{-9}

No nonradioactive liquid or solid wastes are released directly to surface or ground waters from the fuel bundle residue packaging without compaction facility. All liquid and solid waste disposal for the facility is part of the overall FRP operation.

The packaging facility does not require water for cooling purposes and therefore does not contribute heat to the FRP cooling tower.

Radiological Effects. Doses to individuals in the vicinity of the fuel bundle residue packaging without compaction facility were calculated based on the releases of radionuclides listed in Table 5.2.3-19; exposure pathways, demography, and other parameters described for the

reference environment (Appendix A); and mathematical models relating dose to man from radionuclide releases (Appendix B). For planned operation of the packaging facility, the only exposure pathway to man is via airborne effluents; there are no releases to ground or water.

The annual doses to individuals whose habits tend to maximize their dose ("maximum individual") are shown in Table 5.2.3-20. For comparison, the dose to an individual from naturally occurring radioactive sources averages about 0.1 rem/yr.

TABLE 5.2.3-20. Annual Doses to Maximum Individual from Gaseous Effluents Released by the Fuel Bundle Residue Packaging Without Compaction Facility (rem)[a]

Pathway	Total Body	Thyroid (child)[b]	Thyroid[c]	Lung	Bone
	U Recycle, Pu in SHLW or PuO_2 Stored				
Air submersion	3.9×10^{-14}	3.9×10^{-14}	3.9×10^{-14}	3.9×10^{-14}	3.9×10^{-14}
Inhalation	2.4×10^{-13}		1.9×10^{-14}	2.4×10^{-10}	1.1×10^{-12}
Ingestion	5.7×10^{-13}	1.3×10^{-16}	4.0×10^{-16}	2.4×10^{-14}	1.1×10^{-12}
Total	8.5×10^{-13}	3.9×10^{-14}	5.8×10^{-14}	2.4×10^{-10}	2.2×10^{-12}
	U and Pu Recycle				
Air submersion	3.9×10^{-14}	3.9×10^{-14}	3.9×10^{-14}	3.9×10^{-14}	3.9×10^{-14}
Inhalation	3.0×10^{-13}		1.9×10^{-14}	2.7×10^{-10}	2.6×10^{-12}
Ingestion	5.6×10^{-13}	1.3×10^{-16}	4.0×10^{-16}	2.3×10^{-14}	1.1×10^{-12}
Total	8.6×10^{-13}	3.9×10^{-14}	5.8×10^{-14}	2.7×10^{-10}	3.7×10^{-12}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 1.5×10^{-8} sec/m^3.

a. After 30 years of release and accumulation in the environment.
b. Thyroid dose is calculated for a 1-year-old child breathing air containing radioactive effluents and consuming 1 ℓ of milk per day from cows grazing 7 months/yr at the site boundary. Inhalation dose is <2% of total dose.
c. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

The combined dose from gaseous effluents to the population living within an 80-km radius of the plant was calculated using the projected year 2000 population data given in the reference environment. Table 5.2.3-21 summarizes the annual doses received by this population. The annual total-body population dose from naturally occurring sources to the approximately 2 million persons living within an 80-km radius of the plant in the year 2000 would be about 200,000 man-rem compared with the value of about 1.1×10^{-7} man-rem from process sources given in Table 5.2.3-21.

The annual total-body dose to the work force associated with the packaging facility was estimated based on permissible exposure limits and experience of operating plants. The annual occupational dose was calculated to be 15 man-rem. Table 5.2.3-22 summarizes the annual total-body dose to the work force and the general population from process and naturally occurring sources in the year 2000.

The 70-year doses to the maximum individual and to the population within 80 km of the facility are given in Tables 5.2.3-23 and 5.2.3-24 respectively. A summary of the 70-year

total body doses to the work force and the population is given in Table 5.2.3-25. For comparison, the population dose from naturally occurring sources is also given for the year 2000 and amounts to about 14,000,000 man-rem compared with 3.5×10^{-5} man-rem received from the packaging facility.

TABLE 5.2.3-21. Annual Doses to Population (within 80 km) from Gaseous Effluents Released by the Fuel Bundle Residue Packaging Without Compaction Facility (man-rem)(a)

Pathway	Total Body	Thyroid	Lung	Bone
	U Recycle, Pu in SHLW or PuO_2 Stored			
Air submersion	9.1×10^{-9}	9.1×10^{-9}	9.1×10^{-9}	9.1×10^{-9}
Inhalation	5.6×10^{-8}	4.4×10^{-9}	6.2×10^{-5}	3.5×10^{-7}
Ingestion	5.4×10^{-8}	4.0×10^{-11}	2.5×10^{-9}	1.0×10^{-7}
Total	1.1×10^{-7}	1.4×10^{-8}	6.2×10^{-5}	4.5×10^{-7}
	U and Pu Recycle			
Air submersion	9.1×10^{-9}	9.1×10^{-9}	9.1×10^{-9}	9.1×10^{-9}
Inhalation	7.0×10^{-8}	4.4×10^{-9}	6.3×10^{-5}	6.2×10^{-7}
Ingestion	5.4×10^{-8}	4.0×10^{-11}	2.5×10^{-9}	1.0×10^{-7}
Total	1.2×10^{-7}	1.4×10^{-8}	6.3×10^{-5}	7.2×10^{-7}

a. After 30 years of release and accumulation in the environment.

TABLE 5.2.3-22. Summary of Annual Total-Body Doses Received from Operation of the Fuel Bundle Residue Packaging Without Compaction Facility and Naturally Occurring Sources in the Year 2000

	Man-rem
Fuel bundle residue packaging without compaction facility	
Process work force (30 yr)	15
Population (within 80 km)	<0.001
Naturally occurring sources	
Population (within 80 km)	200,000

Total-body dose to the worldwide population results from the annual release of 6.3×10^{-8} Ci of ^{3}H and 1.1×10^{-10} Ci of ^{14}C. The dose for the 30th year of operation was calculated to be 8.4×10^{-9} man-rem, and the 70-year accumulated dose from 30 years of plant operation was calculated to be 4.5×10^{-7} man-rem. The dose to this population from naturally occurring sources for these two periods would be about 6×10^{8} and 4×10^{10} man-rem respectively.

"Health effects" are discussed at the plant level where several processes within the plant are combined. In general, doses at the individual process level are too small for a meaningful discussion of health effects. In this report, 100 to 800 health effects are postulated to occur in the exposed population per million man-rem.

TABLE 5.2.3-23. 70-Year Doses to Maximum Individual from Gaseous Effluents Released by the Fuel Bundle Residue Packaging Without Compaction Facility (rem)

Pathway	Total Body	Thyroid[a]	Lung	Bone
	U Recycle, Pu in SHLW or PuO_2 Stored			
Air submersion	1.2×10^{-12}	1.2×10^{-12}	1.2×10^{-12}	1.2×10^{-12}
Inhalation	4.1×10^{-11}	5.7×10^{-13}	1.5×10^{-9}	5.8×10^{-10}
Ingestion	2.1×10^{-10}	1.3×10^{-14}	2.3×10^{-12}	8.7×10^{-10}
Total	2.5×10^{-10}	1.8×10^{-12}	1.5×10^{-9}	1.5×10^{-9}
	U and Pu Recycle			
Air submersion	1.2×10^{-12}	1.2×10^{-12}	1.2×10^{-12}	1.2×10^{-12}
Inhalation	6.7×10^{-11}	5.7×10^{-13}	1.8×10^{-9}	1.1×10^{-9}
Ingestion	2.1×10^{-10}	1.3×10^{-14}	2.3×10^{-12}	8.4×10^{-10}
Total	2.8×10^{-10}	1.8×10^{-12}	1.8×10^{-9}	1.9×10^{-9}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 1.5×10^{-8} sec/m^3.

a. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

TABLE 5.2.3-24. 70-Year Doses to Population (within 80 km) from Gaseous Effluents Released by the Fuel Bundle Residue Packaging Without Compaction Facility (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
	U Recycle, Pu in SHLW or PuO_2 Stored			
Air submersion	2.7×10^{-7}	2.7×10^{-7}	2.7×10^{-7}	2.7×10^{-7}
Inhalation	9.5×10^{-6}	1.3×10^{-7}	3.6×10^{-4}	1.4×10^{-4}
Ingestion	1.9×10^{-5}	1.3×10^{-9}	2.5×10^{-7}	7.7×10^{-5}
Total	2.9×10^{-5}	4.0×10^{-7}	3.6×10^{-4}	2.2×10^{-4}
	U and Pu Recycle			
Air submersion	2.7×10^{-7}	2.7×10^{-7}	2.7×10^{-7}	2.7×10^{-7}
Inhalation	1.6×10^{-5}	1.3×10^{-7}	4.3×10^{-4}	2.6×10^{-4}
Ingestion	1.9×10^{-5}	1.3×10^{-9}	2.5×10^{-5}	7.5×10^{-5}
Total	3.5×10^{-5}	4.0×10^{-7}	4.6×10^{-4}	3.4×10^{-4}

Ecological Effects. Routine operation of the fuel bundle residue packaging without compaction facility will release little or no heat, chemicals, or liquid effluents to the environment. The inert gases argon and helium will be released to the environment at rates of 12 MT/yr and 0.1 MT/yr, respectively, via the FRP ventilation system. No ecological impacts will result from these discharges.

Noise and human activity at the facility will be small relative to that of the overall FRP complex, of which it is a part, and will produce no ecological impacts.

TABLE 5.2.3-25. Summary of 70-Year Total-Body Doses Received from Operation of the Fuel Bundle Residue Packaging Without Compaction Facility and Naturally Occurring Sources in the Year 2000

	Man-rem
Fuel bundle residue packaging without compaction facility	
Process work force (30 hr)	450
Population (within 80 km)	<0.001
Naturally occurring sources	
Population (within 80 km)	14,000,000

A small amount of heat will be released by the environment via the FRP ventilation system. No environmental effects will result from this release. Approximately 1×10^3 m^3/yr process water will be required for facility operation.

No ecological impacts will be produced by operation of this facility.

Environmental Effects Related to Postulated Accidents. One minor accident associated with fuel bundle residue packaging was identified that would be expected to lead to releases of radioactive material. (This accident and its consequences are the same as those described for compaction treatment in Section 5.2.3.1.) The scenario for this accident is provided in DOE/ET-0028.[2] The accident is listed below.

Accident Number	Description
4.2.3	Zirconium fines fire

Based on the anticipated releases of this minor accident weighted by the expected frequency of occurrence, an average annual burning of 2 kg of zirconium fines was postulated. The estimated quantities of radionuclides released to the atmosphere are presented in Table 5.2.3-26.

An annual dose was calculated for the maximum individual and the regional population. Seventy-year dose commitments were also calculated for these classes. In no case were the resulting maximum individual doses greater than 1.8×10^{-11} rem/yr and most often were several orders of magnitude less. As a consequence, doses from these accidents were considered to not constitute a radiological effect. Although insignificant, the dose from this accident resulted in a total-body dose to the maximum individual of about 1.6×10^{-9} rem/yr, which is about 300 times larger than the corresponding dose from routine releases.

There were no accidents thought to release radioactive materials from the facility in amounts larger than those released by the postulated minor accident. Non-design basis accidents were not considered.

Combustion of zirconium fines is the most plausible accident associated with the operation of the packaging facility. However, potentially toxic or hazardous materials released by such an event will be contained within the facility structure and no release of ecologically important pollutants is expected.

TABLE 5.2.3-26. Radionuclides Released to the Atmosphere from Failure of the Fuel Bundle Residue Packaging Without Compaction Facility (Ci)

Radionuclide	U Recycle, Pu in SHLW or PuO_2 Stored	U and Pu Recycle
^{3}H	4.8×10^{-1}	4.8×10^{-1}
^{14}C	8.4×10^{-7}	8.4×10^{-7}
^{54}Mn	1.5×10^{-7}	1.5×10^{-7}
^{60}Co	3.1×10^{-6}	3.1×10^{-6}
^{63}Ni	3.1×10^{-7}	3.1×10^{-7}
^{90}Sr	2.5×10^{-8}	2.3×10^{-8}
^{95}Zr	6.2×10^{-8}	6.2×10^{-8}
^{95}Nb	1.6×10^{-7}	1.6×10^{-7}
^{137}Cs	3.5×10^{-8}	3.5×10^{-8}
^{144}Ce	9.5×10^{-8}	9.1×10^{-8}
^{238}Pu	1.2×10^{-9}	2.1×10^{-9}
^{239}Pu	1.1×10^{-10}	1.4×10^{-10}
^{240}Pu	1.7×10^{-10}	2.8×10^{-10}
^{241}Pu	4.2×10^{-8}	6.8×10^{-8}
^{241}Am	1.4×10^{-10}	2.7×10^{-10}
^{242}Cm	1.3×10^{-9}	3.8×10^{-9}
^{244}Cm	4.6×10^{-10}	2.7×10^{-9}

5.2.3.4 Comparison of Environmental Effects Among Fuel Residue Treatment Alternatives

Selected aspects of construction and operation of the fuel residue treatment alternatives (compaction, melting, and packaging without treatment) are presented in Tables 5.2.3-27 through 5.2.3-29.

In terms of construction resource commitments there is little on which to base a preference. Compaction facilities do not require significantly more of any resource than does packaging without treatment. Fuel residue melting requires about twice the amount of water and half again as much electricity and gasoline as packaging without treatment. However, the total quantities are not large enough to justify a preference based on these differences.

The packaging without treatment option generally results in the smallest commitment of resources and release of nonradioactive effluents. An exception is in the number of containers required. Melting requires about 40% of the number of containers and compaction requires about 60% as many containers as packaging without compaction. This point may be an important consideration because the number of containers will in part govern the number of shipments required to transport fuel residues to a repository and the amount of space required in a repository.

TABLE 5.2.3-27. Comparison of Resource Commitments for Construction of Alternative Facilities for Fuel Residue Treatment at the FRP

Resource	Compaction	Melting	Packaging Without Compaction
Land, m^2	450	580	540
Water, m^3	4,400	8,400	4,400
Materials			
Steel, MT	620	580	590
Copper, MT	5	15	5.0
Zinc	0.5	0.9	1.0
Lumber, m^3	142	142	142
Concrete, m^3	2,300	2,200	2,000
Energy			
Propane, m^3	42	60	42
Diesel fuel, m^3	420	720	340
Gasoline, m^3	290	360	250
Electricity, kWh	210,000	280,000	180,000
Manpower, man-hr	349,000	480,000	299,000

TABLE 5.2.3-28. Comparison of Nonradiological Aspects of Operating the Alternative Fuel Residue Treatment Facilities

	Compaction	Melting	Packaging Without Compaction
Resource			
Argon, m^3	40,000	10,000	7,000
Helium, m^3	4,000	3,000	700
Cooling water, m^3 (cooling tower makeup)	590	4,800	0
Process water, m^3	10	10	10
Stainless steel, MT	112	73	112
Sand, MT	0	0	650
Waste containers (0.8 m diameter x 3 m long)	280	193	480
Calcium fluoride	0	3.2	0
Electricity, kWh	312,000	3,000,000	25,000
Manpower, man-yr/yr	17	19	8
Nonradioactive Effluents			
Argon, m^3	40,000	10,000	7,000
Helium	4,000	3,000	700
Cooling tower, m^3			
Blowdown (Δt 17°C)	86	720	0
Drift	2.4	20	0
Waste heat, GJ	1,200	10,000	0

TABLE 5.2.3-29. Comparison of Radiological Aspects of Operating the Alternative Fuel Residue Treatment Facilities

	Compaction	Melting	Packaging Without Compaction
Principal Radionuclides Released to the Atmosphere, Ci/yr			
^{3}H	6.3×10^{-8}	1.3×10^{5}	6.3×10^{-8}
^{14}C	1.1×10^{-10}	1.1×10^{-10}	1.1×10^{-10}
^{60}Co	4.1×10^{-6}	4.1×10^{-6}	4.1×10^{-6}
^{90}Sr	3.1×10^{-8}	3.1×10^{-8}	3.1×10^{-8}
^{137}Cs	4.6×10^{-8}	4.6×10^{-8}	4.6×10^{-8}
^{238}Pu	2.8×10^{-9}	2.8×10^{-9}	2.8×10^{-9}
^{239}Pu	1.8×10^{-10}	1.8×10^{-10}	1.8×10^{-10}
^{242}Cm	3.6×10^{-9}	3.6×10^{-9}	3.6×10^{-9}
Dose to Maximum Individual with a 70-year Residence, rem			
Total body	2.8×10^{-10}	1.4×10^{-2}	2.8×10^{-10}
Thyroid	1.8×10^{-12}	1.4×10^{-2}	1.8×10^{-12}
Lung	1.8×10^{-9}	1.4×10^{-2}	1.8×10^{-9}
Bone	1.9×10^{-9}	1.9×10^{-9}	1.9×10^{-9}
(Dose from naturally occurring sources for same period, 7 rem)			
Dose to Regional Population (2,000,000 persons) with a 70-Year Residency, man-rem			
Total body	3.5×10^{-5}	1.7×10^{3}	3.5×10^{-5}
Thyroid	4.0×10^{-7}	1.7×10^{3}	4.0×10^{-7}
Lung	4.3×10^{-4}	1.7×10^{3}	4.6×10^{-4}
Bone	3.4×10^{-4}	3.3×10^{-4}	3.4×10^{-4}
(Dose from naturally occurring sources for same period, $\sim 1.4 \times 10^{7}$ man-rem)			
70-Year Accumulated Dose to Worldwide Population (6×10^{9} persons), man-rem			
Total body	4.5×10^{-7}	3.1×10^{4}	4.5×10^{-7}
(Dose from naturally occurring sources for same period, $\sim 4 \times 10^{10}$ man-rem)			
Dose to Process Work Force (30-year plant life), man-rem			
Total body	600	1,500	450

Note: Accidental doses were negligible for all options. No significant differences were noted between fuel reprocessing options.

Except for ^{3}H, radionuclide releases during routine operation are the same for the different treatment options. About 1.3×10^{5} Ci of ^{3}H is released annually from the melting process in contrast to about 1.3×10^{-4} Ci ^{3}H released from the other two processes. Doses for both compaction and packaging without compaction are negligible. The dose from routine releases of the melting process would amount to about 2×10^{-4} rem/yr to the total body. The nominal total-body dose from naturally occurring sources amounts to about 1×10^{-1} rem/yr. Minor accidents for fuel residue treatment were covered by the same umbrella accident that precludes using these accidents as a basis for choice of option.

It is concluded, therefore, that the additional transportation and disposal requirements associated with the option of packaging fuel residues without treatment will present no significant environmental impacts.

REFERENCES FOR SECTION 5.2.3

1. Alternatives for Managing Wastes from Reactors and Post-Fission Operations in the LWR Fuel Cycle, ERDA-73-43, Energy Research and Development Administration, Washington, DC, May 1976.

2. Technology for Commercial Radioactive Waste Management, DOE/ET-0028, Department of Energy, Washington, DC, in press.

3. Water Quality Criteria, 1972, EPA.R3-73.033, Environmental Protection Agency, Washington, DC, March 1973.

5.2.4 Degraded Solvent Incineration (DOE/ET-0028 Sec. 4.5)

Incineration is the primary method of disposal of degraded waste solvent [typically 30% tributyl phosphate (TBP) in kerosene] where direct storage, calcination, or solidification of organics is not selected. Incineration alternatives include open pan or quiescent burning, combination of quiescent and off-gas burning, and direct solvent feed to a forced-convection incinerator. Quiescent burning provides good retention of radionuclides and residues in the pans (which may be collected in a concentrated form for disposal) while the forced-convection incineration method uses a tower and combustion chamber off-gas treatment system for capture of radionuclides and other possibly noxious pollutants. Forced-convection incineration is in common use in industry and is selected as the reference process for solvent disposal at the reference FRP.

Tributyl phosphate is usually diluted with 50 to 70% kerosene or other normal paraffin hydrocarbon. Waste combustion is facilitated and controlled by auxiliary fuel burners that use propane or natural gas and by combustion air. The solvent is atomized into the combustion chamber and incinerated at 840°C. Dilutent air is introduced at the exhaust port of the combustion chambers, and the temperature of the combustion gases is reduced to below 600°C. Combustion products of carbon dioxide, water vapor, nitrogen, unreacted oxygen, P_2O_5 aerosol from the TBP, and small amounts of particulate and volatilized contaminants are flushed through a quench tower to reduce gas temperatures and to scrub the majority of the contaminants from the gas. Off-gases from the quench tower (65°C) pass through a mist eliminator and finally to the scrubbers, absorbers, and filters.

Other available alternatives include injection into the calciner waste treatment system, purification by chemical washing or ion exchange, and immobilization by solidification. The use of these processes requires more complex and multiple use adaptations of other systems and may not become cost effective unless the annual solvent disposal volume is small.

5.2.4.1 Solvent Incineration Facility Description (DOE/ET-0028 Sec 4.5.1)

The solvent incineration facility will be located within the intermediate-level cell in the reference FRP main process building and will occupy approximately 650 m^2. Operation of the solvent incinerator will be intermittent. Degraded solvent will be batch stored in a feed tank until an inventory of approximately 12 m^3 is reached. At the start of combustion, the burner feed rate will be about 0.3 m^3 per 24 hr. The solvent incinerator is expected to be in operation for about 55 days per year and to dispose of 16 m^3 of solvent compatible with the 2000-MTHM/yr FRP. In addition to full-time automatic system monitoring, about 25% of one operator's time will be required to monitor system operation. Construction of the facility will likely coincide with construction of the reference FRP.

The degraded solvent combustion system will consist of a 0.9-m^3 degraded solvent stripping tank, a 16-m^3 degraded solvent storage and feed tank, feed pump, solvent incinerator, and quench tower. Figure 5.2.4-1 is a flow diagram of the process system. The facility will share ventilation systems, water supply, and utilities and services of the FRP. Water use is primarily associated with the operation of the quench tower. The bottom of this vessel contains about 0.18 m^3 of aqueous scrubber solution. The scrubber solution is continuously bled off to

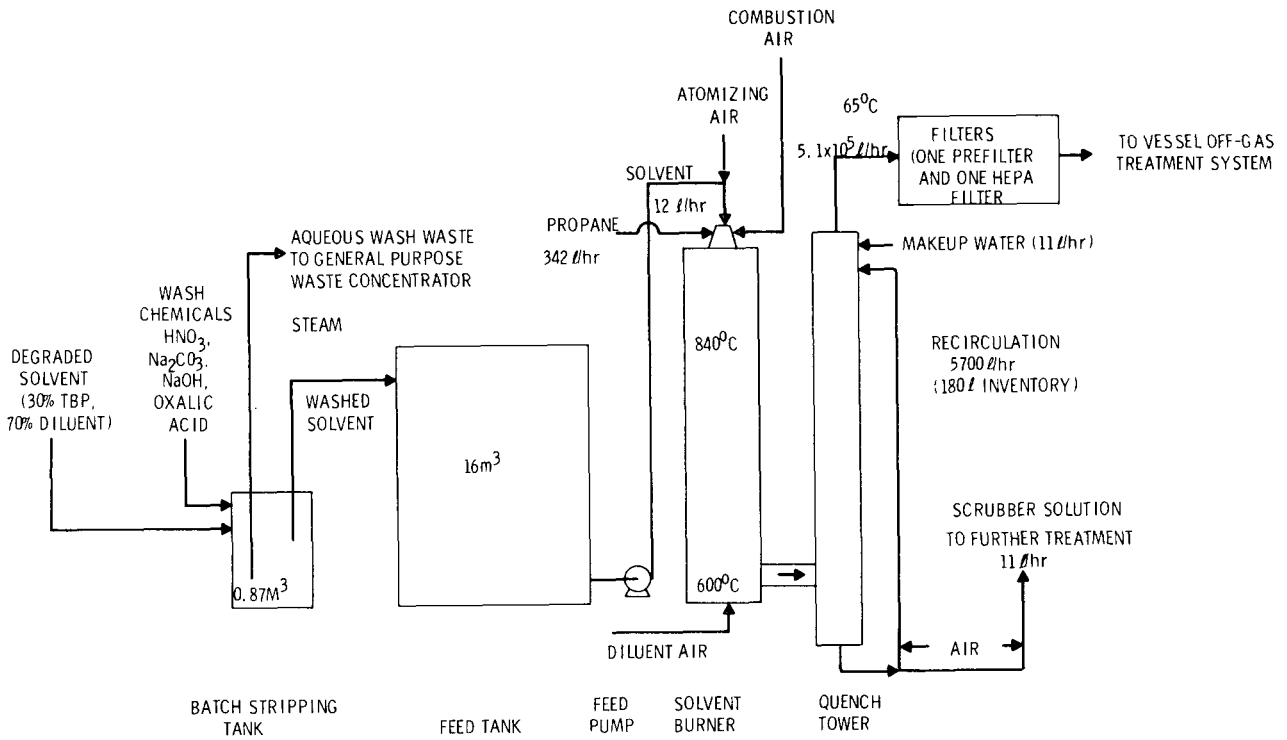

FIGURE 5.2.4-1. Solvent Incineration System Flowsheet

the FRP liquid concentrator. Dilutent makeup water is added at a rate of about 0.2 ℓ/min. About 15 m^3/yr of makeup process water is required. Cooling water required to remove 140 kJ/s of combustion heat for the quench tower during operation will be about 0.07 ℓ/sec with a temperature rise of 28°C.

Except for cell heating, cooling, and ventilation, air flow requirements will consist of 0.14 m^3/sec of exhaust gas and dilutent air, which will pass through the quench scrubber tower and mist eliminator to the FRP atmospheric protection system (APS). Decontamination factors (DF) are estimated to be 10^2 for radionuclides entering the quench tower and mist eliminator, 10 through a prefilter, and 10^3 through the high-efficiency particulate air (HEPA) filter. Further removal of radionuclides will occur in the FRP-APS.

The process cell provides shielding and radioactive material confinement during plant operations. Maintenance work will be done by contact methods requiring cell entry by personnel. Beyond these procedures, there are no unique shielding or handling requirements associated with the solvent incineration system.

Environmental Effects Related to Facility Construction. Some of the factors relating to site preparation and reference facility construction may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of construction activities.

Resource Commitments. A non-high-level liquid degraded solvent incinerator will be an integral part of the reference FRP. The total area required is approximately 650 m^2 and will

be located within the main process building of the FRP. The area committed to solvent incineration will have little or no effect on the size of the main process building and no effect on the area committed for an FRP. As a consequence, analysis of land use attributable to the solvent incineration facility does not appear meaningful.

Water used during the construction period will be 2×10^3 m^3.

Construction materials commited to the solvent incineration facility are:

Steel	220 MT
Copper	4 MT
Zinc	0.9 MT
Aluminum	0.9 MT
Concrete	900 m^3
Lumber	85 m^3

Energy used during construction will be:

Propane	17 m^3
Diesel fuel	174 m^3
Gasoline	117 m^3
Electricity	
Peak demand	100 kW
Total consumption	107,000 kWh

Manpower requirements for construction of the solvent incineration facility amount to 94 man-yr, which will likely be integrated with labor schedules for the FRP.

No additional transportation requirements for the facility have been identified beyond those for the FRP.

No special requirements or limitations for siting or construction of the process cell appear warranted.

Physical and Chemical Effects. Releases resulting from construction of the solvent incineration facility are associated mainly with liquids from facility cleanup and washdown, traffic and equipment exhaust emissions, heat, and sanitary wastes. None of these waste sources were identified to have significant impact or effect on the environment. The 2×10^3 m^3 of water required is expected to come from the R River of the reference environment. No perceptible impact on the river is expected. Less than 10% of the water will be used in construction materials; the rest will be distributed for purposes including but not limited to concrete wetting and washdown, soils stabilization, and sanitary use. No releases of water containing toxic substances are expected.

Ecological Effects. The degraded solvent incineration facility will occupy approximately 650 m^2 of land, or less than one one-thousandth of the 40 ha enclosed within the FRP secured area. No ecological impacts of facility construction beyond those of the overall FRP complex are expected. Temporary destruction of vegetation and displacement of birds and animals will be a minor impact of FRP construction.

Water used during construction of the solvent incineration facility will total about 2.0×10^3 m^3, or a daily use rate of 5.5 m^3, for the estimated construction period of 1 year. This water will come from the common FRP water supply, which will be obtained from the R River near the reference site, and represents an insignificant fraction of the 1.1×10^7 m^3/day average flow. No ecological impacts on the river ecosystem are expected from removal of this volume of water.

Environmental Effects Related to Facility Operation. Some of the factors relating to facility operation may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of facility operation.

Resource Commitments. Resources required during planned operation of the solvent incineration facility, based on 24 hr/day, 55 days per year, are listed in Table 5.2.4-1. None of these requirements were identified to have a significant impact on resource availability to other users. About 25% of one operator's time would be required to monitor system operations.

TABLE 5.2.4-1. Utilities and Materials Required for Operating the Degraded Solvent Incineration Facility

Resource	Average Annual Use
Process water	1.5×10^1 m^3
Cooling water	3.3×10^2 m^3
Propane (STP)	4.5×10^2 m^3
Electricity	2×10^4 kWh

Process Effluents. Heat rejected in the amount of 6.7×10^5 MJ (1.4×10^2 kJ/s) for 55 days of batch operation per year is almost entirely disposed of via cooling water to the FRP cooling tower. The heat is released principally through cooling tower evaporation (5.8×10^{-2} ℓ/sec) and drift (2.7×10^{-4} ℓ/sec). The heat load added to the FRP cooling tower system results in a release of 1.0×10^{-2} ℓ/sec of blowdown to the reference environment surface stream at a Δt of 17°C. A total of 3.3×10^5 ℓ/yr is required as makeup water.

An additional 1.5×10^4 ℓ/yr of water is required as dilutent process water for the quench tower scrubber. This water contains P_2O_5 and small amounts of particulate and volatilized radioactive compounds. The blowdown scrubber solution is cycled to the main FRP general purpose intermediate-level waste liquid concentrators.

Nonradioactive products of TBP combustion released to the atmosphere through the solvent incinerator and FRP off-gas treatment system include carbon dioxide, carbon monoxide, nitrogen, excess oxygen, and trace amounts of water vapor. Operation of the process will result in the release of 9.5 kg of carbon monoxide and 20 kg of NO_x per year. Other possible sources of emissions to the biosphere are secondary emissions from worker activities. These emissions, however, are only a fraction of the secondary emissions from the reference FRP and were not computed.

No direct radioactive or nonradioactive releases to land are projected from the operation of this facility.

The radioactive materials that reach the biosphere after leaving the degraded solvent incineration filter system and passing through the FRP-APS are shown in Table 5.2.4-2. The radionuclides listed are those that will contribute at least 1% to the total dose for a given organ from any pathway.

TABLE 5.2.4-2. Radionuclides Released to the Biosphere from the Degraded Solvent Incineration Facility (Ci/yr)

Radionuclide	U Recycle, Pu in SHLW or PuO_2 Stored	U and Pu Recycle
^{90}Sr	1.2×10^{-15}	1.3×10^{-15}
^{129}I	6.6×10^{-6}	7.0×10^{-6}
^{137}Cs	1.9×10^{-15}	1.9×10^{-15}
^{238}Pu	8.7×10^{-11}	1.5×10^{-10}
^{239}Pu	8.1×10^{-12}	1.0×10^{-11}
^{240}Pu	1.3×10^{-11}	2.0×10^{-11}
^{241}Pu	3.1×10^{-9}	5.0×10^{-9}

The radioactive materials entrained in air are derived from the process off-gas. The total air flow through the process is estimated to be 0.14 m^3/sec.

No radioactive material will be released to the biosphere via liquid waste streams, nor will there be direct releases to the ground.

Other contaminated secondary wastes are generated by changing incinerator filters and by contact maintenance. About 0.1 m^3 of filter media and small amounts of combustible trash will be treated annually. Management of these materials is discussed in Sections 4.3 and 4.4 of DOE/ET-0028.(1)

Physical, Chemical, and Thermal Effects. Heat is released intermittently in the 55 days of annual operation of the incineration facility and will amount to 6.7×10^5 MJ, which is less than 0.3% of the FRP heat load. This additional heat represents about twice the output of a home heating system. The process heat is released to the biosphere via the FRP cooling tower system and will have a negligible impact on air and water quality.

Gaseous releases of carbon monoxide (CO) and nitrogen oxides (NO_x) to the biosphere will produce maximum and average ground level concentrations at the fence line of less than 0.001 $\mu g/m^3$ and 0.002 $\mu g/m^3$ for CO and NO_x respectively. These concentrations are well below the Federal ambient air quality standards.

There will be no radioactive material released directly to water or ground and no nonradioactive material released to the ground.

Radiological Effects. Doses to individuals in the vicinity of the degraded solvent incineration facility were calculated on the releases of radionuclides listed in Table 5.2.4-2; exposure pathways, demography, and other parameters described for the reference environment in Appendix A; and mathematical models relating dose to man from radionuclide releases (Appendix B). For planned operation of the solvent incineration facility, the only exposure pathway to man is via airborne effluents; there are no releases to ground or water.

The annual doses to individuals whose habits tend to maximize their dose ("maximum individual") are shown in Table 5.2.4-3. For comparison, the dose to the total body of an individual from naturally occurring radioactive sources averages about 0.1 rem/yr.

TABLE 5.2.4-3. Annual Doses to Maximum Individual from Gaseous Effluents Released by the Degraded Solvent Incineration Facility (rem)[a]

Pathway	Total Body	Thyroid (child)[b]	Thyroid[c]	Lung	Bone
	U Recycle, Pu in SHLW or PuO_2 Stored				
Air submersion	3.0×10^{-16}	3.0×10^{-16}	3.0×10^{-16}	3.0×10^{-16}	3.0×10^{-16}
Inhalation	1.7×10^{-13}		1.3×10^{-10}	1.2×10^{-12}	5.8×10^{-14}
Ingestion	1.9×10^{-11}	8.0×10^{-11}	1.5×10^{-8}	4.6×10^{-19}	1.8×10^{-11}
Total	1.9×10^{-11}	8.0×10^{-11}	1.5×10^{-8}	1.2×10^{-12}	7.6×10^{-11}
	U and Pu Recycle				
Air submersion	4.4×10^{-16}	4.4×10^{-16}	4.4×10^{-16}	4.4×10^{-16}	4.4×10^{-16}
Inhalation	1.8×10^{-13}		1.4×10^{-10}	2.8×10^{-12}	1.4×10^{-13}
Ingestion	2.0×10^{-11}	8.5×10^{-11}	1.6×10^{-8}	7.1×10^{-19}	2.0×10^{-11}
Total	2.0×10^{-11}	8.5×10^{-11}	1.6×10^{-8}	2.8×10^{-12}	2.0×10^{-11}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 1.5×10^{-8} sec/m^3.

a. After 30 years of release and accumulation in the environment.
b. Thyroid dose is calculated for a 1-year-old child breathing air containing radioactive effluents and consuming 1 ℓ of milk per day from cows grazing 7 months/yr at the site boundary. Inhalation dose is <2% of total dose.
c. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

The combined dose from gaseous effluents to the population living within an 80-km radius of the plant was calculated using the projected year 2000 population data given in the reference environment (Appendix A). Table 5.2.4-4 summarizes the annual doses received by this population. The annual total-body population dose from naturally occurring sources to the approximately 2 million persons living within an 80-km radius of the plant in the year 2000 would be about 200,000 man-rem compared with the value of about 2×10^{-6} man-rem from process sources given in Table 5.2.4-4.

The annual total-body dose to the work force associated with the solvent incineration facility was estimated based on permissible exposure limits and experience of operating plants. The annual occupational dose was calculated to be 2 man-rem. Table 5.2.4-5 summarizes the annual total-body dose to the work force and the general population from process and naturally occurring sources in the year 2000.

TABLE 5.2.4-4. Annual Doses to Population (within 80 km) from Gaseous Effluents Released by the Degraded Solvent Incineration Facility (man-rem)(a)

Pathway	Total Body	Thyroid	Lung	Bone
	U Recycle, Pu in SHLW or PuO_2 Stored			
Air submersion	7.0×10^{-11}	7.0×10^{-11}	7.0×10^{-11}	7.0×10^{-11}
Inhalation	3.9×10^{-8}	3.1×10^{-5}	2.8×10^{-7}	1.4×10^{-8}
Ingestion	1.9×10^{-6}	1.5×10^{-3}	5.2×10^{-14}	1.8×10^{-6}
Total	1.9×10^{-6}	1.5×10^{-3}	2.8×10^{-7}	1.8×10^{-6}
	U and Pu Recycle			
Air submersion	1.0×10^{-10}	1.0×10^{-10}	1.0×10^{-10}	1.0×10^{-10}
Inhalation	4.2×10^{-8}	3.3×10^{-5}	6.6×10^{-7}	3.2×10^{-8}
Ingestion	2.0×10^{-6}	1.6×10^{-3}	8.0×10^{-14}	2.0×10^{-6}
Total	2.0×10^{-6}	1.6×10^{-3}	6.6×10^{-7}	2.0×10^{-6}

a. After 30 years of release and accumulation in the environment.

TABLE 5.2.4-5. Summary of Annual Total-Body Doses Received from Operation of the Degraded Solvent Incineration Facility and Naturally Occurring Sources in the Year 2000

	Man-rem
Degraded solvent incineration facility	
Process work force (30 yr)	2
Population (within 80 km)	<0.001
Naturally occurring sources	
Population (within 80 km)	200,000

The 70-year doses to the maximum individual and to the population within 80 km of the facility are given in Tables 5.2.4-6 and 5.2.4-7 respectively. A summary of the 70-year total-body doses to the work force and the population is given in Table 5.2.4-8. For comparison, the dose to the same population from naturally occurring sources over the 70-year period amounts to about 14,000,000 man-rem, compared with 0.0001 man-rem received from operation of the solvent incineration facility.

There was no contribution to world-wide dose from this process.

"Health effects" for the regional population are discussed at the plant level where several processes within the plant are combined. In general, doses at the individual process level are too small for a meaningful discussion of health effects. In this report, 100 to 800 health effects are postulated to occur in the exposed population per million man-rem.

TABLE 5.2.4-6. 70-Year Doses to Maximum Individual from Gaseous Effluents Released by the Degraded Solvent Incineration Facility (rem)

Pathway	Total Body	Thyroid[a]	Lung	Bone
	U Recycle, Pu in SHLW or PuO_2 Stored			
Air submersion	9.0×10^{-15}	9.0×10^{-15}	9.0×10^{-15}	9.0×10^{-15}
Inhalation	6.2×10^{-12}	4.3×10^{-9}	3.7×10^{-11}	3.4×10^{-11}
Ingestion	1.3×10^{-9}	1.0×10^{-6}	2.5×10^{-17}	8.5×10^{-10}
Total	1.3×10^{-9}	1.0×10^{-6}	3.7×10^{-11}	8.8×10^{-10}
	U and Pu Recycle			
Air submersion	1.3×10^{-14}	1.3×10^{-14}	1.3×10^{-14}	1.3×10^{-14}
Inhalation	7.7×10^{-12}	4.5×10^{-9}	6.3×10^{-11}	8.0×10^{-11}
Ingestion	1.4×10^{-9}	1.1×10^{-6}	3.6×10^{-17}	9.0×10^{-10}
Total	1.4×10^{-9}	1.1×10^{-6}	6.3×10^{-11}	9.8×10^{-10}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 1.5×10^{-8} sec/m^3.

a. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green vegetables (growing season, 4 months/yr).

TABLE 5.2.4-7. 70-Year Doses to Population (within 80 km) from Gaseous Effluents Released by the Degraded Solvent Incineration Facility (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
	U Recycle, Pu in SHLW or PuO_2 Stored			
Air submersion	2.1×10^{-9}	2.1×10^{-9}	2.1×10^{-9}	2.1×10^{-9}
Inhalation	1.4×10^{-6}	1.0×10^{-3}	8.7×10^{-6}	7.7×10^{-6}
Ingestion	1.3×10^{-4}	1.0×10^{-1}	2.9×10^{-12}	8.5×10^{-5}
Total	1.3×10^{-4}	1.0×10^{-1}	8.7×10^{-6}	9.3×10^{-5}
	U and Pu Recycle			
Air submersion	3.0×10^{-9}	3.0×10^{-9}	3.0×10^{-9}	3.0×10^{-9}
Inhalation	1.8×10^{-6}	1.1×10^{-3}	1.2×10^{-5}	1.8×10^{-5}
Ingestion	1.4×10^{-4}	1.1×10^{-1}	3.2×10^{-12}	8.8×10^{-5}
Total	1.4×10^{-4}	1.1×10^{-1}	1.2×10^{-5}	1.1×10^{-4}

TABLE 5.2.4-8. Summary of 70-Year Total-Body Doses Received from Operation of the Degraded Solvent Incineration Facility and Naturally Occurring Sources in the Year 2000

	Man-rem
Degraded solvent incineration facility	
Process work force (30 yr)	60
Population (within 80 km)	<0.001
Naturally occurring sources	
Population (within 80 km)	14,000,000

Ecological Effects. The degraded solvent incineration facility will operate about 55 days per year. Gases produced by solvent combustion include carbon dioxide, water vapor, nitrogen, oxygen, phosphoric anhydride (P_2O_5), and small amounts of particulate and volatile radioactive materials. These gases are passed to the solvent burner quench tower to remove most of the contaminants. From the solvent incineration facility, the gases are passed to the vessel off-gas treatment system for further reduction in contaminant concentration.

Annual nonradioactive gaseous releases from the incineration facility consist of 20 kg of nitrogen oxides and 10 kg of carbon monoxide, or a daily release of about 360 and 180 g, respectively, for the 55 days per year of facility operation. No adverse ecological impacts are expected from these discharges.

Ecological impacts from noise and human activity associated with facility operation will be small and indistinguishable from those of the FRP.

Annual water use during normal operation will be 15 m^3 for process purposes and 3.3×10^2 m^3 for cooling; it will be supplied by the R River near the reference site. The total water use rate for the solvent incineration facility will be less than 0.0001% of the average river flow. Removal of this fraction of water will have no measurable effect on the river ecosystem.

About 15 m^3 of solvent incinerator blowdown will be generated annually. It will be sent to the FRP intermediate-level liquid waste treatment system and will not be released to the environment.

The cooling water will be circulated to the FRP cooling tower. Of this volume, approximately 1.0×10^{-5} m^3/sec at a Δt of 17°C will be discharged as blowdown directly to the R River. Heat from this small discharge will be quickly diluted by the much larger average river flow of about 120 m^3/sec and will not affect aquatic life in the river.

Environmental Effects Related to Postulated Accidents. Three postulated accidents which have been described as plausible for the incineration of combustible wastes are listed below.

Accident Number	Description
4.5.2	Incinerator flame-out explosion
4.5.3	Solvent fire
4.5.4	Explosive material in solvent

The scenario for Accident 4.5.2 is classed as worst case for a moderate accident, incinerator flame-out explosion. It is assumed that 0.019 of the radioactive material treated annually is released over a period of 30 min. The release would be vented to the cell atmosphere. Gaseous and particulate combustion products would be forced through the facility cleanup system with a DF of 10^3 and to the FRP-APS with an additional DF of 10^4 before release to the atmosphere from the FRP 110-m stack. No radioactive materials are projected to be released directly to the surrounding environment or water sources from this accident. The estimated quantities of radionuclides released to the atmosphere are presented in Table 5.2.4-9.

Seventy-year dose commitments were calculated and are presented in Table 5.2.4-10. The doses were calculated for air submersion and inhalation using average annual dispersion factors and a maximum estimated $\overline{\chi}/Q'$ 2800 m from the FRP stack.

TABLE 5.2.4-9. Radionuclides Released to the Biosphere from a Moderate Accident in the Degraded Solvent Incineration Facility (Ci)

Radionuclide	U Recycle, Pu in SHLW or PuO_2 Stored	U and Pu Recycle
^{90}Sr	3.0×10^{-6}	2.8×10^{-6}
^{106}Ru	7.8×10^{-6}	7.2×10^{-6}
^{129}I	2.6×10^{-3}	2.8×10^{-3}
^{134}Cs	5.5×10^{-6}	5.5×10^{-6}
^{137}Cs	4.2×10^{-6}	4.2×10^{-6}
^{144}Ce	1.1×10^{-5}	
^{238}Pu	1.4×10^{-7}	3.0×10^{-5}
^{239}Pu	1.3×10^{-8}	2.8×10^{-6}
^{240}Pu	2.1×10^{-8}	4.3×10^{-6}
^{241}Pu	5.0×10^{-6}	9.6×10^{-4}
^{241}Am	1.7×10^{-8}	
^{242}Cm	1.6×10^{-7}	
^{244}Cm	5.5×10^{-8}	

TABLE 5.2.4-10. 70-Year Dose Commitment to the Maximum Individual from Radionuclides Accidentally Released from the Degraded Solvent Incineration Facility (rem)

Pathway	Skin	Total Body	Thyroid	Lung	Bone
	U Recycle, Pu in SHLW or PuO_2 Stored				
Air submersion	1.6×10^{-9}	6.7×10^{-10}	6.7×10^{-10}	6.7×10^{-10}	6.7×10^{-10}
Inhalation		1.1×10^{-6}	3.4×10^{-4}	7.0×10^{-6}	1.0×10^{-5}
Total	1.6×10^{-9}	1.1×10^{-6}	3.4×10^{-4}	7.0×10^{-6}	1.0×10^{-5}
	U and Pu Recycle				
Air submersion	1.7×10^{-9}	7.0×10^{-10}	7.0×10^{-10}	7.0×10^{-10}	7.0×10^{-10}
Inhalation		8.0×10^{-5}	3.6×10^{-4}	4.1×10^{-4}	1.7×10^{-3}
Total	1.7×10^{-9}	8.0×10^{-5}	3.6×10^{-4}	4.1×10^{-4}	1.7×10^{-3}

Numerically, the largest of these doses is less than the nominal 5×10^{-3} rem variation in dose the individual would have received from naturally occurring sources. No accidents were postulated for the solvent incineration process which would lead to more serious consequences.

REFERENCES FOR SECTION 5.2.4

1. Technology for Commercial Radioactive Waste Management, DOE/ET-0028, Department of Energy, Washington, DC, in press.

5.2.5 Failed Equipment and Other Noncombustible Waste Treatment (DOE/ET-0028 Sec 4.3)

Failed equipment and noncombustible waste are among the solid wastes produced during the operation of fuel reprocessing plants (FRP) and mixed-oxide fuel fabrication plants (MOX FFP). The generation of small items of noncombustible waste is routine and predictable in a nuclear facility. The failure of large items of radioactive process equipment is not routine, however, and can seriously affect operating schedules. Prompt treatment and replacement of such equipment is essential to plant efficiency, including equipment disassembly and packaging for early removal of the failed equipment from the processing area.

5.2.5.1 Failed Equipment and Noncombustible Waste Treatment at a Fuel Reprocessing Plant (DOE/ET-0028 Sec 4.3.1)

This treatment concept prepares FRP failed equipment and other noncombustible waste for shipment to interim storage or a repository. The treatment usually involves some decontamination, disassembly, and packaging of the material. Figure 5.2.5-1 is a schematic flow diagram illustrating treatment procedures. Metal is the primary constituent of FRP failed equipment and noncombustible waste, but substances such as glass and concrete are also present. Reprocessing plant canyon operations provide the largest and most radioactive pieces of failed equipment. Typical large items are dissolvers, solvent extraction columns, and concentrators, which might be up to 3 m in diameter and 10 m in height. Noncombustible scrap includes small hand tools that cannot be economically decontaminated, used light bulbs, wire ends, electrical panels, metal scraps, and glasswares from contaminated areas, and all heating, ventilating, and air conditioning components and accessories within a potentially contaminated system. Extensive experience exists in handling these wastes at Federal facilities. Alternative treatment concepts involve varying degrees of decontamination and disassembly (if needed) for packaging in waste containers.

The reference treatment concept described here has the capacity to handle 440 m^3 of failed equipment and 960 m^3 of noncombustible trash annually. Facilities are provided in the main process building of the FRP in various multipurpose shops and cells designed for general FRP maintenance. Table 5.2.5-1 gives the outputs from this treatment concept.

Environmental Effects Related to Facility Construction. Some of the factors relating to site preparation and reference facility construction may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of construction activities.

Resource Commitments. The failed equipment disassembly and packaging facility will be an integral part of the 400,000 m^2 reference FRP. Land use attributable to this facility is inconsequential compared with the entire FRP and in any event would be preempted by construction of the FRP.

Water used during construction is estimated to be 5.8×10^3 m^3. Withdrawal of this amount of water from the R River (described in the reference environment in Appendix A), with an average flow of 1.0×10^7 m^3/day, is judged to be insignificant with respect to other downstream uses. During the construction period, wells could also supply the amount of water without consequence.

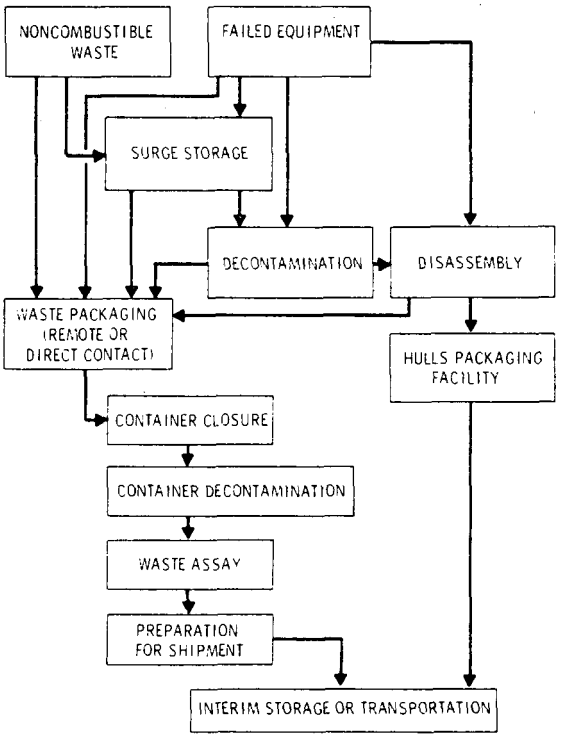

FIGURE 5.2.5-1. Flow Diagram for Treatment of Failed Equipment and Noncombustible Waste at FRP

TABLE 5.2.5-1. Annual Flow of Packaged Failed Equipment and Noncombustible Waste at the FRP

Waste	55-gal Drums	Boxes[a]	Canisters[b]	Activity, Ci	
				Actinides	Fission Products
TRU trash					
Low-level waste	431			1	10
Intermediate-level waste	3,940			400	2,800
TRU equipment					
Low-level waste		50		1	10
Intermediate-level waste	471		71	20	130
PuO_2 trash					
Low-level waste	58			36,000	
PuO_2 equipment					
Low-level waste		10		1,800	

a. Dimensions, 1.2 x 1.8 x 1.8 m.
b. Dimensions, 0.76 m in diameter by 3 m in height.

Materials committed for construction of the failed equipment dissassembly and packaging facility are:

Concrete	3,200 m^3
Steel	900 MT
Copper	9 MT
Aluminum	5 MT
Lumber	240 m^3

Energy resources committed for construction are:

Propane	57 m^3
Diesel fuel	558 m^3
Gasoline	380 m^3
Electricity	
Peak demand	380 kW
Total consumption	250,000 kWh

Manpower requirements for construction of the failed equipment disassembly and packaging facility amount to 220 man-yr, which will likely be integrated with labor schedules for the FRP.

No additional transportation requirements have been identified beyond those for the FRP. No other site-specific requirements have been identified.

Physical and Chemical Effects. Effects on air quality, water quality, water use, and land use from construction of the failed equipment disassembly and packaging facility are indistinguishable from those resulting from construction of the reference FRP (Section 5.1.2).

Ecological Effects. The handling of failed equipment and packaging at the FRP will be accomplished in several facilities, none of which will be devoted solely to this function. Parts of the FRP that have a role in handling failed equipment include the high-level maintenance cell, regulated shops, aqueous makeup, and contaminated storage. An area of about 290 m^2 within these facilities will be devoted to equipment disassembly, which is a fraction of the 40 ha of land required for the FRP secured area. Therefore, the impacts of excavation, dust, noise, and human activity associated with construction of the failed equipment disassembly and packaging facility will be indistinguishable from those of the FRP.

Water used during construction (approximately 5.8×10^3 m^3) will be supplied by the R River near the reference environment. For an assumed construction period of 18 months, the daily water requirements will be about 11 m^3 or an insignificant proportion of the 1.1×10^7 m^3/day average flow of the R River.

Environmental Effects Related to Facility Operation. Some of the factors relating to facility operation may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of operation.

Resource Commitments. Utilities and materials required during planned operation of the failed equipment disassembly and packaging facility are listed in Table 5.2.5-2.

TABLE 5.2.5-2. Utilities and Materials Required for Operating the Failed Equipment Disassembly and Packaging Facility

Resource	Average Annual Use
Water	200 m^3
Acetylene (bottled gas)	5.0×10^{-1} MT
Electricity	7.0×10^{5} kWh
Manpower	7.2 man-yr

The commitment of these resources is considered to be insignificant.

Personnel will be assigned intermittently to perform functions related to treatment of equipment and noncombustible waste.

Process Effluents. The amounts of radioactive materials that reach the biosphere after leaving the failed equipment disassembly and packaging facility and passing through the FRP-APS are shown in Table 5.2.5-3. The radionuclides listed are those that will contribute at least 1% to the total dose for a given organ from any pathway or that are otherwise of interest.

TABLE 5.2.5-3. Radionuclides Released to the Biosphere from Planned Operation of the Failed Equipment Disassembly and Packaging Facility (Ci/yr)

Radionuclide	U Recycle, Pu in SHLW	U Recycle, PuO_2 Stored	U and Pu Recycle
^{90}Sr	2.6×10^{-7}	2.6×10^{-7}	2.5×10^{-7}
^{95}Nb	3.1×10^{-8}	3.1×10^{-8}	3.1×10^{-8}
^{106}Ru	7.0×10^{-7}	7.0×10^{-7}	7.5×10^{-7}
^{125m}Te	9.0×10^{-9}	9.0×10^{-9}	9.5×10^{-9}
^{127m}Te	1.7×10^{-9}	1.7×10^{-9}	1.7×10^{-9}
^{134}Cs	4.8×10^{-7}	4.8×10^{-7}	4.8×10^{-7}
^{137}Cs	3.7×10^{-7}	3.7×10^{-7}	3.8×10^{-7}
^{144}Ce	1.0×10^{-6}	1.0×10^{-6}	9.5×10^{-7}
^{154}Eu	2.2×10^{-8}	2.2×10^{-8}	2.5×10^{-8}
^{238}Pu	1.3×10^{-8}	2.2×10^{-6}	2.2×10^{-6}
^{239}Pu	1.2×10^{-9}	1.5×10^{-7}	1.5×10^{-7}
^{240}Pu	1.8×10^{-9}	3.0×10^{-7}	3.0×10^{-7}
^{241}Pu	4.4×10^{-7}	7.0×10^{-5}	7.0×10^{-5}
^{241}Am	1.5×10^{-9}		
^{242}Cm	1.4×10^{-8}		
^{244}Cm	4.8×10^{-9}		5.8×10^{-8}

No nonradioactive materials will be released to the atmosphere or ground during planned operation of the facility.

Physical, Chemical, and Thermal Effects. With no release of nonradioactive materials to the atmosphere, land, or water, no effects are expected from operation of the failed equipment disassembly and packaging facility. All liquid and solid waste disposal for the facility is part of the overall FRP operation.

Radiological Effects. Doses to individuals in the vicinity of the equipment disassembly and packaging facility were calculated based on the releases of radionuclides listed in Table 5.2.5-3; exposure pathways, demography, and other parameters described for the reference environment in Appendix A; and mathematical models relating dose to man from radionuclide releases (Appendix B). For planned operation of this facility, the only exposure pathway to man is via airborne effluents; there are no releases to ground or water.

The annual doses to individuals whose habits tend to maximize their dose ("maximum individual") are shown in Table 5.2.5-4. For comparison, the dose to an individual from naturally occurring radioactive sources averages about 0.1 rem/yr.

TABLE 5.2.5-4. Annual Doses to Maximum Individual from Gaseous Effluents Released by the Failed Equipment Disassembly and Packaging Facility (rem)[a]

Pathway	Total Body	Thyroid (child)[b]	Thyroid[c]	Lung	Bone
		U Recycle, Pu in SHLW			
Air submersion	4.1×10^{-15}	4.1×10^{-15}	4.1×10^{-15}	4.1×10^{-15}	4.1×10^{-15}
Inhalation	8.0×10^{-13}		2.2×10^{-14}	7.0×10^{-11}	1.1×10^{-11}
Ingestion	5.0×10^{-11}	0	2.4×10^{-16}	6.5×10^{-12}	3.8×10^{-11}
Total	5.0×10^{-11}	4.1×10^{-15}	2.8×10^{-14}	7.7×10^{-11}	4.9×10^{-11}
		U Recycle, PuO_2 Stored			
Air submersion	4.1×10^{-15}	4.1×10^{-15}	4.1×10^{-15}	4.1×10^{-15}	4.1×10^{-15}
Inhalation	4.5×10^{-11}		2.2×10^{-14}	2.7×10^{-9}	1.1×10^{-9}
Ingestion	5.0×10^{-11}	0	2.4×10^{-16}	6.5×10^{-12}	3.9×10^{-11}
Total	9.5×10^{-11}	4.1×10^{-15}	2.6×10^{-15}	2.7×10^{-9}	1.1×10^{-9}
		U and Pu Recycle			
Air submersion	4.2×10^{-15}	4.1×10^{-15}	4.2×10^{-15}	4.2×10^{-15}	4.2×10^{-15}
Inhalation	4.6×10^{-11}		2.4×10^{-14}	2.7×10^{-9}	1.1×10^{-9}
Ingestion	4.8×10^{-11}	0	1.6×10^{-16}	6.5×10^{-12}	3.2×10^{-11}
Total	9.4×10^{-10}	4.1×10^{-15}	2.8×10^{-14}	2.7×10^{-9}	1.1×10^{-9}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 1.5×10^{-8} sec/m^3.

a. After 30 years of release and accumulation in the environment.
b. Thyroid dose is calculated for a 1-year-old child breathing air containing radioactive effluents and consuming 1 ℓ of milk per day from cows grazing 7 months/yr at the site boundary. Inhalation dose is <2% of total dose.
c. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

The combined dose from gaseous effluents to the population living within an 80-km radius of the plant was calculated using the projected year 2000 population data given in the reference environment. Table 5.2.5-5 summarizes the annual doses received by this population. The annual total-body population dose from naturally occurring sources to the approximately 2 million persons living within an 80-km radius of the plant in the year 2000 would be about 200,000 man-rem compared with the value of about 4.0×10^{-5} man-rem received from facility sources as given in Table 5.2.5-5.

TABLE 5.2.5-5. Annual Doses to Population (within 80 km) from Gaseous Effluents Released by the Failed Equipment Disassembly and Packaging Facility (man-rem)[a]

Pathway	Total Body	Thyroid	Lung	Bone
	U Recycle, Pu in SHLW			
Air submersion	9.5×10^{-10}	9.5×10^{-10}	9.5×10^{-10}	9.5×10^{-10}
Inhalation	1.9×10^{-7}	5.0×10^{-9}	1.6×10^{-5}	2.5×10^{-6}
Ingestion	9.5×10^{-6}	2.3×10^{-11}	1.2×10^{-6}	6.5×10^{-6}
Total	9.5×10^{-6}	6.0×10^{-9}	1.7×10^{-5}	9.0×10^{-6}
	U Recycle, PuO_2 Stored			
Air submersion	9.5×10^{-10}	9.5×10^{-10}	9.5×10^{-10}	9.5×10^{-10}
Inhalation	1.1×10^{-5}	5.0×10^{-9}	6.0×10^{-4}	2.5×10^{-4}
Ingestion	9.5×10^{-6}	2.3×10^{-11}	1.2×10^{-6}	6.5×10^{-6}
Total	2.1×10^{-5}	6.0×10^{-9}	6.0×10^{-4}	3.2×10^{-4}
	U and Pu Recycle			
Air submersion	9.5×10^{-10}	9.5×10^{-10}	9.5×10^{-10}	9.5×10^{-10}
Inhalation	1.1×10^{-5}	5.5×10^{-9}	6.5×10^{-4}	2.5×10^{-4}
Ingestion	9.5×10^{-6}	1.4×10^{-11}	1.3×10^{-6}	6.0×10^{-6}
Total	2.1×10^{-5}	6.5×10^{-9}	6.5×10^{-4}	2.6×10^{-4}

a. After 30 years of release and accumulation in the environment.

The annual total-body dose to the work force associated with the failed equipment disassembly and packaging facility was estimated based on permissible exposure limits and experience of operating plants. The annual occupational dose was calculated to be 20 man-rem. Table 5.2.5-6 summarizes the annual total-body dose to the work force and the general population from process and naturally occurring sources in the year 2000.

The 70-year doses to the maximum individual and to the population within 80 km of the facility are given in Tables 5.2.5-7 and 5.2.5-8 respectively. A summary of the 70-year total-body doses to the work force and the population is given in Table 5.2.5-9. For comparison, the population dose from naturally occurring sources over the 70-year period amounts to about 14,000,000 man-rem compared with 1.3×10^{-2} man-rem received from the failed equipment disassembly and packaging facility.

TABLE 5.2.5-6. Summary of Annual Total-Body Doses Received from Operation of the Failed Equipment Disassembly and Packaging Facility and Naturally Occurring Sources in the Year 2000

	Man-rem
Equipment disassembly and packaging facility	
Process work force (30 yr)	20
Population (within 80 km)	<0.001
Naturally occurring sources	
Population (within 80 km)	200,000

TABLE 5.2.5-7. 70-Year Doses to Maximum Individual from Gaseous Effluents Released by the Failed Equipment Disassembly and Packaging Facility (rem)

Pathway	Total Body	Thyroid[(a)]	Lung	Bone
	U Recycle, Pu in SHLW			
Air submersion	1.2×10^{-13}	1.2×10^{-13}	1.2×10^{-13}	1.2×10^{-13}
Inhalation	2.9×10^{-10}	6.5×10^{-13}	2.1×10^{-9}	4.6×10^{-9}
Ingestion	1.7×10^{-9}	7.5×10^{-15}	7.0×10^{-12}	6.5×10^{-9}
Total	2.0×10^{-9}	7.7×10^{-13}	2.1×10^{-9}	1.1×10^{-8}
	U Recycle, PuO_2 Stored			
Air submersion	1.2×10^{-13}	1.2×10^{-13}	1.2×10^{-13}	1.2×10^{-13}
Inhalation	2.9×10^{-8}	6.5×10^{-13}	1.5×10^{-7}	6.0×10^{-7}
Ingestion	1.7×10^{-9}	7.5×10^{-15}	7.0×10^{-12}	7.5×10^{-9}
Total	3.0×10^{-8}	7.7×10^{-13}	1.5×10^{-7}	6.0×10^{-7}
	U and Pu Recycle			
Air submersion	1.3×10^{-13}	1.3×10^{-13}	1.3×10^{-13}	1.3×10^{-13}
Inhalation	2.9×10^{-8}	7.0×10^{-13}	1.5×10^{-7}	6.0×10^{-7}
Ingestion	7.0×10^{-11}	4.8×10^{-15}	7.0×10^{-12}	9.0×10^{-10}
Total	2.9×10^{-8}	7.3×10^{-13}	1.5×10^{-7}	6.0×10^{-7}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 1.5×10^{-8} sec/m^3.

a. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

"Health effects" for regional populations are discussed at the plant level where several processes within the plant are combined. In general, doses at the individual process level are too small for a meaningful discussion of health effects. In this report, 100 to 800 health effects are postulated to occur in the exposed population per million man-rem.

TABLE 5.2.5-8. 70-Year Doses to Population (within 80 km) from Gaseous Effluents Released by the Failed Equipment Disassembly and Packaging Facility (rem)

Pathway	Total Body	Thyroid	Lung	Bone
	U Recycle, Pu in SHLW			
Air submersion	2.9×10^{-8}	2.9×10^{-8}	2.9×10^{-8}	2.9×10^{-8}
Inhalation	6.5×10^{-5}	1.6×10^{-7}	4.8×10^{-4}	1.1×10^{-3}
Ingestion	1.5×10^{-4}	8.0×10^{-10}	7.5×10^{-7}	6.0×10^{-4}
Total	2.2×10^{-4}	1.9×10^{-8}	4.8×10^{-4}	1.7×10^{-3}
	U Recycle, PuO_2 Stored			
Air submersion	2.9×10^{-8}	2.9×10^{-8}	2.9×10^{-8}	2.9×10^{-8}
Inhalation	6.5×10^{-3}	1.6×10^{-7}	3.4×10^{-2}	1.5×10^{-1}
Ingestion	1.5×10^{-4}	8.0×10^{-10}	7.5×10^{-7}	6.5×10^{-4}
Total	6.7×10^{-2}	1.9×10^{-7}	3.4×10^{-2}	1.5×10^{-1}
	U and Pu Recycle			
Air submersion	2.9×10^{-8}	2.9×10^{-8}	2.9×10^{-8}	2.9×10^{-8}
Inhalation	6.5×10^{-3}	1.7×10^{-7}	3.5×10^{-2}	1.5×10^{-1}
Ingestion	7.5×10^{-6}	4.9×10^{-10}	8.0×10^{-7}	9.0×10^{-5}
Total	6.5×10^{-2}	1.7×10^{-7}	3.5×10^{-2}	1.5×10^{-1}

TABLE 5.2.5-9. Summary of 70-Year Total-Body Doses Received from the Failed Equipment Disassembly and Packaging Facility and Naturally Occurring Sources in the Year 2000

	Man-rem
Equipment disassembly and packaging facility	
Process work force (30 yr)	600
Population (within 80 km)	0.013
Naturally occurring sources	
Population (within 80 km)	14,000,000

Ecological Effects. After decontamination, disassembly, and packaging, the output from this facility will go to other facilities for further treatment or storage. Control and cleanup of off-gases will be incidental to the control of off-gases from the chemical process. There will be no environmental discharge of liquid wastes from the facility. The decontamination water will be collected, concentrated, and sent to wet waste immobilization treatment.

Water requirements will be approximately 0.55 m^3/day and will be supplied by the R River of the reference environment. This water demand is an insignificant fraction of the 1.1×10^7 m^3/day average flow of the R River and will not adversely affect the biota of the river.

The routine operation of this facility will have no ecological effects beyond those produced by the FRP.

Environmental Effects Related to Postulated Accidents. One minor accident scenario has been described for the failed equipment disassembly and packaging facility at the FRP. Accident 4.3.1, failed equipment tip over during disassembly.

This accident will release no radioactive or nonradioactive effluents; therefore, no physical, chemical, thermal, or radiological effects are anticipated.

No moderate or severe accidents were postulated within the design basis of the facility. Non-design basis accidents were not considered.

5.2.6 General Trash and Combustible Waste Treatment (DOE/ET-0028 Sec. 4.4)

The FRP will produce contaminated combustible and/or compactable waste materials. These materials include ventilation filters, ion exchange resins, degraded entractant, and general trash. Ventilation filters (roughing and HEPA) are used in nuclear facilities to remove particulates from process and contaminated-area ventilation air. Ion exchange resin wastes are generated during plant processing and waste treatment activities. Degraded extractant is no longer usable extractant (normally 30% tributyl phosphate in hydrocarbon diluent) used in the FRP solvent extraction process. General trash consists primarily of cloth, paper, wood, plastics, rubber, and small amounts of glass and metals generated during maintenance and general support activities.

These wastes have been divided into two categories at the FRP — intermediate-level waste (ILW) and low-level waste (LLW). ILW consists of the general trash with a higher gamma activity level including laboratory and cell wastes, general trash from the PuO_2 conversion facility, ion exchange resins, degraded extractant, and ventilation filters. The LLW consists of the trash having a lower gamma activity level.

Three major alternatives have been used for treating general trash and combustible waste. Two of these alternatives, incineration and packaging without treatment, are described here. Incineration consists of burning the waste and treating the off-gas for removal of radionuclides and other noxious materials, thereby decreasing the waste volume and rendering it noncombustible. Packaging without treatment (ion exchange resins and degraded extractant are excluded from the feed with this alternative) consists of simply packaging general trash and ventilation filters in steel drums for interim storage or burial at the repository. The third alternative, compaction, consists of compacting the waste and packaging it in steel drums for interim storage or burial at the repository. All three methods have been widely used in the nuclear industry although incineration has not been applied to ILW.

Incineration was chosen as the reference treatment because it renders the waste noncombustible and reduces the volume. Packaging without treatment was examined in detail as an alternative since it represents the other end of the spectrum in terms of cost, volume reduction, and flammability of the waste.

5.2.6.1 Incineration Process for Low-Level Waste (DOE/ET-0028 Sec. 4.4.2)

The incineration process considered here is for treatment of LLW generated at an FRP. A simplified flow diagram of the reference LLW incineration process is shown in Figure 5.2.6-1. The process is almost identical to the ILW incineration process described in Section 5.2.6.2. The differences are 1) the LLW feed consists only of general trash, 2) there is no packaged filter media product, and 3) with no ^{129}I present the cleaned off-gas is sent directly to the FRP-APS. The system has the same capacity as the ILW incineration facility and is located adjacent to it. The scrub solution blowdown concentrator is located in the ILW facility and is shared with that facility. Water vapor produced is sent to the vessel off-gas treatment system. Volumes and activities of input and output streams are shown in Table 5.2.6-1.

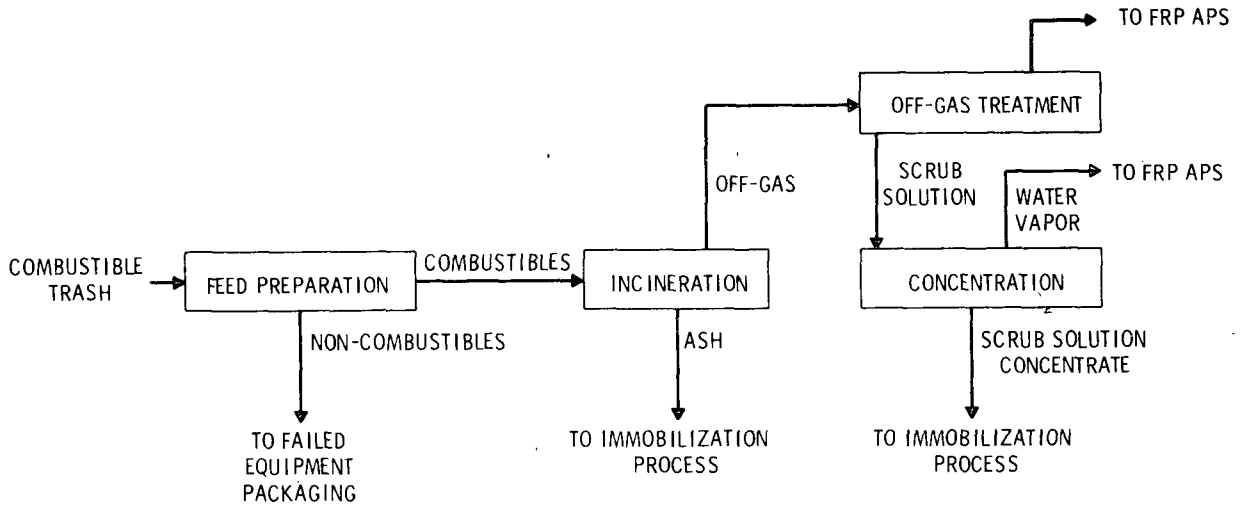

FIGURE 5.2.6-1. Incineration of Low-Level Wastes at the FRP

TABLE 5.2.6-1. Annual Flow for Low-Level Waste Incineration Facility at the FRP

Material	Volume, m^3	Activity, Ci	
		Fission Products	Actinides
Total feed	2.4×10^3	3	4×10^{-1}
Ash to immobilization	1.0×10^2	3	4×10^{-1}
Concentrated blowdown solution to immobilization	2.2×10^2	3×10^{-3}	4×10^{-4}
Cleaned off-gas to APS	6.0×10^6	2×10^{-11}	3×10^{-12}
Water vapor to vessel off-gas system	1.7×10^6	3×10^{-8}	4×10^{-9}

Environmental Effects Related to Facility Construction. Some of the factors relating to site preparation and reference facility construction may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of construction activities.

Resource Commitments. The LLW incineration facility at the FRP will occupy an area of about 520 m^2. This process facility will be an integral part of the FRP, whose structures will occupy an area of about 40 ha. Land use attributable to the incineration facility is inconsequential by comparison and in any event would be preempted by construction of the FRP.

Water used during construction will be approximately 1 x 10^3 m^3.

Materials committed for construction of the facility are:

Steel	90 MT
Copper	0.9 MT
Lumber	25 m^3
Concrete	500 m^3

Energy resources committed for construction are:

Propane	11 m^3
Diesel fuel	110 m^3
Gasoline	76 m^3
Electricity	
Peak demand	120 kW
Total consumption	60,000 kWh

Manpower requirements for construction of the LLW incineration facility amount to 49 man-yr, which will likely be integrated with labor schedules for the FRP.

No additional transportation requirements have been identified beyond those for the FRP. No site-specific requirements have been identified.

Physical and Chemical Effects. Effects on air quality from construction of the LLW incineration facility will be an indistinguishable fraction of those resulting from construction of the reference FRP (Section 5.1.2).

The diversion of about 1000 m^3 of water for construction of the incineration facility will have no significant effect on local water supplies, nor will the use of about 700 m^2 of land for the incineration facility have a significant impact on local land use. Moreover, environmental effects of the facility construction related to land cannot be separated from the effects of the overall FRP construction.

Ecological Effects. The ecological impacts that may result from facility construction will be indistinguishable from those of the overall FRP complex. Possible impacts on the terrestrial environment from construction include the elimination and alteration of vegetation cover; destruction of animal habitat; and the disturbance of animals caused by noise, dust, and human activity. No separate transportation requirements are foreseen for the LLW incineration facility beyond those for the FRP. Because of the small land area involved, the ecological impacts of construction will be indistinguishable from those of the FRP.

Water requirements during the assumed 1-year construction period are 1.0 x 10^3 m^3 and will be supplied by the R River near the reference site. The average annual flow for the R River is 3.9 x 10^9 m^3/yr. Water required for facility construction will be less than 0.001 of the minimum river flow and will not produce an impact on stream biota. Any silt introduced by runoff from the construction site will be imperceptible compared with that for the FRP and is not expected to produce measurable aquatic impacts.

Environmental Effects Related to Facility Operation. Some of the factors relating to facility operation may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of operation.

TABLE 5.2.6-2. Utilities and Materials Required for Operating the Low-Level Waste Incineration Facility

Resource	Average Annual Use
Water	
Process water[a]	3.0×10^3 m^3
Evaporated in cooling tower	7.9×10^3 m^3
Drift	3.8×10^1 m^3
Materials	
Boxes (0.06 m^3-cardboard)	5.3×10^3
Sodium hydroxide	3.0×10^1 MT
Energy	
Electricity	3.5×10^6 kWh
Propane	6.0×10^4 m^3
Manpower	1.3×10^1 man-yr

a. Process water may be recycled water from the FRP.

Process Effluents. The amounts of radioactive materials that reach the biosphere after leaving the FRP incinerator are shown in Table 5.2.6-3. The radionuclides listed are those that will contribute at least 1% of the total dose to a given organ from any pathway or that are otherwise of interest.

Nonradioactive materials released via the FRP-APS stack are as follows:

Pollutant	Amount, MT/yr
HCl	0.1
SO_x	0.2
NO_x	0.4
CO	0.2

During the 4300 hr of operation per year, the LLW incineration facility rejects about 1.3×10^7 MJ to the atmosphere via the FRP cooling tower and 6×10^6 MJ is rejected to the atmosphere via the FRP stack. Consumptive use of 7.9×10^3 m^3/yr of water through evaporation of water in the cooling tower is expected to be without consequence. The contribution to cooling tower blowdown from this process will amount to about 1.4×10^3 m^3/yr of water increased in temperature about 17°C above ambient. Drift from the cooling tower is estimated to be 38 m^3/yr. Total makeup water to be withdrawn from the R River for this process is 9.3×10^3 m^3.

There will be no direct ground disposal of nonradioactive liquid or solid wastes from the LLW incineration facility. All liquid and solid waste disposal for the process is part of the overall FRP operation.

TABLE 5.2.6-3. Radionuclides Released to the Biosphere as a Result of Low-Level Waste Incineration at the FRP (Ci/yr)

Radionuclide	U Recycle, Pu in SHLW or PuO_2 Stored	U and Pu Recycle
^{90}Sr	3.4×10^{-13}	3.2×10^{-13}
^{95}Nb	4.0×10^{-14}	4.0×10^{-13}
^{106}Ru	8.8×10^{-13}	9.9×10^{-13}
^{125m}Te	1.1×10^{-14}	1.2×10^{-14}
^{127m}Te	2.2×10^{-15}	2.2×10^{-15}
^{134}Cs	6.2×10^{-13}	6.2×10^{-13}
^{137}Cs	4.8×10^{-13}	4.9×10^{-13}
^{144}Ce	1.2×10^{-12}	1.2×10^{-12}
^{154}Eu	2.9×10^{-14}	3.2×10^{-14}
^{238}Pu	1.6×10^{-14}	2.9×10^{-14}
^{239}Pu	1.5×10^{-15}	1.9×10^{-15}
^{240}Pu	2.3×10^{-15}	3.8×10^{-15}
^{241}Pu	5.7×10^{-13}	9.4×10^{-13}
^{241}Am	1.9×10^{-15}	3.7×10^{-15}
^{242}Cm	1.8×10^{-14}	5.2×10^{-14}
^{244}Cm	6.2×10^{-15}	3.7×10^{-14}

Physical, Chemical, and Thermal Effects. Atmospheric effects caused by operation of the LLW incineration facility include air quality impacts resulting from emission of nonradioactive pollutants and release of waste heat. Waste heat rejected to the atmosphere amounts to 1.3×10^7 MJ over 4300 hrs of operation which will be an insignificant contribution to the heat rejected by operation of the FRP alone. The atmospheric effect of waste heat rejection from the FRP will be limited to infrequent occurrences of fogging at the outfall of discharge or from the cooling tower.

Average annual and maximum ambient ground level concentrations of pollutants released from the incineration facility at the FRP were computed using $\overline{\chi}/Q'$ values listed in the reference environment. These concentrations are listed in Table 5.2.6-4.

Federal air quality standards currently exist for all pollutants listed in Table 5.2.6-4 except HCL (considering SO_x as SO_2). These standards are 80 and 100 $\mu g/m^3$ for SO_2 and NO_x, respectively, computed as an annual arithematic mean. Carbon monoxide computed at a 1-hr ambient air concentration, has an existing standard of 4×10^4 $\mu g/m^3$. Computed concentrations from incineration at the FRP thus are substantially below Federal standards.

TABLE 5.2.6-4. Ground Level Concentrations[a] of Pollutants Released by the Low-Level Waste Incineration Facility ($\mu g/m^3$)

Pollutant	Maximum	Average
HCl	7.2×10^{-5}	3.6×10^{-5}
SO_x	2.4×10^{-4}	1.2×10^{-4}
NO_x	5.3×10^{-4}	2.6×10^{-4}
CO	1.9×10^{-3}	9.6×10^{-4}

a. At the FRP fence line, 2800 m from the FRP stack.

Currently, a threshold limit value of 5 $\mu g/m^3$ exists for HCL.[1] Computed air concentrations from waste incineration would not exceed that value.

There is no direct disposal of nonradioactive liquid or solid wastes to the land from the incineration process. All liquid and solid waste disposal is part of the overall FRP operation.

Radiological Effects. Doses to individuals in the vicinity of the LLW incineration facility were based on the releases of radionuclides as listed in Table 5.2.6-3; pathways, demography, and other parameters as described in Appendix A; and mathematical models relating dose to man from radionuclide releases as given in Appendix B. For planned operation of the FRP incinerator, the only pathway for radionuclides to man is via airborne effluents; there are no releases to ground or water.

The annual doses to individuals whose habits tend to maximize their dose ("maximum individual") are shown in Table 5.2.6-5. For perspective, the dose to an individual from naturally occurring radioactive sources averages about 0.1 rem/yr.

The combined dose from gaseous effluents to the population living within an 80-km radius of the plant was calculated using the projected year 2000 population data given in the reference environment (Appendix A). Table 5.2.6-6 summarizes the annual doses received by this population. The annual total-body population dose from naturally occurring sources to the approximately 2 million persons living within an 80-km radius of the plant in the year 2000 would be about 200,000 man-rem compared with the value of about 2.9×10^{-13} man-rem received from process sources, as Table 5.2.6-6 shows.

The annual total-body dose to the work force associated with the LLW incineration facility was estimated based on permissible exposure limits and experience of operating plants. The annual occupational dose was calculated to be 50 man-rem. Table 5.2.6-7 summarizes the annual total-body dose to the work force and the general population from process and naturally occurring sources in the year 2000.

TABLE 5.2.6-5. Annual Doses to Maximum Individual from Gaseous Effluents Released by the Low-Level Waste Incineration Facility (rem)(a)

Pathway	Total Body	Thyroid (child)(b)	Thyroid(c)	Lung	Bone
	U Recycle, Pu in SHLW or PuO_2 Stored				
Air submersion	5.3×10^{-21}	5.3×10^{-21}	5.3×10^{-21}	5.3×10^{-21}	5.3×10^{-21}
Inhalation	1.0×10^{-18}		2.9×10^{-20}	8.8×10^{-17}	1.4×10^{-17}
Ingestion	3.6×10^{-18}		3.0×10^{-22}	1.7×10^{-19}	9.5×10^{-18}
Total	4.6×10^{-18}	5.3×10^{-21}	3.4×10^{-20}	8.8×10^{-17}	2.4×10^{-17}
	U and Pu Recycle				
Air submersion	5.3×10^{-21}	5.3×10^{-21}	5.3×10^{-21}	5.3×10^{-21}	5.3×10^{-21}
Inhalation	1.7×10^{-18}		3.1×10^{-20}	1.5×10^{-16}	2.5×10^{-17}
Ingestion	3.5×10^{-18}		3.2×10^{-22}	1.7×10^{-19}	9.0×10^{-18}
Total	5.2×10^{-18}	5.3×10^{-21}	3.6×10^{-20}	1.5×10^{-16}	3.4×10^{-17}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the highest annual average dispersion factor ($\bar{\chi}/Q'$) of 1.5×10^{-8} sec/m^3.

a. After 30 years of release and accumulation in the environment.
b. Thyroid dose is calculated for a 1-year-old child breathing air containing radioactive effluents and consuming 1 ℓ of milk per day from cows grazing 7 months/yr at the site boundary. Inhalation dose is <2% of total dose.
c. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

TABLE 5.2.6-6. Annual Doses to Population (within 80 km) from Gaseous Effluents Released by the Low-Level Waste Incineration Facility (man-rem)(a)

Pathway	Total Body	Thyroid	Lung	Bone
	U Recycle, Pu in SHLW or PuO_2 Stored			
Air submersion	1.2×10^{-15}	1.2×10^{-15}	1.2×10^{-15}	1.2×10^{-15}
Inhalation	2.4×10^{-13}	6.7×10^{-15}	2.1×10^{-11}	3.2×10^{-12}
Ingestion	4.7×10^{-14}	1.2×10^{-17}	5.8×10^{-15}	3.5×10^{-14}
Total	2.9×10^{-13}	7.9×10^{-15}	2.1×10^{-11}	3.2×10^{-12}
	U and Pu Recycle			
Air submersion	1.2×10^{-15}	1.2×10^{-15}	1.2×10^{-15}	1.2×10^{-15}
Inhalation	3.9×10^{-13}	7.2×10^{-15}	3.5×10^{-11}	5.9×10^{-12}
Ingestion	3.3×10^{-13}	3.3×10^{-17}	1.8×10^{-14}	8.1×10^{-13}
Total	7.2×10^{-13}	8.4×10^{-15}	3.5×10^{-11}	6.7×10^{-12}

a. After 30 years of release and accumulation in the environment.

TABLE 5.2.6-7. Summary of Annual Total-Body Doses Received from Operation of the Low-Level Waste Incineration Facility and Naturally Occurring Sources in the Year 2000

	Man-rem
LLW incineration facility	
Process work force (30 yr)	50
Population (within 80 km)	<0.001
Naturally occurring sources	
Population (within 80 km)	200,000

The 70-year doses to the maximum individual and to the population within 80 km of the facility are given in Tables 5.2.6-8 and 5.2.6-9 respectively. A summary of the 70-year total-body doses to the work force and the population is given in Table 5.2.6-10. For comparison, the population dose from naturally occurring sources over the 70-year period amounts to about 14,000,000 man-rem, compared with 3.3×10^{-10} man-rem received from operation of the LLW incineration facility.

TABLE 5.2.6-8. 70-Year Doses to Maximum Individual from Gaseous Effluents Released by the Low-Level Waste Incineration Facility (rem)

Pathway	Total Body	Thyroid[a]	Lung	Bone
	U Recycle, Pu in SHLW or PuO_2 Stored			
Air submersion	1.6×10^{-19}	1.6×10^{-19}	1.6×10^{-19}	1.6×10^{-19}
Inhalation	3.7×10^{-16}	8.6×10^{-19}	2.6×10^{-15}	5.9×10^{-15}
Ingestion	2.2×10^{-15}	9.3×10^{-21}	9.0×10^{-18}	8.7×10^{-15}
Total	2.6×10^{-15}	1.0×10^{-18}	2.6×10^{-15}	1.5×10^{-14}
	U and Pu Recycle			
Air submersion	1.6×10^{-19}	1.6×10^{-19}	1.6×10^{-19}	1.6×10^{-19}
Inhalation	6.5×10^{-16}	9.2×10^{-19}	5.7×10^{-15}	1.1×10^{-14}
Ingestion	2.1×10^{-15}	9.8×10^{-21}	9.0×10^{-18}	8.2×10^{-15}
Total	2.8×10^{-15}	1.1×10^{-18}	5.7×10^{-15}	1.9×10^{-14}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 1.5×10^{-8} sec/m^3.

a. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

TABLE 5.2.6-9. 70-Year Doses to Population from Gaseous Effluents Released by the Low-Level Waste Incineration Facility (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
	U Recycle, Pu in SHLW or PuO_2 Stored			
Air submersion	3.7×10^{-14}	3.7×10^{-14}	3.7×10^{-14}	3.7×10^{-14}
Inhalation	8.7×10^{-11}	2.0×10^{-13}	6.2×10^{-10}	1.4×10^{-9}
Ingestion	1.9×10^{-10}	9.5×10^{-16}	1.0×10^{-12}	7.7×10^{-10}
Total	2.8×10^{-11}	2.4×10^{-13}	6.2×10^{-10}	2.2×10^{-9}
	U and Pu Recycle			
Air submersion	3.7×10^{-14}	3.7×10^{-14}	3.7×10^{-14}	3.7×10^{-14}
Inhalation	1.5×10^{-10}	2.1×10^{-13}	1.3×10^{-9}	2.6×10^{-9}
Ingestion	1.8×10^{-10}	1.0×10^{-15}	1.0×10^{-12}	7.2×10^{-10}
Total	3.3×10^{-10}	2.5×10^{-13}	1.3×10^{-9}	3.3×10^{-9}

TABLE 5.2.6-10. Summary of 70-Year Total-Body Doses Received from Operation of the Low-Level Waste Incineration Facility and Naturally Occurring Sources in the Year 2000

	Man-rem
LLW incineration facility	
Process work force (30 yr)	1,500
Population (within 80 km)	<0.001
Naturally occurring sources	
Population (within 80 km)	14,000,000

"Health effects" for the regional population are discussed at the plant level where several processes within the plant are combined. In general, doses at the individual process level are too small for a meaningful discussion of health effects. In this report, 100 to 800 health effects are postulated to occur in the exposed population per million man-rem.

Ecological Effects. Operation of the LLW incineration facility results in the environmental release of several chemicals in the gaseous effluents. A comparison of the ground level concentrations with air quality standards is given in Table 5.2.6-11.

TABLE 5.2.6-11. Comparison of Ground Level Concentrations of Pollutants Released by the Low-Level Waste Incineration Facility with Air Quality Standards ($\mu g/m^3$)

Pollutant	Maximum Concentration	Average Concentration	Air Quality Standard
HCl	7.2×10^{-5}	3.6×10^{-5}	5×10^{2}
SO_x	2.4×10^{-4}	1.2×10^{-4}	8×10^{1}
NO_x	5.3×10^{-4}	2.6×10^{-4}	1×10^{2}
CO	1.9×10^{-3}	9.6×10^{-4}	4×10^{4}

Because the maximum ground level concentrations are more than four orders of magnitude lower than the air quality standard values, no ecological impacts are expected from these chemical releases.

Approximately 1.9×10^{7} MJ of heat per year for 4300 hrs of operation will be rejected to the atmosphere in the incineration facility gaseous releases. This heat release will have no perceptible effects on the nearby plant and animal communities.

Annual water requirements for the facility are 3×10^{3} m^3 for process uses and 9.3×10^{3} m^3 for cooling tower makeup; this water will be withdrawn from the R River near the reference site. (Process water may be recycled water from the FRP.) The total removal of water will be less than 0.01% of the minimum river flow or less than 0.001% of the annual average river flow and will not produce an impact on the river biota.

After passing through the LLW incineration facility, the process water will be sent to the liquid waste solidification system and will not be released to the environment. The cooling water will go to the FRP cooling tower where about 8 ℓ/min at a Δt of 17°C will be released as blowdown to R River. This small rejection of heat will not affect the river biota.

Environmental Effects Related to Postulated Accidents. Two minor accidents associated with combustible trash incineration were identified. However, neither accident is not expected to lead to any release of radioactive material to the biosphere. The scenario for this accident is provided in DOE/ET-0028[2] and is listed below.

Accident Number	Description
4.4.1	Loss of cooling water to the incinerator off-gas treatment system
4.4.2	Minor fire in feed preparation system

There were three accidents thought to release larger amounts of radioactive materials. These are classified as moderate accidents and are listed below.

Accident Number	Description
4.4.3	Fire in preparation line
4.4.4	Explosion in feed preparation line
4.4.5	Incinerator explosion

Of these accidents, Accident 4.4.5 (incinerator explosion) was judged to be most severe and was taken as representative of the set.

For this accident it was assumed that the explosion occurred in the FRP incinerator high gamma-TRU process line followed by the cell atmosphere release of 0.017 of the total annual activity over a period of 0.5 hr. The radioactive material released by such an event is shown in Table 5.2.6-12.

TABLE 5.2.6-12. Radionuclides Released to the Biosphere from Failure of the Low-Level Waste Incineration Facility (Ci)

Radionuclide	U Recycle, Pu in SHLW or PuO_2 Stored	U and Pu Recycle
^{90}Sr	3.0×10^{-6}	2.8×10^{-6}
^{106}Ru	7.8×10^{-6}	7.2×10^{-6}
^{129}I	2.6×10^{-3}	2.8×10^{-3}
^{134}Cs	5.5×10^{-6}	5.5×10^{-6}
^{137}Cs	4.2×10^{-6}	4.2×10^{-6}
^{144}Ce	1.1×10^{-5}	3.0×10^{-5}
^{238}Pu	1.4×10^{-7}	4.3×10^{-6}
^{239}Pu	1.3×10^{-8}	2.8×10^{-6}
^{240}Pu	2.1×10^{-8}	
^{241}Pu	5.0×10^{-6}	9.6×10^{-4}
^{241}Am	1.7×10^{-8}	
^{242}Cm	1.6×10^{-7}	
^{244}Cm	5.5×10^{-8}	

The 70-year dose commitment to the maximum individual was calculated and is presented in Table 5.2.6-13. Numerically, the largest dose found, (1.7×10^{-3} rem to bone) was on the order of the nominal 5×10^{-3} rem/yr variation in dose from naturally occurring sources and is not considered significant.

TABLE 5.2.6-13. 70-Year Dose Commitment to the Maximum Individual Resulting from Failure of the Low-Level Waste Incineration Facility (rem)

Pathway	Skin	Total Body	Thyroid	Lung	Bone
	U Recycle, Pu in SHLW or PuO_2 Stored				
Air submersion	1.6×10^{-9}	6.7×10^{-10}	6.7×10^{-10}	6.7×10^{-10}	6.7×10^{-10}
Inhalation		1.1×10^{-6}	3.4×10^{-4}	7.0×10^{-6}	1.0×10^{-5}
Total	1.6×10^{-9}	1.1×10^{-6}	3.4×10^{-4}	7.0×10^{-6}	1.0×10^{-5}
	U and Pu Recycle				
Air submersion	1.7×10^{-9}	7.0×10^{-10}	7.0×10^{-10}	7.0×10^{-10}	7.0×10^{-10}
Inhalation		8.0×10^{-5}	3.6×10^{-4}	4.1×10^{-4}	1.7×10^{-3}
Total	1.7×10^{-9}	8.0×10^{-5}	3.6×10^{-4}	4.1×10^{-4}	1.7×10^{-3}

No severe accidents were postulated within the design basis of the facility. Non-design basis accidents were not considered.

No accidents or unusual events have been identified that would result in the release of ecologically significant amounts of radioactive or nonradioactive materials.

5.2.6.2 Incineration Process for Intermediate-Level Waste (DOE/ET-0028 Sec. 4.4.1)

The incineration process considered here is for treatment of intermediate-level wastes (ILW) generated at an FRP. The capacity of the incineration facility is about 2.4×10^5 kg/yr on a 125-day/yr 24-hr/day basis. The process is attached directly to the FRP process building and to the facility for immobilization of wet wastes and particulate solids.

The ILW incineration process is described in the simplified flow diagram in Figure 5.2.6-2. In feed preparation, boxed feed is examined using an x-ray scanner to detect high-density materials. Feed containing such materials is sorted, and high-density combustibles are shredded, as are wooden filter frames after filter media have been removed in a filter media removal and pelletizing press. Pelletized filter media and noncombustibles are packaged in 55-gal drums. Sorted and shredded combustibles are repackaged, and this waste, along with that not requiring sorting, is assayed and sent to temporary storage. From the storage area, waste boxes are placed in the ram feeder, which feeds the controlled-air incinerator. The dual-chamber incinerator has a limited air supply to the lower chamber to maintain quiescent burning and an excess of air plus additional natural gas in the upper chamber to thoroughly burn the evolved gases. The off-gas from the secondary chamber is sent through a high-energy gas-scrubbing system for cooling and for removal of acidic gases and particulates before being sent through HEPA filters and to the FRP vessel off-gas treatment system. Scrubbing solution blowdown is concentrated about sixfold and is sent to the wet waste and particulate solids immobilization facility along with the incinerator ash. Water vapor from the concentrator is sent to the FRP vessel off-gas treatment system. Volumes and activities of the input and output streams of Figure 5.2.6-2 are shown in Table 5.2.6-14.

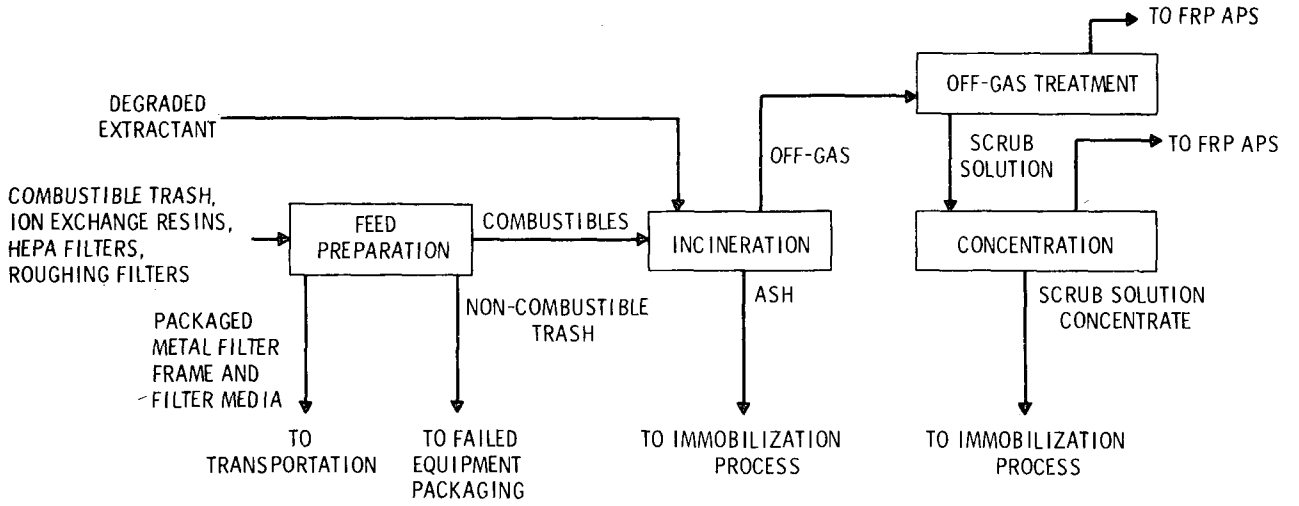

FIGURE 5.2.6-2. Treatment of Combustible Wastes and Filters at the FRP Intermediate-Level Waste Incineration Facility

TABLE 5.2.6-14. Annual Flow for Intermediate-Level Waste Incineration Facility at the FRP

Material	Volume, m^3	Activity, Ci	
		Fission Products	Actinides
Total feed	1.8×10^3	4×10^4	9×10^5
Filter media to disposal, 400 (55-gal) drums	8.0×10^1	3×10^4	7×10^5
Ash to immobilization	7.0×10^1	1×10^4	2×10^5
Concentrated blowdown solution to immobilization	1.5×10^2	7×10^2	9×10^3
Cleaned off-gas to vessel off-gas system	4×10^6 (STP)	8×10^{-2}	7×10^{-5}
Water vapor to vessel off-gas system	1.1×10^6	4×10^{-1}	1×10^{-1}

Environmental Effects Related to Facility Construction. Some of the factors relating to site preparation and reference facility construction may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of construction activities.

Resource Commitments. The ILW incineration facility at the FRP will occupy an area of about 660 m^2. The land commitments are included with those of the FRP; consequently, no analysis of land use attributable solely to the incineration process appears to be meaningful.

Water used during the construction period is approximately 2.3×10^3 m^3.

Materials committed for construction of the facility are:

Steel	300 MT
Copper	0.9 MT
Lumber	60 m^3
Concrete	1500 m^3

Energy resources committed for construction are:

Propane	20 m^3
Diesel fuel	190 m^3
Gasoline	130 m^3
Electricity	
Peak demand	160 kW
Total consumption	100,000 kWh

Manpower requirements for construction of the ILW incineration facility amount to 88 man-yr, which will likely be integrated with labor schedules for the FRP.

No additional transportation requirements for the incineration process have been identified beyond those for the FRP. No site-specific requirements have been identified.

Physical and Chemical Effects. Effects on air quality from construction of the ILW incineration facility will be an indistinguishable fraction of those resulting from construction of the reference FRP (Section 5.1.2).

The diversion of about 2300 m^3 of water for the construction of the ILW incineration facility will have no significant impact on local water supplies nor will the use of about 660 m^2 of land have a significant impact on local land use. Moreover, environmental effects of the facility construction related to land cannot be separated from the effects of the overall FRP construction.

Ecological Effects. The ecological impacts that may result from construction of the ILW incineration facility will be indistinguishable from those of the overall FRP complex. Construction impacts that may occur in the terrestrial environment include the elimination and alteration of vegetation cover; destruction of animal habitat; and the disturbance of animals caused by noise, dust, and human activity. No separate transportation requirements are foreseen for the ILW incineration facility beyond those for the FRP. Because of the small land area involved, the ecological impacts on the terrestrial ecosystem will be indistinguishable from those of the FRP.

Water requirements during an assumed 1-year construction period are 2.3×10^3 m^3 and will be supplied from the R River near the reference site. This is less than 0.01% of the recorded minimum flow of the R River, and withdrawal of this volume of water will not produce an adverse environmental effect. The quantity of silts that may reach nearby surface waters from the construction site will be imperceptible compared with those from the FRP, and they are not expected to produce measurable aquatic impacts.

Environmental Effects Related to Facility Operation. Some of the factors relating to facility operation may have an effect on the environment and the natural resources of the surrounding area. The information that follows provides a basis for evaluating the effect of operation.

Resource Commitments. Resources required during planned operation of the ILW incineration facility at the FRP are listed in Table 5.2.6-15.

TABLE 5.2.6-15. Utilities and Materials Required for Operating the Intermediate-Level Waste Incineration Facility

Resource	Average Annual[a] Use
Water	
Process water[b]	1.5×10^3 m^3
Cooling tower make up	6.3×10^3 m^3
Drift	2.6×10^1 m^3
Materials	
Barrels (55-gal drums)	4.0×10^2
Sodium hydroxide	2.0×10^1 MT
Cardboard boxes (0.06 m^3)	5.1×10^3
Energy	
Electricity	2.6×10^6 kWh
Propane	4.5×10^4 m^3
Manpower	1.4×10^1 man-yr

a. Based on 3000 hours operation/year.
b. Process water may be recycled from the FRP.

Process Effluents. The amounts of radioactive materials that reach the biosphere after leaving the FRP incinerator are shown in Table 5.2.6-16. The radionuclides listed are those that will contribute at least 1% of the total dose to a given organ from any pathway or that are otherwise of interest.

TABLE 5.2.6-16. Radionuclides Released to the Biosphere as a Result of Incineration of Intermediate-Level Waste at the FRP (Ci/yr)

Radionuclide	U Recycle, Pu in SHLW	U Recycle, PuO_2 Stored	U and Pu Recycle
^{3}H	4.7×10^{-1}	4.7×10^{-1}	4.7×10^{-1}
^{90}Sr	3.8×10^{-9}	4.0×10^{-9}	3.8×10^{-9}
^{129}I	1.3×10^{-1}	1.3×10^{-1}	1.4×10^{-1}
^{137}Cs	5.3×10^{-9}	5.7×10^{-9}	5.8×10^{-9}
^{238}Pu	7.4×10^{-9}	1.6×10^{-7}	2.9×10^{-7}
^{239}Pu	7.0×10^{-10}	1.5×10^{-8}	1.9×10^{-9}
^{240}Pu	1.1×10^{-9}	2.3×10^{-8}	3.8×10^{-8}
^{241}Pu	2.6×10^{-7}	5.7×10^{-6}	9.4×10^{-6}

Nonradioactive materials released via the FRP-APS stack are as follows:

Pollutant	Amount, MT/yr
HCl	0.07
SO_x	0.12
NO_x	0.27
CO	0.13

The ILW incineration facility produces about 1.7×10^7 MJ during 3000 hrs of operation per year that must be rejected to the atmosphere. This heat represents about 1% of the total FRP heat rejection. About two thirds of the heat will be rejected by a facility cooling tower. About one third of the heat will be released directly to the atmosphere.

From the 40 ℓ/sec of cooling water circulated to the cooling tower, a blowdown of 0.1 ℓ/sec can be expected. No wastes will be released to ground.

Physical, Chemical, and Thermal Effects. Atmospheric effects resulting from operation of the ILW incineration facility include air quality impacts from emission of nonradioactive pollutants and release of waste heat.

Annual average and maximum ambient ground level concentrations of pollutants released from an incineration process at the FRP were computed using $\overline{\chi}/Q'$ values listed in the reference environment. These concentrations are compared with air quality standards in Table 5.2.6-17.

TABLE 5.2.6-17. Comparison of Ground Level Concentrations[a] of Pollutants Released by the Intermediate-Level Waste Incineration Facility with Air Quality Standards ($\mu g/m^3$)

Pollutant	Maximum Concentration	Average Concentration	Air Quality Standard
HCl	5.8×10^{-5}	2.9×10^{-5}	5×10^2
SO_x	1.4×10^{-4}	9.6×10^{-5}	8×10^1
NO_x	4.2×10^{-4}	2.6×10^{-4}	1×10^2
CO	1.5×10^{-3}	7.7×10^{-4}	4×10^4

a. At the FRP fence line, 2800 m from the FRP stack.

At present, Federal air quality standards exist for all pollutants listed in Table 5.2.6-17 except HCl (considering SO_x as SO_2). These standards are 80 and 100 $\mu g/m^3$ for SO_2 and NO_x, respectively, computed as an annual arithmetic mean. Carbon monoxide, computed at a 1-hr ambient air concentration, has an existing standard of 4×10^4 $\mu g/m^3$. Computed concentrations from incineration at the FRP thus are substantially below Federal standards.

Currently, a threshold limit value of 5 $\mu g/m^3$ exists for HCl.[1] Computed air concentrations from incineration would not exceed that value.

The atmospheric effect of waste heat rejection will be limited to minor additions to fogging from the cooling tower.

All liquid and solid waste disposal for the ILW incineration facility is part of the overall FRP operation, and effects on water quality for this process will be indistinguishable from those of the FRP.

The incineration process contributes about 0.1 ℓ/sec of water at about 17°C Δt to the FRP cooling tower blowdown discharge during 3000 hr of operation per year. The process requires the diversion of about 7,900 m^3 of water annually of which 940 m^3 is returned to receiving water bodies as part of the cooling tower blowdown and the remaining amount is used comsumptively. Use of this water will have no impact on local water supplies.

Radiological Effects. Doses to individuals in the vicinity of the ILW incineration facility were calculated based on the releases of radionuclides as listed in Table 5.2.6-16; pathways, demography, and other parameters as described in Appendix A; and mathematical models relating dose to man from radionuclide releases as given in Appendix B. For planned operation of the ILW incineration facility the only pathway for radionuclides to man is via airborne effluents; there are no releases to ground or water.

The annual doses to individuals whose habits tend to maximize their dose ("maximum individual") are shown in Table 5.2.6-18. For perspective, the dose to an individual from naturally occurring radioactive sources averages about 0.1 rem/yr.

TABLE 5.2.6-18. Annual Doses to Maximum Individual from Gaseous Effluents Released by the Intermediate-Level Waste Incineration Facility (rem)[a]

Pathway	Total Body	Thyroid (child)[b]	Thyroid[c]	Lung	Bone
		U Recycle, Pu in SHLW			
Air submersion	6.0×10^{-12}		6.0×10^{-12}	6.0×10^{-12}	6.0×10^{-12}
Inhalation	3.5×10^{-9}		2.6×10^{-6}	2.0×10^{-8}	4.1×10^{-12}
Ingestion	3.8×10^{-7}	1.6×10^{-6}	3.0×10^{-4}	1.4×10^{-9}	2.0×10^{-7}
Total	3.8×10^{-7}	1.6×10^{-6}	3.0×10^{-4}	2.1×10^{-8}	2.0×10^{-7}
		U Recycle, PuO_2 Stored			
Air submersion	6.0×10^{-12}		6.0×10^{-12}	6.0×10^{-12}	6.0×10^{-12}
Inhalation	3.5×10^{-9}		2.6×10^{-6}	2.0×10^{-8}	8.4×10^{-11}
Ingestion	3.8×10^{-7}	1.6×10^{-6}	3.0×10^{-4}	1.4×10^{-9}	2.0×10^{-7}
Total	3.8×10^{-7}	1.6×10^{-6}	3.0×10^{-4}	2.1×10^{-8}	2.0×10^{-7}
		U and Pu Recycle			
Air submersion	6.4×10^{-12}		6.4×10^{-12}	6.4×10^{-12}	6.4×10^{-12}
Inhalation	3.7×10^{-9}		2.8×10^{-6}	2.1×10^{-8}	1.4×10^{-10}
Ingestion	4.1×10^{-7}	1.7×10^{-6}	3.2×10^{-4}	1.4×10^{-9}	2.1×10^{-7}
Total	4.1×10^{-7}	1.7×10^{-6}	3.2×10^{-4}	2.2×10^{-8}	2.1×10^{-7}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the highest annual average dispersion factor ($\bar{\chi}/Q'$) of 1.5×10^{-8} sec/m^3.

a. After 30 years of release and accumulation in the environment.

b. Thyroid dose is calculated for a 1-year-old child breathing air containing radioactive effluents and consuming 1 ℓ of milk per day from cows grazing 7 months/yr at the site boundary. Inhalation dose is <2% of total dose.

c. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

The combined dose from gaseous effluents to the population living within an 80-km radius of the plant was calculated using the projected year 2000 population data given in the reference environment (Appendix A). Table 5.2.6-19 summarizes the annual dose received by this population. The annual total-body population dose from naturally occurring sources to the approximately 2 million persons living within an 80-km radius of the plant in the year 2000 would be about 200,000 man-rem compared with the value of about 4.1×10^{-2} man-rem from process sources, as given in Table 5.2.6-19.

TABLE 5.2.6-19. Annual Doses to Population (within 80 km) from Gaseous Effluents Released by the Intermediate-Level Waste Incineration Facility (man-rem)(a)

Pathway	Total Body	Thyroid	Lung	Bone
	U Recycle, Pu in SHLW			
Air submersion	1.4×10^{-6}	1.4×10^{-6}	1.4×10^{-6}	1.4×10^{-6}
Inhalation	8.2×10^{-4}	6.1×10^{-1}	4.6×10^{-3}	9.6×10^{-7}
Ingestion	3.8×10^{-2}	2.9×10^{1}	1.3×10^{-4}	2.0×10^{-2}
Total	3.8×10^{-2}	2.9×10^{1}	4.7×10^{-3}	2.0×10^{-2}
	U Recycle, PuO_2 Stored			
Air submersion	1.4×10^{-6}	1.4×10^{-6}	1.4×10^{-6}	1.4×10^{-6}
Inhalation	8.3×10^{-4}	6.1×10^{-1}	4.7×10^{-3}	2.0×10^{-5}
Ingestion	3.8×10^{-2}	2.9×10^{1}	1.3×10^{-4}	2.0×10^{-2}
Total	3.8×10^{-2}	2.9×10^{1}	4.8×10^{-3}	2.0×10^{-2}
	U and Pu Recycle			
Air submersion	1.5×10^{-6}	1.5×10^{-6}	1.5×10^{-6}	1.5×10^{-6}
Inhalation	8.7×10^{-4}	6.5×10^{-1}	5.0×10^{-3}	3.3×10^{-5}
Ingestion	4.0×10^{-2}	3.2×10^{1}	1.3×10^{-4}	2.1×10^{-2}
Total	4.1×10^{-2}	3.2×10^{1}	5.1×10^{-3}	2.1×10^{-2}

a. After 30 years of release and accumulation in the environment.

The annual total-body dose to the work force associated with the ILW incineration facility was estimated based on permissible exposure limits and experience of operating plants. The annual occupational dose was calculated to be 60 man-rem. Table 5.2.6-20 summarizes the annual total-body dose to the work force and the general population from process and naturally occurring sources in the year 2000.

TABLE 5.2.6-20. Summary of Annual Total-Body Doses Received from Operation of the Intermediate-Level Waste Incineration Facility and Naturally Occurring Sources in the Year 2000

	Man-rem
ILW incineration facility (U and Pu recycle)(a)	
Process work force (30 yr)	60
Population (within 80 km)	0.041
Naturally occurring sources	
Population (within 80 km)	200,000

a. Use of the other two recycle modes (U recycle with Pu in SHLW and U recycle with PuO_2 stored) will result in annual total-body doses of 10% less.

The 70-year doses to the maximum individual and to the population within 80 km of the facility are given in Tables 5.2.6-21 and 5.2.6-22 respectively. A summary of the 70-year total-body doses to the work force and the population is given in Table 5.2.6-23. For comparison, the population dose from naturally occurring sources over the 70-year period amounts to about 14,000,000 man-rem, compared with 3 man-rem received from operation of the ILW incineration facility.

"Health effects" for the regional population are discussed at the plant level where several processes within the plant are combined. In general, doses at the individual process level are too small for a meaningful discussion of health effects. In this report, 100 to 800 health effects are postulated to occur in the exposed population per million man-rem.

TABLE 5.2.6-21. 70-Year Doses to Maximum Individual from Gaseous Effluents Released by the Intermediate-Level Waste Incineration Facility (rem)

Pathway	Total Body	Thyroid[a]	Lung	Bone
	U Recycle, Pu in SHLW			
Air submersion	1.8×10^{-10}	1.8×10^{-10}	1.8×10^{-10}	1.8×10^{-10}
Inhalation	1.1×10^{-7}	8.6×10^{-5}	6.0×10^{-7}	2.3×10^{-9}
Ingestion	2.6×10^{-5}	2.0×10^{-2}	4.5×10^{-8}	9.2×10^{-6}
Total	2.6×10^{-5}	2.0×10^{-2}	6.5×10^{-7}	9.2×10^{-6}
	U Recycle, Pu_2 Stored			
Air submersion	1.8×10^{-10}	1.8×10^{-10}	1.8×10^{-10}	1.8×10^{-10}
Inhalation	1.7×10^{-7}	8.6×10^{-5}	6.1×10^{-7}	4.8×10^{-8}
Ingestion	2.6×10^{-5}	2.0×10^{-2}	4.5×10^{-8}	9.2×10^{-6}
Total	2.6×10^{-5}	2.0×10^{-2}	6.6×10^{-7}	9.2×10^{-6}
	U and Pu Recycle			
Air submersion	1.9×10^{-10}	1.9×10^{-10}	1.9×10^{-10}	1.9×10^{-10}
Inhalation	8.1×10^{-8}	9.1×10^{-5}	6.5×10^{-7}	8.1×10^{-8}
Ingestion	2.8×10^{-5}	2.2×10^{-2}	4.5×10^{-8}	9.9×10^{-6}
Total	2.9×10^{-5}	2.2×10^{-2}	7.0×10^{-7}	9.9×10^{-6}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 1.5×10^{-8} sec/m^3.

a. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

TABLE 5.2.6-22. 70-Year Doses to Population from Gaseous Effluents Released by the Intermediate-Level Waste Incineration Facility (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
	U Recycle, Pu in SHLW			
Air submersion	4.2×10^{-5}	4.2×10^{-5}	4.2×10^{-5}	4.2×10^{-5}
Inhalation	2.7×10^{-2}	2.0×10^{1}	1.4×10^{-1}	5.3×10^{-4}
Ingestion	2.6	2.0×10^{3}	4.3×10^{-3}	9.2×10^{-1}
Total	2.6	2.0×10^{3}	1.4×10^{-1}	9.2×10^{-1}
	U Recycle, PuO_2 Stored			
Air submersion	4.2×10^{-5}	4.2×10^{-5}	4.2×10^{-5}	4.2×10^{-5}
Inhalation	2.7×10^{-2}	2.0×10^{1}	1.1×10^{-2}	2.7×10^{-2}
Ingestion	2.6	2.0×10^{3}	4.3×10^{-3}	9.2×10^{-1}
Total	2.6	2.0×10^{3}	1.5×10^{-2}	9.5×10^{-1}
	U and Pu Recycle			
Air submersion	4.5×10^{-5}	4.5×10^{-5}	4.5×10^{-5}	4.5×10^{-5}
Inhalation	2.9×10^{-2}	2.1×10^{1}	1.5×10^{-1}	1.9×10^{-2}
Ingestion	2.8	2.2×10^{3}	4.3×10^{-3}	9.9×10^{-1}
Total	2.8	2.2×10^{3}	1.5×10^{-1}	1.0

TABLE 5.2.6-23. Summary of 70-Year Total-Body Doses Received from Operation of the Intermediate-Level Waste Incineration Facility and Naturally Occurring Sources in the Year 2000

	Man-rem
ILW incineration facility	
Process work force (30 yr)	1,800
Population (within 80 km)	3
Naturally occurring sources	
Population (within 80 km)	14,000,000

Ecological Effects. Operation of the ILW incineration facility will release several nonradioactive chemicals in the gaseous effluents. Since the maximum ground level concentrations are several orders of magnitude lower than the air quality standards, no ecological impacts are expected from these chemical releases.

Approximately 1.3×10^{7} MJ of heat will be released to the atmosphere by the incineration facility. This will have no perceptible effect on nearby plant and animal communities.

Annual water requirements for the facility are 1.5×10^{3} m^3 for process and 6.3×10^{3} m^3 for cooling and will be supplied from the R River near the reference site. The total removal of water will be less than 0.1% of the minimum recorded river flow, and the removal of this volume of water will not adversely affect the river.

The waste process water will be sent to liquid waste treatment and will not be released to the environment. The cooling water will go to the FRP cooling tower where about 5 ℓ/min at a Δt of 17°C will be released as blowdown to the R River. This small rejection of heat will not affect the river biota.

Environmental Effects Related to Postulated Accidents. Two minor accidents associated with the ILW incineration facility were identified but no releases of radioactive materials to the environment are postulated for this event. The scenario for the accident is provided in ERDA 77-85.[2] The accident is listed below.

Accident Number	Description
4.4.1	Loss of cooling water to incinerator off-gas system
4.4.2	Minor fire in fuel preparation system

There were three accidents thought to release larger amounts of radioactive materials. These are classified as moderate accidents and are listed below.

Accident Number	Description
4.4.3	Fire in preparation line
4.4.4	Explosion in feed preparation line
4.4.5	Incinerator explosion

Of these accidents, Accident 4.4.5 (incinerator explosion) was judged to be most severe and was taken as representative of the set. (This accident and its consequences were also discussed in Section 5.2.6.1.)

For this accident it was assumed that the explosion occurred in the FRP incinerator high gamma-TRU process line followed by the release to cell atmosphere of 0.017 of the total annual activity over 0.5 hr. The radioactive material released to the biosphere from such an event is shown in Table 5.2.6-24.

TABLE 5.2.6-24. Radionuclides Released to the Biosphere from Failure of the Intermediate-Level Waste Incineration Facility (Ci)

Radionuclide	U Recycle, Pu in SHLW or PuO_2 Stored	U and Pu Recycle
^{90}Sr	3.0×10^{-6}	2.8×10^{-6}
^{106}Ru	7.8×10^{-6}	7.2×10^{-6}
^{129}I	2.6×10^{-3}	2.8×10^{-3}
^{134}Cs	5.5×10^{-6}	5.5×10^{-6}
^{137}Cs	4.2×10^{-6}	4.2×10^{-6}
^{144}Ce	1.1×10^{-5}	3.0×10^{-5}
^{238}Pu	1.4×10^{-7}	4.3×10^{-6}
^{239}Pu	1.3×10^{-8}	2.8×10^{-6}
^{240}Pu	2.1×10^{-8}	
^{241}Pu	5.0×10^{-6}	9.6×10^{-4}
^{241}Am	1.7×10^{-8}	
^{242}Cm	1.6×10^{-7}	
^{244}Cm	5.5×10^{-8}	

The 70-year dose commitment to the maximum individual was calculated and is presented in Table 5.2.6-25. Numerically, the largest dose found (1.7×10^{-3} rem to bone) was on the order of the nominal 5×10^{-3} rem/yr variation in dose from naturally occurring sources and is not considered significant.

No severe accidents were postulated within the design basis of the facility. Non-design basis accidents were not considered.

TABLE 5.2.6-25. 70-Year Dose Commitment to the Maximum Individual Resulting from Failure of the Intermediate-Level Waste Incineration Facility (rem)

Pathway	Skin	Total Body	Thyroid	Lung	Bone
	U Recycle, Pu in SHLW or PuO_2 Stored				
Air submersion	1.6×10^{-9}	6.7×10^{-10}	6.7×10^{-10}	6.7×10^{-10}	6.7×10^{-10}
Inhalation		1.1×10^{-6}	3.4×10^{-4}	7.0×10^{-6}	1.0×10^{-5}
Total	1.6×10^{-9}	1.1×10^{-6}	3.4×10^{-4}	7.0×10^{-6}	1.0×10^{-5}
	U and Pu Recycle				
Air submersion	1.7×10^{-9}	7.0×10^{-10}	7.0×10^{-10}	7.0×10^{-10}	7.0×10^{-10}
Inhalation		8.0×10^{-5}	3.6×10^{-4}	4.1×10^{-4}	1.7×10^{-3}
Total	1.7×10^{-9}	8.0×10^{-5}	3.6×10^{-4}	4.1×10^{-4}	1.7×10^{-3}

No accidents or unusual events have been identified that would result in the release of ecologically significant amounts of radioactive or nonradioactive materials.

5.2.6.3 Packaging Without Treatment of Low-Level Wastes at an FRP (DOE/ET-0028 Sec 4.4.4)

Packaging of FRP low-level wastes (LLW) without treatment is an alternative to incineration or compaction of these wastes prior to packaging. The minimum treatment process for LLW consists of receiving low-level general trash in sealed plastic bags, assaying the waste for fissile material content, hand-placing the waste into 55-gal steel drums, capping and palletizing the drums for transport, and storing the palletized drums to await transport. The facility has a capacity of about 3800 m^3 of treated waste per year and includes a storage capacity for 3 months' waste production. Volumes and activities of input and output streams are shown in Table 5.2.6-26.

TABLE 5.2.6-26. Annual Flow for the Low-Level Waste Minimum Treatment and Packaging Facility at an FRP

Material	Volume, m^3	Activity, Ci	
		Fission Products	Actinides
Total feed	2400	2.8	0.4
Drummed waste to disposal (12,000 55-gal drums)	2400	2.8	0.4

The LLW facility is attached to the FRP process building. The facility includes space for drum loading, assay, and capping; shielded untreated waste and filled drum storage areas; and a truck loading bay.

Environmental Effects Related to Facility Construction. Some of the factors relating to site preparation and reference facility construction may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of construction activities.

Resource Commitments. The area occupied by the LLW packaging without treatment facility will be 850 m^2, which includes the new drum storage and truck loading bay. This area is considered to be an integral part of the FRP, therefore no separate discussion of land use impact seems warranted.

Water usage during construction will be approximately 2.3×10^3 m^3.

Materials committed for construction of the LLW packaging without treatment facility are:

Steel	270 MT
Copper	2.7 MT
Lumber	120 m^3
Concrete	1700 m^3

Energy resources committed for construction are:

Propane	20 m^3
Diesel fuel	190 m^3
Gasoline	130 m^3
Electricity	
Peak demand	150 kW
Total consumption	100,000 kWh

Manpower requirements for construction of the LLW packaging without treatment facility will amount to 85 man-yr, which will likely be integrated with labor schedules for the FRP.

No additional transportation requirements for the facility have been identified beyond those for the FRP. No other site-specific requirements have been identified.

Physical and Chemical Effects. Effects on air quality from construction of the LLW packaging without treatment facility at the FRP will be an indistinguishable fraction of those resulting from construction of the FRP (Section 5.1.2).

The use of about 860 m^2 of land for the LLW packaging without treatment facility is not expected to have any impact on local land use. The diversion of about 2300 m^3 of water for the construction of this facility will have no impact on local water supplies. In general, however, environmental effects of the facility construction related to land and water cannot be separated from the effects of the overall FRP construction.

Ecological Effects. The LLW packaging without treatment facility at the FRP will require approximately 860 m^2 of land, which is included in the 40 ha within the FRP exclusion area. The ecological impacts of construction of this facility will be indistinguishable from those of the FRP. Construction of the facility will contribute insignificantly to the overall FRP destruction of vegetation and animal habitat and the disturbance of animals by noise, dust, and human activity.

Water requirements during an assumed 1-year construction period will be about 2.3×10^3 m^3 and will be supplied from the R River near the reference site. This volume of water is less than 0.01% of the minimum recorded river flow and will have no detectable impact on the aquatic ecosystem.

Environmental Effects Related to Facility Operation. Some of the factors relating to facility operation may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of operation.

Resource Commitments. Annual supply, utility, and staffing requirements during operation of the LLW minimum treatment and packaging facility at the FRP are listed below:

Resource	Annual Requirement
55-gal Steel Drums	1.2×10^4
Wooden pallets	3.0×10^3
Electricity, kWh	1×10^5
Manpower, man-yr	3.2

Process Effluents. During operation of the LLW minimum treatment and packaging facility there are no planned releases of radioactive materials to air, water, or ground; therefore there are no pathways for radionuclides to man.

Except for release of 3×10^5 MJ of heat in ventilation air operation of the packaging facility will produce no nonradioactive pollutants or waste heat for release to the air, water, or ground. No process or cooling water will be required.

Physical, Chemical, and Thermal Effects. Since there will be no planned direct release of pollutants from the LLW minimum treatment and packaging facility, no effects will occur. Liquid and solid waste disposal for the facility is part of the overall FRP operation.

Radiological Effects. No radioactive materials will be released by the LLW minimum treatment and packaging facility at the FRP; therefore there will be no radiological effects resulting from routine operation.

Ecological Effects. No nonradioactive pollutants will be released by the LLW minimum treatment and packaging facility at the FRP; consequently, no ecological impacts are expected from routine operation.

Environmental Effects Related to Postulated Accidents. Two minor accidents were postulated for minimum packaging of general trash and combustible waste at the FRP. The accident scenarios are described in DOE/ET-0028[2] and are listed below.

Accident Number	Description
4.4.6	Ruptured waste bag spill to floor
4.4.7	Fire in one barrel of bagged trash

Accident 4.4.6 was judged to release no radioactive material. Accident 4.4.7 was considered to be no worse than a fire in the bitumen immobilization facility; the consequences of that Accident 4.7.7 were therefore assigned to Accident 4.4.6.

The estimated quantities of radionuclides released to the atmosphere are presented in Table 5.2.6-27.

TABLE 5.2.6-27. Radionuclides Released to the Atmosphere from a Minor Accident in the Low-Level Waste Minimum Treatment and Packaging Facility at the FRP (Ci)

Radionuclide	U and Pu Recycle	U Recycle
^{3}H	5.0×10^{-5}	5.0×10^{-5}
^{14}C	1.3×10^{-12}	1.3×10^{-12}
^{60}Co	4.9×10^{-12}	4.9×10^{-12}
^{90}Sr	7.3×10^{-12}	7.8×10^{-12}
^{95}Zr	4.1×10^{-11}	4.1×10^{-11}
^{95}Nb	9.1×10^{-11}	9.1×10^{-11}
^{106}Ru	2.3×10^{-9}	2.0×10^{-9}
^{134}Cs	1.4×10^{-11}	1.4×10^{-11}
^{137}Cs	1.1×10^{-11}	1.1×10^{-11}
^{238}Pu	6.6×10^{-11}	3.7×10^{-11}
^{239}Pu	4.3×10^{-12}	3.5×10^{-12}
^{240}Pu	8.8×10^{-12}	5.4×10^{-12}
^{241}Pu	2.2×10^{-9}	1.3×10^{-9}

Annual does and 70-year dose commitments were calculated for these releases for the maximum individual and the regional population, using average annual dispersion factors. In no case was the resulting dose greater than 1×10^{-11} rem for any individual dose and most often was several orders of magnitude less and does not constitute a radiological impact.

There is one accident thought to release radioactive materials in amounts larger than those released by minor accidents. The accident was classified as moderate and is discussed below.

Accident Number	Description
4.4.8	Spent HEPA filter spilled to floor

Accident 4.4.8 was considered to be no worse than a process off-gas cleanup system failure in a waste solidification facility; therefore the consequences of that Accident 4.1.8 were assigned to Accident 4.4.8. That accident was also discussed in Section 5.2.2.

The estimated quantities of radionuclides released to the atmosphere are presented in Table 5.2.6-28. The 70-year dose commitment to the maximum individual from this accident is presented in Table 5.2.6-29.

TABLE 5.2.6-28. Radionuclides Released to the Atmosphere from a Moderate Accident in the Low-Level Waste Minimum Treatment and Packaging Facility at the FRP (Ci)

Radionuclide	U Recycle, Pu in SHLW	U Recycle, PuO_2 Stored	U and Pu Recycle
^{90}Sr	1.2×10^{-3}	1.2×10^{-3}	1.2×10^{-3}
^{95}Nb	1.4×10^{-4}	1.4×10^{-4}	1.4×10^{-4}
^{106}Ru	3.2×10^{-3}	3.2×10^{-3}	3.6×10^{-3}
^{125m}Te	4.1×10^{-5}	4.1×10^{-5}	4.5×10^{-5}
^{127m}Te	7.9×10^{-6}	7.9×10^{-6}	8.1×10^{-6}
^{134}Cs	2.3×10^{-3}	2.3×10^{-3}	2.3×10^{-3}
^{137}Cs	1.7×10^{-3}	1.7×10^{-3}	1.8×10^{-3}
^{144}Ce	4.7×10^{-3}	4.7×10^{-3}	4.5×10^{-3}
^{154}Eu	1.0×10^{-4}	1.0×10^{-4}	1.2×10^{-4}
^{238}Pu	5.9×10^{-5}	3.0×10^{-7}	
^{239}Pu	5.5×10^{-6}	2.8×10^{-8}	3.4×10^{-8}
^{240}Pu	8.5×10^{-6}		
^{241}Pu	1.9×10^{-3}		
^{241}Am	7.0×10^{-6}	7.0×10^{-6}	1.3×10^{-5}
^{242}Cm	6.6×10^{-5}	6.6×10^{-5}	1.9×10^{-4}
^{244}Cm	2.3×10^{-5}	2.3×10^{-5}	1.3×10^{-4}

TABLE 5.2.6-29. 70-Year Dose Commitment to the Maximum Individual from a Moderate Accident in the Low-Level Waste Minimum Treatment and Packaging Facility at the FRP (rem)

Organ	U Recycle, Pu in SHLW	U Recycle, PuO_2 Stored	U and Pu Recycle
Total body	3×10^{-4}	1×10^{-4}	2×10^{-4}
Thyroid	6×10^{-7}	6×10^{-7}	7×10^{-7}
Lung	2×10^{-3}	1×10^{-3}	3×10^{-3}
Bone	4×10^{-3}	8×10^{-4}	2×10^{-3}
Skin	2×10^{-7}	2×10^{-7}	2×10^{-7}

The largest dose calculated is on the order of the annual variation in dose received from naturally occurring sources and is expected to be without consequence.

No severe accidents were postulated within the design basis of the facility. Non-design basis accidents were not considered. No accidents or unusual events have been identified that would result in the release to the environment of significant amounts of nonradioactive materials.

5.2.6.4 Packaging Without Treatment of Intermediate-Level Wastes at an FRP (DOE/ET-0028 Sec. 4.4.3)

Packaging FRP intermediate-level wastes (ILW) without treatment is an alternative to incineration or compaction of the wastes prior to packaging. A flow diagram for the steps involved in the packaging of ILW without treatment is shown in Figure 5.2.6-3. The steps consist of receiving shielded waste carriers (shielded drums) containing wastes sealed in plastic bags from the FRP, opening and removing this bagged waste and transferring it to new steel drums if necessary, assaying the drums for fissile material content, lidding the drums, decontaminating and inspecting the drums, and palletizing and finally storing the filled drums. All operations are carried out remotely in shielded cells. Palletized drums are loaded out of the facility for shipment to either interim storage or a repository. The general trash is packaged into 55-gal drums, and the HEPA filters are packaged in 80-gal drums. The facility has a capacity of about 2400 m^3/yr and includes a preshipment storage capacity for 3 months' production. Volumes and activities of input and output streams are shown in Table 5.2.6-30.

The facility is directly attached to the FRP processing building. The facility consists of a series of shielded cells in which operations are performed remotely. Figure 5.2.6-3 lists the major equipment items.

Environmental Effects Related to Facility Construction. Some of the factors relating to site preparation and reference facility construction may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of construction activities.

Resource Commitments. The ILW packaging without treatment facility at the FRP will occupy an area of about 1100 m^2, which includes a filled drum vault of 470 m^2. This facility is designed to be an integral part of the FRP.

Water usage during the construction period will be approximately 3.4×10^3 m^3.

Materials committed for construction of the ILW packaging without treatment facility are:

Steel	450 MT
Copper	0.9 MT
Lumber	250 m^3
Concrete	2900 m^3

Energy resources committed for construction are:

Propane	25 m^3
Diesel fuel	270 m^3
Gasoline	170 m^3
Electricity	
Peak demand	200 kW
Total consumption	130,000 kWh

Manpower requirements for construction of the ILW minimum treatment and packaging facility will amount to 115 man-yr, which will likely be integrated with labor schedules for the FRP..

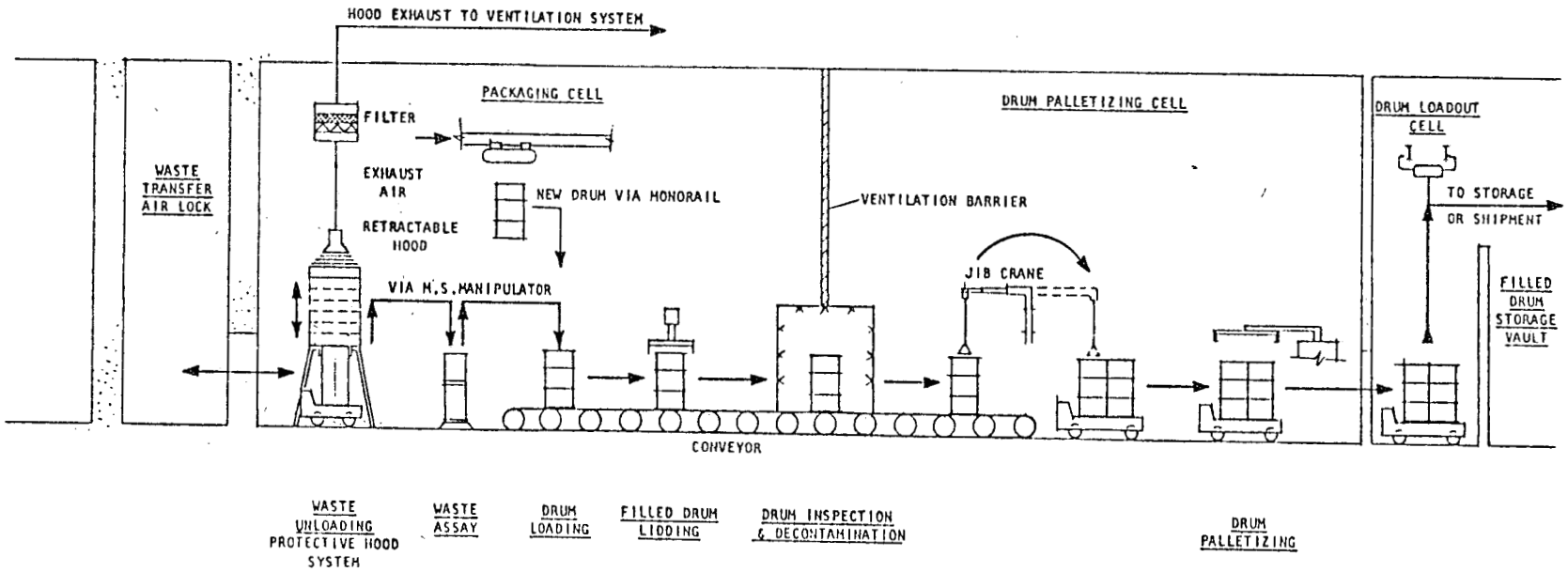

FIGURE 5.2.6-3. Flow Diagram for Packaging Intermediate-Level Waste with Minimum Treatment at an FRP

TABLE 5.2.6-30. Annual Flow for the Intermediate-Level Waste Without Treatment Packaging Facility at an FRP

Material	Volume, m^3	Activity, Ci	
		Fission Products	Actinides
Total feed	1740	4.4×10^4	9×10^5
Drummed waste to disposal (2900 80-gal drums)	320	2.8×10^4	7×10^{-5}
Drummed waste to disposal (7200 55-gal drums)	1420	1.4×10^4	2×10^5

No additional transportation requirements for the ILW minimum treatment and packaging facility have been identified beyond those for the FRP. No other site-specific requirements have been identified.

Physical and Chemical Effects. Effects on air quality from construction of the ILW minimum treatment and packaging facility will be an indistinguishable fraction of those resulting from construction of the FRP (Section 5.1.2).

The diversion of about 3400 m^3 of water for the construction of the facility is expected to have no impact on local water supplies.

The use of about 1100 m^2 of land for the ILW minimum treatment and packaging facility is not expected to have a significant impact on local land use. Moreover, environmental effects of the facility construction related to land cannot be separated from the effects of the overall FRP construction.

Ecological Effects. The packaging of radioactive wastes with minimum treatment is part of the reference FRP and the land requirements are included with those of the FRP. Approximately 1100 m^2 of the 400,000 m^2 within the FRP secured area will be occupied by the packaging facility.

Impacts to the terrestrial environment will be indistinguishable from those of the FRP. Construction impacts that may occur include the elimination and alteration of vegetation cover; destruction of animal habitat; and the disturbance of animals caused by noise, dust, and human activity. No separate transportation needs are required for the facility beyond those of the FRP. Because of the small land area involved, the ecological impacts to the land will be slight.

Water requirements during an assumed 1-year construction period are 3.4×10^3 m^3 and will be supplied from the R River near the reference site. This volume will constitute less than 0.01% of the minimum river flow and will not produce an impact on the stream ecosystem.

Environmental Effects Related to Facility Operation. Some of the factors relating to facility operation may have an effect on the environment and the material resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of operation.

Resource Commitments. Annual supply, utility, and staffing requirements during operation of the ILW minimum treatment and packaging facility at the FRP are listed below:

Resource	Annual Requirement
55-gal steel drums	7.2×10^3
80-gal steel drums	2.9×10^3
Wooden pallets	2.6×10^3
Electricity, kWh	3×10^5
Manpower, man-yr	3.3

Process Effluents. During operation of the ILW packaging without treatment facility there are no planned releases of radioactive material to air, water, or ground; therefore, there are no pathways for radionuclides to man.

Operation of the packaging facility will produce no nonradioactive pollutants or waste heat for release to the air, water, or ground. No process or cooling water will be required.

Physical, Chemical, and Thermal Effects. Since there will be no planned direct release of pollutants from the ILW minimum treatment and packaging facility, no effects will occur. Liquid and solid waste disposal for the facility is part of the overall FRP operation.

Radiological Effects. No radioactive material will be released by the ILW minimum treatment and packaging facility at the FRP; therefore, there will be no radiological effects resulting from routine operation.

Ecological Effects. There will be no release of nonradioactive liquids or solids to the surrounding land or water. No process water is required. Therefore, no ecological impacts will result from routine operation of this facility.

Environmental Effects Related to Postulated Accidents. Two minor accidents were postulated for minimum packaging of general trash and combustible waste at the reference FRP. The accident scenarios are described in ERDA 77-85[2] and are listed below.

Accident Number	Description
4.4.6	Ruptured waste bag spill to floor
4.4.7	Fire in one barrel of bagged trash

Accident 4.4.6 was judged to release no radioactive material. Accident 4.4.7 was considered to be no worse than a fire in the bitumen immobilization facility; the consequences of that Accident 4.7.7 were therefore assigned to Accident 4.4.6. (This accident and its consequences were also discussed in Section 5.2.6.3.)

The estimated quantities of radionuclides released to the atmosphere are presented in Table 5.2.6-31.

Annual doses and 70-year dose commitments were calculated for these releases for the maximum individual and the regional population, using average annual dispersion factors. In no case was the resulting dose greater than 1×10^{-11} rem for any individual dose and most often was several orders of magnitude less and does not constitute a radiological impact. any individual of less than 1×10^{-6} rem is considered negligible and does not constitute a radiological impact.

TABLE 5.2.6-31. Radionuclides Released to the Atmosphere from a Minor Accident in the Intermediate-Level Waste Minimum Treatment and Packaging Facility (Ci)

Radionuclide	U Recycle, Pu in SHLW or PuO_2 Stored	U and Pu Recycle
^{3}H	5.0×10^{-5}	5.0×10^{-5}
^{14}C	1.3×10^{-12}	1.3×10^{-12}
^{60}Co	4.9×10^{-12}	4.9×10^{-12}
^{90}Sr	7.8×10^{-12}	7.3×10^{-12}
^{95}Zr	4.1×10^{-11}	4.1×10^{-11}
^{95}Nb	9.1×10^{-11}	9.1×10^{-11}
^{106}Ru	2.0×10^{-9}	2.3×10^{-9}
^{134}Cs	1.4×10^{-11}	1.4×10^{-11}
^{137}Cs	1.1×10^{-11}	1.1×10^{-11}
^{238}Pu	3.7×10^{-11}	6.6×10^{-11}
^{239}Pu	3.5×10^{-12}	4.3×10^{-12}
^{240}Pu	5.4×10^{-12}	8.8×10^{-12}
^{241}Pu	1.3×10^{-9}	2.2×10^{-9}

There is one accident thought to release radioactive materials in amounts larger than those released by minor accidents. The accident was classified as moderate and is discussed below.

Accident Number	Description
4.4.8	Spent HEPA filter spilled to floor

Accident 4.4.8 was considered to be no worse than a process off-gas cleanup system failure in a waste solidification facility; therefore the consequences of that Accident 4.1.8 were assigned to Accident 4.4.8. That accident and its consequences were also discussed in Sections 5.2.2 and 5.6.2.3.

The estimated quantities of radionuclides released to the atmosphere are presented in Table 5.2.6-32. The 70-year dose commitment to the maximum individual from this accident is presented in Table 5.2.6-33. The largest dose calculated is on the order of the annual variation in dose received from naturally occurring sources and is expected to be without consequence.

No severe accidents were postulated within the design basis of the facility. Non-design basis accidents were not considered. No accidents or unusual events have been identified that would result in the release to the environment of significant amounts of nonradioactive materials.

TABLE 5.2.6-32. Radionuclides Released to the Atmosphere from a Moderate Accident in the Intermediate-Level Waste Minimum Treatment and Packaging Facility at the FRP (Ci)

Radionuclide	U Recycle, Pu in SHLW	U Recycle, PuO_2 Stored	U and Pu Recycle
^{90}Sr	1.2×10^{-3}	1.2×10^{-3}	1.2×10^{-3}
^{95}Nb	1.4×10^{-4}	1.4×10^{-4}	1.4×10^{-4}
^{106}Ru	3.2×10^{-3}	3.2×10^{-3}	3.6×10^{-3}
^{125m}Te	4.1×10^{-5}	4.1×10^{-5}	4.5×10^{-5}
^{127m}Te	7.9×10^{-6}	7.9×10^{-6}	8.1×10^{-6}
^{134}Cs	2.3×10^{-3}	2.3×10^{-3}	2.3×10^{-3}
^{137}Cs	1.7×10^{-3}	1.7×10^{-3}	1.8×10^{-3}
^{144}Ce	4.7×10^{-3}	4.7×10^{-3}	4.5×10^{-3}
^{154}Eu	1.0×10^{-4}	1.0×10^{-4}	1.2×10^{-4}
^{238}Pu	5.9×10^{-5}	3.0×10^{-7}	
^{239}Pu	5.5×10^{-6}	2.8×10^{-8}	3.4×10^{-8}
^{240}Pu	8.5×10^{-6}		
^{241}Pu	1.9×10^{-3}		
^{241}Am	7.0×10^{-6}	7.0×10^{-6}	1.3×10^{-5}
^{242}Cm	6.6×10^{-5}	6.6×10^{-5}	1.9×10^{-4}
^{244}Cm	2.3×10^{-5}	2.3×10^{-5}	1.3×10^{-4}

TABLE 5.2.6-33. 70-Year Dose Commitment to the Maximum Individual from a Moderate Accident in the Intermediate-Level Waste Minimum Treatment and Packaging Facility at the FRP (rem)

Organ	U Recycle, Pu in SHLW	U Recycle, PuO_2 Stored	U and Pu Recycle
Total body	3×10^{-4}	1×10^{-4}	2×10^{-4}
Thyroid	6×10^{-7}	6×10^{-7}	7×10^{-7}
Lung	2×10^{-3}	1×10^{-3}	3×10^{-3}
Bone	4×10^{-3}	8×10^{-4}	2×10^{-3}
Skin	2×10^{-7}	2×10^{-7}	2×10^{-7}

5.2.6.5 Comparison of Environmental Effects of General Trash and Combustible Waste Treatments at the FRP

Selected aspects of construction and operation of the general trash and combustible waste treatment alternatives (incineration and packaging with minimum treatment) are presented in Tables 5.2.6-34 through 5.2.6-36.

TABLE 5.2.6-34. Comparison of Resource Commitments for Construction of Alternative General Trash and Combustible Waste Treatment Facilities at the FRP (LLW and ILW)

Resource	Incineration		Without Treatment	
	LLW	ILW	LLW	ILW
Land, m^2	520	660	855	1100
Water, m^3	1.1×10^3	2.3×10^3	2.3×10^3	3.4×10^3
Materials				
Steel, MT	9.0×10^1	3.0×10^2	2.7×10^2	4.5×10^2
Copper, MT	9.0×10^{-1}	9.0×10^{-1}	2.7	9.0×10^{-1}
Lumber, m^3	2.5×10^1	6.0×10^1	1.2×10^2	2.5×10^2
Concrete, m^3	5.0×10^2	1.5×10^3	1.7×10^3	2.9×10^3
Energy				
Propane, m^3	1.1×10^1	2.0×10^1	2.0×10^1	2.5×10^1
Diesel fuel, m^3	1.1×10^2	1.9×10^2	1.9×10^2	2.7×10^2
Gasoline, m^3	7.6×10^1	1.3×10^2	1.3×10^2	1.7×10^2
Electricity, kWh	6.0×10^4	1.0×10^5	1.0×10^5	1.3×10^5
Manpower, man-hr	9.8×10^4	1.75×10^5	1.7×10^5	2.3×10^5

Because of the larger storage area needed for the packaging without treatment facility, two to four times more water and materials will be needed for its construction as for construction of the incineration facility. Energy requirements are comparable. Resource commitments are either too small or not sufficiently different between the alternatives to form a basis for selection.

In terms of process operation, the packaging without treatment process requires only a nominal amount of electricity and manpower. Incineration requires cooling water, about ten times the electricity, and a number of other materials not required in the minimum treatment and packaging process. The incineration process approximately doubles the pollutant load released to the atmosphere from the FRP.

Minimum treatment of combustible ILW and LLW results in the need for 19,200 55-gal (0.2 m^3) drums per year and 2,900 80-gal (0.3 m^3) drums per year. The ILW incineration process requires 400 drums per year for packaging HEPA filter media and an additional 2,930 55-gal drums per year for containment of incinerator ash and scrubber blowdown if such wastes are immobilized by cement or an additional 940 55-gal drums per year if immobilized by bitumen. (Immobilization of wastes is discussed in Section 5.2.7.) Thus, the total of 19,200 55-gal and 2,900 80-gal drums per year compares with a total of about 3,300 55-gal drums if cement immobilization is used and about 1,300 if bitumen immobilization is used. In terms of 55-gal drums, minimum treatment of incinerator wastes requires the use of 6 times more drums than those needed for cement immobilization and 15 times more drums than those needed for bitumen immobilization. The number of drums may not be important in terms of resource commitments, but the number also reflects transportation requirements and final isolation volume requirements.

TABLE 5.2.6-35. Comparison of Nonradiological Aspects of Operating Alternative General Trash and Combustible Waste Treatment Facilities at the FRP (LLW and ILW)

	Annual Quantity			
	Incineration		Without Treatment	
	LLW	ILW	LLW	ILW
Water				
Evaporated, m^3	7.9×10^3	5.4×10^3		
Drift, m^3	3.8×10^1	2.6×10^1		
Blowdown, m^3	1.4×10^3	9.4×10^5		
Makeup, m^3	9.3×10^3	6.4×10^6		
Materials				
Boxes (0.06 m^3-cardboard)	5.3×10^3	5.1×10^3		
Drums				
55-gal		4.0×10^2	1.2×10^4	7.2×10^3
80-gal				2.9×10^3
Sodium hydroxide, MT	3.0×10^1	2.0×10^1		
Wooden pallets			3.0×10^3	2.6×10^3
Energy				
Electricity, kWh	3.5×10^6	2.6×10^6	1.0×10^5	3.0×10^5
Propane, m^3	6.0×10^4	4.5×10^4		
Manpower, man-yr	1.35×10^1	1.35×10^1	3.2	3.3
Nonradioactive effluents				
HCl, MT	1.0×10^{-1}	7.0×10^{-2}		
SO_x, MT	1.8×10^{-1}	1.2×10^{-1}		
NO_x, MT	4.0×10^{-1}	2.7×10^{-1}		
CO, MT	1.9×10^{-1}	1.3×10^{-1}		
Waste heat				
Via cooling tower, MJ	1.9×10^7	1.3×10^7		
Via vessel off-gas, MJ	6.5×10^6	4.7×10^6		
Via ventilation air, MJ			3.0×10^5	

In the packaging without treatment of combustible wastes, 12,700 drums have surface activities of <0.2 R/hr and 36 drums can be shipped by truck at one time. Thus, about 353 trips from the FRP to a repository will be required annually. About 6,500 drums have surface activities in the range of 0.2 to 1 R/hr and will be shipped 36 at one time in a shielded container. Thus, about 180 trips are needed to deliver these drums to the repository. About 2,900 drums (80-gal) have surface activities of >10 R/hr and will be shipped six at one time in more heavily shielded containers. Thus, about 483 shipments are needed to deliver these drums. The total trips necessary amount to 1020 per year. The reference distance from the FRP to a repository is 2.4×10^3 km so that the annual shipping distance would be about 2.4×10^6 km one way. Since the containers must be returned, the total distance chargeable to minimum treatment of combustible waste would be about 4.8×10^6 km.

TABLE 5.2.6-36. Comparison of Radiological Aspects of Operating Alternative General Trash and Combustible Waste Treatment Facilities at the FRP

	Incineration	Packaging Without Treatment
Principal Radionuclides Released to the Atmosphere, Ci/yr		
^{3}H	4.7×10^{-1}	
^{90}Sr	3.8×10^{-9}	8.0×10^{-12}
^{129}I	1.4×10^{-1}	7.0×10^{-6}
^{137}Cs	5.8×10^{-9}	1.3×10^{-11}
^{238}Pu	2.9×10^{-7}	1.5×10^{-10}
^{239}Pu	1.9×10^{-9}	1.1×10^{-11}
^{240}Pu	3.8×10^{-8}	2.0×10^{-11}
^{241}Pu	9.4×10^{-6}	5.0×10^{-9}
Dose to Maximum Individual from 70-Year Residency (30-year plant life), rem		
Total body	2.9×10^{-5}	1.4×10^{-9}
Thyroid	2.2×10^{-2}	1.1×10^{-6}
Lung	7.0×10^{-7}	4.5×10^{-11}
Bone	9.9×10^{-6}	5.4×10^{-10}
(Dose from naturally occurring sources for same period, 7 rem)		
Dose to Regional Population from 70-Year Residency (2 million persons, 30-year plant life), man-rem		
Total body	2.8	1.4×10^{-4}
Thyroid	2.2×10^{3}	1.1×10^{-1}
Lung	1.2	1.1×10^{-5}
Bone	5.3	5.9×10^{-5}
(Dose from naturally occurring sources for same period, 1.4×10^{7} man-rem)		
Dose to Process Work Force (30-year plant life), man-rem		
Total body	1.8×10^{3}	2.4×10^{2}
70-Year Dose Commitment to Maximum Individual from Most Serious Accident Identified, rem		
Total body	8×10^{-5}	2×10^{-4}

Notes: No radioactive material is released from either process to water or ground. The effects of processing intermediate-level wastes are given. The effects of processing low-level wastes are 6 to 7 orders of magnitude lower.

If the incineration process is chosen and is followed by cement immobilization, 2388 drums will have surface activities of <0.2 R/hr and if shipped 36 at a time will result in 66 trips per year. Another 547 drums of ash will have surface activities of 1 to 10 R/hr and when shipped 14 at a time will add 39 trips. If cement immobilization is selected, a total of 105 trips per year taken would be with a total round-trip distance of 5×10^5 km/yr.

If the incineration process is followed by bitumen immobilization of ash and scrubber blowdown, 684 drums will have surface activities of <0.2 R/hr and if shipped 36 drums per trip will result in 19 trips. Another 256 drums of ash will have surface activities of >10 R/hr and at 6 drums per trip will result in 43 trips. The total trips to the repository would be 62 per year for a total round-trip distance of 3×10^5 km/yr.

This analysis indicates that, in terms of transportation costs (i.e., fuel, exhaust emissions, and nonradiological traffic injuries and fatalities), incineration with cement immobilization is about 1/10 that of the minimum treatment option and bitumen immobilization is about 1/16 that of the minimum treatment option.

Trucks used to ship non-high-level transuranic (TRU) wastes plus their cargo are expected to weigh about 23 MT. At a rate of 2.2×10^4 MT-km/m^3 of diesel fuel, the fuel requirements will amount to about 1.0×10^{-3} m^3/km. Thus, minimum treatment requires about 5000 m^3 of diesel fuel annually. The incineration option with cement immobilization of ash and scrubber blowdown requires about 510 m^3 of diesel fuel annually. Similarly, incineration with bitumen immobilization requires about 310 m^3 of diesel fuel annually. If six 2000-MTHM FRPs and one 1500-MTHM FRP each operate for 30 years, an equivalent of about 200 FRP-years will result in consumption of about 990,000 m^3 of diesel fuel for the minimum treatment option, about 100,000 m^3 for incineration with cement immobilization, and about 63,000 m^3 for the bitumen immobilization option. Thus, about 900,000 m^3 of diesel fuel could be saved by opting for either the cement immobilization or bitumen immobilization of incineration ash and blowdown.

Another consideration is the number of traffic fatalities resulting from such transportation requirements. The total distance through the year 2050 for the minimum treatment option is estimated at about 1.2×10^9 km. At a fatality rate of 0.047 per million kilometers, about 58 fatalities could be expected. For the cement immobilization option about five fatalities would occur and for the bitumen immobilization option about three fatalities would occur. For perspective, about 2.8 million Americans will have lost their lives in traffic accidents over the 70-year period.

In the above analysis, the assumption was made that transportation of non-high-level transuranic wastes would be by truck. Though not calculated at this time, some savings apparently could be realized in fuel, exhaust emissions, and traffic injuries and fatalities if wastes are shipped by rail.

For this same period, the dose to the population from direct radiation received from passing waste shipments can be calculated from the product of the dose received from direct radiation of 7.5 man-rem per million kilometers and the distance one way. For minimum treatment of combustible wastes and a distance of 6.0×10^8 km, a population dose of 4500 man-rem is obtained. At an assumed 10,000 man-rem per fatal cancer or serious genetic effect, direct radiation from shipment

of untreated combustible waste does not result in even one such case. The health effects from the incineration facility's contribution to direct dose from transportation would be even less significant.

In radiological terms, routine operation of the minimum treatment and packaging facility results in no release of radioactive materials to the atmosphere. The principal radionuclide released in the incineration process is ^{129}I, which results in a 70-year residency dose to the regional population of 2.2×10^3 man-rem to the thyroid, based on one FRP. The dose for the same period from incineration would add about 20% to the dose from treated dissolver off-gas. The dose to the process work force for incineration is about eight times that for the minimum treatment and packaging process.

In the absence of other environmental impacts associated with cementation or bitumenization, it is concluded that incineration of combustible waste followed by bitumen immobilization is the process with the least environmental impact; cement immobilization is only slightly less advantageous.

REFERENCES FOR SECTION 5.2.6

1. American Conference of Governmental Industrial Hygienists, Threshold Limit Values for Current Year (1976), ACGIH, Cincinnati, Ohio, 1976.

2. Technology for Commercial Radioactive Waste Management, DOE/ET-0028, Department of Energy, Washington, DC, in press.

5.2.7 Wet Wastes and Particulate Solids (DOE/ET-0028 Sec. 4.7)

The operation of any facility in the post-fission nuclear fuel cycle results in the generation of radioactive concentrated liquids, wet wastes, and particulate solids. Prior to shipping and disposing of these wastes, their immobilization to a liquid-free form is necessary. This step may be done by a variety of methods, each with unique process characteristics. Immobilization of these wet wastes in bitumen and cement is discussed here as applied to an FRP. Another alternative, urea-formaldehyde immobilization, which requires process equipment similar to cement immobilization, has not been considered in detail in this Statement.

5.2.7.1 Bitumen Immobilization at the FRP (DOE/ET-0028 Sec. 4.7.1)

Immobilization of radioactive wet wastes in bitumen involves mixing the waste form with liquid bitumen or asphalt binder and placing it in a 55-gal drum. The temperature of the binder (above 100°C) evaporates the free water, thus reducing the waste volume. The use of bitumen to immobilize radioactive wastes has been well demonstrated, largely through extensive operating experience in Europe. As discussed in ERDA 76-43,[1] several types of bitumen immobilization processes have been developed. This present study selects a continuous screw extruder process for the following reasons:

- The screw extruder bitumenization process operates at lower temperatures and with shorter residence times than the batch process, thus minimizing off-gas problems.
- The reference process uses well-demonstrated technology.
- The process is commercially available in the United States.

The reference bitumen immobilization facility is assumed to be an integral part of the FRP and constructed to withstand design basis earthquakes and tornados. The facility is designed to process all transuranic (TRU) and some non-TRU wastes generated in the FRP, although the non-TRU wastes are outside the scope of this report. A process flow diagram of the bitumen immobilization facility is shown Figure 5.2.7-1, with the material balance shown in Table 5.2.7-1.

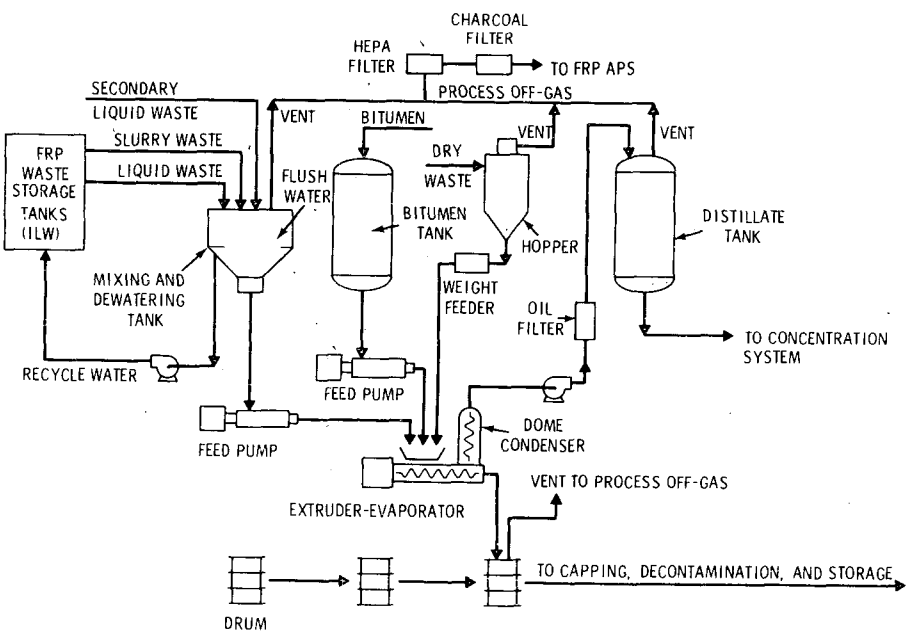

FIGURE 5.2.7-1. Process Flow Diagram for an FRP Bitumen Immobilization Facility

TABLE 5.2.7-1. Annual Flow of Primary and Secondary Wastes at an FRP Bitumen Immobilization Facility

Material	Volume, m^3	Mass, kg	Activity, Ci[a]
Waste feed	870	910,000	1.5×10^6
Bitumen	330	350,000	0
Empty drums (2528)	550	63,200	0
Distillate	560	560,000	2.4×10^2
Filled drums (2528)	550	770,000	1.5×10^6
Off-gas[b]			1×10^{-3}

a. At 1.5 years out of reactor.
b. 820 m^3/hr of air.

Environmental Effects Related to Facility Construction. Some of the factors relating to site preparation and reference facility construction may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of construction activities.

Resource Commitments. The bitumen immobilization facility will occupy an area of about 860 m^2. This facility will be an integral part of the reference FRP, whose structures will occupy an area of about 400,000 m^2. Land committed to the facility is inconsequential by comparison and in any event would be preempted by construction of the FRP.

Water used during construction is estimated to be 3600 m^3. Withdrawal of this amount of water from the R River (with an average flow of 1.0×10^7 m^3/day) is judged to be insignificant with respect to downstream uses. During the construction period, wells could also supply the required amount of water without consequence.

Materials committed for construction of the bitumen immobilization facility are:

Concrete	1500 m^3
Steel	450 MT
Copper	7 MT
Lumber	94 m^3

These quantities are judged to be insignificant in terms of resource use.

Energy resources used during construction are:

Propane	38 m^3
Diesel fuel	340 m^3
Gasoline	230 m^3
Electricity	
Peak demand	350 kW
Total consumption	220,000 kWh

These quantities represent an additional 2 to 4% of the amount required for construction of the FRP.

Manpower requirements estimated for construction of the bitumen immobilization facility amount to 140 man-yr, which will likely be integrated with labor schedules for the FRP.

No separate transportation requirements for the facility have been identified beyond those for the FRP. No additional site requirements beyond those for the FRP are identifiable.

No unique environmental effects are associated with construction of this facility beyond those for the FRP.

Physical and Chemical Effects. The effects on air quality, water quality, and land use from construction of a bitumen immobilization facility will be an indistinguishable fraction of those resulting from construction of the FRP.

Ecological Effects. The bitumen immobilization facility will occupy an area less than 1% the size of the 40-ha FRP exclusion area. The construction impacts that may result are destruction or alteration of vegetation, or the disturbance of animal habitat from noise, dust, and human activity. These effects will be indistinguishable from the overall effects of the FRP. No additional transportation facilities beyond those needed for the FRP will be required.

The water requirement is less than 0.1% of the minimum recorded river flow. Withdrawal of this amount of water will not adversely affect the stream biota.

No ecological impacts beyond those of the FRP complex will result from construction of the bitumen immobilization facility.

Environmental Effects Related to Facility Operation. Some of the factors relating to facility operation may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of operation.

Resource Commitments. Resources required during planned operation of the FRP bitumen immobilization process are given in Table 5.2.7-2.

TABLE 5.2.7-2. Utilities and Materials Required for Operating the Bitumen Immobilization Facility at the FRP

Resource	Average Annual Use
Cooling water	8.7×10^2 m^3
Process water	8.4×10^3
Materials	
Stainless steel drums	2.5×10^3
Bitumen	3.5×10^2 MT
Electricity	4.8×10^5 kWh
Manpower	5.4 man-yr

Process Effluents. The nonradioactive releases to the atmosphere will be limited to water vapors, small amounts of suspended particulate matter, and local odors from the bitumen. The total annual release of vaporized excess water in the gaseous emissions will be 2.7×10^2 MT.

The bitumen immobilization process contributes about 130 m^3/yr of water to the FRP cooling tower blowdown discharge during 5200 hr of operation per year. The process requires the diversion of about 870 m^3 of water annually for cooling tower makeup. The total waste heat released to the atmosphere amounts to 1.8×10^6 MJ over 200 days per year.

There is no direct disposal of nonradioactive liquid or solid wastes to ground from the bitumen immobilization facility. All liquid and solid waste disposal for the facility is part of the overall FRP operation.

The amounts of radioactive materials that reach the biosphere after leaving the bitumen immobilization facility and passing through the FRP atmospheric protection system (APS) are shown in Table 5.2.7-3. The radionuclides listed are those contributing at least 1% of the total dose to a given organ from any pathway or that are otherwise of interest.

TABLE 5.2.7-3. Radionuclides Released to the Biosphere from the FRP Bitumen Immobilization Facility (Ci/yr)

Radionuclide	U Recycle, Pu in SHLW or PuO_2 Stored	U and Pu Recycle
^{3}H	8.4×10^{2}	8.4×10^{2}
^{14}C	6.6×10^{-14}	6.6×10^{-14}
^{60}Co	2.5×10^{-9}	2.5×10^{-9}
^{90}Sr	5.1×10^{-9}	4.8×10^{-9}
^{95}Zr	2.0×10^{-8}	2.0×10^{-8}
^{95}Nb	4.6×10^{-8}	4.6×10^{-8}
^{106}Ru	1.0×10^{-6}	1.1×10^{-6}
^{129}I	2.1×10^{-5}	2.2×10^{-5}
^{134}Cs	9.4×10^{-9}	9.4×10^{-9}
^{137}Cs	7.2×10^{-9}	7.2×10^{-9}
^{238}Pu	2.2×10^{-8}	5.6×10^{-8}
^{239}Pu	2.1×10^{-9}	3.7×10^{-9}
^{240}Pu	3.2×10^{-9}	7.4×10^{-9}
^{241}Pu	7.9×10^{-7}	1.8×10^{-6}

Radionuclides are entrained in process off-gas. Estimated off-gas rates are 20 m^3/hr from liquid-handling process vents, 400 m^3/yr from waste solids-handling process vents, and 400 m^3/hr from the two filling station ventilation hoods for a total of 820 m^3/hr. This represents about 0.03% of the total air flow through the FRP-APS.

Physical, Chemical, and Thermal Effects. The odors from the bitumen will be comparable to the odors from roofing or paving activities. Procedures to reduce noxious odors from the bitumen immobilization facility in order to prevent detection beyond the site boundary may be required. In terms of air quality impact, the amount of suspended particulate matter released will result in air concentrations at the fence line that are several orders of magnitude below existing Federal ambient air quality standards.

The bitumen immobilization facility will contribute about 1.8×10^6 MJ of heat over about 200 days/yr. Of this amount, one third will be released directly to the atmosphere and the remainder via drift and evaporation of water from the FRP cooling tower. The microclimate effects from this release are considered to be insignificant.

The facility cooling water will contribute about 1.3×10^2 m^3/yr to the FRP cooling tower blowdown, which will be discharged to the R River at a Δt of 17°C. This total represents less than 0.1% of the FRP cooling requirements and will have an imperceptible effect on the thermal plume resulting from release of blowdown and once-through cooling water from the reference FRP.

None of the operations associated with this process will result in direct effects on land. All liquid and solid waste disposal for the process is part of the overall FRP operation.

Radiological Effects. Doses to individuals in the environs of the bitumen immobilization facility were calculated based on the releases of radionuclides as listed in Table 5.2.7-3; pathways, demography, and other parameters as described in Appendix A; and mathematical models relating dose to man from radionuclide releases as given in Appendix B. For planned operation of the bitumen immobilization facility the only exposure pathway to man is via airborne effluents; there are no releases to ground or water.

The annual doses to individuals whose habits tend to maximize their dose ("maximum individual") are shown in Table 5.2.7-4. For perspective, the dose to an individual from naturally occurring radioactive sources averages about 0.1 rem/yr.

The combined dose from gaseous effluents to the population living within an 80-km radius of the plant was calculated using the projected year 2000 population data given in the reference environment (Appendix A). Table 5.2.7-5 summarizes the annual doses received by this population. The annual population dose from naturally occurring sources to the approximately 2 million persons living within an 80-km radius of the plant in the year 2000 would be about 200,000 man-rem compared with the highest value of about 0.3 man-rem received from process sources as given in Table 5.2.7-5.

The annual total-body dose to the work force associated with the bitumen immobilization facility was estimated based on permissible exposure limits and experience of operating plants. The annual occupational dose was calculated to be 3 man-rem. Table 5.2.7-6 summarizes the annual total-body dose to the work force and general public from process and naturally occurring sources in the year 2000.

TABLE 5.2.7-4. Annual Doses to Maximum Individual from Gaseous Effluents Released by the FRP Bitumen Immobilization Facility (rem)[a]

Pathway	Total Body	Thyroid (child)[b]	Thyroid[c]	Lung	Bone
	U Recycle, Pu in SHLW or PuO_2 Stored				
Air submersion	1.6×10^{-15}	1.6×10^{-15}	1.6×10^{-15}	1.6×10^{-15}	1.6×10^{-15}
Inhalation	4.4×10^{-7}		4.4×10^{-7}	4.4×10^{-7}	1.7×10^{-11}
Ingestion	2.5×10^{-6}	1.4×10^{-6}	2.6×10^{-6}	2.5×10^{-6}	3.2×10^{-11}
Total	2.9×10^{-6}	1.4×10^{-6}	3.0×10^{-6}	2.9×10^{-6}	4.9×10^{-11}
	U and Pu Recycle				
Air submersion	1.7×10^{-15}	1.7×10^{-15}	1.7×10^{-15}	1.7×10^{-15}	1.6×10^{-15}
Inhalation	4.4×10^{-7}		4.4×10^{-7}	4.4×10^{-7}	2.8×10^{-11}
Ingestion	2.5×10^{-6}	1.4×10^{-6}	2.6×10^{-6}	2.5×10^{-6}	3.4×10^{-11}
Total	2.9×10^{-6}	1.4×10^{-6}	3.0×10^{-6}	2.9×10^{-6}	6.2×10^{-11}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the highest annual average dispersion factor ($\bar{\chi}/Q'$) of 1.5×10^{-8} sec/m^3.

a. After 30 years of release and accumulation in the environment.
b. Thyroid dose is calculated for a 1-year-old child breathing air containing radioactive effluents and consuming 1 ℓ of milk per day from cows grazing 7 months/yr at the site boundary. Inhalation dose is <2% of total dose.
c. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

TABLE 5.2.7-5. Annual Doses to Population (within 80 km) from Gaseous Effluents Released by the FRP Bitumen Immobilization Facility (man-rem)[a]

Pathway	Total Body	Thyroid	Lung	Bone
	U Recycle, Pu in SHLW or PuO_2 Stored			
Air submersion	3.6×10^{-10}	3.6×10^{-10}	3.6×10^{-10}	3.6×10^{-10}
Inhalation	1.0×10^{-1}	1.0×10^{-1}	1.0×10^{-1}	3.9×10^{-6}
Ingestion	2.3×10^{-1}	2.4×10^{-1}	2.3×10^{-1}	3.2×10^{-6}
Total	3.3×10^{-1}	3.4×10^{-1}	3.3×10^{-1}	7.1×10^{-6}
	U and Pu Recycle			
Air submersion	3.9×10^{-10}	3.9×10^{-10}	3.9×10^{-10}	3.9×10^{-10}
Inhalation	1.0×10^{-1}	1.0×10^{-1}	1.0×10^{-1}	6.5×10^{-6}
Ingestion	2.3×10^{-1}	2.4×10^{-1}	2.3×10^{-1}	3.4×10^{-6}
Total	3.3×10^{-1}	3.4×10^{-1}	3.3×10^{-1}	1.0×10^{-5}

a. After 30 years of release and accumulation in the environment.

TABLE 5.2.7-6. Summary of Annual Total-Body Doses Received from Operation of the FRP Bitumen Immobilization Facility and Naturally Occurring Sources in the Year 2000

	Man-rem
Bitumen immobilization facility	
Process work force (30 yr)	3
Population (within 80 km)	0.3
Naturally occurring sources	
Population (within 80 km)	200,000

The 70-year doses to the maximum individual and to the population within 80 km of the facility are given in Tables 5.2.7-7 and 5.2.7-8 respectively. A summary of the 70-year total-body doses to the work force and the population is given in Table 5.2.7-9. For comparison, the population dose from naturally occurring sources over the 70-year period amounts to about 14,000,000 man-rem, compared with 11 man-rem received from the bitumen immobilization facility.

Total-body dose to the worldwide population is limited to that received from the release of 8.4×10^{2} Ci of ^{3}H and 6.6×10^{-14} Ci of ^{14}C; no ^{85}Kr is released during the bitumen immobilization process at the FRP. The worldwide population dose for the 30th year of plant operation was calculated to be 5.7 man-rem, and the 70-year accumulated dose from 30 years of operation was calculated to be 2.0×10^{2} man-rem. The dose to this population from naturally occurring radioactive sources for these two periods would be about 6×10^{8} and 4.5×10^{10} man-rem respectively.

TABLE 5.2.7-7. 70-Year Doses to Maximum Individual from Gaseous Effluents Released by the FRP Bitumen Immobilization Facility (rem)

Pathway	Total Body	Thyroid[a]	Lung	Bone
	U Recycle, Pu in SHLW or PuO_2 Stored			
Air submersion	4.7×10^{-14}	4.7×10^{-14}	4.7×10^{-14}	4.7×10^{-14}
Inhalation	1.3×10^{-5}	1.3×10^{-5}	1.3×10^{-5}	9.5×10^{-9}
Ingestion	8.1×10^{-5}	8.4×10^{-5}	8.1×10^{-5}	1.6×10^{-9}
Total	9.4×10^{-5}	9.7×10^{-5}	9.4×10^{-5}	1.1×10^{-8}
	U and Pu Recycle			
Air submersion	5.0×10^{-14}	5.0×10^{-14}	5.0×10^{-14}	5.0×10^{-14}
Inhalation	1.3×10^{-5}	1.3×10^{-5}	1.3×10^{-5}	1.6×10^{-8}
Ingestion	8.1×10^{-5}	8.5×10^{-5}	8.1×10^{-5}	1.7×10^{-9}
Total	9.4×10^{-4}	9.8×10^{-5}	9.4×10^{-5}	1.8×10^{-8}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 1.5×10^{-8} sec/m^3.

a. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

TABLE 5.2.7-8. 70-Year Doses to Population (within 80 km) from Gaseous Effluents Released by the FRP Bitumen Immobilization Facility (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
	U Recycle, Pu in SHLW or PuO_2 Stored			
Air submersion	1.1×10^{-8}	1.1×10^{-8}	1.1×10^{-8}	1.1×10^{-8}
Inhalation	3.1	3.1	3.1	2.2×10^{-3}
Ingestion	7.6	8.0	7.6	1.6×10^{-4}
Total	1.1×10^{1}	1.1×10^{1}	1.1×10^{1}	2.4×10^{-3}
	U and Pu Recycle			
Air submersion	1.2×10^{-8}	1.2×10^{-8}	1.2×10^{-8}	1.2×10^{-8}
Inhalation	3.1	3.1	3.1	3.7×10^{-3}
Ingestion	7.6	8.0	7.6	1.7×10^{-4}
Total	1.1×10^{1}	1.1×10^{1}	1.1×10^{1}	3.9×10^{-3}

TABLE 5.2.7-9. Summary of 70-Year Total-Body Doses Received from Operation of the FRP Bitumen Immobilization Facility and Naturally Occurring Sources in the Year 2000

	Man-rem
Bitumen immobilization facility	
Process work force (30 yr)	90
Population (within 80 km)	11
Naturally occurring sources	
Population (within 80 km)	14,000,000

"Health effects" for the regional population are discussed at the plant level where several processes within the plant are combined. In general, doses at the individual process level are too small for a meaningful discussion of health effects. In this report, 100 to 800 health effects are postulated to occur in the exposed population per million man-rem.

Ecological Effects. During normal operation (5200 hr/yr) the bitumen immobilization facility will reject about 1.8×10^{6} MJ of heat to the environment. Of this amount, approximately one third will be released directly to the atmosphere and an additional two thirds to the drift and water vapor from the FRP cooling tower. No adverse effects to the nearby plant and animal communities will result from this heat release.

Cooling water requirements will be about 8.7×10^{2} m^3/yr and will be supplied by the R River near the reference site. This withdrawal represents less than about 0.0001% of the minimum recorded low daily flow of the river and will not have a perceptible effect on the river biota. The facility cooling water will contribute approximately 1.3×10^{2} m^3/yr to the FRP cooling tower blowdown, which will be discharged to the R River at a Δt of 17°C. This water will be rapidly diluted by the much larger volume river flow and will produce no adverse ecological effects.

Environmental Effects Related to Postulated Accidents. A number of minor accidents associated with bitumen immobilization were identified which would be expected to lead to releases of radioactive material. Scenarios for these accidents are provided in DOE/ET-0028.[2] The accidents are listed below.

Accident Number	Description
4.7.1	Overfill waste drum
4.7.2	Drum filling control valve failure
4.7.3	Drum-fill-level detector failure
4.7.4	Container drop or rupture
4.7.5	Leakage in waste in transfer line
4.7.6	Bitumen fire

Based on the anticipated releases of these minor accidents, weighted by their expected frequency of occurrence, an average annual release was postulated. The estimated quantities of radionuclides released to the atmosphere are presented in Table 5.2.7-10.

TABLE 5.2.7-10. Radionuclides Released to the Atmosphere from Minor Accidents in the FRP Bitumen Immobilization Facility (Ci/yr)

Radionuclide	U Recycle, Pu in SHLW or PuO_2 Stored	U and Pu Recycle
^{3}H	5.0×10^{-5}	5.0×10^{-5}
^{14}C	1.3×10^{-12}	1.3×10^{-12}
^{60}Co	4.9×10^{-12}	4.9×10^{-12}
^{90}Sr	7.8×10^{-12}	7.3×10^{-12}
^{95}Zr	4.1×10^{-11}	4.1×10^{-11}
^{95}Nb	9.1×10^{-11}	9.1×10^{-11}
^{106}Ru	2.0×10^{-9}	2.3×10^{-9}
^{134}Cs	1.4×10^{-11}	1.4×10^{-11}
^{137}Cs	1.1×10^{-11}	1.1×10^{-11}
^{238}Pu	3.7×10^{-11}	6.6×10^{-11}
^{239}Pu	3.5×10^{-12}	4.3×10^{-12}
^{240}Pu	5.4×10^{-12}	8.8×10^{-12}
^{241}Pu	1.3×10^{-9}	2.2×10^{-9}

Annual doses and 70-year dose commitments for the maximum individual and the regional population were calculated for these accident releases, using average annual dispersion factors. In no case was the resulting dose greater than 6×10^{-12} rem for any individual dose and most often was several orders of magnitude less and does not constitute a radiological impact.

There were several accidents thought to involve larger releases of radioactive material. These are classed as moderate accidents and are listed below.

Accident Number	Description
4.7.7	Cell HEPA failure with any minor accident
4.7.8	Cell HEPA failure with bitumen fire (in FRP-TRU process line)

Of these accidents, Accident 4.7.8 (cell HEPA failure with bitumen fire) was judged to be most severe and was taken as representative of the set.

For this accident it was assumed that six open barrels catch fire during filling operations and that 1% of the radioactive material in 1 kg of fixed wastes is released to the cell atmosphere from each barrel. A release period of 30 min is assumed. Expected frequency of this accident is 0.003 per year. A moderate release of radioactive material could occur if a HEPA filter failed (from improper installation or smoke damage) concurrently.

The radioactive release associated with such an event is presented in Table 5.2.7-11. The 70-year dose commitment to the maximum individual was calculated and is presented in Table 5.2.7-12. Numerically, the largest of these dose values is on the order of the nominal 5×10^{-3} rem/yr variation in dose received from naturally occurring sources. No accidents were postulated for the bitumen immobilization facility which would lead to more serious consequences. Non-design basis accidents were not considered.

TABLE 5.2.7-11. Radionuclides Released to the Atmosphere from a Moderate Accident in the FRP Bitumen Immobilization Facility (Ci)

Radionuclide	U Recycle, Pu in SHLW or PuO_2 Stored	U and Pu Recycle
^{3}H	1.3×10^{-4}	1.3×10^{-4}
^{14}C	3.4×10^{-9}	3.4×10^{-9}
^{60}Co	1.3×10^{-8}	
^{90}Sr	2.0×10^{-8}	1.9×10^{-8}
^{95}Zr	1.1×10^{-7}	
^{95}Nb	2.4×10^{-7}	2.4×10^{-7}
^{106}Ru	5.5×10^{-6}	6.0×10^{-6}
^{125m}Te	7.0×10^{-10}	
^{134}Cs	3.7×10^{-8}	
^{137}Cs	2.9×10^{-8}	2.9×10^{-8}
^{238}Pu	9.5×10^{-8}	1.7×10^{-7}
^{239}Pu	9.0×10^{-9}	1.1×10^{-8}
^{240}Pu	1.4×10^{-8}	
^{241}Pu	3.4×10^{-6}	5.5×10^{-6}

TABLE 5.2.7-12. 70-Year Dose Commitment to the Maximum Individual Resulting from a Moderate Accident in the FRP Bitumen Immobilization Facility (rem)

Pathway	U Recycle, Pu in SHLW or PuO_2 Stored	U and Pu Recycle
Air submersion		
Total body	1.3×10^{-11}	1.4×10^{-11}
Skin	1.2×10^{-10}	1.3×10^{-10}
Inhalation		
Total body	2.7×10^{-7}	4.5×10^{-7}
Bone	6.0×10^{-6}	9.5×10^{-6}
Lung	1.7×10^{-6}	2.7×10^{-6}
Thyroid	4.3×10^{-10}	4.3×10^{-10}

No ecological effects would be expected from the release of small quantities of materials identified in the postulated accidents.

5.2.7.2 Cement Immobilization at the FRP (DOE/ET-0028 Sec. 4.7.2)

Immobilization of radioactive wet wastes in cement involves mixing the wastes with cement, placing the mixture into drums, and allowing the mixture to harden to a water-free product. Cement immobilization of radioactive wastes has been widely used in the United States. A variety of cementation technologies have been developed, including in-drum mixers, drum tumblers, and in-line mixers, each of which is described in ERDA 76-43.[1] For use in this study, a drum-tumbling system has been selected based on the following reasons:

- Both liquid and dry wastes may be immobilized without altering the commercially available technology.
- The wastes are mixed inside the drums thus preventing external solidification of the waste-cement mixture.

The reference cement immobilization facility is assumed to be an integral part of the FRP and constructed to withstand design basis earthquakes and tornados. As with the bitumen immobilization facility, the facility will handle all TRU and most non-TRU wastes at the FRP (although only TRU wastes are within the scope of this report). The process flow diagram of the cement immobilization facility is shown in Figure 5.2.7-2, with the annual flow shown in Table 5.2.7-13.

Environmental Effects Related to Facility Construction. Some of the factors relating to site preparation and reference facility construction may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of construction activities.

Resource Commitments. The cement immobilization facility will occupy an area of about 960 m^2. This process facility will be an integral part of the reference FRP, whose structures will occupy an area of about 40 ha. Land commitment attributable to the immobilization facility is inconsequential by comparison and in any event would be preempted by construction of the FRP.

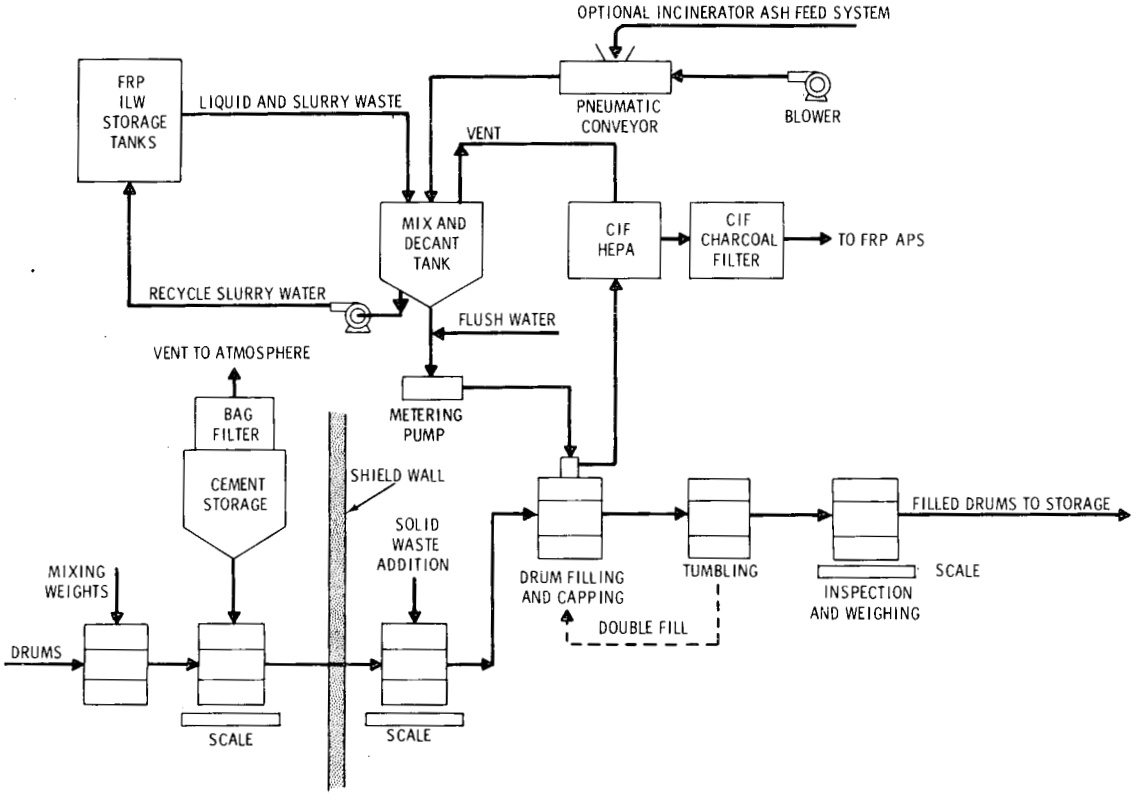

FIGURE 5.2.7-2. Process Flow Diagram for Cement Immobilization at the FRP

TABLE 5.2.7-13. Annual Flow of Primary and Secondary Wastes at the FRP Cement Immobilization Facility

Material	Volume, m^3	Mass, kg	Activity, Ci[a]
Waste feed	8.7×10^2	9.1×10^5	1.5×10^6
Cement	7.4×10^2	1.1×10^6	0
Empty drums (5600)	1.2×10^3	1.4×10^5	0
Filled drums (5600)	1.2×10^3	2.2×10^6	1.5×10^6
Off-gas[b]			1×10^{-3}

a. At 1.5 years out of reactor.
b. 10 m^3/hr of air.

Water used during construction is estimated to be 4000 m^3. Withdrawal of this amount of water from the R River, described in the reference environment (average flow of 1.0×10^7 m^3/day), is judged to be insignificant with respect to other downstream uses. During the construction period, wells could also supply the required amount of water without consequence.

Materials committed for construction of the ILW cement immobilization facility are:

Steel	500 MT
Copper	1 MT
Lumber	200 m^3
Concrete	3000 m^3

Energy resources committed for construction are:

Propane	30 m^3
Diesel fuel	300 m^3
Gasoline	230 m^3
Electricity	
Peak demand	250 kW
Total consumption	160,000 kWh

Manpower requirements for construction of the cement immobilization facility amount to 280,000 man-hr, which will likely be integrated with labor schedules for the FRP.

No additional transportation requirements for the cement immobilization facility have been identified beyond those for the FRP. No other site-specific requirements have been identified.

Physical and Chemical Effects. Effects on air and water quality from construction of the cement immobilization facility will be an indistinguishable fraction of those resulting from construction of the reference FRP (Section 5.4.1).

Ecological Effects. There will be no construction impacts from the cement immobilization facility apart from those of the reference FRP. Land area requirements are on the order of 960 m^2 and are included in the 40-ha land requirements for the FRP.

Water used during the 4-year construction period of the entire FRP is approximately 1.8×10^5 m^3 and will be withdrawn from the R River at the reference site. This amounts to less than the 0.02% of the river low flow and will not have an impact on the river biota. Since water used for the construction of the cement immobilization system is only a small percentage (0.003%) of that required for the entire FRP, no ecological impacts are anticipated.

Environmental Effects Related to Facility Operation. Some of the factors relating to facility operation may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of operation.

Resource Commitments. Resources required during planned operation of the cement immobilization facility are given in Table 5.2.7-14.

TABLE 5.2.7-14. Utilities and Materials Required for Operating the FRP Cement Immobilization Facility

Resource	Average Annual Use
Process water	4.4×10^3 m^3
Cooling water	1.3×10^2 m^3
Portland cement	1.1×10^3 MT
Steel drums (55 gal)	5.6×10^3
Electricity	9.5×10^4 kWh
Manpower	3.7 man-yr/yr

Process Effluents. The amounts of radioactive materials that reach the biosphere after leaving the cement immobilization system and passing through the reference FRP atmospheric protection system (APS) are shown in Table 5.2.7-15. The radionuclides listed are those that will contribute at least 1% to the total dose to a given organ from any pathway or that are otherwise of interest. Treatment with and without incineration was considered, and source terms were found to be nearly identical.

The radionuclides entrained in air are derived from process off-gas. The total air flow through the process is estimated to be 0.003 m^3/sec or less than 0.1% of the total flow of air through the FRP-APS. No radioactive material will be released to the biosphere via liquid effluent streams.

Cement dust will be released to the atmosphere as a result of the immobilization process. During normal operation the facility will release approximately 0.5 MT/yr with a maximum hourly concentration of about 0.001 $\mu g/m^3$.

During normal operation the cement immobilization facility will release a total of 2.7×10^5 MJ of heat to the atmosphere over 80 days of operation per year.

TABLE 5.2.7-15. Radionuclides Released to the Biosphere from the FRP Cement Immobilization Facility (Ci/yr)

Radionuclide	U Recycle, Pu in SHLW or PuO_2 Stored	U and Pu Recycle
^{3}H	8.4×10^{-1}	8.4×10^{-1}
^{14}C	6.6×10^{-14}	6.6×10^{-14}
^{60}Co	2.5×10^{-9}	2.5×10^{-9}
^{90}Sr	4.6×10^{-9}	4.3×10^{-9}
^{95}Zr	2.0×10^{-8}	2.0×10^{-8}
^{95}Nb	4.6×10^{-8}	4.6×10^{-8}
^{106}Ru	1.0×10^{-6}	1.1×10^{-6}
^{129}I	2.1×10^{-5}	2.2×10^{-5}
^{134}Cs	8.4×10^{-9}	8.4×10^{-9}
^{137}Cs	6.4×10^{-9}	6.5×10^{-9}
^{238}Pu	3.0×10^{-8}	5.3×10^{-8}
^{239}Pu	2.8×10^{-9}	3.5×10^{-9}
^{240}Pu	4.3×10^{-9}	7.0×10^{-9}
^{241}Pu	1.1×10^{-6}	1.7×10^{-6}

There are no direct releases of nonradioactive liquid or solid wastes to surface or ground waters from the cement immobilization facility. All liquid and solid waste disposal for the process is part of the overall FRP operation.

Physical, Chemical, and Thermal Effects. The release of 0.5 MT of cement dust to the atmosphere and a contribution of 2.5×10^5 MJ over 80 days per year are not expected to have any discernible effects.

About 4.5×10^3 m^3 of water will be required. There are no planned releases of liquid or solid waste to the ground. About 19 m^3 of cooling tower blowdown will be released to the R River annually.

Radiological Effects. Doses to individuals in the vicinity of the cement immobilization facility were calculated based on the releases of radionuclides listed in Table 5.2.7-15; exposure pathways, demography, and other parameters described for the reference environment in Appendix A; and mathematical models relating dose to man from radionuclide releases as given in Appendix B. For planned operation of the cement immobilization facility the only exposure pathway to man is via airborne effluents; there are no releases to ground or water.

The annual doses to individuals whose habits tend to maximize their dose ("maximum individual") are shown in Table 5.2.7-16. For perspective, the dose to an individual from naturally occurring radioactive sources averages about 0.1 rem/yr.

TABLE 5.2.7-16. Annual Doses to Maximum Individual from Gaseous Effluents Released by the FRP Cement Immobilization Facility (rem)[a]

Pathway	Total Body	Thyroid (child)[b]	Thyroid[c]	Lung	Bone
	U Recycle, Pu in SHLW or PuO_2 Stored				
Air submersion	1.6×10^{-15}		1.6×10^{-15}	1.6×10^{-15}	1.6×10^{-15}
Inhalation	4.4×10^{-10}		8.5×10^{-10}	4.9×10^{-10}	1.6×10^{-11}
Ingestion	2.6×10^{-9}	1.7×10^{-9}	5.0×10^{-8}	2.5×10^{-9}	3.2×10^{-11}
Total	3.0×10^{-9}	1.7×10^{-9}	5.0×10^{-8}	3.0×10^{-9}	4.8×10^{-11}
	U and Pu Recycle				
Air submersion	1.6×10^{-15}		1.6×10^{-15}	1.6×10^{-15}	1.6×10^{-15}
Inhalation	4.4×10^{-10}		8.7×10^{-10}	5.2×10^{-10}	2.6×10^{-11}
Ingestion	2.6×10^{-9}	1.7×10^{-9}	5.3×10^{-8}	2.5×10^{-9}	3.4×10^{-11}
Total	3.0×10^{-9}	1.7×10^{-9}	5.3×10^{-8}	3.0×10^{-9}	7.0×10^{-11}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the highest annual average dispersion factor ($\bar{\chi}/Q'$) of 1.5×10^{-8} sec/m^3.

a. After 30 years of release and accumulation in the environment.

b. Thyroid dose is calculated for a 1-year-old child breathing air containing radioactive effluents and consuming 1 ℓ of milk per day from cows grazing 7 months/yr at the site boundary. Inhalation dose is <2% of total dose.

c. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

The combined dose from gaseous effluents to the population living within an 80-km radius of the plant was calculated using the projected year 2000 population data given in the reference environment. Table 5.2.7-17 summarizes the annual doses received by this population. The annual total-body population dose from naturally occurring sources to the approximately 2 million persons living within an 80-km radius of the plant in the year 2000 would be about 200,000 man-rem compared with the value of about 0.0003 man-rem received from process sources as given in Table 5.2.7-17.

The annual total-body dose to the work force associated with the cement immobilization facility was estimated based on permissible exposure limits and experience of operating plants. The annual dose was calculated to be 3 man-rem. Table 5.2.1-18 summarizes the annual total-body dose to the work force and the general population from process and naturally occurring sources in the year 2000.

TABLE 5.2.7-17. Annual Doses to Population (within 80 km) from Gaseous Effluents Released by the FRP Cement Immobilization Facility (man-rem)[a]

Pathway	Total Body	Thyroid	Lung	Bone
	U Recycle, Pu in SHLW or PuO_2 Stored			
Air submersion	3.6×10^{-10}	3.6×10^{-10}	3.6×10^{-10}	3.6×10^{-10}
Inhalation	1.0×10^{-4}	2.0×10^{-4}	1.1×10^{-4}	3.6×10^{-6}
Ingestion	2.4×10^{-4}	5.0×10^{-3}	2.3×10^{-4}	3.2×10^{-6}
Total	3.4×10^{-4}	5.2×10^{-3}	3.4×10^{-4}	6.8×10^{-6}
	U and Pu Recycle			
Air submersion	3.8×10^{-10}	3.8×10^{-10}	3.8×10^{-10}	3.8×10^{-10}
Inhalation	1.0×10^{-4}	2.0×10^{-4}	1.2×10^{-4}	6.1×10^{-6}
Ingestion	2.4×10^{-4}	5.2×10^{-3}	2.3×10^{-4}	3.4×10^{-6}
Total	3.4×10^{-4}	5.4×10^{-3}	3.5×10^{-4}	9.5×10^{-6}

a. After 30 years of release and accumulation in the environment.

TABLE 5.2.7-18. Summary of Annual Total-Body Doses Received from Operation of the FRP Cement Immobilization Facility and Naturally Occurring Sources in the Year 2000

	Man-rem
Cement immobilization facility	
Process work force	3
Population (within 80 km)	<0.001
Naturally occurring sources	
Population (within 80 km)	200,000

The 70-year doses to the maximum individual and to the population within 80 km of the facility are given in Tables 5.2.7-19 and 5.2.7-20 respectively. A summary of the 70-year total-body doses to the work force and the population is given in Table 5.2.7-21. For comparison, the population dose from naturally occurring sources over the 70-year period amounts to about 14,000,000 man-rem compared with 0.001 man-rem received from the reference facility.

TABLE 5.2.7-19. 70-Year Dose to Maximum Individual from Gaseous Effluents Released by the FRP Cement Immobilization Facility (rem)

Pathway	Total Body	Thyroid[a]	Lung	Bone
	U Recycle, Pu in SHLW or PuO_2 Stored			
Air submersion	4.7×10^{-14}	4.7×10^{-14}	4.7×10^{-14}	4.7×10^{-14}
Inhalation	1.4×10^{-8}	2.6×10^{-8}	1.6×10^{-8}	8.9×10^{-9}
Ingestion	8.5×10^{-8}	3.4×10^{-6}	8.1×10^{-8}	1.6×10^{-9}
Total	9.9×10^{-8}	3.4×10^{-6}	9.7×10^{-8}	1.1×10^{-8}
	U and Pu Recycle			
Air submersion	4.9×10^{-14}	4.9×10^{-14}	4.9×10^{-14}	4.9×10^{-14}
Inhalation	1.4×10^{-8}	2.7×10^{-8}	1.7×10^{-8}	1.5×10^{-8}
Ingestion	8.5×10^{-8}	3.5×10^{-6}	8.1×10^{-8}	1.7×10^{-9}
Total	9.9×10^{-8}	3.5×10^{-6}	9.8×10^{-8}	1.7×10^{-8}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the highest annual average dispersion factor ($\bar{\chi}/Q'$) of 1.5×10^{-8} sec/m^3.

a. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

TABLE 5.2.7-20. 70-Year Doses to Population (within 80 km) from Gaseous Effluents Released by the FRP Cement Immobilization Facility (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
	U Recycle, Pu in SHLW or PuO_2 Stored			
Air submersion	1.1×10^{-8}	1.1×10^{-8}	1.1×10^{-8}	1.1×10^{-8}
Inhalation	3.2×10^{-3}	6.2×10^{-3}	3.7×10^{-3}	2.1×10^{-3}
Ingestion	8.0×10^{-3}	3.3×10^{-1}	7.6×10^{-3}	1.6×10^{-4}
Total	1.1×10^{-2}	3.4×10^{-1}	1.1×10^{-2}	2.3×10^{-3}
	U and Pu Recycle			
Air submersion	1.2×10^{-8}	1.2×10^{-8}	1.2×10^{-8}	1.2×10^{-8}
Inhalation	3.3×10^{-3}	6.4×10^{-3}	4.0×10^{-3}	3.5×10^{-3}
Ingestion	8.0×10^{-3}	3.5×10^{-1}	7.6×10^{-3}	1.7×10^{-4}
Total	1.1×10^{-2}	3.5×10^{-1}	1.2×10^{-2}	3.7×10^{-3}

TABLE 5.2.7-21. Summary of 70-Year Total-Body Doses Received from Operation of the FRP Cement Immobilization Facility and Naturally Occurring Sources in the Year 2000

	Man-rem
Cement immobilization facility	
Process work force (30 yr)	90
Population (within 80 km)	0.001
Naturally occurring sources	
Population (within 80 km)	14,000,000

Total-body dose to the worldwide population is limited to that received from the release of 8.4×10^{2} Ci of ^{3}H and 6.6×10^{-14} of ^{14}C; no ^{85}Kr is released during the bitumenization process. The worldwide population dose for the 30th year of plant operation was calculated to be 5.7 man-rem, and the 70-year accumulated dose from 30 years of plant operation was calculated to be 2.0×10^{2} man-rem. The dose to this population from naturally occurring radioactive sources for these two periods would be about 6×10^{8} and 4×10^{10} man-rem respectively.

"Health effects" for the regional population are discussed at the plant level where several processes within the plant are combined. In general, doses at the individual process level are too small for a meaningful discussion of health effects. In this report, 100 to 800 health effects are postulated to occur in the exposed population per million man-rem of total body dose.

Ecological Effects. No adverse impacts are expected from routine operation of the cement immobilization system. The release of 40 kJ/s is less than 0.15% of the total heat released from the FRP and is not expected to produce any ecological impact.

Cement dust will be released to the atmosphere at a rate of 0.5 MT/yr. The maximum hourly concentration of cement particles in the air will be on the order of 1.6×10^{-3} $\mu g/m^3$. These are small fractions of background concentration of aerosols that are 60 to 200 $\mu g/m^3$ in urban areas and 10 to 60 $\mu g/m^3$ in nonurban areas. The Federal ambient air quality standard is 75 $\mu g/m^3$ for the annual geometric mean and allows only one annual occurrence greater than 260 $\mu g/m^3$ for a 24-hr average. The maximum offsite deposition of cement dust will be at the FRP fence line and will be about 200 $\mu g\ m^{-2}\ yr^{-1}$. Because both the air concentrations and deposition rates are small when compared with air quality standards, no ecological impacts will be expected from facility atmospheric discharges.

Approximately 4.4×10^{3} m^3 of process water will be required for facility operation. However, all of this water will be obtained from internal plant water recovery and recycle operation; none will be withdrawn from ground or surface water supplies.

About 19 m^3 of cooling tower blowdown will be released annually to the R River via the FRP cooling system. This release is not expected to adversely affect other uses of the river.

Environmental Effects Related to Postulated Accidents. Several minor accidents associated with cement immobilization were identified but none are expected to lead to releases of radioactive material; consequently, no environmental effects will occur. Scenarios for these accidents are provided in DOE/ET-0028.[2] The accidents are listed below.

Accident Number	Description
4.7.1	Overfill waste drum
4.7.2	Drum filling control valve failure
4.7.3	Drum-fill-level detector failure
4.7.4	Container drop or rupture
4.7.5	Leakage in waste in transfer line

No moderate or severe accidents were postulated within the design basis of the facility. Non-design basis accidents were not considered.

5.2.7.3 Comparison of Wet Waste Immobilization Alternatives for the Fuel Reprocessing Plant

Resource commitments, energy requirements, and effluent releases have been compared for the intermediate-level waste (ILW) immobilization facilities at the FRP. These comparisons also apply to the low-level waste (LLW) facilities. During construction, approximately equal commitments of water, fuel, and energy resources will be required for both bitumen and cement immobilization facilities. The cement immobilization facility will require about twice as much lumber and one-half more cement than the bitumen immobilization facility. The bitumen immobilization facility will use seven times more copper than the cement immobilization facility. Resource commitments are not significant in either case and uncertainties in estimates could account for some differences. No significant differences are seen in the chemical, thermal, or ecological effects related to construction. Table 5.2.7-22 summarizes resource commitments of construction.

TABLE 5.2.7-22. Comparison of Resource Commitments for Waste Immobilization Facility Construction at an FRP(a)

Resource	Bitumenization Process	Cementation Process
Land, m^2	8.6×10^2	9.6×10^2
Water, m^3	3.6×10^3	4.0×10^3
Materials		
Concrete, m^3	1.5×10^3	3.0×10^3
Steel, MT	4.5×10^2	5.0×10^2
Copper, MT	7	1
Lumber, m^3	9.4×10^1	2.0×10^2
Energy		
Propane, m^3	3.8×10^1	3.0×10^1
Diesel fuel, m^3	3.4×10^2	3.0×10^2
Gasoline, m^3	2.3×10^2	2.3×10^2
Electricity, kWh	2.2×10^5	1.6×10^5
Manpower, man-hr	2.8×10^5	2.8×10^5

a. Quantities are for the ILW facility. There are no significant differences for the LLW facility.

Materials used during facility operation are different (bitumen versus cement) but consist of about the same quantities for both facilities. The cement immobilization process would add about 0.5 MT/yr of cement dust to the atmosphere, whereas bitumen would be released from the bitumen process. Airborne bitumen will cause strong, unpleasant odors near the facility. However, procedures for release of the material from the FRP stack and dispersion in the atmosphere would be expected to reduce the odor to acceptable levels at the site boundary. Table 5.2.7-23 summarizes nonradiological aspects of immobilization facility operation.

TABLE 5.2.7-23. Comparison of Nonradiological Aspects of Waste Immobilization Facility Operation at the FRP

Resource	Annual Quantity	
	Bitumenization Process	Cementation Process
Water consumed, m^3	9.0×10^3	1.3×10^3
Materials		
Stainless steel drums (55-gal)	2.5×10^3	5.6×10^3
Portland cement, MT		1.1×10^3
Bitumen, MT	3.5×10^2	
Electricity, kWh	4.8×10^5	9.5×10^4
Manpower, man-yr	5.4	3.7
Nonradioactive effluents released to atmosphere		
Bitumen, MT	Not quantified	
Cement dust, MT		0.5
Heat released to atmosphere, MJ	1.8×10^6	2.7×10^5

Tritium releases, which are controlling factors in terms of total-body dose, are 1000 times higher for the bitumen immobilization facility; dose to the process work force is higher by a factor of 30. Although there is a large difference in doses between processes, the actual doses are extremely small. For the bitumen process the largest dose to an individual is only about 0.01% of the dose from natural sources for the same period. Doses from radioactive materials released during the most serious postulated accident are only 1% of the routine doses.

Table 5.2.7-24 lists the radionuclides released to the environment from operation of the bitumenization and cementation facilities, and Table 5.2.7-25 summarizes the doses received from routine facility operation. During routine operation, radiological impacts will be 100 to 1000 times greater using the bitumen process.

The overall environmental effects of the two processes are similar. The release of radioactive material from the bitumen process, while much larger than that from the cementation process, is inconsequential. The ease of handling, lack of waste heat, and low probability of fire and other accidents during operation and storage are noteworthy advantages to the reference cementation process.

TABLE 5.2.7-24. Principal Radionuclides Released to the Atmosphere from Operation of the Alternative Facilities for Immobilization of Wet Wastes and Particulate Solids at the FRP (Ci/yr)

Radionuclides	Bitumenization Process	Cementation Process
^{3}H	8.4×10^{2}	8.4×10^{-1}
^{14}C	6.6×10^{-14}	6.6×10^{-14}
^{60}Co	2.5×10^{-9}	2.5×10^{-9}
^{90}Sr	4.8×10^{-9}	4.3×10^{-9}
^{95}Zr	2.0×10^{-8}	2.0×10^{-8}
^{95}Nb	4.6×10^{-8}	4.6×10^{-8}
^{106}Ru	1.1×10^{-6}	1.1×10^{-6}
^{129}I	2.2×10^{-5}	2.2×10^{-5}
^{134}Cs	9.4×10^{-9}	8.4×10^{-9}
^{137}Cs	7.2×10^{-9}	6.5×10^{-9}
^{238}Pu	5.6×10^{-8}	5.3×10^{-8}
^{239}Pu	3.7×10^{-9}	3.5×10^{-9}
^{240}Pu	7.4×10^{-9}	7.0×10^{-9}
^{241}Pu	1.8×10^{-6}	1.7×10^{-6}

TABLE 5.2.7-25. Doses Received from Operation of the Alternative Facilities for Immobilization of Wet Wastes and Particulate Solids at the FRP

	Bitumenization Process	Cementation Process
	Dose to Maximum Individual, 70-Year Residency, rem[a]	
Total body	9.4×10^{-5}	9.9×10^{-8}
Thyroid	9.8×10^{-5}	3.5×10^{-6}
Lung	9.4×10^{-5}	9.8×10^{-8}
Bone	1.8×10^{-8}	1.7×10^{-8}
(Dose from naturally occurring sources for same period, 7 rem)		
	Dose to Regional Population (2×10^6 persons), 70-Year Residency, man-rem[a]	
Total body	1.1×10^{1}	1.1×10^{-2}
Thyroid	1.1×10^{1}	3.5×10^{-1}
Lung	1.1×10^{1}	1.2×10^{-2}
Bone	3.9×10^{-3}	3.7×10^{-3}
(Dose from naturally occurring sources for same period, 1.4×10^7 man-rem)		
	70-Year Accumulated Dose to Worldwide Population (6.4×10^9 persons), man-rem[a]	
^{3}H	2.0×10^{2}	2.0×10^{-1}
^{14}C	2.6×10^{-10}	2.6×10^{-10}
^{85}Kr	0	0
Total	2.0×10^{2}	2.0×10^{-1}
(Dose from naturally occurring sources for same period, 4.5×10^{10}, man-rem)		
	Dose to Process Work Force, man-rem[b]	
Total body	9.0×10^{1}	3
	Dose to Maximum Individual from Most Serious Postulated Accident, 70-Year Dose Commitment, rem	
Total body	9.0×10^{-7}	0

Note: Minor and moderate accident doses are negligible for either process. No radioactive materials are released to water or ground from either process.

a. For 30 years of plant operation and accumulation of radionuclides in the environment.

b. 30 years of plant operation.

REFERENCES FOR SECTION 5.2.7

1. Alternatives for Managing Wastes from Reactors and Post-Fission Operations in the LWR Fuel Cycle, ERDA 76-43, Energy Research and Development Administration, Washington, DC, May, 1976.

2. Technology for Commercial Radioactive Waste Management, DOE/ET-0028, Department of Energy, Washington, DC, in press.

5.3 INTERIM STORAGE OF RADIOACTIVE WASTES AT A FUEL REPROCESSING PLANT

5.3 INTERIM STORAGE OF RADIOACTIVE WASTES AT A FUEL REPROCESSING PLANT (DOE/ET-0028 Sec. 5)

Radioactive wastes generated during fuel reprocessing will be stored for periods of up to five years at the FRP. The wastes will then be transported to an independent storage facility or directly to a geologic disposal facility. These wastes include high-level liquid waste (HLLW), solidified high-level waste (SHLW), fuel residues, intermediate- and low-level transuranic wastes, and plutonium oxide (PuO_2). Storage for ^{85}Kr will be provided for 50 years, at which time the remaining bottled gas (less than 4% of initial inventory) will be released to the atmosphere.

Storage alternatives considered have been selected primarily on the basis of available technology. These storage methods are believed to provide a reasonable basis for estimates of environmental effects.

5.3.1 High-Level Liquid Waste (DOE/ET-0028 Sec. 5.1)

The reference high-level liquid waste (HLLW) interim storage facility is a subsurface cluster of tanks surrounding an auxiliary equipment building. The HLLW storage facility is adjacent to the FRP process building, the cooling towers, and the retention basis. The center of the interim storage facility is about 150 m from the main process building. Close proximity permits gravity flow of the HLLW from the concentrator surge tank in the FRP through the diverters and into the storage tanks.

The six HLLW storage tanks that encircle the waste tank equipment building, as Figure 5.3.1-1 illustrates, are fabricated of stainless steel and are contained in a reinforced concrete vault

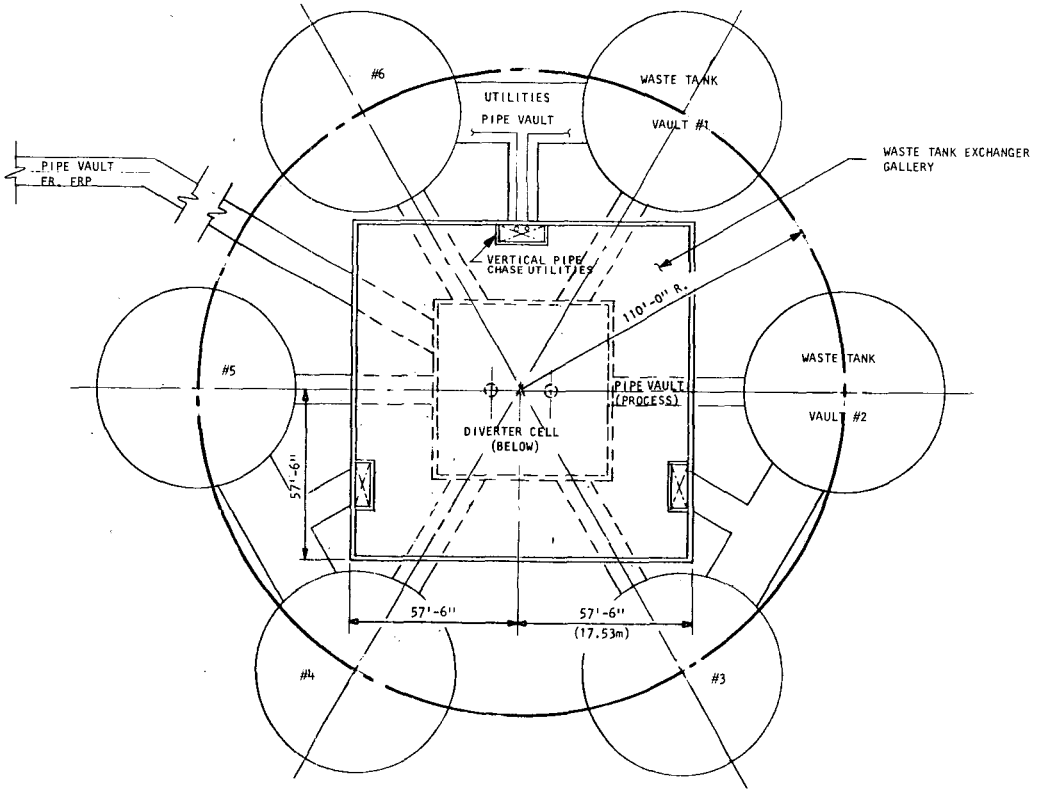

FIGURE 5.3.1-1. Top View of the Waste Tank Equipment Building and Storage Tank for High-Level Liquid Waste at the FRP

lined with stainless steel. Each tank is cooled by water flowing through cooling coils to a cooling tower. The purpose of cooling is to remove radioactive decay heat, which otherwise may cause a breach of containment, and to maintain the waste temperature below 60°C. The building houses most of the auxiliary equipment, services, and controls required for facility operation. The diverter cell, which controls HLLW routing to the tanks, is beneath the heat exchanger gallery in the waste tank equipment building. Its central location minimizes the distance of gravity flow from the diverter to the storage tanks.

A large emergency cooling water pond (used as a standby source of cooling water) is located within a separately fenced secured area about 300 m from the FRP boundary. The location of this pond obviates undue moisture effects on the FRP area from the large body of water. The cooling pond occupies an area of 24 ha, reaches a depth of 3 m, and has 0.6 m of freeboard. A 15-cm layer of impermeable clay, which is covered with 0.3 m of graded aggregate, prevents the water from seeping underground. The total capacity of this pond is 7×10^5 m^3.

A retention basin, to which radioactively contaminated cooling water can be routed, is 93 m wide, 118 m long, and 3.7 m deep at the high water line. The basin is lined with concrete, has an underlayer of clay 15 cm thick, and has a capacity of 3.7×10^4 m^3. It also has an additional 0.6 m of freeboard.

The HLLW tanks, piping vaults, diverter cell, the emergency cooling water piping, the off-gas system, and waste tank equipment building, the utilities pipe vaults, and the emergency cooling water pump house are all designed to Category I specifications. (Category I structures are designed to withstand maximum predictable natural phenomena.)

The storage tanks are designed to safely contain acidic HLLW for a minimum of 100 years. The tanks are 17 m in diameter and 6 m high and have a net tank storage volume of 1140 m^3 with 10% freeboard. Double containment is used in the construction of the tanks, consisting of a primary stainless steel container encased in a stainless steel liner to the full height of liquid fill. Both containers are supported by and encased in a reinforced concrete vault.

The concrete vault that contains the HLLW tank has an inside diameter of 18 m and an inside height of 8 m. The vault floor is 1.2 m thick. The walls are 0.9 m thick and support a top 1.5 m thick. A stainless steel vault liner, 0.64 cm thick, covers the floor and extends 5.5 m up the vault wall. This secondary container is designed to support the primary container and to prevent any leak from the primary container from entering the ground.

Continuous monitoring of the integrity of the primary container is provided. This is accomplished by supporting the primary container off the floor of the secondary container by stainless steel strips and sloping the floor of the secondary container from all directions to a vault sump. Any liquid drains to the sump and is detected by liquid level indicators. Periodic assessment of the secondary container's integrity is provided by collecting channels installed behind all the welds in the wall liner and by a monitoring space under the floor liner. To check the integrity of the vault liner the channel system is filled with water and the level of water in the channels and vault is monitored. In addition, there is sufficient annular space between the primary and secondary containers to allow visual inspection using television cameras.

The HLLW is retrievable, and the tank is designed for eventual emptying and decommissioning. Equipment for transferring waste is installed in both the primary and secondary containers, and spare equipment is provided. To avoid possible corrosion and tank decontamination problems, the tank design eliminates obstructions on the tank bottom that could result in the buildup of solids.

5.3.1.1 Environmental Effects Related to Facility Construction

Some aspects of construction of the HLLW interim storage facility may have an effect on the natural resources and environment of the surrounding area. The following information is provided to form a basis for evaluating the effects of construction activities.

Resource Commitments. The HLLW interim storage facility including the separate fenced emergency cooling water pond will be included with the reference FRP. Land commitment attributable to the HLLW interim storage facility represents about 1% of the FRP 2400 ha requirement.

Water used during construction of the facility is estimated to be 7×10^4 m^3. Withdrawal of this amount of water from the R River (average flow of 1.0×10^7 m^3/day) is judged to be insignificant with respect to other downstream uses.

Materials committed for construction of the HLLW interim storage facility are:

Steel	6,200 MT
Copper	14 MT
Zinc	9 MT
Aluminum	2 MT
Lumber	700 m^3
Concrete	18,400 m^3

Energy resources used during construction are:

Propane	680 m^3
Diesel fuel	6,800 m^3
Gasoline	4,500 m^3
Electricity	
Peak demand	1,200 kW
Total consumption	3,400,000 kWh

Manpower required during construction will amount to 3000 man-yr, which will likely be integrated with labor schedules for the FRP.

There are no site-specific or transportation requirements beyond those of the FRP.

Physical and Chemical Effects. The effects on air quality from construction of the HLLW interim storage facility will be indistinguishable from those resulting from construction of the reference FRP. Possible introduction of silt through erosion of cleared areas will be limited by proper ditching and contouring of land.

Ecological Effects. Construction of the HLLW interim storage facility will produce no impacts beyond those associated with the FRP. Impacts will include elimination or alteration

of vegetation; destruction of animal habitat; and the disturbance of animals by noise, dust, and human activity. Total land use, included within the FRP, encompasses about 2.4 ha or about 6% of the 40 ha within the FRP exclusion area. An additional 25.6 ha will be required outside the FRP exclusion area for the emergency cooling water reservoir.

A total of 7×10^4 m^3 of water from the R River will be used during construction of the HLLW interim storage facility. Withdrawal of the total amount on a daily basis will amount to less than 1% of the R River minimum flow, which will have no measurable impact upon the aquatic ecosystem.

A common system will probably be constructed to supply water to all facilities within the FRP complex. Procedures will be required to minimize disruption of current patterns and disturbance of the river bottom during construction of the intake for this system. The intake will be designed to prevent significant quantities of aquatic organisms from being entrained in the water withdrawn from the R River.

5.3.1.2 Environmental Effects Related to Facility Operation

Some aspects of facility operation may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effects of operation.

Resource Commitments. Resources required during operation of the HLLW interim storage facility are listed in Table 5.3.1-1.

The commitment of water for the storage facility is insignificant compared with the average flow of the R River (3.9×10^9 m^3/yr) and is about 30% of that required for the reference FRP. At minimum recorded flow of the R River the daily requirement for makeup water is about 0.25% of the river flow.

TABLE 5.3.1-1. Utilities and Materials Required for Operation of the High-Level Liquid Waste Interim Storage Facility

Resource	Average Annual Use
Water, m^3	
Makeup for cooling tower	4.1×10^5
Sanitary	3.6×10^3
Other	6.0×10^4
Oil, m^3	7×10^{-1}
Gasoline, m^3	1.5
Electricity, kWh	8.8×10^6

Process Effluents. The quantities of radioactive materials that will be released to the biosphere during operation of the HLLW interim storage facility are listed in Table 5.3.1-2. The radionuclides listed are those that will contribute at least 1% of the total dose to a given

TABLE 5.3.1-2. Radionuclides Released to the Biosphere from Operation of the High-Level Liquid Waste Interim Storage Facility (Ci/yr)

Radionuclide	U Recycle	U and Pu Recycle
^{3}H	2.7×10^{4}	2.7×10^{4}
^{90}Sr	5.2×10^{-5}	4.9×10^{-5}
^{95}Nb	6.1×10^{-6}	6.1×10^{-6}
^{106}Ru	1.4×10^{-3}	1.5×10^{-3}
^{129}I	1.3×10^{-4}	1.4×10^{-4}
^{134}Cs		9.6×10^{-5}
^{137}Cs	7.4×10^{-5}	7.4×10^{-5}
^{144}Ce	2.0×10^{-4}	1.9×10^{-4}
^{154}Eu	4.4×10^{-6}	4.9×10^{-6}
^{238}Pu	1.2×10^{-8}	
^{239}Pu	1.2×10^{-9}	1.4×10^{-9}
^{241}Am	3.0×10^{-7}	5.7×10^{-7}
^{242}Cm	2.8×10^{-6}	7.9×10^{-6}
^{244}Cm	9.6×10^{-7}	5.8×10^{-6}

organ from any pathway to man or that are otherwise of interest. These radionuclides will be released to the environment via the FRP stack after they have passed through the atmospheric protection system.

The FRP will generate sufficient waste to fill one tank each year. After 1 year of operation the HLLW produced will require removal of 3.5×10^{8} MJ/yr of waste heat. The result of this heat removal will be evaporation of 1.3×10^{5} m^3 of water from the cooling tower, a release of cooling tower blowdown of 2.3×10^{4} m^3/yr, and drift of 6.6×10^{2} m^3/yr. When the facility has reached full capacity it will require removal of 8.5×10^{8} MJ of waste heat, thus resulting in evaporation of 3.5×10^{5} m^3/yr of water from the cooling tower, blowdown of 6.1×10^{4} m^3/yr, and drift of 1.7×10^{3} m^3/yr.

Physical, Chemical, and Thermal Effects. The annual release of 8.5×10^{8} MJ of heat to the atmosphere via the 2.4×10^{9} MJ/yr FRP cooling tower is not expected to contribute measurably to effects on the environment.

Annual emissions of nonradioactive gases from the high level liquid waste storage facility include the following:

H_2O	1.1×10^3 MT
N_2	2.3×10^4
O_2	7.0×10^3
NO_x	2.2×10^2

of these NO_x may be of interest as an atmospheric pollutant. The predicted average and maximum concentrations of NO_x at the FRP fenceline are 4 and 10 $\mu g/m^3$ respectively.

There will be no planned releases of nonradioactive liquid or solid waste to surface or ground waters. Liquid and solid waste disposal is part of the overall FRP operation.

Radiological Effects. Radiation doses in the vicinity of the HLLW interim storage facility were calculated based on the releases of radionuclides as listed in Table 5.3.1-2; exposure pathways, demography, and other parameters described for the reference environment in Appendix A; and mathematical models relating dose to man from radionuclide releases (Appendix B). For planned operation of the storage facility the only exposure pathway to man and the environment is via airborne effluents; there are no planned releases to ground or water.

The annual doses to individuals whose habits tend to maximize their dose ("maximum individual") are shown in Table 5.3.1-3. For perspective, the dose to an individual from naturally occurring radioactive sources averages about 0.1 rem/yr.

TABLE 5.3.1-3. Annual Doses to the Maximum Individual from Gaseous Effluents Released by the High-Level Liquid Waste Interim Storage Facility (rem)

Pathway	Total Body	Thyroid (child)[a]	Thyroid[b]	Lung	Bone
		U Recycle			
Air submersion	1.2×10^{-12}	1.2×10^{-12}	1.2×10^{-12}	1.2×10^{-12}	1.2×10^{-12}
Inhalation	1.4×10^{-5}		1.4×10^{-5}	1.4×10^{-5}	9.8×10^{-10}
Ingestion	8.1×10^{-5}	4.7×10^{-5}	8.1×10^{-5}	8.1×10^{-5}	1.6×10^{-9}
Total	9.5×10^{-5}	4.7×10^{-5}	9.5×10^{-5}	9.5×10^{-5}	2.6×10^{-9}
		U and Pu Recycle			
Air submersion	1.3×10^{-12}	1.3×10^{-12}	3.1×10^{-12}	1.3×10^{-12}	1.3×10^{-12}
Inhalation	1.4×10^{-5}		1.4×10^{-5}	1.4×10^{-5}	2.0×10^{-9}
Ingestion	8.1×10^{-5}	4.7×10^{-5}	8.1×10^{-5}	8.1×10^{-5}	1.6×10^{-9}
Total	9.5×10^{-5}	4.7×10^{-5}	9.5×10^{-5}	9.5×10^{-5}	3.6×10^{-10}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the highest annual average dispersion factor ($\bar{\chi}/Q'$) of 1.5×10^{-8} sec/m^3.

a. Thyroid dose is calculated for a 1-year-old child breathing air containing radioactive effluents and consuming 1 ℓ of milk per day from cows grazing 7 months/yr at the site boundary. Inhalation dose is <2% of total dose.

b. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

The combined dose from gaseous effluents to the population living within an 80-km radius of the plant was calculated using the projected year 2000 population data given in the reference environment. Table 5.3.1-4 summarizes the annual doses received by this population. The annual total-body population dose from naturally occurring sources to the approximately 2 million persons living within an 80-km radius of the plant in the year 2000 would be about 200,000 man-rem compared with the value of about 11 man-rem received from the storage facility as given in Table 5.3.1-4.

TABLE 5.3.1-4. Annual Doses to the Population (within 80 km) from Gaseous Effluents Released by the High-Level Liquid Waste Interim Storage Facility (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
		U Recycle		
Air submersion	2.9×10^{-7}	2.9×10^{-7}	2.9×10^{-7}	2.9×10^{-7}
Inhalation	3.3	3.3	3.3	2.3×10^{-4}
Ingestion	7.5	7.5	7.5	1.5×10^{-4}
Total	1.1×10^{1}	1.1×10^{1}	1.1×10^{1}	3.8×10^{-4}
		U and Pu Recycle		
Air submersion	3.0×10^{-7}	3.0×10^{-7}	3.0×10^{-7}	3.0×10^{-7}
Inhalation	3.3	3.3	3.3	4.6×10^{-4}
Ingestion	7.5	7.5	7.5	1.5×10^{-4}
Total	1.1×10^{1}	1.1×10^{1}	1.1×10^{1}	6.1×10^{-4}

The annual total-body dose to the work force associated with the HLLW interim storage facility was based on permissible exposure limits and experience of operating plants. The annual occupational dose was calculated to be 30 man-rem. Table 5.3.1-5 summarizes the annual total-body dose to the work force and the general population from process and naturally occurring sources.

TABLE 5.3.1-5. Summary of Annual Total-Body Doses Received from Operation of the High-Level Liquid Waste Interim Storage Facility and from Naturally Occurring Sources

	Dose, man-rem
HLLW interim storage facility	
Process work force	30
Population (within 80 km)	11
Naturally occurring sources	
Population (within 80 km)	200,000

The 70-year doses to the maximum individual and to the population within 80 km of the facility are given in Tables 5.3.1-6 and 5.3.1-7 respectively. A summary of the 70-year

TABLE 5.3.1-6. 70-Year Dose to the Maximum Individual from Gaseous Effluents Released by the High-Level Liquid Waste Interim Storage Facility (rem)

Pathway	Total Body	Thyroid[a]	Lung	Bone
		U Recycle		
Air submersion	3.7×10^{-11}	3.7×10^{-11}	3.7×10^{-11}	3.7×10^{-11}
Inhalation	4.2×10^{-4}	4.2×10^{-4}	4.2×10^{-4}	1.8×10^{-7}
Ingestion	2.6×10^{-3}	2.6×10^{-3}	2.6×10^{-3}	1.3×10^{-6}
Total	3.0×10^{-3}	3.0×10^{-3}	3.0×10^{-3}	1.5×10^{-6}
		U and Pu Recycle		
Air submersion	3.9×10^{-11}	3.9×10^{-11}	3.9×10^{-11}	3.9×10^{-11}
Inhalation	4.2×10^{-4}	4.2×10^{-4}	4.2×10^{-4}	5.0×10^{-7}
Ingestion	2.6×10^{-3}	2.6×10^{-3}	2.6×10^{-3}	1.3×10^{-6}
Total	3.0×10^{-3}	3.0×10^{-3}	3.0×10^{-3}	1.8×10^{-6}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 1.5×10^{-8} sec/m^3.

a. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

TABLE 5.3.1-7. 70-Year Dose to the Population (within 80 km) from Gaseous Effluents Released by the High-Level Liquid Waste Interim Storage Facility (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
		U Recycle		
Air submersion	8.7×10^{-6}	8.7×10^{-6}	8.7×10^{-6}	8.7×10^{-6}
Inhalation	9.9×10^{1}	9.9×10^{1}	9.9×10^{1}	4.2×10^{-2}
Ingestion	2.4×10^{2}	2.4×10^{2}	2.4×10^{2}	1.2×10^{-3}
Total	3.4×10^{2}	3.4×10^{2}	3.4×10^{2}	4.3×10^{-2}
		U and Pu Recycle		
Air submersion	9.1×10^{-6}	9.1×10^{-6}	9.1×10^{-6}	9.1×10^{-6}
Inhalation	9.9×10^{1}	9.9×10^{1}	9.9×10^{1}	1.2×10^{-1}
Ingestion	2.4×10^{2}	2.4×10^{2}	2.4×10^{2}	1.1×10^{-1}
Total	3.4×10^{2}	3.4×10^{2}	3.4×10^{2}	2.3×10^{-1}

total-body dose to the work force and the population is given in Table 5.3.1-8. For comparison, the population dose from naturally occurring sources is also given for the year 2000 and amounts to about 14,000,000 man-rem compared with 340 man-rem received from operation of the HLLW interim storage facility.

Health effects are discussed at the plant level where several processes within the FRP are combined. In general, doses at the individual process level are too small for a meaningful treatment of health effects. In this report, 100 to 800 health effects are postulated to result in the exposed population per million man-rem.

TABLE 5.3.1-8. Summary of 70-Year Total-Body Doses Received from Operation of the High-Level Liquid Waste Interim Storage Facility and from Naturally Occurring Sources

	Dose, man-rem
HLLW interim storage facility	
Process work force (30 yr)	900
Population (within 80 km)	340
Naturally occurring sources	
Population (within 80 km)	14,000,000

Ecological Effects. Approximately 4.5×10^5 m^3 of water per year will be withdrawn from the R River for secondary cooling and sanitary purposes. This amounts to less than 1% of the minimum flow of the R River and will have an immeasurable effect upon the aquatic ecosystem. The cooling water is circulated through cooling towers that dissipate about 8.5×10^8 MJ/yr of heat to the atmosphere. About 1.7×10^3 m^3/yr of water will be released in the cooling tower drift, and 6.1×10^4 m^3/yr of water will be discharged as blowdown. The blowdown will be released to the R River near the reference site. The estimated increase in water temperature (Δt) of this effluent will be about 17°C at the point of discharge. Because of the small volume of the blowdown relative to the flow of the river, rapid dilution will take place and no thermal effects on the river organisms are expected. Similarly the wide dispersion and small volume heat release in drift will not be of consequence to terrestrial plants and animals.

About 16 MT of salt will be released annually to the environment from the cooling tower. About 66% or 10.3 MT of this amount will be discharged in the tower blowdown and 5.3 MT in the drift. This would result in a salt concentration in the drift and blowdown of about 200 ppm.

There is evidence that soils containing 0.1 to 0.5% salt will begin to be incompatible for plant growth.[2,3] The time required to accumulate 0.5% salt in the soil 50 m from the cooling tower is calculated to be about 100 years. This estimate is based on the assumption that no leaching of salt (which probably would not be the case under natural conditions) occurs below 10 cm from the soil surface. Since the facility is planned to operate for only 30 years, no adverse impacts to vegetation are expected from the discharge of salt in the drift. Salt concentrations of 200 ppm are also well below toxicity limits to aquatic organisms,[4] and the discharge of this material to the river will not be harmful to biota in the R River.

Approximately 21 MT of phosphates and chromates used in the treatment of the cooling water will be released in the cooling tower drift and blowdown. If it is assumed that equal amounts of phosphates and chromates are present, the concentration of these materials will be about 100 ppm. This is within the range of chromate concentrations that are toxic to fish,[5] but rapid dilution, if discharged to the R River or similar water bodies, will reduce chromate levels to tolerable limits. Although 100 ppm of phosphate is several orders of magnitude above that found in natural surface waters, phosphorus is often the essential nutrient that is growth limiting in freshwater; therefore the introduction of phosphates to the R River is not expected to be detrimental.

Chromates discharged to land in the tower drift are within the 1 to 5000 ppm normal chromium content reported for American soils[6] and probably will not be harmful to vegetation. Phosphate releases to land are also within acceptable limits.

5.3.1.3 Environmental Effects Related to Postulated Accidents

A number of minor accidents associated with the HLLW interim storage facility were identified but none are expected to result in releases of radioactive material to the environment. Scenarios for the following minor accidents are provided in DOE/ET-0028.[1]

Accident Number	Description
5.1.1	Loss of normal electrical power
5.1.2	Leak from diversion equipment
5.1.3	Temporary loss of sparge/purge air
5.1.4	Loss of normal secondary coolant supply
5.1.5	Temporary loss of exhaust blower

A number of moderate and severe accidents were also identified. Scenarios for these accidents, which are listed below, are also provided DOE/ET-0028.[6]

Accident Number	Description
	Moderate
5.1.6	Filter fire
5.1.7	Breach of waste tank with sound secondary liner
5.1.8	Off-gas momentarily bypasses HEPA filter
	Severe
5.1.9	Waste overflows in diversion equipment cell

One accident, that of a waste overflow in a diversion equipment cell was initially thought to be a severe accident and an analysis of its consequences was developed. It has since been determined that the reference design precludes occurrence of this accident. As a consequence it is considered to be a nondesign basis accident; however, the consequence have been retained as an upper bound as all of the moderate accidents listed above.

For this accident it is assumed that diversion equipment fails, thus causing the diversion equipment cell to be filled with HLLW at a rate of 100 ℓ/min. This accident, which has an expected frequency of 1×10^{-4} per year, results in 300 ℓ of HLLW spilled on the ground surface; 150 ℓ of the spill enters the storm water drainage system with 0.1 ℓ released off site during cleanup. The quantities of radioactive materials released are given in Table 5.3.1-9.

The 1-year dose and 70-year dose commitment to the maximum individual were calculated and are presented in Tables 5.3.1-10 and 5.3.1-11 respectively. The 1-year total-body doses

are within the range of doses received from natural sources. First-year lung doses are 100 times greater than normal background doses received from naturally occurring sources.

No discernible ecological effects are expected from these releases.

TABLE 5.3.1-9. Radioactive Material Released During a Waste Overflow Accident at the High-Level Liquid Waste Interim Storage Facility (Ci)

Radionuclide	U Recycle	U and Pu Recycle
^{3}H	6.1×10^{-3}	6.1×10^{-3}
^{90}Sr	1.2×10^{1}	1.1×10^{1}
^{106}Ru	3.0×10^{1}	3.4×10^{1}
^{127m}Te	7.5×10^{-2}	4.3×10^{-1}
^{125m}Te	3.9×10^{-1}	1.3×10^{-1}
^{129}I	3×10^{-8}	3.2×10^{-8}
^{134}Cs	2.1×10^{1}	2.1×10^{1}
^{137}Cs	1.6×10^{1}	1.7×10^{1}
^{144}Ce	4.5×10^{1}	4.3×10^{1}
^{239}Pu	2.6×10^{-4}	3.2×10^{-4}
^{241}Am	6.6×10^{-2}	7.7×10^{-2}
^{242}Cm	6.2×10^{-1}	1.8
^{244}Cm	2.1×10^{-1}	1.3

TABLE 5.3.1-10. One-Year Dose to the Maximum Individual from a Waste Overflow Accident at the High-Level Liquid Waste Interim Storage Facility (rem)

Pathway	Skin	Total Body	Thyroid	Lung	Bone
		U Recycle			
Air submersion	4.2×10^{-3}	1.3×10^{-3}	1.3×10^{-3}	1.3×10^{-3}	1.3×10^{-3}
Inhalation		2.0×10^{-1}	1.1×10^{-2}	1.2×10^{1}	1.6
Total	4.2×10^{-3}	2.0×10^{-1}	1.2×10^{-2}	1.2×10^{1}	1.6
		U and Pu Recycle			
Air submersion	4.3×10^{-3}	1.3×10^{-3}	1.3×10^{-3}	1.3×10^{-3}	1.3×10^{-3}
Inhalation		3.2×10^{-1}	1.2×10^{-2}	2.7×10^{1}	3.3
Total	4.3×10^{-3}	3.2×10^{-1}	1.3×10^{-2}	2.7×10^{1}	3.3

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the time-integrated atmospheric dispersion coefficient (E/Q) is 1.1×10^{-4} sec/m^3.

TABLE 5.3.1-11. 70-Year Dose Commitment to the Maximum Individual from a Waste Overflow Accident at the High-Level Liquid Waste Interim Storage Facility (rem)

Pathway	Skin	Total Body	Thyroid	Lung	Bone
		U Recycle			
Air submersion	4.2×10^{-3}	1.3×10^{-3}	1.3×10^{-3}	1.3×10^{-3}	1.3×10^{-3}
Inhalation		2.0	1.1×10^{-2}	1.9×10^{1}	1.4×10^{1}
Total	4.2×10^{-3}	2.0	1.2×10^{-2}	1.9×10^{1}	1.4×10^{1}
		U and Pu Recycle			
Air submersion	4.3×10^{-3}	1.3×10^{-3}	1.3×10^{-3}	1.3×10^{-3}	1.3×10^{-3}
Inhalation		3.5	1.2×10^{-2}	4.8×10^{1}	4.0×10^{1}
Total	4.3×10^{-3}	3.5	1.3×10^{-2}	4.8×10^{1}	4.0×10^{1}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the time-integrated atmospheric dispersion coefficient (E/Q) is 1.1×10^{-4} sec/m^3.

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5.3.2 Solidified High-Level Waste (DOE/ET-0028 Sec. 5.4)

Solidified high-level waste (SHLW), as described in Section 5.2, is generated from calcination of high-level liquid waste (HLLW), which may be followed by vitrification. The SHLW is packaged in stainless steel canisters and placed in a deionized water pool similar to the water basins for spent fuel storage. The pool is a stainless-steel-lined reinforced concrete pool that may be covered or open to the storage building. The water is treated by filtering and ion exchange and is maintained at a temperature below about 49°C. Because SHLW must be at least 5 years old before it can be accepted at a deep geologic repository, interim storage for SHLW must be provided at the FRP.

Stainless steel is selected for the canisters because of its integrity, corrosion resistance in water, and economy. Less expensive materials such as carbon steel would corrode in

water (which would affect water chemistry), jeopardize package integrity, decrease visibility in the pool, and complicate water decontamination. In addition, most potential container materials, other than carbon steel, are more expensive than stainless steel.

The water basins are below-grade, water-filled pools that receive and store SHLW. Demineralized water from the basin is circulated through heat exchangers, filters, and an ion exchanger to remove heat and radioactive material. Cooling towers are provided as a secondary cooling water circuit for heat removal. There are no major chemical processes used in the water basin storage facility for SHLW.

The water basin storage facility, as illustrated in Figure 5.3.2-1, consists of eight water basins and has the capacity to receive and store more than 5 years' production of SHLW from the FRP. Basin storage capacity is 3500 SHLW canisters that are 30 cm in diameter by 3.2 m long. The facility also has pool storage capacity for 500 additional canisters. The reference FRP will produce approximately 3300 canisters of SHLW in borosilicate glass over a 5-year period.

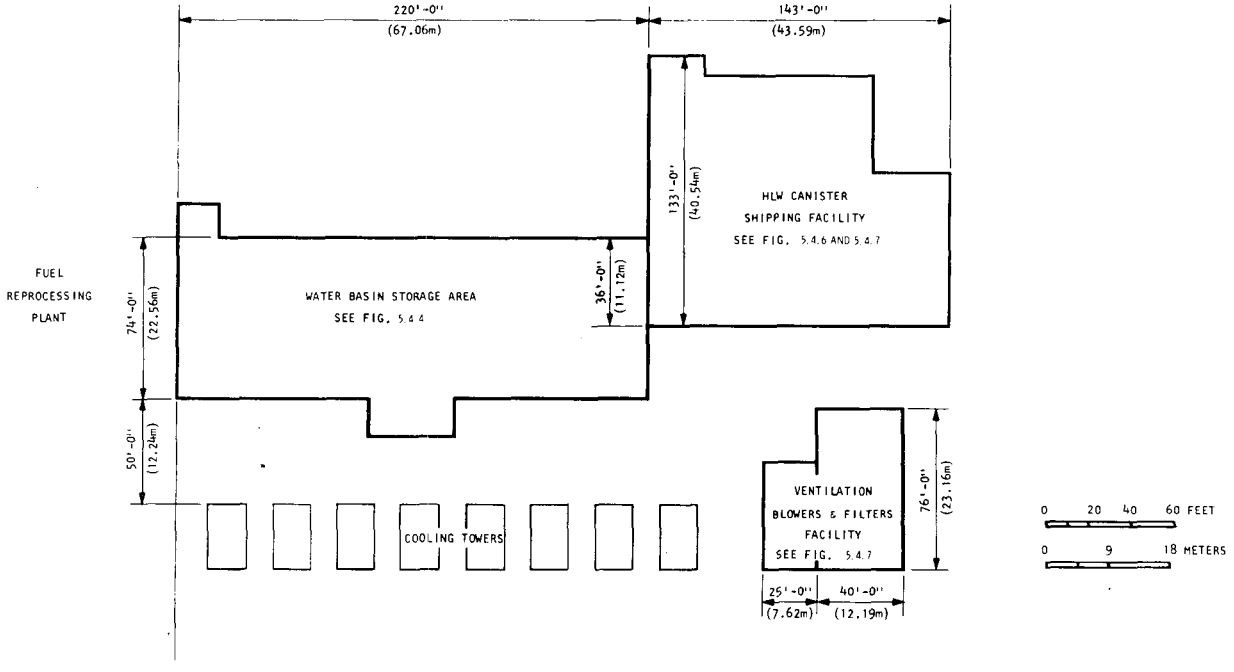

FIGURE 5.3.2-1. Plot Plan of the Water Basin Storage Facility for Solidified High-Level Waste at the FRP

The water basin storage facility has a design heat removal capacity of 8.5×10^8 MJ/yr per basin. If the FRP reprocesses spent fuel as early as 1-1/2 years after reactor discharge and if the HLLW is solidified during or shortly after reprocessing, each canister of vitrified HLLW can have a heat generation rate as high as 79 MJ/hr. The shipping facility is designed for a maximum of 36 MJ/hr per canister but canisters are normally not to be shipped until the heat

generation rate is less than 18 MJ/hr per canister. This requires interim storage of the canisters at the FRP until the decay heat output is reduced to the lower level.

A canister shipping facility, which adjoins the storage facility, has the capability of receiving the SHLW canisters removed from the storage basins and placing them in remote cells for inspection and testing. Canisters of proven integrity are placed in shipping casks and loaded onto railcars or trucks for transportation off site. The storage and shipping facilities share common use of the FRP utilities, services, and support facilities such as personnel areas, laboratories, health physics warehousing, shops, and maintenance.

5.3.2.1 Environmental Effects Related to Facility Construction

Some aspects of site preparation and reference facility construction may have an effect on the environment and the natural resources of surrounding areas. The following information is provided to form a basis for estimating the effects of construction activities.

Resource Commitments. The water basin storage facility for SHLW will occupy approximately 1.2 ha or 3% of 40 ha within the FRP exclusion area and includes both the water basin and canister shipping facilities. The land committed to the water basin storage facility is a small fraction of the total area of the FRP and will be insignificant compared with the total land set aside for this plant. Construction of the canister shipping facility may be deferred for up to 5 years after completion of the FRP.

Water used during construction will be about 2.6×10^4 m^3 and will be used in two stages: 1) 1.5×10^4 m^3 for construction of water basins and 2) 1.1×10^4 m^3 for the canister shipping facility. Withdrawal of these quantities of water from the R River (average flow 1.0×10^7 m^3/day) for facility construction is judged to have an insignificant effect on downstream uses of the river water.

Initial filling of the eight water basins will require about 6.4×10^3 m^3 of demineralized water. Assuming that this water comes from the R River and that filling occurs over a 5-day period, this volume of water will constitute less than 1% of the R River at low flow and will not impair other uses of river water.

Materials to be used during construction of the water storage basin facility for SHLW are:

	Water Basins	Canister Shipping	Total
Steel, MT	2000	820	2800
Copper, MT	36	45	81
Zinc, MT	5	3	8
Concrete, m^3	5700	3820	9500
Lumber, m^3	472	236	710

Energy resources used during construction are:

	Water Basins	Canister Shipping	Total
Propane, m^3	151	76	230
Diesel fuel, m^3	1514	757	2300
Gasoline, m^3	1136	379	1500
Electricity			
Peak demand, kW	300	300	600
Total consumption, MWh	700	400	1100

These quantities represent an additional 15 to 30% of the amounts required for construction of the reference FRP.

Manpower requirements for the water basin storage facility and the canister shipping facility amount to 720 man-yr and 440 man-yr, respectively, which will be integrated with the labor schedules of the FRP. Facility construction will extend over 1.5 years.

A railroad track from the FRP main spur to the shipping facility will be required. No other site-specific transportation requirements will be needed.

Physical and Chemical Effects. The effects of construction of the water basin storage facility for SHLW will be indistinguishable from those resulting from construction of the reference FRP. Atmospheric pollutants will include gaseous and particulate materials from the combustion of fossil fuels by construction equipment, and the generation of fugitive dust during site clearing and excavation. Release of these materials will be controlled to meet applicable Federal air quality standards. Possible introduction of silt through the erosion of cleared areas will be limited by proper ditching and contouring of the land.

Ecological Effects. Construction of the water basin storage facility for SHLW will produce no impacts beyond those associated with the FRP. Impacts will include elimination or alteration of vegetation; destruction of animal habitat; and the disturbance of animals by noise, dust, and human activity. Total land use, included within the FRP, encompasses about 1.2 ha or about 3% of the 40 ha within the FRP exclusion area and includes both the water basin storage and the canister shipping facility.

A total of 2.6×10^4 m^3 of water from the R River will be used in two stages: 1) 1.5×10^4 m^3 for construction of the water basins and 2) 1.1×10^4 m^3 for the canister shipping facility. Withdrawal of the total amount on a daily basis will amount to less than 1% of the R River minimum flow. This would have no measurable impact upon the aquatic ecosystem.

A common system will probably be constructed to supply water to all facilities within the FRP complex. Procedures will be required to minimize disruption of current patterns and disturbance of the river bottom during construction of the intake for this system. The intake will be designed to prevent removal of significant numbers of aquatic organisms by entrainment in the water withdrawn from the river.

5.3.2.2 Environmental Effects Related to Facility Operation

Some aspects of facility operation may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effects of operation.

Resource Commitments. Resources required during planned operation of the water basin storage facility are given in Table 5.3.2-1.

The commitment of water is insignificant compared with the average flow of the R River (3.9×10^9 m^3/yr), which will serve as the source of water for the facility. This water commitment is a small fraction of that required for the reference FRP (1.4×10^6 m^3/yr).

TABLE 5.3.2-1. Utilities and Materials Required for Operation of the Water Basin Storage Facility for Solidified High-Level Waste

Resource	Average Annual Use
Water consumed, m^3	4.1×10^5
Sodium hydroxide (5%), m^3	1.5×10^2
Nitric acid (5%), m^3	1.0×10^2
Detergent, m^3	2.2
Oil, m^3	3.8×10^2
Electricity, kWh	4.4×10^7
Manpower, man-yr	3.2×10^1

Process Effluents. The quantities of radioactive materials that will be released to the biosphere by the water basin storage facility are given in Table 5.3.2-2. The radionuclides

TABLE 5.3.2-2. Radionuclides Released to the Biosphere from the Water Basin Storage Facility for Solidified High-Level Waste

Radionuclide	Amount Released, Ci/yr		
	U Recycle, Pu in SHLW	U Recycle, PuO_2 Stored	U and Pu Recycle
^{90}Sr	1.3×10^{-5}	1.3×10^{-5}	1.2×10^{-5}
^{106}Ru	3.4×10^{-5}	3.4×10^{-5}	3.8×10^{-5}
^{125m}Te	4.4×10^{-7}	4.4×10^{-7}	4.8×10^{-7}
^{127m}Te	9.0×10^{-8}	8.5×10^{-8}	8.5×10^{-8}
^{134}Cs	2.4×10^{-4}	2.4×10^{-4}	2.4×10^{-4}
^{137}Cs	1.9×10^{-4}	1.9×10^{-4}	1.9×10^{-4}
^{144}Ce	5.0×10^{-5}	5.0×10^{-5}	4.8×10^{-5}
^{238}Pu	6.0×10^{-7}	3.1×10^{-9}	
^{239}Pu	6.0×10^{-8}	2.9×10^{-10}	3.6×10^{-10}
^{240}Pu	9.0×10^{-8}		
^{241}Pu	2.2×10^{-5}		
^{241}Am	7.5×10^{-8}	7.5×10^{-8}	1.4×10^{-7}
^{242}Cm	7.0×10^{-7}	7.0×10^{-7}	2.0×10^{-6}
^{244}Cm	2.4×10^{-7}	2.4×10^{-7}	1.4×10^{-6}

listed are those that will contribute at least 1% of the total dose to a given organ from any pathway or that are otherwise of interest. These radionuclides will be released to the environment via the FRP stack after they have passed through the FRP atmospheric protection system. The basin primary water system is a closed circuit to prevent potentially contaminated water from reaching the environment. There are no planned releases of radioactive liquids to the biosphere.

During normal operation of the storage facility no nonradioactive process materials will be released directly to the ground. About 1.9 ℓ/sec of water at a ΔT of about 17°C will be released as cooling tower blowdown to the R River near the FRP reference site or to a retention pond at the facility site. Approximately 18 MT of salt will be released annually from the cooling towers (66% or 10.3 MT in the blowdown and 34% or 5.3 MT in the tower drift). These releases would result in a salt concentration of 200 ppm in the drift and blowdown. In addition the concentration of chemicals in the blowdown will be about tenfold greater than that of the R River because of cooling water evaporation in the towers.

The heat released via the cooling towers will be 8.5×10^8 MJ/yr. The blowdown necessary to control the concentrations of salt will release 6.1×10^4 m^3/yr while 3.5×10^5 m^3/yr of water will be evaporated from the cooling tower.

Physical, Chemical, and Thermal Effects. The release of heat to the atmosphere will not have a measurable effect on the environment near the water basin storage facility. The heat and chemicals released to the R River in the cooling tower blowdown will be quickly diluted by the much greater volume of the river flow and will be imperceptible a short distance downstream of the point of discharge.

Radiological Effects. Radiation doses in the vicinity of the water basin storage facility for SHLW were calculated based on the releases of quantities of radionuclides listed in Table 5.3.2-2; exposure pathways, demography, and other parameters described for the reference environment in Appendix A; and mathematical models relating dose to man from radionuclide releases (Appendix B). For planned operation of the water storage basin facility the only exposure pathway to man and the environment is via airborne effluents; there are no planned releases to ground or water.

The annual doses to individuals whose habits tend to maximize their dose ("maximum individual") are shown in Table 5.3.2-3. For perspective, the dose to an individual from naturally occurring radioactive sources averages about 0.1 rem/yr.

The combined dose from gaseous effluents to the population living within an 80-km radius of the plant was calculated using the projected year 2000 population data given in the reference environment. Table 5.3.2-4 summarizes the annual doses received by this population. The annual population total-body dose from naturally occurring sources to the approximately 2 million persons living within an 80-km radius of the plant in the year 2000 would be about 200,000 man-rem compared with the value of about <0.001 man-rem received from the water basin storage facility, as given in Table 5.3.2-5.

TABLE 5.3.2-3. Annual Doses to the Maximum Individual from Gaseous Effluents Released by the Water Basin Storage Facility for Solidified High-Level Waste (rem)

Pathway	Total Body	Thyroid[a] (child)	Thyroid[b]	Lung	Bone
		U Recycle, Pu in SHLW			
Air submersion	1.7×10^{-12}	1.7×10^{-12}	1.7×10^{-12}	1.7×10^{-12}	1.7×10^{-12}
Inhalation	6.5×10^{-11}		1.1×10^{-12}	3.4×10^{-9}	5.5×10^{-9}
Ingestion	6.0×10^{-10}		1.2×10^{-14}	6.5×10^{-10}	6.5×10^{-9}
Total	7.2×10^{-10}	1.7×10^{-12}	2.8×10^{-12}	4.1×10^{-9}	1.2×10^{-8}
		U Recycle, Pu Stored as PuO_2			
Air Submersion	1.7×10^{-12}	1.7×10^{-12}	1.7×10^{-12}	1.7×10^{-12}	1.7×10^{-12}
Inhalation	7.5×10^{-11}		1.1×10^{-12}	2.7×10^{-9}	2.5×10^{-10}
Ingestion	6.0×10^{-10}		1.2×10^{-14}	6.5×10^{-11}	6.5×10^{-10}
Total	7.2×10^{-10}	1.7×10^{-12}	2.8×10^{-12}	2.7×10^{-9}	9.0×10^{-10}
		U and Pu Recycle			
Air submersion	1.8×10^{-12}	1.8×10^{-12}	1.8×10^{-12}	1.8×10^{-12}	1.8×10^{-12}
Inhalation	9.0×10^{-11}		1.2×10^{-12}	4.5×10^{-9}	5.0×10^{-10}
Ingestion	5.5×10^{-10}		1.3×10^{-14}	6.5×10^{-11}	6.0×10^{-10}
Total	6.4×10^{-10}	1.8×10^{-12}	3.0×10^{-12}	4.6×10^{-9}	1.1×10^{-9}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the highest annual average dispersion factor ($\bar{\chi}/Q'$) of 1.5×10^{-8} sec/m^3.

a. Thyroid dose is calculated for a 1-year-old child breathing air containing radioactive effluents and consuming 1 ℓ of milk per day from cows grazing 7 months/yr at the site boundary. Inhalation dose is <2% of total dose.
b. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegitables (growing season, 4 months/yr).

TABLE 5.3.2-4. Annual Doses to the Population (within 80 km) from Gaseous Effluents Released by the Water Basin Storage Facility for Solidified High-Level Waste (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
		U Recycle, Pu in SHLW		
Air submersion	4.0×10^{-7}	4.0×10^{-7}	4.0×10^{-7}	4.0×10^{-7}
Inhalation	2.1×10^{-5}	2.6×10^{-7}	8.0×10^{-4}	1.4×10^{-4}
Ingestion	6.0×10^{-5}	1.3×10^{-9}	7.0×10^{-6}	6.5×10^{-5}
Total	8.1×10^{-5}	6.6×10^{-7}	8.1×10^{-4}	2.1×10^{-4}
		U Recycle, Pu Stored as PuO_2		
Air submersion	4.0×10^{-7}	4.0×10^{-7}	4.0×10^{-7}	4.0×10^{-7}
Inhalation	1.7×10^{-5}	2.6×10^{-7}	6.0×10^{-4}	6.0×10^{-5}
Ingestion	6.0×10^{-5}	1.3×10^{-9}	7.0×10^{-6}	6.5×10^{-5}
Total	7.7×10^{-5}	6.6×10^{-7}	6.1×10^{-7}	1.3×10^{-4}
		U and Pu Recycle		
Air submersion	4.1×10^{-7}	4.1×10^{-7}	4.1×10^{-7}	4.1×10^{-7}
Inhalation	2.1×10^{-5}	2.8×10^{-7}	1.1×10^{-3}	1.2×10^{-4}
Ingestion	6.0×10^{-5}	1.3×10^{-9}	7.0×10^{-6}	6.0×10^{-5}
Total	8.1×10^{-5}	6.9×10^{-7}	1.1×10^{-3}	1.8×10^{-4}

TABLE 5.3.2-5. Summary of Annual Total-Body Doses Received from Operation of the Water Basin Storage Facility for Solidified High-Level Waste and from Naturally Occurring Sources

	Dose, man-rem
Water basin storage facility	
Process work force	120
Population (within 80 km)	<0.001
Naturally occurring sources	
Population (within 80 km)	200,000

The annual estimated total-body dose to the work force associated with the water basin storage facility was based on permissible exposure limits and experience of operating plants. The annual occupational dose was calculated to be 120 man-rem.

The 70-year doses to the maximum individual and to the population within 80 km of the facility are given in Tables 5.3.2-6 and 5.3.2-7 respectively. A summary of the 70-year

TABLE 5.3.2-6. 70-Year Doses to the Maximum Individual from Gaseous Effluents Released by the Water Basin Storage Facility for Solidified High-Level Waste (rem)

Pathway	Total Body	Thyroid	Lung	Bone
	U Recycle, Pu in SHLW			
Air submersion	5.0×10^{-11}	5.0×10^{-11}	5.0×10^{-11}	5.0×10^{-11}
Inhalation	1.6×10^{-9}	3.3×10^{-11}	1.0×10^{-8}	2.3×10^{-7}
Ingestion	1.1×10^{-7}	3.7×10^{-13}	3.5×10^{-9}	3.5×10^{-7}
Total	1.1×10^{-7}	8.3×10^{-11}	1.4×10^{-8}	5.8×10^{-7}
	U Recycle, Pu Stored as PuO_2			
Air submersion	5.0×10^{-11}	5.0×10^{-11}	5.0×10^{-11}	5.0×10^{-11}
Inhalation	7.5×10^{-9}	3.3×10^{-11}	6.0×10^{-8}	4.6×10^{-8}
Ingestion	1.1×10^{-7}	3.7×10^{-3}	3.5×10^{-9}	3.5×10^{-7}
Total	1.2×10^{-7}	8.3×10^{-11}	6.4×10^{-8}	5.0×10^{-7}
	U and Pu Recycle			
Air submersion	5.0×10^{-11}	5.0×10^{-11}	5.0×10^{-11}	5.0×10^{-11}
Inhalation	1.3×10^{-8}	3.6×10^{-11}	1.5×10^{-7}	1.3×10^{-7}
Ingestion	1.0×10^{-7}	3.9×10^{-13}	3.5×10^{-9}	3.2×10^{-7}
Total	1.1×10^{-7}	8.6×10^{-11}	1.5×10^{-7}	4.5×10^{-7}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 1.5×10^{-8} sec/m^3.

a. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

TABLE 5.3.2-7. 70-Year Doses to the Population (within 80 km) from Gaseous Effluents Released by the Water Basin Storage Facility for Solidified High-Level Waste (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
	U Recycle, Pu in SHLW			
Air submersion	1.2×10^{-5}	1.2×10^{-5}	1.2×10^{-5}	1.2×10^{-5}
Inhalation	3.7×10^{-3}	7.5×10^{-6}	2.4×10^{-2}	5.5×10^{-1}
Ingestion	1.0×10^{-2}	3.8×10^{-8}	3.8×10^{-4}	3.1×10^{-2}
Total	1.4×10^{-2}	2.0×10^{-5}	2.4×10^{-2}	5.8×10^{-1}
	U Recycle, Pu Stored as PuO_2			
Air submersion	1.2×10^{-5}	1.2×10^{-5}	1.2×10^{-5}	1.2×10^{-5}
Inhalation	1.8×10^{-3}	7.5×10^{-5}	1.4×10^{-2}	1.1×10^{-2}
Ingestion	1.0×10^{-2}	3.9×10^{-8}	3.9×10^{-4}	3.1×10^{-2}
Total	1.2×10^{-2}	8.7×10^{-5}	1.4×10^{-2}	4.2×10^{-2}
	U and Pu Recycle			
Air submersion	1.2×10^{-5}	1.2×10^{-5}	1.2×10^{-5}	1.2×10^{-5}
Inhalation	2.9×10^{-3}	8.5×10^{-6}	3.4×10^{-2}	2.9×10^{-2}
Ingestion	9.5×10^{-3}	4.1×10^{-8}	3.9×10^{-4}	2.9×10^{-2}
Total	1.2×10^{-2}	2.1×10^{-5}	3.4×10^{-2}	5.8×10^{-2}

total-body doses to the work force and the population is given in Table 5.3.2-8. For comparison, the population dose from naturally occurring sources is also given for the year 2000 and is about 14,000,000 man-rem compared with 1.4×10^{-2} man-rem received from the storage facility.

TABLE 5.3.2-8. Summary of 70-Year Total-Body Doses Received from Operation of the Water Basin Storage Facility for Solidified High-Level Waste and from Naturally Occurring Sources

	Dose, man-rem
Water basin storage facility	
Process work force (30 yr)	3,600
Population (within 80 km)	<.014
Naturally occurring sources	
Population (within 80 km)	14,000,000

Health effects for the regional population are discussed at the plant level where several processes within the FRP are combined. In general, doses at the individual process level are too small for a meaningful analysis of health effects. In this report, 100 to 800 health effects are postulated to occur in the exposed population per million man-rem.

Ecological Effects. Approximately 4.1×10^5 m^3 of water per year will be withdrawn from the R River for secondary cooling and sanitary purposes. This amounts to less than 1% of the minimum flow of the R River and will have an immeasurable effect upon the aquatic ecosystem. The cooling water is circulated through cooling towers that dissipate about 8.5×10^8 MJ/yr of waste heat to the atmosphere. About 3.5×10^5 m^3/yr of the cooling water will be evaporated, 1.7 m^3/yr will be released in the cooling tower drift, and 6.1×10^4 m^3/yr will be discharged as blowdown. The estimated ΔT will be about 17°C at the point of discharge. Because of the small volume of the blowdown relative to the flow of the river, rapid dilution will take place and no thermal effects on the river organisms are expected. Similarly the wide dispersion and small volume heat release in drift will not be of consequence to terrestrial plants and animals.

About 18 MT of salt will be released annually to the environment from the cooling tower. About 66% or 10.3 MT of this amount will be discharged in the tower blowdown and 5.3 MT in the drift. This would result in a salt concentration in the drift and blowdown of about 200 ppm. There is evidence that soils containing 0.1 to 0.5% salt will begin to be incompatible for plant growth.[1,2] The time required to accumulate 0.5% salt in the soil 50 m from the cooling tower is calculated to be about 100 years. This estimate is based on the conditions of no leaching of salt (which probably would not be the case under natural conditions) 10 cm below the surface soil. Consequently, no adverse effects to vegetation are expected from the discharge of salt in the drift. Salt concentrations of 200 ppm are also well below toxicity limits to aquatic organisms,[3] and the discharge of this material to the river will not be harmful to the biota in the river.

Approximately 21 MT of phosphates and chromates used in the treatment of the cooling water will be released in the cooling tower drift and blowdown. If it is assumed that equal amounts of phosphates and chromates are present, the concentration of these materials will be about 100 ppm. This is within the range of chromate toxicity to fish.[4] However, if this material is discharged to the R River, rapid dilution will reduce chromate levels to tolerable limits. Although 100 ppm of phosphate is several orders of magnitude above that found in natural surface waters, phosphorus is often the essential nutrient that is growth limiting in freshwater, and the introduction of phosphates to the R River is not expected to be detrimental.

Chromates discharged to land in the tower drift are within the 1 to 5000 ppm normal chromium content reported for American soils[5] and will not be harmful to vegetation. Phosphate releases to land are also within acceptable limits.

5.3.2.3 Environmental Effects Related to Postulated Accidents

A number of minor accidents associated with the water basin storage facility for SHLW were identified but none are expected to lead to releases of radioactive material to the environment. Scenarios for these accidents are provided in DOE/ET-0028.[6] The accidents are as follows:

Accident Number	Description
5.4.1	Loss of normal electrical power
5.4.2	Loss of normal cooling water supply
5.4.3	Reduction of normal cooling water supply
5.4.4	Ventilation system failure
5.4.5	Leak in water treatment system
5.4.6	Failure of secondary cooling loop

Several moderate and severe accidents were also identified. Scenarios are provided in DOE/ET-0028[6] and the accidents are listed below.

Accident Number	Description
	Moderate
5.4.7	Canister failure in storage basin
5.4.8	Failure of basin liner
5.4.9	Dropping shipping cask into cask well
5.4.10	Dropping canister into storage basin
5.4.11	Failure of primary cooling loop
	Severe
5.4.12	Concrete cover block falls into storage pool
5.4.13	Contamination of secondary cooling water
5.4.14	Fire in storage basin building
5.4.15	Design basis tornado

Of these accidents, only Accident 5.4.13 has been postulated to result in the release of radioactive materials to the environment; therefore, this accident was taken as an upper bound of the set.

It was assumed that material leaking from an SHLW canister was transferred to the secondary cooling water and that the radioactive material contained in about 7 g of calcine was released to the atmosphere over a 3-hr period from the mechanical-draft cooling tower. The release was assumed to occur at ground level. The quantity of radioactive materials released is given in Table 5.3.2-9.

The 1-year dose and 70-year dose commitment to the maximum individual were calculated and are presented in Tables 5.3.2-10 and 5.3.2-11. The one-year total-body doses are within the range of doses received from natural sources. Lung doses during the first year, however, are two orders of magnitude higher than doses from natural sources.

No discernible ecological effects are expected from the releases.

TABLE 5.3.2-9. Radioactive Material Released to the Biosphere During an Accidental Contamination of Secondary Cooling Water at the Water Basin Storage Facility for Solidified High-Level Waste (Ci)

Radionuclide	Pu in SHLW U Recycle, or PuO_2 Stored	U and Pu Recycle
^{3}H	6.0×10^{-3}	6.0×10^{-3}
^{90}Sr	1.2×10^{1}	1.1×10^{1}
^{106}Ru	3.0×10^{1}	3.4×10^{1}
^{125m}Te	3.9×10^{-1}	4.2×10^{-1}
^{127m}Te	7.5×10^{-2}	7.7×10^{-2}
^{129}I	3.0×10^{-8}	3.2×10^{-8}
^{134}Cs	2.1×10^{1}	2.1×10^{1}
^{137}Cs	1.6×10^{1}	1.7×10^{1}
^{144}Ce	4.5×10^{1}	4.3×10^{1}
^{239}Pu	2.6×10^{-4}	3.2×10^{-4}
^{241}Am	6.6×10^{-2}	1.3×10^{-1}
^{242}Cm	6.2×10^{-1}	1.8
^{244}Cm	2.1×10^{-1}	1.3

TABLE 5.3.2-10. One-Year Dose to the Maximum Individual from Contamination of Secondary Cooling Water at the Water Basin Storage Facility for Solidified High-Level Waste (rem)

Pathway	Skin	Total Body	Thyroid	Lung	Bone
		U Recycle			
Air submersion	4.2×10^{-3}	1.3×10^{-3}	1.3×10^{-3}	1.3×10^{-3}	1.3×10^{-3}
Inhalation		2.0×10^{-1}	1.1×10^{-2}	1.2×10^{1}	1.6
Total	4.2×10^{-3}	2.0×10^{-1}	1.2×10^{-2}	1.2×10^{1}	1.6
		U and Pu Recycle			
Air submersion	4.3×10^{-3}	1.3×10^{-3}	1.3×10^{-3}	1.3×10^{-3}	1.3×10^{-3}
Inhalation		3.2×10^{-1}	1.2×10^{-2}	2.7×10^{1}	3.3
Total	4.3×10^{-3}	3.2×10^{-1}	1.3×10^{-2}	2.7×10^{1}	3.3

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the time-integrated atmospheric dispersion coefficient (E/Q) is 1.1×10^{-4} sec/m^3.

TABLE 5.3.2-11. 70-Year Dose Commitment to the Maximum Individual from Contamination of Secondary Cooling Water at the Water Basin Storage Facility for Solidified High-Level Waste (rem)

Pathway	Skin	Total Body	Thyroid	Lung	Bone
		U Recycle			
Air submersion	4.2×10^{-3}	1.3×10^{-3}	1.3×10^{-3}	1.3×10^{-3}	1.3×10^{-3}
Inhalation		2.0	1.1×10^{-2}	1.9×10^{1}	1.4×10^{1}
Total	4.2×10^{-3}	2.0	1.2×10^{-2}	1.9×10^{1}	1.4×10^{1}
		U and Pu Recycle			
Air submersion	4.3×10^{-3}	1.3×10^{-3}	1.3×10^{-3}	1.3×10^{-3}	1.3×10^{-3}
Inhalation		3.5	1.2×10^{-2}	4.8×10^{1}	4.0×10^{1}
Total	4.3×10^{-3}	3.5	1.3×10^{-2}	4.8×10^{1}	4.0×10^{1}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the time-integrated atmospheric dispersion coefficient (E/Q) is 1.1×10^{-4} sec/m^3.

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5.3.3 Interim Storage of Fuel Residues (DOE/ET-0028 Sec. 5.2)

Current concepts for interim storage of fuel residues specify placing them in canisters and storing the canisters in vaults or in surface caisson storage facilities. A third option is to use spent fuel storage basins for storing both fuel residues and fuel residue canisters. Any of these interim storage methods could be implemented at an FRP or at an independent site. Because the options of vault storage and surface caisson storage are representative of available technology, they have been selected for analysis in this report. The surface storage facility is chosen as the reference facility. Similar techniques have been used for retrievable storage of radioactive wastes at government installations.

5.3.3.1 Vault Storage (DOE/ET-0028 Sec. 5.2.1)

The fuel residue vault storage facility comprises a modular arrangement of partially buried reinforced concrete cells. The individual cells have roof slabs 1.2 m thick in which removable shielding plugs are built to allow storage and retrieval of fuel residues. A 60-ton gantry crane runs over one-half of the roof slab area to handle the transfer cask, the hulls transfer device, and the shielding plugs. The vault is cooled by natural air circulation.

A typical individual vault storage cell has two compartments, each with a capacity to store 156 canisters for a total of 312 canisters per cell. Eight cells are provided to store 2496 canisters of fuel residues generated from 5 years' operation of the FRP.

The floor slab of each storage compartment is sloped toward a longitudinal floor drain that ends in a floor sump. Here, any liquid from the vault cell is monitored before release to a retention pond located outside the vault. Run-off from the roof slab is directed through surface drains to the retention pond where, after monitoring, it is released to the site drainage system.

Several screened air intake structures are provided on each side of the vault to permit air to enter the cell and circulate around the stored canisters. Hot air will leave through vents located at the center of the structure, where monitors are installed to detect any release of airborne contamination.

Each storage space is a galvanized steel pipe sleeve with a plate welded to its bottom and suspended from the roof slab to supply the necessary containment for any material that may leak from the fuel residue container. In the event leakage occurs, the material will be held by this secondary container to prevent its escape. Closure at the shielding plug is made with neoprene gaskets to provide complete containment.

The vault storage cells are reinforced-concrete structures with galvanized carbon steel interior supports and sleeves for the fuel residue containers. The cells are designed to Category I specifications, which require the capacity to withstand maximum predictable natural phenomena.

Environmental Effects Related to Facility Construction. Some aspects of site preparation and reference facility construction may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of construction activities.

Resource Commitments. The vault storage facility with a capacity of 2496 canisters will occupy about 8 ha. Another 2 ha will be required to be cleared for construction storage, work yards, temporary buildings, and parking. This facility will be included with the reference FRP, whose structures will occupy about 40 ha. Land commitment attributable to the vault storage facility represents 25% of the FRP requirement.

Water used during the 3-year construction period is estimated to be 6×10^4 m^3. Withdrawal of this amount of water from the R River (average flow of 1.0×10^7 m^3/day) is judged to be insignificant with respect to other downstream uses. During the construction period, wells could probably supply the required amount of water without consequence.

Materials committed for construction of the fuel residue vault storage facility are:

Steel	14,500 MT
Copper	9 MT
Lead	45 MT
Lumber	3,140 m^3
Concrete	59,000 m^3

Energy resources used during construction are:

Propane	450 m^3
Diesel fuel	4,500 m^3
Gasoline	3,000 m^3
Electricity	
Peak demand	1,250 kW
Total consumption	2,280,000 kWh

Manpower requirements for construction of the vault storage facility will amount to 2000 man-yr, which will likely be integrated with labor schedules for the FRP.

Transportation requirements include a short onsite road designed for trucks hauling fuel residue casks. There are no specific site requirements for this facility beyond those identified for the FRP.

Physical and Chemical Effects. Effects on air quality from construction of the vault storage facility will be indistinguishable from those resulting from construction of the reference FRP.

The diversion of about 6 x 10^4 m^3 of water for construction of the vault storage facility is not expected to affect local water supplies. Excavation for four 37- x 129-m rectangular vaults to a depth of about 5 m below ground surface and for a 25- x 50-m (approx.) rectangular retention basin to a depth of about 3 m is not expected to have a significant effect on groundwater movement. Construction activities for the facility and access road may affect surface drainage and may cause sediment run-off and temporarily impair nearby surface water quality. The construction of the facility will coincide with the FRP construction, and effects will be inseparable from the effects of the overall FRP construction.

Ecological Effects. There will be no construction impacts for the vault storage facility apart from those of the reference FRP. Land area requirements are approximately 8 ha and are included in the 40-ha land requirements for the FRP. An additional 2 ha will be required for construction storage, temporary buildings and labor parking.

During the 3-year construction period 6 x 10^4 m^3 of water will be used. This will come from the common FRP water supply to be obtained from the R River near the reference site. It represents an insignificant fraction (0.6%) of the average daily river flow of 1.1 x 10^7 m^3. No ecological impacts on the river ecosystem are expected from this volume of water removal.

when compared with those from construction of the overall FRP complex. No ecological effects are expected to result from emissions related to construction of the vault storage facility.

Environmental Effects Related to Facility Operation. Some aspects of facility operation may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effects of operation.

Resource Commitments. Resources required during operation of the fuel residue vault storage facility are listed in Table 5.3.3-1. The commitment of these resources is insignificant in comparison with total FRP requirements.

TABLE 5.3.3-1. Utilities and Materials Required for Operation of the Fuel Residue Vault Storage Facility

Resource	Average Annual Use
Diesel fuel, m^3	7.6
Electricity, kWh	5,000,000
Manpower, man-yr	2

Process Effluents. Routine operation of the storage facility will produce no nonradioactive pollutants for release to the atmosphere.

For operation of the storage facility there are no planned releases of radioactive material to air, water, or ground; therefore there are no pathways for radionuclides to man.

An estimated 4.9×10^4 m^3/yr from storm run-off (assuming an annual precipitation of 0.76 m), will be diverted to a retention basin to check for radioactive contamination. The capacity assumed for the retention basin is adequate to store about one-half of the storm run-off (about 8000 m^3) from the maximum potential 24-hr precipitation of 0.13 m.*

Total heat load from the facility will be about 1.8×10^3 MJ/hr. This heat will be released directly to the atmosphere by natural convection and conduction through a vent in the vault storage facility roof.

Physical, Chemical, and Thermal Effects. No physical or chemical effects are expected from the operation of this facility.

Total heat load from the vault storage facility is about 1.8×10^3 MJ/hr. However, no effects are expected from the release of this heat.

Radiological Effects. No radiological effects are expected from routine operation of the vault storage facility since there are no planned releases of radioactive material to air, water, or ground.

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* In this instance and others where the retention basin is not sufficient to contain the runoff from a single credible storm, modifications in basin capacity will be required so that all storm run-off will be retained for radiological monitoring before release to the environment.

Ecological Effects. The vault storage facility will be used only for temporary storage of fuel residues. Because no processing takes place in this facility, there will be no process effluents released during normal operation. Less than 8 m^3 of fossil fuel will be burned each year to operate equipment; thus the release of minor incremental emissions to the air will produce no ecological impact.

Water use for sanitary purposes will amount to approximately 2×10^2 m^3/yr to be supplied by the common FRP water supply system from the R River. This volume represents an insignificant portion of the river flow and no impacts on the river ecosystem are expected from its removal. A portion of the water will be returned through the FRP sanitary sewer for treatment and will result in no ecological effects related to this facility.

No ecological effects are expected from the release of 1.8×10^7 MJ/yr of heat to the atmosphere since it represents only a small increment of the total release rate of 2.6×10^9 MJ/yr of waste heat from the FRP operation.

Environmental Effects Related to Postulated Accidents. No minor accidents resulting in the release of radioactive materials to the biosphere were identified for operation of the design basis vault storage facility, no non-design basis accidents were considered.

One accident was postulated to have a potential for releasing radioactive material. The scenario for this accident is given in DOE/ET-0028[1] and the accident is listed below.

Accident Number	Description
5.2.1	Waste zirconium hulls canister breached by drop

For this accident it was assumed that a canister containing 1320 kg of zirconium hulls is breached, exposing 0.14 of the contained metal to the atmosphere. About 5.4×10^{-4} of the exposed material is assumed to be entrained in the atmosphere. A ground level release period of 1 hr and a 1.5-year storage decay time out of the reactor is assumed. The estimated frequency of this accident is 0.2 per year. The radioactive material associated with such an event is given in Table 5.3.3-2.

The 70-year dose commitment to the maximum individual was calculated and is presented in Table 5.3.3-3. Numerically, the largest of these dose values are on the order of the dose that an individual would have received from naturally occurring sources during 1 year.

No serious accidents were postulated within the design basis of the facility. Non-design basis accidents were not considered.

5.3.3.2 Subsurface Storage (DOE/ET-0028 Sec. 5.2.2)

The fuel residue subsurface storage facility provides temporary storage for fuel residues. It is operated and maintained from within its own security fence; however, utilities, equipment maintenance, and personnel support facilities are provided from the FRP.

TABLE 5.3.3-2. Radionuclides Released to the Atmosphere from Breach of a Waste Zirconium Hulls Canister in the Fuel Residue Vault Storage Facility (Ci)

Radionuclide	U Recycle	U and Pu Recycle
^{3}H	2.2×10^{-2}	2.2×10^{-2}
^{14}C	2.1×10^{-5}	2.1×10^{-5}
^{60}Co	3.5×10^{-2}	3.5×10^{-2}
^{90}Sr	1.1×10^{-2}	1.1×10^{-2}
^{95}Zr	2.9×10^{-2}	2.9×10^{-2}
^{106}Ru	3.3×10^{-2}	3.0×10^{-2}
^{125m}Te	4.2×10^{-4}	3.9×10^{-4}
^{127m}Te	7.5×10^{-5}	7.4×10^{-5}
^{134}Cs	2.1×10^{-2}	2.1×10^{-2}
^{137}Cs	1.6×10^{-2}	1.6×10^{-2}
^{144}Ce	4.2×10^{-2}	4.4×10^{-2}
^{238}Pu	9.6×10^{-4}	5.4×10^{-4}
^{239}Pu	6.3×10^{-5}	5.1×10^{-5}
^{241}Pu	3.2×10^{-2}	1.9×10^{-2}
^{242}Cm	1.7×10^{-3}	6.1×10^{-4}
^{244}Cm	1.3×10^{-3}	2.1×10^{-4}

TABLE 5.3.3-3. 70-Year Dose Commitment to the Maximum Individual Resulting from a Canister Breach Accident in the Fuel Residue Vault Storage Facility (rem)

Pathway	Skin	Total Body	Thyroid	Lung	Bone
		U Recycle			
Air submersion	7.3×10^{-6}	4.2×10^{-6}	4.2×10^{-6}	4.2×10^{-6}	4.2×10^{-6}
Inhalation		8.1×10^{-3}	1.2×10^{-5}	7.4×10^{-2}	1.4×10^{-1}
Total	7.3×10^{-6}	8.1×10^{-3}	1.6×10^{-5}	7.4×10^{-2}	1.4×10^{-1}
		U and Pu Recycle			
Air submersion	7.2×10^{-6}	4.2×10^{-6}	4.2×10^{-6}	4.2×10^{-6}	4.2×10^{-6}
Inhalation		4.7×10^{-3}	1.1×10^{-5}	3.7×10^{-2}	7.3×10^{-2}
Total	7.2×10^{-6}	4.7×10^{-3}	1.5×10^{-5}	3.7×10^{-2}	7.3×10^{-2}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the time-integrated atmospheric dispersion coefficient (E/Q) is 1.1×10^{-4} sec/m^3.

The surface storage facility consists of two parallel above-grade berms constructed from suitable soil materials; residue containers are stored in individual steel caissons within the berms. Figure 5.3.3-1 illustrates a typical berm. The individual storage positions have removable shielding plugs 1.2 m thick to allow for storage and retrieval of containers with a

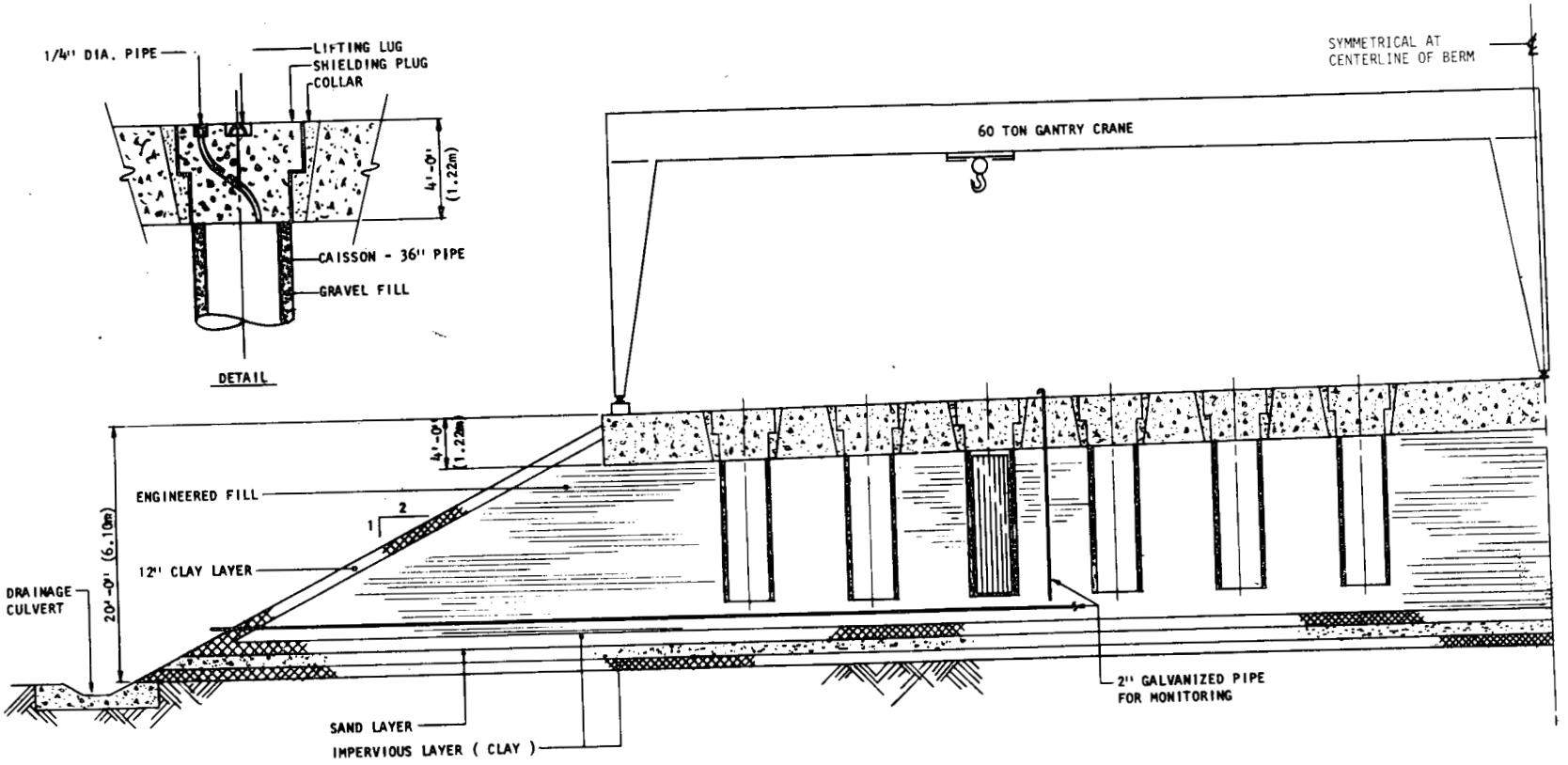

FIGURE 5.3.3-1. Typical Berm at the Surface Storage Facility for Fuel Residues at the FRP

special transfer device. A 54.5 MT gantry crane runs over one-half of the berm and handles the fuel residue cask, the transfer device, and the shielding plugs. Cooling of the berms is achieved by conduction through the soils.

The berm has two equal sections, each with a capacity to store 624 canisters or a total of 1248 canisters per berm. Run-off from the berm as well as internal drainage will be directed to the peripheral drains and on to the retention pond for release to the site drainage system after monitoring.*

The berm is compacted to 95% of its maximum dry density. Galvanized steel caissons are placed on 1.1-m drilled holes, and granular material is filled between the berm and the caissons to isolate the caissons from the adjacent fill material. Shielding plugs with matching collars are installed and centered on each caisson, and a concrete slab 1.2 m thick is poured on top of the berm.

Each storage space consists of a galvanized steel pipe sleeve 0.9 m in diameter with a plate welded to its bottom and suspended from the slab to supply the necessary containment for any material that may leak from the stored canister. Gravel is backfilled around the outside of the pipe. In the event leakage occurs, the leaking material will be held by this secondary container. Closure at the shielding plug is made with neoprene gaskets to provide complete containment.

Environmental Effects Related to Facility Construction. Some aspects of site preparation and reference facility construction may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of construction activities.

Resource Commitments. The fuel residue subsurface storage facility will occupy an area of about 12 ha. It will be included with the reference FRP, whose structures will occupy about 40 ha. Another 2 ha will be cleared for construction storage, work yards, temporary buildings, and parking. Land commitment attributable to the vault storage facility would represent about 35% of the FRP requirement.

Water used during the 3-year construction period is estimated to be 1.5×10^4 m^3. Withdrawal of this amount of water from the R River (average flow of 1.0×10^7 m^3/day) is judged to be insignificant with respect to other downstream uses. During the construction period, wells can probably supply the amount of water without consequence.

Materials committed for construction of the surface storage facility are:

Steel	3,600 MT
Copper	4.5 MT
Lead	45 MT
Lumber	1,040 m^3
Concrete	16,800 m^3

* At this writing no provision has been made in case the retention pond contents, after monitoring, are not acceptable for release to the environs. Additional storage ponds could, however, be built to store the radioactive material until it has decayed to acceptable levels or has been removed from the water. This feature occurs throughout this report where retention ponds are mentioned.

Energy resources used during construction are:

Propane	120 m^3
Diesel fuel	1,780 m^3
Gasoline	800 m^3
Electricity	
Peak demand	570 kW
Total consumption	590,000 kWh

Manpower requirements during construction of the surface storage facility will amount to 520 man-yr, which will likely be integrated with labor schedules for the FRP.

Transportation requirements include a short onsite road (<2 km) designed for trucks hauling fuel residue casks. There are no other site-specific requirements for this facility beyond those identified for the FRP.

Physical and Chemical Effects. Effects on air quality from construction of the surface storage facility will be indistinguishable from those resulting from construction of the reference FRP.

Over the planned period of construction the diversion of about 1.5×10^4 m^3 of water for the construction of the surface storage facility will have no significant impact on local water supplies. Excavation for a 25- x 50-m (approx.) rectangular retention basin to a depth of about 3 m is not expected to significantly affect groundwater movement. Construction activities for the facility and access road will affect surface drainage and may cause sediment run-off and temporarily impair nearby surface water quality. The construction of the facility will coincide with the FRP construction and effects will also be inseparable from the effects of the overall FRP construction.

Ecological Effects. There will be no construction impacts for the surface storage facility apart from those of the reference FRP. Land area requirements are on the order of 12 ha and are included in the 40 ha requirements for the FRP.

During the 1.75-year construction period 1.5×10^4 m^3 of water will be used. This will come from the common FRP water supply to be obtained from the R River near the reference site. It represents an insignificant fraction (<0.2%) of the daily river flow of 1.1×10^7 m^3. No ecological impacts on the river ecosystem are expected from removal of this volume of water.

Energy consumption during construction will include approximately 2×10^3 m^3 of fossil fuels. The emissions resulting from burning these fuels may result in occasional locally elevated levels of hydrocarbons and nitrogen oxides. The quantities of emissions will be minor when compared with those from construction of the overall FRP complex. No ecological effects are expected to result from emissions related to construction of the surface storage facility.

Environmental Effects Related to Facility Operation. Some aspects of facility operation may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effects of operation.

Resource Commitments. Resources required during operation of the fuel residue surface storage facility are listed in Table 5.3.3-4. The commitment of these resources is insignificant in comparison with total FRP requirements.

TABLE 5.3.3-4. Utilities and Materials Required for Operation of the Fuel Residue Surface Storage Facility

Resource	Average Annual Use
Diesel fuel, m^3	7.6
Electricity, kWh	5,000,000
Manpower, man-yr	2

Process Effluents. Routine operation of this facility will produce no pathways for radionuclides to man since there are no planned releases of radioactive material to air, water, or ground.

An estimated 73,000 m^3/yr from storm run-off (assuming annual precipitation of 0.76 m) will be diverted to a retention basin (3800 m^3 capacity) to check for radioactive contamination. The capacity assumed for the retention basin is adequate to store about one-half of the storm run-off (about 8000 m^3) from the maximum potential 24-hr precipitation of 0.13 m.

Total heat load from this facility will be about 1.8×10^3 MJ/hr. This heat will be released directly to the atmosphere by natural convection and conduction through a vent in the roof of the surface storage facility.

Physical, Chemical, and Thermal Effects. Total heat load from this surface storage facility is about 1.8×10^3 MJ/hr. No effects are expected from the vented release of this heat.

Radiological Effects. No radiological effects are expected from routine operation of the surface storage facility since there are no planned releases to air, water, or ground.

Ecological Effects. Because no processing takes place in this facility, no process effluents will be released during normal operation. Less than 8 m^3 of fossil fuel will be burned each year to operate equipment; thus the release of minor incremental emissions to the air will produce no ecological impact.

No ecological effects are expected from the release of 1.6×10^7 MJ/yr of heat to the atmosphere since it represents only a fraction (<1%) of the total release rate of 2.6×10^9 MJ/yr of waste heat from FRP operation.

Environmental Effects Related to Postulated Accidents. No minor accidents resulting in the release of radioactive materials to the biosphere were identified for operation of the design basis surface storage facility.

One accident was postulated to have a potential for releasing radioactive material. The scenario for this accident is given in DOE/ET-0028[1] and the accident is listed below.

Accident Number	Description
5.2.1	Waste zirconium hulls canister breached by drop

This accident and its consequences are the same as those described in Section 5.3.3.1. The radioactive material associated with such an accident is given in Table 5.3.3-2. The 70-year dose commitment to the maximum individual was calculated and is presented in Table 5.3.3-3.

No serious accidents were postulated within the design basis of the facility. Non-design basis accidents were not considered.

5.3.3.3 Comparison of Environmental Effects Between Alternatives for Storage of Fuel Residues at the FRP

Selected aspects of construction and operation of fuel residue storage alternatives (vault and surface storage) are presented for comparison in Table 5.3.3-5.

TABLE 5.3.3-5. Comparison of Resource Commitments for Construction of Alternative Fuel Residue Storage Facilities

Resource	Vault Storage	Subsurface Storage
Land, ha	8	1.2×10^{1}
Water, m^3	6×10^{4}	1.5×10^{4}
Materials		
Steel, MT	1.5×10^{4}	3.6×10^{3}
Copper, MT	9	4.5
Lead, MT	4.5×10^{1}	4.5×10^{1}
Lumber, m^3	3.1×10^{3}	1.0×10^{3}
Concrete, m^3	5.9×10^{4}	1.7×10^{4}
Energy		
Propane, m^3	4.5×10^{2}	1.2×10^{2}
Diesel fuel, m^3	4.5×10^{3}	1.8×10^{3}
Gasoline, m^3	3.0×10^{3}	8.0×10^{2}
Electricity, kWh	2.3×10^{6}	5.9×10^{5}
Manpower, man-yr	2.0×10^{3}	5.2×10^{2}

Land resources committed to construction of the surface storage facility are 50% greater than those committed for construction of the vault storage facility. Construction of the vault storage facility, however, requires four times more water, materials, and energy than does construction of the surface storage facility.

Resources committed to operation of either facility are the same as are radiological aspects from operations and postulated accidents.

REFERENCES FOR SECTION 5.3.3

1. Technology for Commercial Radioactive Waste Management, DOE/ET-0028, Department of Energy, Washington, DC, in press.

5.3.4 Intermediate-Level Transuranic Wastes (DOE/ET-0028 Sec. 5.3)

Non-high-level transuranic wastes are classified into two categories according to surface dose rates: 1) low-level wastes, which have a surface dose of less than 0.2 rem/hr; and 2) intermediate-level wastes, which have a surface dose rate of greater than 0.2 rem/hr. Containers for intermediate-level wastes consist of 55-gal drums and canisters 0.76 m in diameter by 3 m long. Containers for low-level wastes are 55-gal drums and steel boxes (1.2 x 1.8 x 1.8 m) each of which has a storage capacity equivalent to 12 55-gal drums.

Four interim storage concepts are considered: 1) outdoor surface storage of low-level transuranic wastes, 2) indoor unshielded storage of low-level transuranic wastes, 3) outdoor subsurface storage of intermediate-level transuranic wastes, and 4) indoor shielded storage of intermediate-level transuranic wastes. Facilities for storage of up to 5 years of these wastes are required at the FRP. The reference facilities are outdoor surface storage for low-level transuranic wastes (Section 5.3.5) and outdoor subsurface storage for intermediate-level transuranic wastes.

5.3.4.1 Outdoor Subsurface Storage of Intermediate-Level Transuranic Wastes at an FRP (DOE/ET-0028 Sec. 5.3.3)

The reference FRP at full production generates intermediate-level transuranic wastes at the rate of 8200 55-gal drums/yr. A storage capacity for about 33,000 55-gal drums is needed to accommodate intermediate-level transuranic wastes generated during the first 5 years of operation at 80% of full production. The outdoor subsurface storage facility provides storage for intermediate-level transuranic wastes contained in steel drums. The reference storage facility consists of a berm in which 504 storage vaults are constructed. Each vault has the capacity to store five 55-gal steel drums. A road is built over the center of the berm for equipment access during drum burial operations. A retention pond is provided to collect runoff from the berm. Water collected is monitored for contamination and, if found to be within permissible limits, is released through the surface drainage system. Figure 5.3.4-1 shows a plot plan of the outdoor subsurface storage facility for intermediate-level transuranic wastes.

Environmental Effects Related to Facility Construction. Some aspects of site preparation and facility construction may have an effect on the environment and natural resources of the surrounding area. The following information is provided to form a basis for evaluating the effects of construction activities.

Resource Commitments. The outdoor subsurface storage facility, including a retention pond and personnel building, will require an area of about 7.7 ha. The land commitment is included with that of the FRP.

Water used in construction is estimated to be 400 m^3. Withdrawal of this amount of water from the R River (average flow of 1.0×10^7 m^3/day) is judged to be insignificant with respect to other downstream uses.

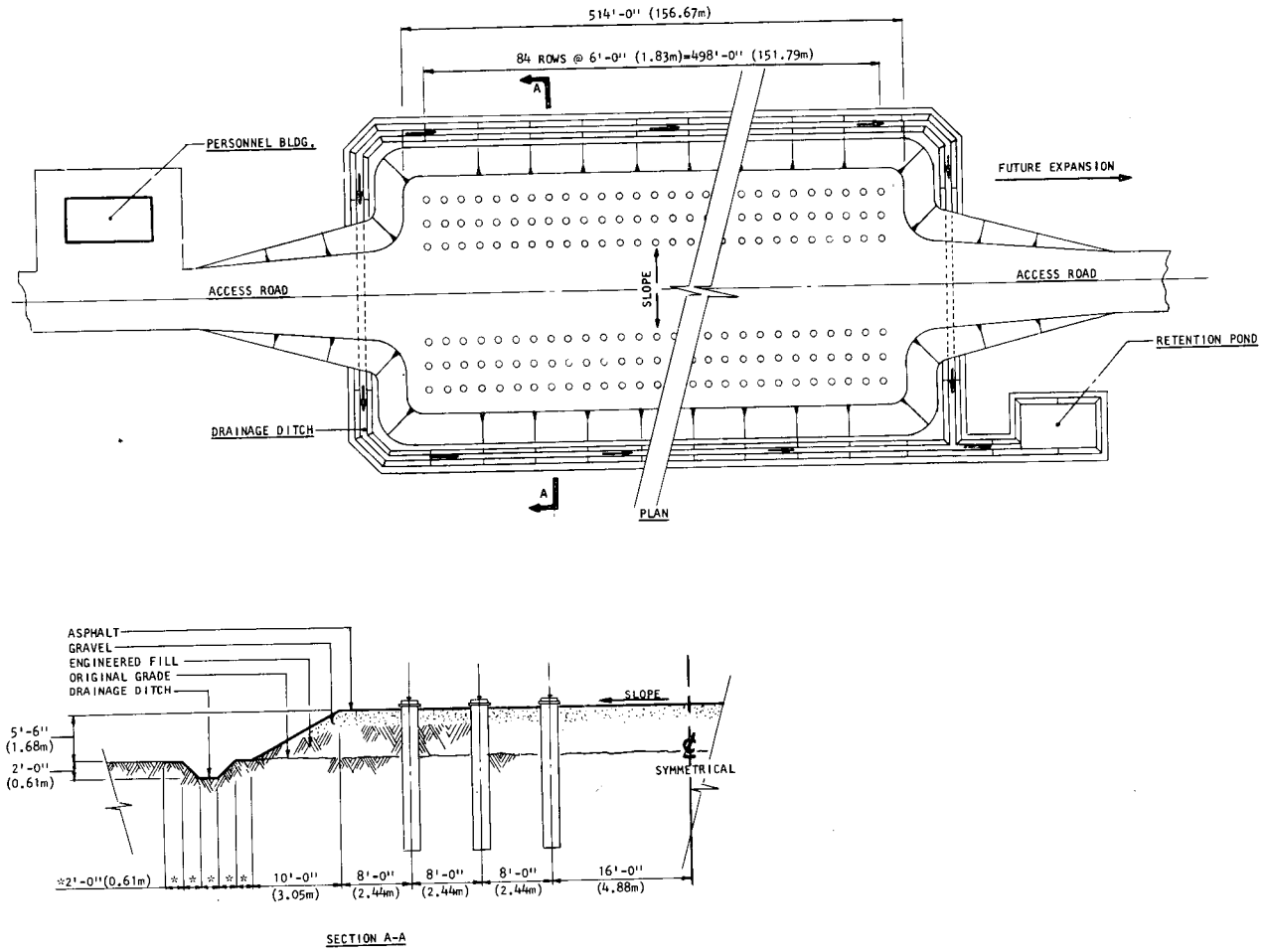

FIGURE 5.3.4-1. Plot Plan of the Outdoor Subsurface Storage Facility for Intermediate-Level Transuranic Wastes

Materials committed for construction of the outdoor subsurface storage facility having a 32,800 drum capacity are:

Steel	6500 MT
Lead	160 MT
Lumber	650 m^3
Concrete	5200 m^3

Energy resources used during construction are:

Propane	52 m^3
Diesel fuel	520 m^3
Gasoline	340 m^3
Electricity	
Peak demand	520 kW
Total consumption	260 MWh

Manpower requirements during construction of the outdoor subsurface storage facility (32,800 drum capacity) amount to 220 man-yr, which will likely be integrated with labor schedules for the FRP.

No separate transportation requirements or other site-specific requirements have been identified for the outdoor subsurface storage facility beyond those for the FRP.

Physical and Chemical Effects. The diversion of about 400 m^3 of water for construction of the outdoor subsurface storage facility will not have a significant impact on local water supplies. Excavation for the waste drums and the storm water retention pond is not expected to significantly affect groundwater movement. Backfilling of the berm (24 m wide by 160 m long by 1.7 m high) for the storage vaults may cause sediment run-off. This will be controlled by ditching and land contouring.

The use of about 7.7 ha of land for the outdoor subsurface storage facility is not expected to have a significant impact on local land use. Moreover, environmental effects of the facility construction related to both water and land use cannot be separated from the effects of the overall FRP construction.

Pollutants will be released to the atmosphere through the combustion of about 900 m^3 of fossil fuels by construction equipment and the generation of dust by grading and excavation. These emissions will be small compared with those of the overall FRP construction and will be well below Federal air quality standards at the FRP fenceline.

Ecological Effects. No ecological impacts from facility construction beyond those of the overall FRP complex are expected. Destruction of vegetation and displacement of birds and animals will be a small part of the impacts of FRP construction. No separate or additional transportation requirements for the subsurface storage facility are expected nor have any unique environmental effects associated with construction of this facility been identified.

During construction, about 400 m^3 of water will be used. This will come from the common FRP water supply to be obtained from the R River and represents an insignificant fraction of the 3.9×10^9 m^3 average annual river flow. No ecological impacts on the river ecosystems are expected from this volume of water removal.

About 520 m^3 of diesel fuel, 340 m^3 of gasoline, and 52 m^3 of propane will be burned to supply energy for equipment used during construction. Levels of air pollutants generated through the burning of these fuels will be well below Federal air quality standards and will not result in ecological impacts.

Environmental Effects Related to Facility Operation. Some aspects of operation of the outdoor subsurface storage facility for intermediate-level transuranic wastes may have an effect on the environment and natural resources of the surrounding area. The following information is provided to form a basis for evaluating the effects of operation.

Resource Commitments. Resources required during planned operation of the outdoor subsurface storage facility are given in Table 5.3.4-1.

TABLE 5.3.4-1. Utilities and Materials Required for Operating the Outdoor Subsurface Storage Facility for Intermediate-Level Transuranic Wastes

Resource	Average Annual Use
Water, m^3	76
Diesel fuel, m^3	23
Dessicant, MT	7.4
Electricity, kWh	70,000
Manpower, man-yr	3.2

Process Effluents. There will be no planned releases of radioactive materials to the biosphere during operation of the facility.

The combustion of fossil fuels by vehicles used in the handling and storage operation will release pollutants to the atmosphere. Approximately 23 m^3 of diesel fuel will be burned annually by trucks. The quantities of fuel combustion products released to the environment will be several orders of magnitude below Federal air quality standards for hydrocarbons, nitrogen and sulfur oxides, carbon monoxide, and particulates.

Physical, Chemical, and Thermal Effects. There will be no direct releases of nonradioactive liquid or solid wastes to surface or groundwaters or to land from operation of the outdoor subsurface storage facility. All liquid and solid waste disposal is part of the overall FRP operation.

Storm drainage estimated at 6100 m^3 per year (assuming an average annual precipitation of 0.76 m) is diverted to a retention basin to check for radioactive contamination before it is released to the FRP drainage system.

The release of vehicle fuel combustion products to the atmosphere will be well below the acceptable amounts listed in Federal air quality standards.

Radiological Effects. There will be no planned releases of radioactive material during normal facility operation.

Ecological Effects. Because no pollutants will be released to the atmosphere (except for small amounts from vehicle exhausts) no ecological effects are expected from normal facility operation. Land requirements are small (7.7 ha) and are included in the 40-ha area required for the FRP structures. Annual water use (76 m^3) is an insignificant fraction of the flow of the R River, the source of water for the facility.

Environmental Effects Related to Postulated Accidents. Four minor accidents were postulated for the outdoor subsurface storage facility for intermediate-level transuranic wastes. Scenarios for these accidents are provided in DOE/ET-0028[1] and the accidents are listed below.

Accident Number	Description
5.3.1	Mechanical breach of waste barrel
5.3.2	Dislodge of surface contamination
5.3.3	Overpressure of container
5.3.4	Rust-through of steel container

The worst-case minor accident, mechanical breach of a waste barrel (Accident 5.3.1), is taken as representative of the set. This accident is postulated to occur 0.027 times per year or about once every 37 years. The breach is postulated to release 5×10^{-3} of a container filled with 1.5-year-old solidified unincinerated intermediate-level transuranic waste. It was further assumed that 5×10^{-3} of the released material is entrained in the atmosphere in 0.5 hr. The radionuclides released are given in Table 5.3.4-2.

TABLE 5.3.4-2. Radionuclides Released to the Atmosphere from Breach of a Waste Barrel at the Outdoor Subsurface Storage Facility for Intermediate-Level Transuranic Wastes

Radionuclide	Release, Ci
^{14}C	8.7×10^{-11}
^{60}Co	3.2×10^{-6}
^{90}Sr	5.1×10^{-6}
^{95}Zr	2.7×10^{-5}
^{95}Nb	6.0×10^{-5}
^{106}Ru	1.3×10^{-3}
^{125m}Te	1.8×10^{-7}
^{127m}Te	3.3×10^{-8}
^{134}Cs	9.5×10^{-6}
^{137}Cs	7.3×10^{-6}
^{238}Pu	2.4×10^{-5}
^{239}Pu	2.3×10^{-6}
^{240}Pu	3.5×10^{-6}
^{241}Pu	8.7×10^{-4}
^{244}Cm	5.4×10^{-7}

The 1-year dose and 70-year dose commitment to the maximum individual from these radionuclides are given in Tables 5.3.4-3 and 5.3.4-4 respectively. The largest of the doses given in Table 5.3.4-3 is on the order of 0.3% of the dose the individual would have received from naturally occurring sources during the year.

TABLE 5.3.4-3. One-Year Dose to the Maximum Individual from Breach of a Waste Barrel at the Outdoor Subsurface Storage Facility for Intermediate-Level Transuranic Wastes (rem)

Pathway	Total Body	Thyroid	Lung	Bone
Air submersion	2.1×10^{-11}	2.1×10^{-11}	2.1×10^{-11}	2.1×10^{-11}
Inhalation	1.9×10^{-8}	1.5×10^{-11}	1.4×10^{-6}	4.2×10^{-7}
Total	1.9×10^{-8}	3.6×10^{-11}	1.4×10^{-6}	4.2×10^{-7}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the time-integrated atmospheric dispersion coefficient (E/Q) is 1.1×10^{-4} sec/m^3.

TABLE 5.3.4-4. 70-Year Dose Commitment to the Maximum Individual from Breach of a Waste Barrel at the Outdoor Subsurface Storage Facility for Intermediate-Level Transuranic Wastes (rem)

Pathway	Total Body	Thyroid	Lung	Bone
Air submersion	7.9×10^{-10}	7.9×10^{-10}	7.9×10^{-10}	7.9×10^{-10}
Inhalation	1.1×10^{-5}	4.4×10^{-10}	6.9×10^{-5}	2.4×10^{-4}
Total	1.1×10^{-5}	1.2×10^{-9}	6.9×10^{-5}	2.4×10^{-4}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the time-integrated atmospheric dispersion coefficient (E/Q) is 1.1×10^{-4} sec/m^3.

One accident is postulated to release radioactive materials in amounts greater than those released during minor accidents. This accident is described in DOE/ET-0028 as Accident 5.3.8: crane drops drum.

Accident Number	Description
5.3.8	Crane drops drum

This accident involves the rupturing of a drum of compacted filter media from the FRP. Rupture occurs when the drum is dropped from the bridge crane, thus releasing 5×10^{-5} of the contents to the atmosphere over a 1-hr period. Source terms for this accident are given in Table 5.3.4-5.

The first-year dose and 70-year dose commitment to the maximum individual from release of these radionuclides are given in Tables 5.3.4-6 and 5.3.4-7 respectively. Numerically, the largest dose from this accident amounts to about 4% of the total dose the individual would have received from naturally occurring sources over the 70-year period.

5.3.4.2 Indoor Shielded Storage of Intermediate-Level Transuranic Wastes (DOE/ET-0028 Sec. 5.3.4)

A storage capacity for about 32,800 55-gal drums is needed to accomodate intermediate-level transuranic wastes generated during the first 5 years of FRP operation at 80% of full production.

TABLE 5.3.4-5. Radionuclides Released to the Atmosphere from a Canister Drop from the Bridge Crane at the Outdoor Subsurface Storage Facility for Intermediate-Level Transuranic Wastes

Radionuclide	Release, Ci		
	U and Pu Recycle	U Recycle, Pu in SHLW	U Recycle, Pu Stored as PuO_2
^{90}Sr	1.5×10^{-4}	1.8×10^{-4}	1.6×10^{-4}
^{95}Nb	1.9×10^{-5}	2.1×10^{-5}	1.9×10^{-5}
^{106}Ru	4.8×10^{-4}	4.8×10^{-4}	4.2×10^{-4}
^{125m}Te	6.0×10^{-6}	6.2×10^{-6}	5.5×10^{-6}
^{127m}Te	1.1×10^{-6}	1.2×10^{-6}	1.1×10^{-6}
^{129}I	8.8×10^{-11}	9.2×10^{-11}	8.2×10^{-11}
^{134}Cs	3.0×10^{-4}	3.4×10^{-4}	3.0×10^{-4}
^{137}Cs	2.3×10^{-4}	2.6×10^{-4}	2.3×10^{-4}
^{144}Ce	6.0×10^{-4}	7.0×10^{-4}	6.2×10^{-4}
^{154}Eu	1.5×10^{-5}	1.5×10^{-5}	1.4×10^{-5}
^{238}Pu	2.8×10^{-3}	8.7×10^{-6}	1.1×10^{-3}
^{239}Pu	1.8×10^{-4}	8.1×10^{-7}	1.4×10^{-4}
^{240}Pu	3.6×10^{-4}	1.3×10^{-6}	2.2×10^{-4}
^{241}Pu	9.0×10^{-2}	3.1×10^{-4}	5.5×10^{-2}

TABLE 5.3.4-6. First-Year Dose to the Maximum Individual from a Canister Drop from the Bridge Crane at the Outdoor Subsurface Storage Facility for Intermediate-Level Transuranic Wastes (rem)

Pathway	Total Body	Thyroid	Lung	Bone
	U and Pu Recycle			
Air submersion	1.9×10^{-8}	1.9×10^{-8}	1.9×10^{-8}	1.9×10^{-8}
Inhalation	4.2×10^{-4}	1.6×10^{-7}	2.7×10^{-2}	9.9×10^{-3}
Total	4.2×10^{-4}	1.8×10^{-7}	2.7×10^{-2}	9.9×10^{-3}
	U Recycle, Pu in SHLW			
Air submersion	2.1×10^{-8}	2.1×10^{-8}	2.1×10^{-8}	2.1×10^{-8}
Inhalation	4.6×10^{-6}	1.7×10^{-7}	2.8×10^{-4}	5.8×10^{-5}
Total	4.6×10^{-6}	1.9×10^{-7}	2.8×10^{-4}	5.8×10^{-5}
	U Recycle, Pu Stored as PuO_2			
Air submersion	1.9×10^{-8}	1.9×10^{-8}	1.9×10^{-8}	1.9×10^{-8}
Inhalation	2.2×10^{-4}	1.5×10^{-7}	1.2×10^{-2}	5.3×10^{-3}
Total	2.2×10^{-4}	1.7×10^{-7}	1.2×10^{-2}	5.3×10^{-3}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the time-integrated atmospheric dispersion coefficient (E/Q) is 1.1×10^{-4} sec/m^3.

TABLE 5.3.4-7. 70-Year Dose Commitment to the Maximum Individual from a Canister Drop from the Bridge Crane at the Outdoor Subsurface Storage Facility for Intermediate-Level Transuranic Wastes (rem)

Pathway	Total Body	Thyroid	Lung	Bone
	U-and-Pu Recycle			
Air submersion	1.9×10^{-8}	1.9×10^{-8}	1.9×10^{-8}	1.9×10^{-8}
Inhalation	1.3×10^{-2}	1.6×10^{-7}	6.8×10^{-2}	2.9×10^{-1}
Total	1.3×10^{-2}	1.8×10^{-7}	6.8×10^{-2}	2.9×10^{-1}
	U Recycle, Pu in SHLW			
Air submersion	2.1×10^{-8}	2.1×10^{-8}	2.1×10^{-8}	2.1×10^{-8}
Inhalation	7.5×10^{-5}	1.7×10^{-7}	5.3×10^{-4}	1.2×10^{-3}
Total	7.5×10^{-5}	1.9×10^{-7}	5.3×10^{-4}	1.2×10^{-3}
	U Recycle, Pu Stored as PuO_2			
Air submersion	1.9×10^{-8}	1.9×10^{-8}	1.9×10^{-8}	1.9×10^{-8}
Inhalation	6.9×10^{-3}	1.5×10^{-7}	3.0×10^{-2}	1.4×10^{-1}
Total	6.9×10^{-3}	1.7×10^{-7}	3.0×10^{-2}	1.4×10^{-1}

The indoor shielded storage facility for intermediate-level transuranic wastes has two operational areas – the service area, which includes the drum receiving room, control room, and offices; and the storage area, which consists of a series of heavily shielded twin cells separated by structural partitions. The storage portion of each cell is 6.1 m^2 and 5.2 m high with an additional height of 3.7 m designated as crane travel area; the cell walls are 0.9 m thick. Each cell has the capacity to store five layers of drums with 100 drums in each layer. The layers are separated by sheets of plywood. Air circulation through the storage area is provided by ventilation openings located in the roof and walls of each cell.

Because of the possibility of high dose rates, the facility is operated by remote control. A 10-MT bridge crane is used for waste handling. Positioning, viewing, and unloading of drums is aided by two cameras located at the crane bridge level and by spotlights that illuminate the work area. When maintenance work is required the crane can be moved to the crane maintenance area, which is separated from the storage area by a shielding door.

Environmental Effects Related to Facility Construction. Some aspects of facility site preparation and construction may have an effect on the environment and natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effects of construction activities.

Resource Commitments. The indoor shielded storage facility will occupy about 0.32 ha. This land commitment, which is included with that of the FRP, is by itself insignificant.

Water used during construction is estimated to be 5000 m^3. Withdrawal of this amount of water from the R River (average flow of 1.0×10^7 m^3/day) is judged to be insignificant with respect to other downstream uses.

Materials committed to construction of the indoor shielded storage facility (32,800 drum capacity) are:

Steel	1500 MT
Lead	20 MT
Lumber	570 m^3
Concrete	9300 m^3

Energy resources committed to construction are:

Propane	62 m^3
Diesel fuel	33 m^3
Gasoline	400 m^3
Electricity	
Peak demand	660 kW
Total consumption	300,000 kWh

Manpower requirements for construction of the indoor shielded storage facility will amount to approximately 260 man-yr, which will likely be integrated with labor schedules for the FRP.

No separate transportation requirements for the indoor shielded storage facility have been identified beyond those for the FRP. No site-specific requirements beyond those of the FRP have been identified.

Physical and Chemical Effects. Construction of the indoor shielded storage facility will require the diversion of about 5000 m^3 of water. This water use is not expected to have a significant impact on local water supplies.

The use of about 0.32 ha of land for the indoor shielded storage facility is not expected to have a significant impact on local land use. Moreover, environmental effects of the facility construction related to both water and land cannot be separated from the effects of the overall FRP construction.

Grading and excavation activities during construction will generate fugitive dust. In addition, there will be atmospheric releases of fossil fuel combustion products (sulfur and nitrogen oxides, hydrocarbons, and carbon monoxide) from construction equipment and vehicle traffic. The quantities of these materials discharged to the atmosphere will be within the limits set by Federal air quality standards.

Noise caused by construction activities will vary with day-to-day schedules, variations in equipment operations, and other factors. At the FRP property fenceline, the noise levels will be within acceptable limits and within the plant boundaries noise levels will be monitored to ensure conformance with appropriate Federal and local regulations.

Ecological Effects. The indoor shielded storage facility will have a storage capacity of 32,000 55-gal drums and will occupy an area of approximately 0.32 ha. The facility will be located on a fraction of the total land occupied by the FRP.

No ecological impacts from construction of this facility beyond those of the overall FRP are expected. Destruction of vegetation and displacement of birds and animals will be a small part of that resulting from FRP construction. No separate or additional transportation requirements for the indoor shielded storage facility are expected nor have any unusual or unique environmental effects been identified from construction of the facility.

During an assumed 1-year construction period for the facility, water use will be about 5000 m^3. This water will come from the common FRP water supply obtained from the R River and represents an insignificant fraction of the 3.9×10^9 m^3 average annual river flow. No environmental impacts on the river ecosystem are expected from this volume removal.

Materials needed to supply energy during construction of the facility include 620 m^3 of diesel fuel, 410 m^3 of gasoline, and 62 m^3 of propane. Pollutant emissions from the burning of these fuels will result in air concentrations below the Federal air quantity standards; no ecological impacts are expected as a result of fuel consumption.

Environmental Effects Related to Facility Operation. Some aspects of operation of the indoor shielded storage facility may have an effect on the environment and natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating these effects.

Resource Commitments. Resources committed to operation of the facility are given in Table 5.3.4-8.

TABLE 5.3.4-8. Utilities and Materials Required for Operation of the Indoor Shielded Storage Facility for Intermediate-Level Transuranic Wastes

Resource	Average Annual Use
Diesel fuel, m^3	11
Plywood sheets, m^2	2,400
Electricity, kWh	200,000
Manpower, man-yr	3.2

Process Effluents. During normal facility operation there will be no planned releases of radioactive or nonradioactive liquid or solid wastes to land or surface waters. Sanitary waste water will be sent to the common FRP sewer.

Approximately 11 m^3 of diesel fuel will be burned annually by the vehicles used in the waste handling and storage operations. Atmospheric combustion products released by the burning of vehicle fuel will be well below the Federal air quality limits for hydrocarbons, carbon monoxide, and sulfur and nitrogen oxides.

Physical, Chemical, and Thermal Effects. In the absence of pollutants released to ground or surface waters and with only a small discharge of air pollutants from the combustion of fossil fuels, little environmental impact is expected from normal operation of the facility. The 0.32 ha of land occupied by the waste storage area will be unavailable for other uses during the life of the facility.

Radiological Effects. Because no radioactive materials are planned for release to the biosphere during normal facility operation, there will be no radiological effects.

Ecological Effects. Normal operation of the indoor shielded storage facility will result in no significant environmental effects. The only identified nonradioactive materials to be released from the facility during normal operation are emissions from burning fuels and from sanitary water use. Approximately 11 m^3/yr of diesel fuel will be used, which will generate only insignificant levels of air pollutants.

Ecological impacts from noise and human activities associated with facility operation will be small and indistinguishable from those of the FRP complex. No unique or unusual ecological impacts have been identified as a result of normal operation of the indoor shielded storage facility.

Environmental Effects Related to Postulated Accidents. Five minor accidents were postulated for the indoor shielded storage facility. Scenarios are provided in DOE/ET-0028[1] and the accidents are listed below.

Accident Number	Description
5.3.1	Mechanical breach of waste barrel
5.3.2	Dislodge of surface contamination
5.3.3	Overpressure of container
5.3.4	Rust-through of steel container
5.3.7	Fire in storage stack

The worst-case minor accident, mechanical breach of a waste barrel (Accident 5.3.1), is taken as representative of the set. This accident and its consequences are identical to those discussed in Section 5.3.4.1. The radionuclides released are given in Table 5.3.4-2.

The 1-year dose and 70-year dose commitment to the maximum individual from these radionuclides are given in Tables 5.3.4-3 and 5.3.4-4 respectively. The largest of the doses given in Table 5.3.4-3 is on the order of 0.3% of the dose the individual would have received from naturally occurring sources during the year.

One accident is postulated to release radioactive materials in amounts greater than those released during minor accidents. It is classified as a moderate accident and is listed below.

Accident Number	Description
5.3.8	Crane drops drum

This accident and its consequences are the same as those presented in Section 5.3.4.1. The radionuclides released during this accident are presented in Table 5.3.4-5.

The 1-year dose and 70-year dose commitment to the maximum individual from the release of these radioactive materials are given in Tables 5.3.4-6 and 5.3.4-7 respectively. The largest of the doses given in these tables is only 0.003% of the dose the individual would have received from naturally occurring sources.

5.3.4.3 Comparison of Environmental Effects Between Storage Alternatives for Intermediate-Level Transuranic Wastes

Selected aspects of construction and operation of alternative storage facilities for intermediate-level transuranic wastes (outdoor subsurface and indoor shielded storage) are presented in Tables 5.3.4-9 and 5.3.4-10.

TABLE 5.3.4-9. Comparison of Resource Commitments for Construction of Alternative Storage Facilities for Intermediate-Level Transuranic Wastes

Resource	Outdoor Subsurface Storage	Indoor Shielded Storage
Land, ha	7.7	3.2×10^{-1}
Water, m^3	4.0×10^2	5.0×10^3
Materials		
Steel, MT	6.5×10^3	1.5×10^3
Lead, MT	1.6×10^2	2.0×10^1
Lumber, m^3	6.5×10^2	5.7×10^2
Concrete, m^3	5.2×10^3	9.3×10^3
Energy		
Propane, m^3	5.2×10^1	6.2×10^1
Diesel fuel, m^3	5.2×10^2	3.3×10^1
Gasoline, m^3	3.4×10^2	4.0×10^2
Electricity, kWh	2.6×10^5	3.0×10^5
Man power, man-yr	2.2×10^2	2.6×10^2

TABLE 5.3.4-10. Comparison of Resource Commitments for Operation of Alternative Storage Facilities for Intermediate-Level Transuranic Wastes

Resource	Outdoor Subsurface Storage	Indoor Shielded Storage
Electricity, kWh	7.0×10^4	2×10^5
Diesel fuel, m^3	2.3×10^1	1.1×10^1
Manpower, man-hr	3.2	3.2

Land committed to construction of the outdoor subsurface storage facility is about 25 times greater than that required for the indoor shielded facility. Construction and operation of the indoor shielded storage facility requires about the same amount of materials and energy as that required by the outdoor subsurface storage facility. Radiological aspects of operations and accidents for both storage alternatives are the same. In general, environmental impacts associated with alternatives for storing intermediate-level wastes are not sufficiently different to warrant a choice based on environmental considerations.

REFERENCES FOR SECTION 5.3.4

1. Technology for Commercial Radioactive Waste Management, DOE/ET-0028, Department of Energy, Washington, DC, in press.

5.3.5 Low-Level Transuranic Wastes (DOE/ET-0028 Sec. 5.3)

Two concepts are available for interim storage of low-level transuranic wastes: outdoor surface storage and indoor unshielded storage. Low-level transuranic waste storage is required for 5 years of operation of an FRP. After that time the waste is shipped to a waste repository or, in the event that a repository is not available, it is shipped to an independent waste storage facility.

5.3.5.1 Outdoor Storage of Low-Level Transuranic Wastes at FRP (DOE/ET-0028 Sec. 5.3.1)

An outdoor surface storage facility is designed to store solid low-level transuranic wastes contained in 55-gal drums and steel boxes on an above-ground asphalt slab. The containers of waste are ultimately covered by an earth fill for weather protection.

This storage concept has been used for low-level transuranic wastes generated at government facilities (also known as transuranic storage area type of storage). At full production the annual generation rate of low-level transuranic wastes at the FRP totals 2710 55-gal drums and 60 1.2 x 1.8 x 1.8 m boxes. A storage capacity equivalent to 15,000 55-gal drums is needed for the first 5 years of operation at 80% of full production at the FRP. The basic construction module holds 10,000 55-gal drums.* Further details of the outdoor surface storage facility for low-level transuranic wastes may be found in Section 5.3.1 of DOE/ET-0028.[1] Figure 5.3.5-1 shows a plot plan of the outdoor surface storage facility for low-level transuranic wastes.

Environmental Effects Related to Facility Construction. Some aspects of site preparation and construction of the outdoor surface storage facility may have an impact on the environment and the natural resources of the surrounding area. The following information is provided to form a basis for estimating the effects of construction activities.

Resource Commitments. The outdoor surface storage facility for low-level transuranic wastes will be located at the FRP and the effects of construction will be largely inseparable from those of the FRP. The facility will occupy about 0.36 ha or about 1% of the area required by the FRP. Since this land commitment is included in that required for the FRP, no separate analysis of land use is presented.

Water used during construction will be approximately 100 m^3. Withdrawal of this amount of water from the R River (average flow of 1.0 x 10^7 m^3/day) is judged to be insignificant with respect to other downstream uses.

Materials committed for construction of the outdoor surface sotrage facility for low-level transuranic wastes are:

Steel	52 MT
Copper	1.5 MT
Lumber	15 m^3
Concrete	110 m^3

* Using cost data as a basis, construction requirements for 5 years' storage of 15,000 55-gal drums were escalated 10%.

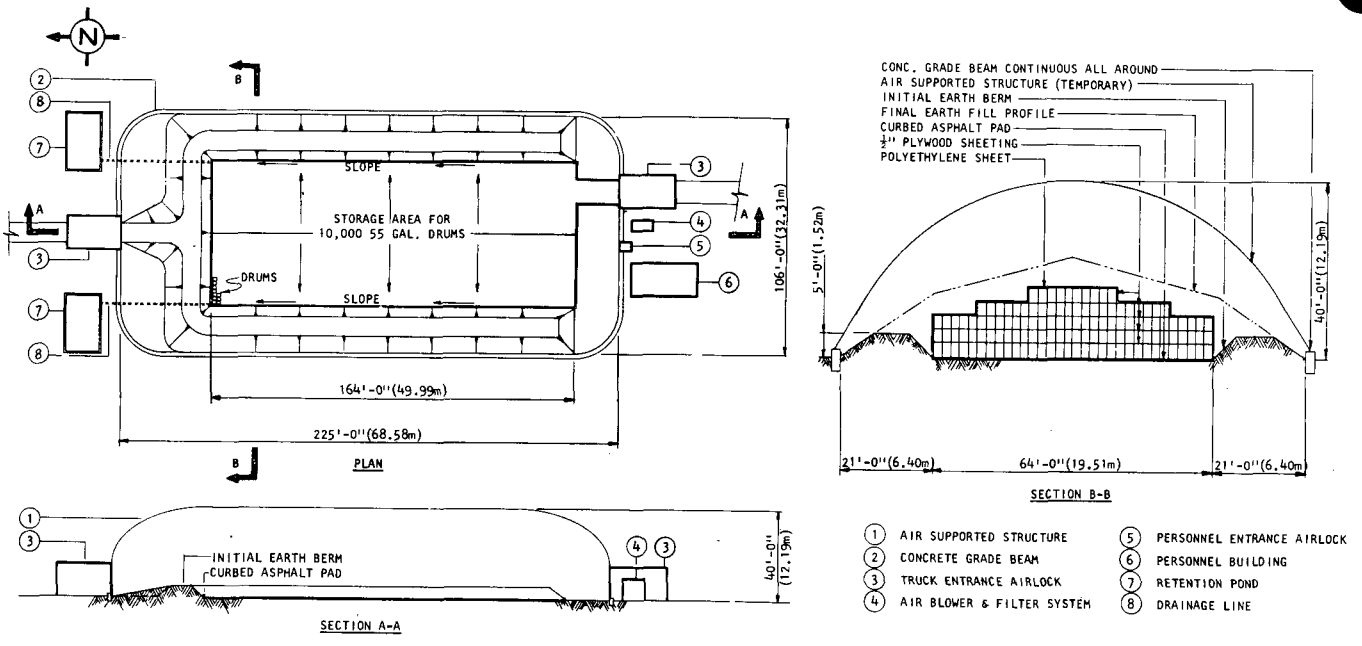

FIGURE 5.3.5-1. Plot Plan and Section View of the Outdoor Storage Facility for Low-Level Transuranic Wastes

Energy resources used during construction are:

Propane	1.1 m^3
Diesel fuel	11 m^3
Gasoline	7.5 m^3
Electricity	
Total consumption	<10,000 kWh (negligible)

Manpower requirements for construction of the outdoor surface storage facility amount to 6.8 man-yr, which will likely be integrated with labor schedules for the FRP.

No separate transportation or site-specific requirements have been identified beyond those required for the FRP.

Physical and Chemical Effects. About 100 m^3 of water will be required during facility construction and will be supplied from the R River near the reference site. This is less than 0.001% of the average annual river flow and its removal will not interfere with other river water uses.

Excavation for the waste storage area and storm water retention ponds and filling for the earth berm surrounding the storage area is not expected to significantly affect groundwater movement. There may be some water erosion of the area cleared for construction, but this will be controlled by ditching and land contouring. No substantial siltation of nearby surface waters is expected for construction activities.

Air pollutants will be released through the burning of fossil fuel by construction equipment, and dust will be generated by grading and excavation. These releases will be small, however, compared with those of the overall FRP construction and environmental impacts and are not expected to be significant. In general, the environmental effects of facility construction related to water and land use cannot be separated from the effects of FRP construction.

Ecological Effects. No ecological impacts of facility construction beyond those of the overall FRP complex are expected. Destruction of vegetation and displacement of birds and animals will be a small part of that caused by FRP construction. No separate or additional transportation requirements for the surface storage facility are expected, nor have any unusual or unique environmental effects been identified.

Water used during construction will be supplied from the common FRP water supply (withdrawn from the R River) and will constitute an insignificant fraction of the river flow. No ecological impacts on the river ecosystem are expected from water use during construction of this facility. Air pollutants generated during construction by the burning of fossil fuels and the generation of dust will result in insignificant air concentrations; however, no ecological impacts of any significance will result.

Environmental Effects Related to Facility Operation. Some of the factors relating to operation of the outdoor surface storage facility may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effects of operation.

Resource Commitments. Resources required for operation of outdoor surface storage facility for low-level transuranic wastes are given in Table 5.3.5-1.

TABLE 5.3.5-1. Utilities and Materials Required for Operation of the Outdoor Surface Storage Facility for Low-Level Transuranic Wastes

Resource	Average Annual Use
Plastic (sheets), m^2	650
Plywood, m^2	1000
Diesel fuel, m^3	5.3
Electricity, kWh	70,000
Manpower, man-yr	1.4

The commitments of these resources will have an insignificant environmental effect. Land use (0.36 ha) will be included with that of the FRP and of itself will not have a significant environmental impact.

Process Effluents. No radioactive materials will be released to the biosphere during normal operation of the outdoor surface storage facility.

The combustion of fossil fuels by vehicles used in the handling and storage operation will release nonradioactive pollutants to the atmosphere. About 5.3 m^3 of diesel fuel will be

burned annually by trucks. The quantities of fuel combustion products released to the environment will be several orders of magnitude below Federal air quality standards for hydrocarbons, nitrogen and sulfur oxides, carbon monoxide, and particulates.

There will be no direct releases of nonradioactive liquid or solid wastes to the land or to the surface or groundwaters from operation of the outdoor surface storage facility. All liquid and solid waste disposal will be part of the overall FRP operation.

Storm drainage, estimated at 1100 m^3/yr (assuming an average annual precipitation of 0.6 m), will be diverted to two retention basins to check for radioactive contamination before being released to the FRP drainage system. Sediment run-off may occur during backfilling of the stored drums with a 0.9-m layer of soil.

Physical, Chemical, and Thermal Effects. The release of vehicle combustion products to the atmosphere will be well below the acceptable amounts listed in Federal air quality standards.

Because no radioactive or nonradioactive liquid effluents are planned for release during facility operation, no environmental effects will result.

Radiological Effects. Because no radioactive material is planned for release to the biosphere, there will be no radiological effects.

Ecological Effects. No ecological effects of any significance will result during normal operation of the outdoor surface storage facility. Approximately 5.3 m^3 of fossil fuel will be burned per year during normal operation. The air pollutants resulting from emissions due to consumption of this fuel will have an insignificant ecological effect.

Water required for facility operation will amount to approximately 68 m^3/yr; this amount represents less than 0.0001% of the average flow of the R River, the source of water for FRP water supply system. Facility sanitary waste water will go to the common FRP sewer system and will not result in significant environmental impact.

There will be no ecological effects to terrestrial or aquatic ecosystems during normal operation of the surface storage facility. No unusual or unique nonradioactive effluents have been identified for this facility.

Environmental Effects Related to Postulated Accidents. Four minor accidents were postulated for the outdoor surface storage facility. Scenarios are provided in DOE/ET-0028[1] and the accidents are listed below.

Accident Number	Description
5.3.1	Mechanical breach of waste barrel
5.3.2	Dislodge of surface contamination
5.3.3	Overpressure of container
5.3.4	Rust-through of steel container

The worst-case minor accident, mechanical breach of a waste barrel (Accident 5.3.1), is taken as representative of the set. This accident and its consequences are identical to those

discussed in Section 5.3.4.1. The radionuclides released are given in Table 5.3.4-2. The 1-year dose and 70-year dose commitment to the maximum individual from these radionuclides are given in Tables 5.3.4-3 and 5.3.4-4 respectively. The largest of the doses given in Table 5.3.4-3 is on the order of 0.3% of the dose the individual would have received from naturally occurring sources during the year.

Two accidents were postulated to release radioactive materials in amounts greater than those released during minor accidents. These are classified as moderate accidents and are listed below.

Accident Number	Description
5.3.5	Fire in storage stack
5.3.6	Tornado strikes transuranic storage area during stacking operation

The tornado strike during stacking operation (Accident 5.3.6) was judged to be the more severe of these two accidents and is treated as the representative accident. This accident and its consequences are the same as those presented in Section 5.3.4.1. The radionuclides released during this accident are given in Table 5.3.4-5.

The 1-year dose and 70-year dose commitment to the maximum individual from the release of these radioactive materials are given in Tables 5.3.4-6 and 5.3.4-7 respectively. The largest of the doses given in these tables is only 0.003% of the dose the individual would have received from naturally occurring sources.

5.3.5.2 Indoor Unshielded Storage of Low-Level Transuranic Wastes (DOE/ET-0028 Sec. 5.3.2)

The indoor unshielded storage facility is a modular thin-slab precast reinforced-concrete structure that is designed to store low-level transuranic wastes contained in 55-gal steel drums and 1.2 x 1.8 x 1.0 m steel boxes. The concept provides a favorable storage environment for waste packages that prolongs package life and permits storage and retrieval operations year round in all kinds of weather. At full production the annual generation rate of low-level transuranic wastes at the FRP totals 2868 55-gal drums and 60 1.2 x 1.8 x 1.8 m boxes. A storage capacity equivalent to 15,000 55-gal drums is needed for the first 5 years of operation at 80% of full production. This capacity is met by two basic storage units with a total storage capacity of 16,800 55-gal drums.

Environmental Effects Related to Facility Construction. Some aspects of site preparation and construction of the indoor unshielded storage facility may have an impact on the environment and the natural resources of the surrounding area. The following information is provided to form a basis for evaluating the effects of construction activities.

Resource Commitments. The indoor unshielded storage facility (including the personnel building) will occupy an area of about 1600 m^3. This land commitment is included with that of the overall FRP.

Water used during construction of the facility will be approximately 4×10^2 m^3. Withdrawal of this amount of water from the R River (average flow of 1.0×10^7 m^3/day) is insignificant with respect to other downstream uses.

Materials committed for construction of the indoor unshielded storage facility (15,000 drum storage capacity) for low-level transuranic wastes are:

Steel	120 MT
Lumber	20 m^3
Concrete	1000 m^3

Energy resources committed for construction are:

Propane	8 m^3
Diesel fuel	80 m^3
Gasoline	40 m^3
Electricity	
Peak demand	60 kW
Total consumption	40,000 kWh

Manpower requirements for facility construction amount to 12 man-yr, which will likely be integrated with labor schedules for the FRP.

No separate transportation or site requirements have been identified for this facility beyond those for the FRP.

Physical and Chemical Effects. Construction of the indoor unshielded storage facility requires the diversion of about 400 m^3 of water. Use of this amount of water is not expected to have a significant impact on local water supplies.

The use of about 1600 m^2 of land for the indoor unshielded storage facility is not expected to have a significant impact on local land use. Moreover, environmental effects of the facility construction related to water and land use cannot be separated from the effects of the overall FRP construction.

The burning of approximately 40 and 80 m^3 of gasoline and diesel fuel, respectively, will release pollutants to the atmosphere. The levels of hydrocarbons, carbon monoxide, particulates, and nitrogen and sulfur oxides will be well below the limits specified in the Federal air quality standards. There will also be some generation of dust by the construction activities. These will be largely confined to the area occupied by the overall FRP complex.

Ecological Effects. No ecological impacts of facility construction beyond those of the overall FRP complex are expected. Destruction of vegetation and displacement of birds and animals will be a small part of that caused by FRP construction. No separate or additional transportation requirements for the indoor shielded storage facility are expected, nor have any unique or unusual environmental effects been identified which would result from construction of the facility.

Water used during the construction period is estimated to be 400 m^3, which would be supplied by the common FRP water supply. This supply obtains water from the R River and the volume required during construction of this facility represents an insignificant fraction of the river flow. No ecological impacts on the river's ecosystems are expected to result from this volume of water removal.

Approximately 130 m^3 of fossil fuel will be burned during construction of the facility. The emissions from combustion of these fuels will contribute an insignificant amount of effluents compared with those of the overall FRP complex. Thus, no separate or identifiable impacts on terrestrial organisms are expected to result from emissions caused by fuel combustion.

Environmental Effects Related to Facility Operation. Some aspects of facility operation may have an effect on the environmental and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effects of facility operation.

Resource Commitments. The resources required for the planned operation of the indoor unshielded storage facility are given in Table 5.3.5-2. The commitment of these resources will have an insignificant effect on the environment.

TABLE 5.3.5-2. Utilities and Materials Required for Operation of the Indoor Unshielded Storage Facility for Low-Level Transuranic Wastes

Resource	Average Annual Use
Diesel fuel, m^3	2.6
Plywood (sheets), m^3	1,400
Electricity, kWh	70,000
Manpower, man-yr	1.4

Process Effluents. During normal operation of the facility no radioactive materials are planned for release to the environment.

Approximately 57 m^3 of water will be discharged annually to the FRP sewer system.

Combustion of up to 2.6 m^3/yr of diesel fuel by trucks and other equipment will release small quantities of pollutants to the atmosphere. The amounts of these combustion products will be a small fraction of those released from the FRP and will be well within Federal air quality standards.

Physical, Chemical, and Thermal Effects. There will be no direct releases of radioactive or nonradioactive liquid or solid wastes to land, surface, or groundwaters from the indoor unshielded storage facility. All liquid and solid waste disposal will be part of the overall FRP operation.

The small releases to the atmosphere of fossil fuel combustion products will be within Federal air quality limits and will contribute only a fraction of those resulting from the overall FRP operation.

Radiological Effects. Because no radioactive materials will be released to the biosphere during operation of the indoor unshielded storage facility, there will be no radiological effects.

Ecological Effects. Normal operation of the indoor unshielded storage facility will result in no significant ecological effects. No unique or unusual effluents are expected to result from normal operation of this facility.

The land area occupied by this facility for the temporary storage of radioactive wastes will be unavailable for wildlife production, agriculture, or other use for the life of the facility. However, since it is located within the FRP, the land would be unavailable for these uses even if the waste storage were not built and operated.

Environmental Effects Related to Postulated Accidents. Two accidents were postulated to release radioactive materials to the atmosphere. These are classified as moderate accidents; the scenarios are provided in DOE/ET-0028[1] and the accidents are listed as follows:

Accident Number	Description
5.3.5	Fire in storage stack
5.3.6	Tornado strikes waste storage area during stacking operation

The tornado strike during stacking operation (Accident 5.3.6) is judged to be the most severe of these two accidents and is treated as the representative accident. This accident and its consequences are the same as those presented in Section 5.3.4.1. The radionuclides released during the accident are given in Tables 5.3.4-5.

The 1-year dose and 70-year dose commitment to the maximum individual from the release of these radioactive materials are given in Tables 5.3.4-6 and 5.3.4-7 respectively. The largest of the doses given in these tables is only 0.003% of the dose the individual would have received from naturally occurring sources.

5.3.5.3 Comparison of Environmental Effects Between Storage Alternatives for Low-Level Transuranic Wastes

Selected aspects of construction and operation of alternative storage facilities (outdoor surface and indoor unshielded storage) for low-level transuranic wastes are presented in Tables 5.3.5-3 and 5.3.5-4.

The indoor unshielded storage facility requires substantially greater resource commitments than the outdoor surface storage facility. Operational requirements for either storage option are similar. Radiological aspects of operations and accidents are the same.

TABLE 5.3.5-3. Comparison of Resource Commitments for Construction of Alternative Storage Facilities for Low-Level Transuranic Wastes

Resources	Outdoor Surface Storage	Indoor Unshielded Storage
Land, ha	3.6×10^{-1}	1.6×10^{-1}
Water, m^3	1.0×10^{2}	4.0×10^{2}
Material		
Steel, MT	5.2×10^{1}	1.2×10^{2}
Copper, MT	1.5	
Lumber, m^3	1.5×10^{1}	2.0×10^{1}
Concrete, m^3	1.1×10^{2}	1.0×10^{3}
Energy		
Propane, m^3	1.1	8
Diesel fuel, m^3	1.1×10^{1}	8.0×10^{1}
Gasoline, m^3	7.5	4.0×10^{1}
Electricity, kWh	$<1.0 \times 10^{4}$	4.0×10^{4}
Manpower, man-yr	6.8	1.2×10^{1}

TABLE 5.3.5-4. Comparison of Resource Commitments for Operation of Alternative Storage Facilities for Low-Level Transuranic Wastes

Resources	Outdoor Surface Storage	Indoor Unshielded Storage
Electricity, kWh	7.0×10^{4}	7.0×10^{4}
Plastic sheets	6.5×10^{2}	
Plywood sheets	1.0×10^{3}	1.4×10^{3}
Diesel fuel, m^3	5.3	2.6
Manpower, man-yr	1.4	1.4

REFERENCES FOR SECTION 5.3.5

1. Technology for Commercial Radioactive Waste Management, DOE/ET-0028, Department of Energy, Washington, DC, in press.

5.3.6 Interim Storage of Plutonium Oxide (DOE/ET-0028 Sec. 5.5)

In the event spent fuel reprocessing for recycle of uranium alone should prove acceptable and attractive, interim storage of large quantities of plutonium might be necessary until a permanent solution to the use or disposal of plutonium could be defined. Storage of plutonium in the form of a plutonium compound (separate from fission products and other waste products) would afford ease of retrieval should recycle of plutonium as a fuel be adopted in the future.

Current regulations require that plutonium be shipped as a solid chemical compound. Since shipment of plutonium may be necessary both to and from a plutonium storage facility, plutonium oxide is currently the preferred chemical form. Plutonium oxide (PuO_2) has a high melting point and good irradiation stability; it is compatible with metals and easy to prepare.[1]

Plutonium could be stored at a fuel reprocessing plant (FRP) or at any large existing Federal nuclear site. Storage at a Federal site would be mandatory if Federal custody of plutonium is required in the future. In the United States the only large-scale facility built specifically for storing commercial power reactor plutonium was operated by the New York State Atomic and Space Development Authority near Buffalo, New York. The plutonium was stored as plutonium nitrate solution in stainless steel containers that held about 5 kg of plutonium each. This facility is now closed and no plutonium is in storage there. At present, plutonium is stored in small quantities (hundreds of kilograms or less) at several locations around the country. This material is used for weapons and weapons research and for advanced reactor research and development. Storage methods vary and do not meet design needs for large-scale storage.

The facility described in this section is referred to as a 30-MT interim plutonium-oxide storage facility. It will store plutonium oxide that has been separated from uranium and radioactive wastes at an FRP. The plutonium will be stored at the interim plutonium-oxide storage facility until its status as a fuel or waste is resolved.

Storage of large quantities of plutonium oxide must provide for 1) ensured protection against the accumulation of a critical mass or self-sustaining chain reaction; 2) removal of radioactive decay heat and, if necessary, hazardous materials generated in the radioactive decay process; 3) radiation shielding for operating personnel; 4) protection against diversion or theft of fissile materials; and 5) protection of the health and safety of the general public.

Upon arrival at the interim plutonium-oxide storage facility, the shipping container (pressure vessel and overpack designated as PPP-1) is removed from the carrier truck by an electric forklift truck. The shipping container is brought into the storage facility via a transfer air lock and placed in an entrance chamber to an inspection and transfer cell. Maintenance personnel remove the container's overpack lid, and the container is lifted to the entrance port. A power manipulator, remotely controlled from outside the cell, removes the entrance port plug and lifts the pressure vessel into the inspection and transfer cell. The pressure vessel is then placed in the maintenance rack for inspection; the same rack is used for all pressure vessel maintenance (inspections, repairs, venting, etc.). Figure 5.3.6-1 shows an operation flow diagram of this storage facility.

The PPP-1 pressure vessel (now the storage container) is inspected and decontaminated as necessary. The power manipulator is used to remove the exit port plug and transfer the container to the shielded transfer cask positioned below the exit port. Another electric forklift truck moves the container in the transfer cask to the cask transfer gallery.

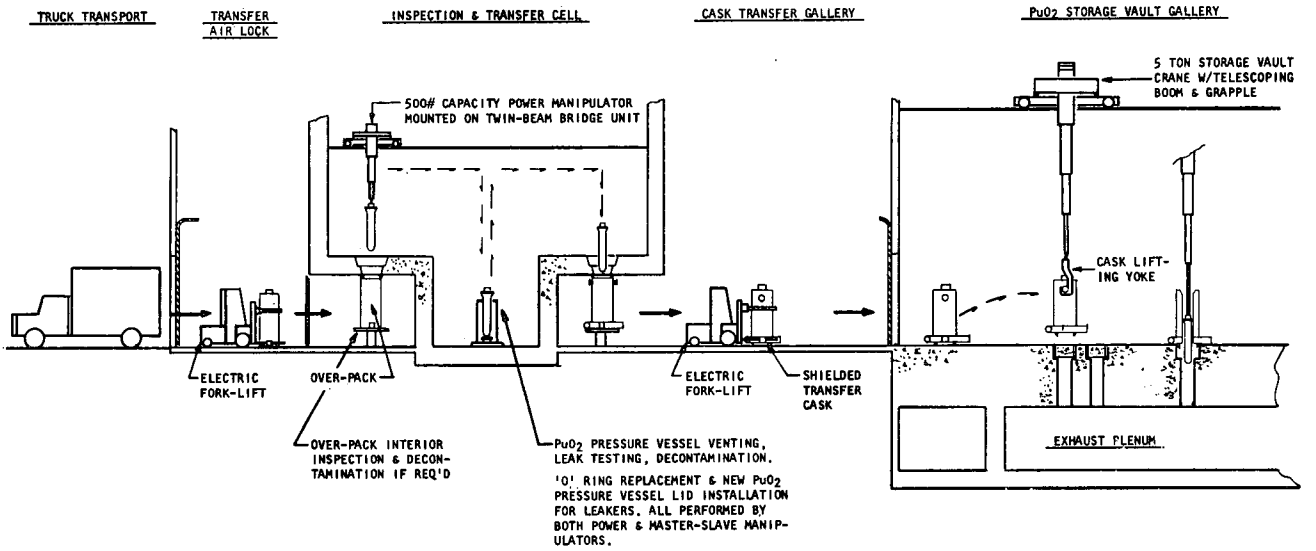

FIGURE 5.3.6-1. Operations Flow Diagram of the Interim Plutonium-Oxide Storage Facility

The pressure is equalized between the plutonium oxide storage vault and the transfer gallery, and the vault door is opened. The transfer cask is then placed on the storage vault floor using the forklift truck. The vault door is resealed and leak tested, and storage vault negative pressure is reestablished. The bridge crane and grapple, controlled remotely from the control room of the storage facility, engage the transfer cask and storage container and position them over an empty storage hole. The shield plug will have been removed previously by the crane. The storage container is lowered from the transfer shield into the storage hole and the crane grapple disengaged. The shield plug is replaced and the transfer shield stored.

During all operations involving movement of the storage container, operating personnel observe the position and attitude of the container through a shielded viewing window in the control room. All tools, fixtures, and equipment in the storage vault have been designed to enable operation and maintenance with a minimum of radiation exposure. The forklift trucks may be used in the storage vault for backup and limited emergency handling if the building crane is out of service. Administrative controls will ensure that at all times only a safe number of storage containers are handled in the storage vault or the inspection and transfer cell. Removal of a container from a storage location would be a reverse operation. The interim plutonium-oxide storage facility has a maximum handling and processing capacity of eight to ten containers (approximately 320 kg of plutonium oxide) in a 24-hr day.

Storage of plutonium oxide over an extended period produces 1) molecular oxygen and hydrogen gases from the radiolytic decomposition of water not removed from the plutonium product, and 2) elemental helium gas from the alpha radiation decay of plutonium and plutonium daughter products. These gases will collect in the storage containers as container pressures increase. Container venting may be required to limit pressures resulting from gas buildup

and container temperature variation and to prevent accumulation of an explosive concentration of hydrogen and oxygen. Venting operations, if required by final design of the PPP-1 container, will be performed at regular intervals as determined by calculations of the container pressure and gas contents.

The storage container is equipped with a vent to remove such gases from the container. The shield plug is removed and portable shielding is placed over the storage hole. The container is then placed in the portable shield and moved to the inspection and transfer cell for venting and maintenance. After venting, the container is leak tested, checked for contamination, and returned to the storage hole. The vented gases go through the atmospheric protection system, which consists of a roughing filter and three HEPA filters.

Normal operation of the storage facility includes monitoring of temperatures, pressures, and air flows associated with the plutonium oxide cooling system; preventative and corrective maintenance on facility equipment; facility security; and housekeeping.

5.3.6.1 Environmental Effects Related to Facility Construction

Some aspects of site preparation and reference facility construction may have an effect on the environment and natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effects of construction activities.

Resource Commitments. The 30-MT interim plutonium-oxide storage facility will occupy 2 ha at the FRP. The land commitments are included with those of the FRP.

Water used during the construction period will be approximately 12,500 m^3. Withdrawal of this quantity of water from the R River (average flow of 1.0×10^7 m^3/day) is insignificant with respect to other downstream uses.

Materials committed for construction of the interim plutonium-oxide storage facility are:

Concrete	6,650 m^3
Steel	2,000 MT
Copper	36 MT
Zinc	9 MT
Aluminum	9 MT
Lumber	360 m^3

Energy resources committed for construction are:

Propane	106 m^3
Diesel fuel	1,060 m^3
Gasoline	720 m^3
Electricity	
Peak demand	590 kW
Total consumption	540,000 kWh

Manpower requirements for construction of the storage facility will amount to 470 man-yr, which will likely be integrated with labor schedules for the FRP.

No specific transportation requirements or site-specific requirements have been identified for the storage facility beyond those for the FRP.

Physical and Chemical Effects. Effects on air quality from construction of the interim plutonium-oxide storage facility will be indistinguishable from those resulting from construction of the FRP.

The diversion of about 12,000 m^3 of water for construction of the facility will have no impact on local water supply. Moreover, aquatic effects caused by facility construction cannot be separated from the effects of the overall FRP construction.

The use of 2 ha of land for construction of the storage facility will have no significant impact on local land use.

Ecological Effects. Approximately 2 ha will be required for the interim plutonium-oxide storage facility, which will be located within the 40-ha FRP exclusion area. The impacts on the terrestrial environment will be indistinguishable from those of the FRP and may include the destruction or alteration of vegetation; the destruction of animal habitat; and the disturbance of birds and mammals by noise, dust, and human activity. No separate transportation facilities, beyond those identified for the FRP, will be required.

Approximately 1.2×10^4 m^3 of water will be required during an assumed 2-year construction period and will be obtained from the R River near the reference site. Water used will constitute less than 0.01% of the minimum flow of the R River and will have an insignificant impact on the river ecosystem.

5.3.6.2 Environmental Effects Related to Facility Operation

Some aspects of facility operation may have an effect on the environment and natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effects of operation.

Resource Commitments. Resource requirements for operation of the interim plutonium-oxide storage facility are given in Table 5.3.6-1. The commitment of these resources is not significant in terms of total FRP requirements.

TABLE 5.3.6-1. Utilities and Materials Required for Operating the Interim Plutonium-Oxide Storage Facility (30-MT 5 yr capacity)

Resource	Average Annual Use
Process water, m^3	2.7×10^4
Oil, m^3	3.8×10^1
Electricity, kWh	4.6×10^6
Manpower, man-yr	4.7×10^1

Process Effluents. No radioactive material is planned for release to the air, water, or ground during normal operation of the interim plutonium-oxide storage facility.

During storage of plutonium oxide, sensible heat will be generated and transferred to the atmosphere by natural convection via the FRP stack. The amount of heat released is 3.5×10^7 MJ/yr which is approximately 1% of the total released from the FRP production facilities.

No nonradioactive liquid or solid wastes will be released to the land or water during planned operation of the storage facility.

Physical, Chemical, and Thermal Effects. The amount of heat released from the interim plutonium-oxide storage facility is about 4% of the total sensible heat released from the 110-m FRP stack and is not expected to have any significant effect.

Radiological Effects. No radioactive material will be released to air, water, or ground during planned operation of the storage facility; therefore, there are no pathways to man.

Ecological Effects. Since the interim plutonium-oxide storage facility involves only storage of plutonium oxide powder in vessels that have been sealed elsewhere, there is no anticipated release of nonradioactive gaseous or liquid effluents to the environment. The air that cools the plutonium oxide storage containers is passed through a multiple filter before being released to the atmosphere. About 3.5×10^7 MJ/yr of heat will be released to the atmosphere.

During normal operation about 2.7×10^4 m^3 of water is required annually for sanitary purposes, fire fighting, and cooling. This water will be supplied by the R River near the reference site and represents approximately 1% and 0.05% of the minimum and average river flow respectively. Therefore, withdrawal of this fraction of the river flow will have no significant impact on the river ecosystem.

5.3.6.3 Environmental Effects Related to Postulated Accidents

Two minor and two moderate accidents were postulated for the interim plutonium-oxide storage facility. It was concluded that none of these accidents would result in the release of radioactive material to the biosphere. The accident scenarios are provided in DOE/ET-0028[2] and the accidents are listed below.

Accident Number	Description
	Minor
5.5.1	Loss of normal electrical power
5.5.2	Temporary loss of ventilation blower
	Moderate
5.5.3	Decontamination of trash fire
5.5.4	Storage container leakage

Severe accidents associated with the FRP storage facility that could release radioactive materials to the environment are listed below.

Accident Number	Description
5.5.5	Plutonium spill
5.5.6	Criticality

For Accident 5.5.5 it was assumed that a breach in one storage container resulted in the release of 200 g of plutonium oxide to the filters over a period of 30 min. The radioactive material associated with such an event is shown in Table 5.3.6-2.

TABLE 5.3.6-2. Radionuclides Released from a Plutonium Spill Accident at the Interim Plutonium-Oxide Storage Facility

Radionuclide	Release, Ci
^{238}Pu	5.2×10^{-11}
^{239}Pu	5.2×10^{-12}
^{240}Pu	8.1×10^{-12}
^{241}Pu	1.2×10^{-9}
^{241}Am	2.2×10^{-11}

The 70-year dose commitment to the maximum individual was calculated and is presented in Table 5.3.6-3. The largest dose calculated was 3.2×10^{-9} rem to the bone via inhalation, which is six orders of magnitude less than the nominal 5.0×10^{-3} rem/yr variation in dose at a given location that the individual would have received from naturally occurring sources.

TABLE 5.3.6-3. 70-Year Dose Commitment to the Maximum Individual from a Plutonium Spill Accident at the Interim Plutonium-Oxide Storage Facility (rem)

Pathway	Total Body	Thyroid	Lung	Bone
Air submersion	8.0×10^{-18}	8.0×10^{-18}	8.0×10^{-18}	8.0×10^{-18}
Inhalation	1.6×10^{-10}		9.4×10^{-10}	3.2×10^{-9}
Total	1.6×10^{-10}	8.0×10^{-18}	9.4×10^{-10}	3.2×10^{-9}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the time-integrated atmospheric dispersion coefficient (E/Q) is 1.1×10^{-4} sec/m^3.

For Accident 5.5.6 it was assumed that material from a criticality event of 10^{19} fissions was released to the facility filters over a period of 15 min. Approximately 200 g of stored plutonium oxide plus the material listed in Table 5.3.6-4 were released.

The major contribution to all doses from the criticality accident was received from the fission products generated in the accident. The 70-year dose commitment to the maximum individual was calculated and is given in Table 5.3.6-5. Numerically, the largest dose was that to the thyroid and amounted to about 4% of the dose the individual would have received over the 70-year period from naturally occurring sources.

TABLE 5.3.6-4. Radionuclides Released During a Criticality Accident at the Interim Plutonium-Oxide Storage Facility

Radionuclide	Release, Ci
^{85}Kr	1.5×10^{-4}
^{87}Kr	1.0×10^{2}
^{88}Kr	6.3×10^{1}
^{89}Kr	4.0×10^{3}
^{129}I	4.3×10^{-11}
^{131}I	1.8×10^{-1}
^{133}I	3.7×10^{1}
^{134}I	4.7×10^{1}
^{135}I	1.2×10^{1}
^{138}Xe	1.2×10^{3}

TABLE 5.3.6-5. 70-Year Dose Commitment to the Maximum Individual from a Criticality Accident at the Interim Plutonium-Oxide Storage Facility (rem)

Pathway	Skin	Total Body	Thyroid	Lung	Bone
Air submersion	7.5×10^{-2}	4.9×10^{-2}	4.9×10^{-2}	4.9×10^{-2}	4.9×10^{-2}
Inhalation		3.0×10^{-4}	1.0×10^{-1}	3.2×10^{-3}	9.9×10^{-5}
Total	7.5×10^{-2}	4.9×10^{-2}	1.5×10^{-1}	5.2×10^{-2}	4.9×10^{-2}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the time-integrated atmospheric dispersion coefficient (E/Q) is 1.1×10^{-4} sec/m^3.

REFERENCES FOR SECTION 5.3.6

1. O. J. Wick, ed., Plutonium — A Guide to the Technology, U.S. Atomic Energy Commission, Gordon and Breach, Science Publishers, NY, 1967.

2. Technology for Commercial Radioactive Waste Management, DOE/ET-0028, Department of Energy, Washington, DC, in press.

5.3.7 Interim Storage of Krypton (DOE/ET-0028 Sec. 5.6)

Krypton will be removed from the dissolver off-gas, placed in pressurized gas cylinders, and stored on site at the FRP. Removal of ^{85}Kr from the dissolver off-gas is discussed in Section 5.2.1.

The krypton storage facility consists of a hot cell facility to receive and examine the gas cylinders and a series of storage cells. The facility will be constructed initially to store 10 years of production wastes from the 2000-MTHM/yr FRP. Provisions are made for the storage area to be expanded every 10 years to a total of 40 years of additional storage capacity (the reference facility will operate for 30 years). The facility is designed to be functional,

in terms of leakage containment and recovery, for 50 years after the last cylinder is filled and placed in the storage cells.

The krypton storage facility has the capability to receive the cylinders of ^{85}Kr, examine them for cylinder integrity, transfer the contents of leaking cylinders to empty cylinders, and transfer the cylinders into storage cells. All operations are conducted remotely and/or with shielding to protect operators from radiation. While in storage, cylinders are monitored for leakage of ^{85}Kr. In the event a leaking cylinder is discovered, it is moved back to the hot cell and its contents are transferred to a new cylinder. Figure 5.3.7-1 illustrates the krypton storage facility.

5.3.7.1 Environmental Effects Related to Facility Construction

Some aspects of site preparation and reference facility construction may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effects of construction activities.

Resource Commitments. The krypton storage facility will occupy about 4 ha. This facility is planned for inclusion within the FRP site boundary (2400 ha). The 4 ha includes the area for the three-phase storage facility necessary for 50-year storage capacity of recovered krypton. An additional 6 ha will be required during facility construction for storage, workyards, labor parking, and temporary buildings.

Water used during construction will amount to 1.9×10^4 m^3 for the first construction phase (for first 10 years' production of krypton) and 1.3×10^4 m^3 during each of the two additional construction phases (second and third decades of krypton production). Withdrawal of these quantities of water from the R River (average flow of 1.0×10^7 m^3/day) will not interfer with other downstream uses.

Materials and resources committed for construction of the krypton storage facility are as follows:

	Phase I	Phases 2 and 3	Total
Materials			
Steel, MT	1,800	2,400	4,200
Copper, MT	36	36	72
Zinc, MT	36	54	90
Lumber, m^3	590	900	1,490
Concrete, m^3	6,500	11,000	17,500
Energy resources			
Propane, m^3	180	240	420
Diesel fuel, m^3	1,180	2,400	3,600
Gasoline, m^3	1,200	1,600	2,800
Electricity			
Peak demand, kW	600	760	1,400
Total consumption, kWh	884,000	1,200,000	2,084,000

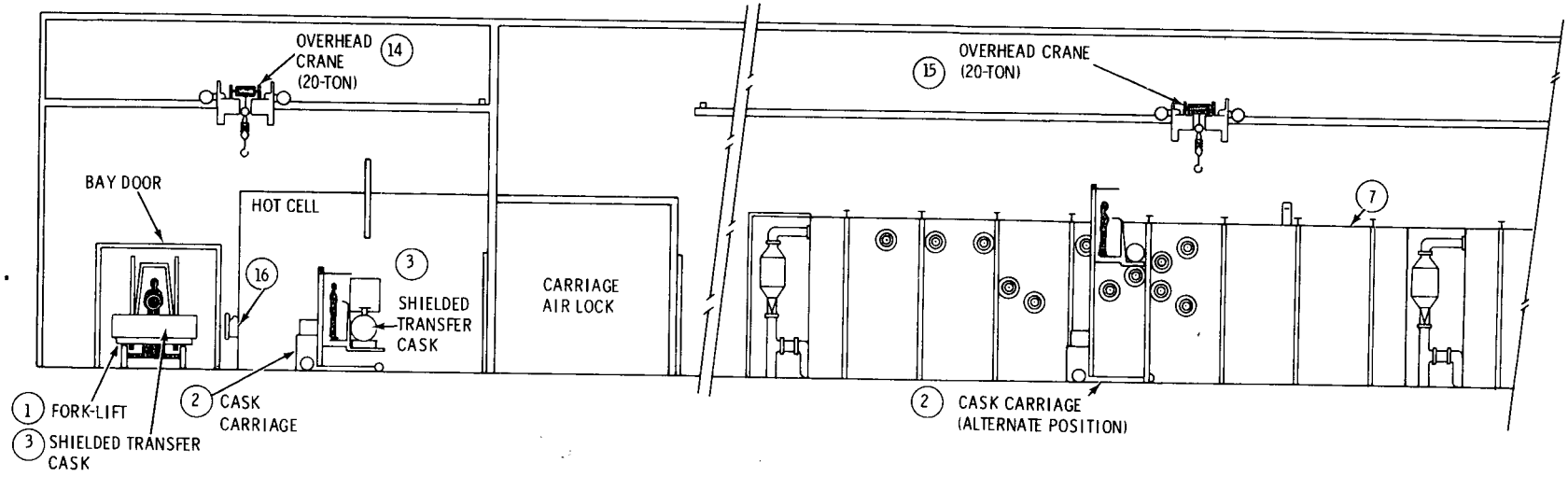

FIGURE 5.3.7-1. Krypton Storage Facility at the FRP

Manpower requirements for construction of the krypton storage facility will amount to 780 man-yr for Phase 1 and 1,200 man-yr for Phases 2 and 3 for a total of 2,000 man-yr. The initial construction phase of this facility would probably coincide with that of the FRP, and construction schedules would be coordinated accordingly.

No specific identifiable transportation requirements for the krypton storage facility have been identified beyond those for the FRP.

Physical and Chemical Effects. Effects on air quality from construction of the krypton storage facility will be a small fraction of those resulting from construction of the reference FRP.

The krypton storage facility will be constructed in three phases over a period of 30 years, with construction occurring during 2 years of each 10-year period. The construction of the first phase will coincide with the FRP construction. Consequently, environmental effects of the facility construction related to water will be a small fraction of the effects of the overall FRP construction for the first phase. The diversion of about 19,000 m^3 of water for the construction of the first phase and the diversion of about 13,000 m^3 of water for the construction of each of the following two phases for the krypton storage facility will have no impacts on local water supplies.

If good construction practices are used, the clearing of about 4 ha during the construction of the first phase will have little, if any, effect on surface drainage patterns, soil erosion, and nearby surface water quality. Impacts are expected to be negligible during the construction of the following two phases since the land clearing for all three phases will be completed during the construction of the first phase.

Ecological Effects. Although the krypton storage facility will occupy a separate enclosure within the FRP, the first phase of its construction will coincide with and be inseparable from the ecological impacts of the FRP construction. These will include the destruction of vegetation and animal habitat and the disturbance of birds and mammals through noise, dust, and human activity. The later phases of facility construction, to occur between the tenth and thirtieth years of facility operation, will have similar but perhaps lesser impacts because they will not be additive to those of the FRP.

No new roads or railroads beyond those required by the FRP will be needed.

The overall impacts to the terrestrial environment will be slight and will be related to the reallocation of land from its present use to that of the krypton storage facility.

Water will be supplied from the R River near the reference site. Assuming a 2-year period for each construction phase, the construction water requirements will be 0.02% or less of the minimum river flow and will have an imperceptible impact on the river ecosystem.

5.3.7.2 Environmental Effects Related to Facility Operation

Some aspects of facility operation may have an effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effects of operation.

Resource Commitments. Resources required during planned operation of the krypton storage facility are:

	Annual Average Use
Electricity, kWh	1×10^7
Manpower, man-yr	7.5

The commitment of these resources is considered to be negligible.

Process Effluents. It is assumed that occasional minor failures and accidents would result in the release in any 1 year's time of 0.1% of the total ^{85}Kr in storage during that year. The total quantity in storage would increase by 145 storage cylinders each year for the planned 30-year lifetime but be slightly decreased by radioactive decay of the 10.7 year half-life of ^{85}Kr. At the end of 50 years of storage, the residual ^{85}Kr from each year of operation would be released to the atmosphere through the krypton storage facility ventilation system to the FRP stack. A plot of the resulting annual releases is shown in Figure 5.3.7-2. The total quantity of ^{85}Kr released to the atmosphere for the entire 80 years of krypton storage facility operation would be 2.2×10^7 Ci. This includes 2.3×10^6 Ci from leakage and 2×10^7 Ci from emptying storage canisters after 50 years.*

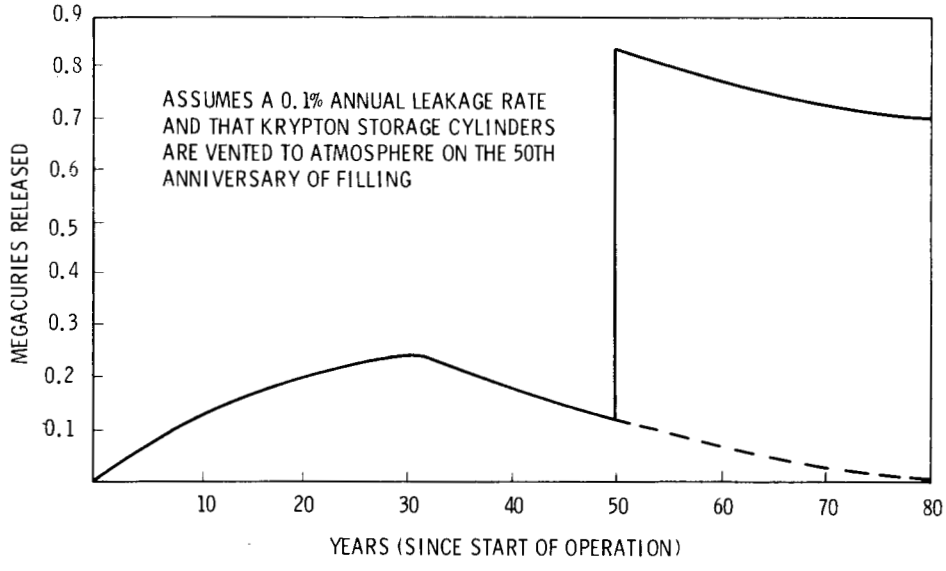

FIGURE 5.3.7-2. Annual Releases of ^{85}Kr from the Krypton Storage Facility at the Fuel Reprocessing Plant

During normal operation of the krypton storage facility, no nonradioactive materials will be released to the atmosphere. There are no direct releases of liquid or solid wastes to surface or ground waters or to land from the facility. All liquid and solid waste disposal for the facility, including sanitary sewage disposal, is part of the overall FRP operation.

* It may be necessary to retain the krypton in cylinders for an additional 2 to 3 years to ensure that the total release of krypton to the atmosphere is maintained within limits (see Section 5.2.1).

Physical, Chemical, and Thermal Effects. With the absence of release of nonradioactive materials to the atmosphere and a maximum contribution of 1.0×10^7 MJ of heat, no effects to the atmosphere are expected from operation of the krypton storage facility.

All liquid and solid waste disposal for the process is part of the overall FRP operation. Therefore, there will be no direct effect of disposal of nonradioactive liquid or solid wastes from the facility.

Radiological Effects. The doses received from krypton storage facility operations as a function of time are listed in Table 5.3.7-1 for the maximum individual. The total-body doses for the maximum individual from releases of krypton are substantially less than the nominal variation in dose from naturally occurring sources. The skin doses are about two orders of magnitude higher but are still less than nominal variations in the dose from naturally occurring sources. In comparison, the dose to the maximum individual from naturally occurring sources for the 80-year period would be about 8 rem.

TABLE 5.3.7-1. Doses to the Maximum Individual from Releases at the Krypton Storage Facility (rem)

	Total Body	Skin
Leakage		
15th year	1.3×10^{-6}	1.2×10^{-4}
30th year	1.8×10^{-6}	1.7×10^{-4}
80 years accumulated	1.7×10^{-5}	1.6×10^{-3}
Venting		
Annual (begin in 50th year)	5.0×10^{-6}	4.7×10^{-4}
30 years accumulated	1.5×10^{-4}	1.4×10^{-2}
Total dose from venting and leakage (80 years)	1.7×10^{-4}	1.6×10^{-2}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 1.5×10^{-8} sec/m^3.

The total-body dose to the regional population from leakage and venting of krypton at the krypton storage facility would amount to 40 man-rem over an 80-year period. During this same time the regional population would have received 16,000,000 man-rem from naturally occurring sources.

Dose to the worldwide population from releases at the FRP and the krypton storage facility are given in Table 5.3.7-2 for four 70-year generations.

Applying the factor of 100 to 800 health effects per million man-rem, from four to 30 health effects are postulated to occur in the world population over 280 years. During the same period about 2×10^{10} people will have died from unrelated causes.

TABLE 5.3.7-2. Doses to the Worldwide Population from Releases from the Krypton Storage Facility and the FRP

Generation	Dose, man-rem		
	FRP	Krypton Storage Facility	Total
First (1980-2050)	2.5×10^4	6.0×10^3	3×10^4
Second (2050-2120)	8.2×10^2	7.2×10^3	8×10^3
Third (2120-2190)	9.3	9.2×10^1	1×10^2
Fourth (2190-2260)	0.1	1	1
Total for 280 Years			3.8×10^4

Ecological Effects. There will be no environmental discharge of solid, liquid, or gaseous nonradioactive effluents during operation of the krypton storage facility. Process and sanitary water requirements will be supplied from the R River near the reference site. Process water will be used in chillers, air compressors, and the heating and ventilation system; sanitary water will be needed for restrooms, showers, and drinking. Sanitary water discharged will be processed in a sewage treatment facility. The volume of water to be used has not been defined, but it will be less than the amount needed for other FRP facilities that will require water for cooling and that have been judged to have an insignificant impact on R River biota (e.g., waste solvent incineration and incineration of trash and combustible wastes, Sections 5.2.4 and 5.2.6).

5.3.7.3 Environmental Effects Related to Postulated Accidents

One minor accident was identified for the krypton storage facility but no release of krypton is expected from that event. (See also Table 5.6.4 of DOE/ET-0028.[1]) The scenario is provided in DOE/ET-0028[1] and the accident is listed below.

Accident Number	Description
5.6.1	Loss of storage cell coolant

Several accidents are postulated to release radioactive material in amounts larger than those released during the minor accident. These are classified as moderate accidents and are listed below.

Accident Number	Description
5.6 2	Krypton cylinder ruptured in storage cell or hot cell
5.6.3	Krypton cylinder corrodes
5.6.4	Krypton cylinder ruptured in operating area or storage corridor

Of the three accidents, krypton cylinder ruptured in operating area or storage corridor (Accident 5.6.4) was judged to be more severe and was taken as representative of the set. For this accident, it was assumed that 130 kCi of ^{85}Kr is released to the environment via the FRP stack as a result of rupture of one cylinder. The estimated frequency of occurrence of such an accident is once in 20 years. The 1-year dose and 70-year dose commitment to the maximum individual were calculated and are presented in Table 5.3.7-3.

TABLE 5.3.7-3. Dose Commitment to the Maximum Individual Received from a Moderate Accident in the Krypton Storage Facility (rem)

Pathway	1-Year Dose	70-Year Dose
Air submersion		
Total body	5.3×10^{-3}	5.3×10^{-3}
Skin	5.2×10^{-1}	5.2×10^{-1}

Notes: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 1.5×10^{-8} sec/m^3. The total-body dose to the maximum individual is on the order of the nominal annual variation in dose received from naturally occurring sources.

Worldwide population doses from releases of ^{85}Kr were also calculated. The 1-year dose was calculated for the thirtieth year of operation of the facility since the stored inventory of krypton is largest at that time. One-year and 70-year total-body dose commitments to the worldwide population were calculated to be 53 and 1800 man-rem respectively. For comparison, the worldwide dose from naturally occurring sources (0.1 rem/yr) would be 6.4×10^8 man-rem and 4.5×10^{10} man-rem for the 1-year dose and 70-year dose commitment respectively.

The greater hazard potential from storage of krypton would exist for a worker who might be present in the operating area or storage corridor at the time of an accident rather than for the maximum individual, regional population, or worldwide population. The dose to a worker was calculated and the results are given in Table 5.3.7-4, assuming a constant release rate from a ruptured cylinder, dispersion within the room or corridor based on normal air flow, and exposure of the worker for 1 min before leaving the area. The total-body doses are equivalent to about 1 to 2 years of the maximum allowable occupational dose.

TABLE 5.3.7-4. Dose to a Worker Resulting from a Moderate Accident in the Krypton Storage Facility (rem)

Pathway	Operating Area	Storage Corridor
Air submersion		
Skin	440	610
Total body	6	8
Inhalation		
Lung	8	12

Nonradiological aspects of such an accident include structural damage; injury could also be serious in the event that pressure is suddenly released from a cylinder that is not adequately restrained during handling. (Because of facility design, however, inadequate restraint of storage cylinders is not considered credible.) A further nonradiological consequence of krypton storage results from the decay of ^{85}Kr to ^{85}Rb. Although ^{85}Rb is a stable element, in

a radioactive sense, it is like sodium and potassium in that it reacts violently with and ignites spontaneously in air. About 250 g of rubidium would be present in each cylinder at the end of the storage period of 50 years. The form that this material would be in has not been determined. Nevertheless, rubidium peroxide is toxic and as a consequence some care may be required in disposing of used krypton storage cylinders.

REFERENCES FOR SECTION 5.3.7

1. Technology for Commercial Radioactive Waste Management, DOE/ET-0028, Department of Energy, Washington, DC, in press.

5.4 COMBINED EFFECTS OF WASTE MANAGEMENT AT THE REFERENCE FRP

5.4 COMBINED EFFECTS OF WASTE MANAGEMENT AT THE REFERENCE FRP

The reference fuel reprocessing plant (FRP) contains 13 reference waste management facilities and is designed for a uranium and plutonium recycle mode. The waste management facilities comprise the following processes:

- high-level liquid waste vitrification
- fuel residue packaging without compaction
- failed equipment disassembly and packaging
- incineration of general trash and combustible waste
- cement immobilization facility for wet wastes and particulate solids
- dissolver off-gas treatment: Ru, I. C and Kr removal
- vessel and process off-gas treatment; I removal
- atmospheric protection system
- krypton storage
- outdoor near-surface interim storage for packaged fuel residues
- outdoor surface interim storage for low-level TRU wastes
- indoor shielded interim storage for intermediate-level TRU wastes
- indoor water basin interim storage for solidified high-level waste

The environmental effect of waste management at the reference FRP is the sum of the effects of these facilities.

5.4.1 Environmental Effects Related to Construction

Some aspects of site preparation and construction of the reference waste management facilities may have some effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effect of construction activities.

5.4.1.1 Resource Commitments

The production facilities of the FRP will require an area of about 2400 ha. Within this area approximately 60 ha will be cleared for plant construction and 40 ha will be occupied by the reference FRP installations. In addition, about 49 ha will be needed for a two-lane highway, railroad spur, and electrical transmission lines. Waste management facilities will require approximately 19 ha within the facility. Since the facilities devoted to waste management and fuel reprocessing will share the same general area and utilities, no clear separation can be made of the potential impacts of construction for these two types of activities.

The buffer zone surrounding the waste management facilities and within the 2400-ha restricted area will be controlled to limit or prohibit its use for agriculture or recreation. This will tend to increase its use and value as a relatively undisturbed wildlife habitat.

Water used for construction will amount to about 1.4×10^5 m^3 and will be supplied from the R River near the reference site. Withdrawal of this amount of water from the R River, described in the reference environment (average flow of 1.0×10^7 m^3/day), is judged to be insignificant with respect to other downstream uses.

Materials committed for construction of the FRP and its associated waste management facilities are:

	FRP	Waste Management	Total
Steel, MT	2.5×10^4	1.8×10^4	4.3×10^4
Copper, MT	1.4×10^2	2.0×10^2	3.4×10^2
Zinc, MT	9	1.0×10^2	1.1×10^2
Aluminum, MT	2.2×10^2	5	2.2×10^2
Lumber, m^3	4.7×10^3	5.1×10^3	9.8×10^3
Concrete, m^3	1.2×10^5	7.8×10^4	2.0×10^5
Lead, MT	---	6.5×10^1	6.5×10^1

Energy resources committed for construction are:

	FRP	Waste Management	Total
Propane, m^3	1.5×10^3	1.3×10^3	2.8×10^3
Diesel fuel, m^3	7.6×10^3	1.2×10^4	2.0×10^4
Gasoline, m^3	9.8×10^3	8.7×10^3	1.8×10^4
Electricity, kWh	7.4×10^5	6.4×10^6	7.1×10^6

Manpower requirements for the construction of the reference FRP amount to 6,500 man-yr spread over 4 years. The peak labor force will require about 700 individuals. Construction of waste management facilities will require about 4,000 man-yr. Labor schedules for the FRP will be coordinated with requirements for each FRP waste management facility. Total manpower requirements will be 11,000 man-yr.

5.4.1.2 Physical and Chemical Effects

Nonradioactive pollutants will be released to the atmosphere during construction from combustion of gasoline and diesel fuel in construction equipment, fugitive dust from clearing and excavation, and particulate emissions from concrete batching operations. The annual quantities of these materials discharged to the atmosphere are given in Table 5.4.1-1.

TABLE 5.4.1-1. Nonradioactive Pollutants Discharged to the Atmosphere During Construction of the Reference Fuel Reprocessing Plant

Pollutant	Construction and Vehicle Travel to Site, MT/yr	Air Concentrations	Primary National Standards,(a) $\mu g/m^3$
Carbon monoxide	4800	6,900 $\mu g/m^3$, construction; 15,000 $\mu g/m^3$, vehicle travel	40,000 (1 hr standard)(b)
Hydrocarbons	510	2.2% of rural area emissions	160(c)
Nitrogen oxides	500	3.2% of rural area emissions	
Sulfur dioxide	24	7 $\mu g/m^3$	
Particulates	840	30 $\mu g/m^3$	75(d)

a. Source: A. C. Stern, H. C. Wohlers, R. W. Boubel, and W. P. Lowery, Fundamentals of Air Pollution, Academic Press, New York, 1973.
b. 1 hour average not be exceeded more than once per year.
c. 3 hour average during 6 to 9 a.m. daily.
d. Annual geometric mean never to be exceeded.

The impact of these emissions on the ambient air quality was predicted using established modeling procedures.[1,2] Results of the predictions indicate the maximum concentration of particulates off the immediate construction site is 30 $\mu g/m^3$. The maximum areal extent of the impact occurs about 3 km from the site boundary to the southeast, where an increase in the particulate concentration of 5 $\mu g/m^3$ is predicted. Particulate concentrations on the construction site, however, were found to exceed 100 $\mu g/m^3$.

5.4.1.3 Ecological Effects

Construction will remove permanently (for the life of the plant) about 21 ha from its present use for agriculture and wildlife at the reference site. While this change in land use will eliminate its utility as habitat for wildlife, no significant ecological impacts to the region are expected. Disturbance of animals from fugitive dust, noise, and human activities during construction will be confined mainly to the 2400 ha FRP restricted area. Erosion caused by run-off may deposit silt in nearby surface waters unless attention is given to control drainage by proper ditching, grading, and silt catchment. After construction is completed and vegatation is reestablished or surfacing is completed in the disturbed areas, this erosion problem will be reduced.

The FRP will require about 1.8×10^5 m^3 of water; water used during construction of the combined FRP and waste management facilities construction will be approximately 3.1×10^5 m^3. If as a "worst case" it is assumed that construction could be completed in 1 year, the water used would be about 0.5% of the recorded minimum low flow of the R River or less than 0.01% of the average river flow. Removal of this volume of water from the R River, or from rivers having similar flow characteristics, should have an insignificant impact on the stream biota.

Presumably a common water intake from the R River will supply the construction and operational water needs of both the FRP and the waste management facilities. This intake should be located to minimize any alteration of flow patterns and properly screened to reduce the numbers of aquatic organisms entrained in the FRP water system. Care should also be exercised to keep the disturbance of the river bottom at a minimum during intake construction.

The maximum concentrations of particulates, sulfur dioxide, and carbon monoxide will occur within the 2400 ha FRP restricted area. Particulate concentrations at the construction site are estimated to exceed Federal ambient air standards on site. Calculated carbon monoxide and hydrocarbon levels are only a small fraction of the existing rural air concentrations near the reference site. Concentrations of the other materials are below acceptable standards. Consequently, no measurable detrimental effects on the terrestrial ecosystem are anticipated.

REFERENCES FOR SECTION 5.4.1

1. Air Quality Impacts Due to Construction of LWR Waste Management Facilities, URS 7073-01-01, URS Company, San Mateo, CA, 1977, p. 49.

2. Compilation of Air Pollutant Emission Factors, AP 42, Environmental Protection Agency, Research Triangle Park, NC, April 1973.

5.4.2 Environmental Effects Related to Facility Operation

Some aspects of facility operation may have some effect on the environment and the natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effects of operation.

5.4.2.1 Resource Commitments

Resources required during planned operation of the waste management facilities at the FRP are given in Table 5.4.2-1.

TABLE 5.4.2-1. Utilities and Materials Required for Planned Operation of the Waste Management Facilities at the FRP

Resource	Average Annual Use
Materials	
Acetylene	5.0×10^{-1}
Stainless steel, MT	2.2×10^{2}
CaO, MT	1.4
Gas cylinders	1.5×10^{2}
Frit, MT	2.5×10^{2}
Sand, MT	6.5×10^{2}
Cement, MT	1.1×10^{3}
Caustic, m^3	8.0
HNO_3, m^3	1.1×10^{1}
NaOH, MT	5.0×10^{1}
NH_3, MT	1.4×10^{2}
Argon, m^3	8.7×10^{3}
Helium, m^3	1.4×10^{3}
Liquid nitrogen, MT	4.0×10^{2}
Silver zeolite, m^3	2.2×10^{1}
Silica gel, m^3	5.0×10^{-1}
Detergent, MT	2.7×10^{-1}
55-gal drums	6.0×10^{3}
Waste canisters	
0.76 x 3.05 m	4.8×10^{2}
0.3 x 3 m	6.6×10^{2}
Cardboard boxes	
(30 x 30 x 60 cm)	1.0×10^{4}
Plastic sheets, m^2	6.5×10^{2}
Filters	3.2×10^{2}
Plywood, m^2	3.4×10^{3}
Utilities	
Water consumed, m^3	4.4×10^{5}
Electricity, kWh	9.0×10^{7}
Diesel fuel, m^3	2.4×10^{1}
Propane, m^3	2.8×10^{5}
Oil, m^3	3.8×10^{2}
Manpower, man-yr	1.5×10^{2}

5.4.2.2 Process Effluents

Table 5.4.2-2 shows the amounts of radioactive materials that reach the biosphere after leaving the FRP and passing through the reference FRP atmospheric protection system. The radionuclides are entrained in air derived from process off-gas. The total air flow through the FRP atmospheric protection system is estimated to be 120 m^3/sec. The radionuclides listed are those that will contribute at least 1% to the total dose for a given organ for any pathway or that are otherwise of interest. Treatment both with and without incineration was considered, and source terms of the radioactive material were found to be nearly identical.

TABLE 5.4.2-2. Radionuclides Released to the Biosphere Annually from the Reference FRP with Operation of the Waste Management Facilities

	U Recycle, SHLW	U Recycle, PuO_2 Stored	U and Pu Recycle
^{3}H	7.4×10^{5}	7.4×10^{5}	7.4×10^{5}
^{14}C	1.2×10^{1}	1.2×10^{1}	1.2×10^{1}
^{85}Kr	1.8×10^{6}	1.8×10^{6}	1.7×10^{6}
^{90}Sr	5.4×10^{-5}	5.6×10^{-5}	5.2×10^{-5}
^{106}Ru	6.8	6.8	7.6
^{129}I	2.0×10^{-1}	2.0×10^{-1}	2.2×10^{-1}
^{137}Cs	7.8×10^{-5}	7.8×10^{-5}	7.8×10^{-5}
^{234}U	---	---	6.8×10^{-3}
^{236}U	6.4×10^{-3}	6.4×10^{-3}	5.2×10^{-3}
^{238}U	6.4×10^{-3}	6.4×10^{-3}	6.4×10^{-3}
^{238}Pu	1.2×10^{-4}	1.2×10^{-4}	2.2×10^{-4}
^{239}Pu	1.2×10^{-5}	1.2×10^{-5}	1.2×10^{-5}
^{240}Pu	1.8×10^{-5}	1.8×10^{-5}	2.9×10^{-5}
^{241}Pu	4.4×10^{-2}	4.4×10^{-2}	7.2×10^{-3}

An annual leak rate of 0.1% of the ^{85}Kr in the krypton storage facility is assumed. The amount in storage, however, is not constant. It will increase by 145 storage cylinders* per year during the 30-year plant life but will also decrease because of radioactive decay. At the end of 50 years of storage the residual ^{85}Kr will be released to the atmosphere (less than 4% of initial inventory). The total amount of ^{85}Kr released to the atmosphere will be 7.6×10^{7} Ci less 5.4×10^{7} Ci released during operations, 2.3×10^{6} Ci released from leakage over the 50-year storage, and 2×10^{7} Ci released from cylinders after 50 years of storage.

There are no planned releases of radioactive material to the biosphere via liquid effluent streams. Nonradioactive effluents released to the atmosphere during FRP operations are listed in Table 5.4.2-3.

* Each containing about 1×10^{5} Ci ^{85}Kr in 42.5 ℓ at a pressure of 34 atmospheres.

TABLE 5.4.2-3. Nonradioactive Pollutants Released to the Atmosphere During Operation of the Reference FRP Waste Management Facilities

Pollutant	Amount Released, MT/yr	Fenceline Concentration (2800 m), $\mu g/m^3$		Standards, $\mu g/m^3$
		Maximum	Average	
Nitrogen oxides	1.4	0.05	0.025	1.0×10^{2}(a,c)
Carbon monoxide	0.3	0.003	0.001	4×10^{4}(a,c)
Sulfur oxide	0.3	<0.003	<0.001	8.0×10^{1}(a,d)
Ammonia	10	0.4	0.2	1.8×10^{4}(b)
Hydrochloric acid	0.17	<0.001	<0.001	7.0×10^{3}(b)
Argon	12	0.01	0.007	1.5×10^{7}(a)
Nitrogen	1200	0.9	0.5	8.7×10^{8}(a)
Oxygen	720	0.5	0.3	2.7×10^{8}(a)
Hydrogen	0.8	0.001	<0.001	4.0×10^{1}(a)
Helium	0.1	<0.001	<0.001	
Particulates	0.5	<0.001	<0.001	7.5(a,e)

a. A. C. Stern, H. D. Wohlers, R. W. Boubel, and W. P. Lowery, Fundamentals of Air Pollution, Academic Press, New York, 1973.
b. Threshold Limit Values for Current Year (1976), American Conference of Governmental Industrial Hygienists, Cincinnati, OH, 1976.
c. 1 hour average not to be exceeded more than once per year.
d. Annual average never to be exceeded.
e. Annual geometric mean.

About 1.9×10^{9} MJ per year (75 MW) of heat will be rejected to the atmosphere via the main FRP cooling tower. About 5% of this heat release is for periods of maximum use of the waste treatment facilities. Another 6.3×10^{8} MJ per year (25 MW) of heat is released via the FRP stack. Of that amount about 8% originates in waste treatment facilities.

A separate cooling tower system is used to dissipate about 8.5×10^{8} MJ/yr (27 MW) of waste heat from the solidified high-level waste interim storage facility. Less than 3×10^{7} MJ per year (1 MW) of waste heat are dissipated to the atmosphere from the krypton and fuel residue storage facilities.

In total and during maximum waste treatment usage about 1×10^{9} MJ per year (32 MW) of heat are released to the atmosphere. The overall maximum heat load of the FRP and waste treatment and interim storage facilities is on the order of 4×10^{9} MJ per year (130 MW).

The maximum contribution of waste management facilities to the reference FRP cooling tower blowdown would be 6.7×10^{4} m^3/yr at a ΔT of 17°C. About 1.9×10^{3} m^3 of water per year would be lost as drift.

Assuming that chlorine will be used as a biocide in the cooling tower, chlorine would be expected to be present in the cooling tower drift and flowdown. The chloride concentration in the circulating cooling tower water was estimated to be 17 mg/ℓ.

5.4.2.3 Physical, Chemical, and Thermal Effects

The rejection of about 1×10^9 MJ of waste heat per year is comparable to that rejected from a city or town and is not expected to produce any significant effect on the environment.

Annual average and maximum ground level concentrations of pollutants released from the reference FRP system were computed using $\bar{\chi}/Q'$ values developed from data presented in the reference environment (Appendix A) for the 110-m FRP stack release. These concentrations are listed in Table 5.4.2-3.

Federal air quality standards currently exist for nitrogen oxides, carbon monoxide, and sulfur oxide. These standards of 100 $\mu g/m^3$ and 80 $\mu g/m^3$ for nitrogen oxides and sulfur oxide,[1] respectively, are not exceeded. The standard for carbon monoxide is also not exceeded.

Concentrations of the other pollutants can be compared with threshold limit values (TLV) or concentrations of gases that naturally exist in the atmosphere. The values are also listed in Table 5.4.2-3 with the TLV concentrations. By comparison, predicted concentrations of pollutents in air from waste management operation at the FRP will be a small percentage of Federal standards or naturally occurring gaseous concentrations.

Water required for operation of the reference FRP cooling tower will be about 1.1×10^6 m^3/yr. Of this amount, the reference waste management facilities will require about 4.9×10^5 m^3/yr. As long as this water is drawn from sources such as the R River (40-year minimum flow of 2×10^8 m^3/yr), no significant effects on local water supplies are anticipated.

The total amount of water discharged as cooling tower blowdown to the R River from the reference FRP waste management system is about 6.7×10^4 m^3/yr at an increase in temperature of 17°C. Chemical characteristics of blowdown from the cooling towers are estimated based on a tenfold concentration of R River water and are shown in Table 5.4.2-4.

The thermal and chemical discharges to the R River will be quickly diluted by the river water. At average river flow, dilution of the residual chlorine will be about 750-fold. Near-ambient river thermal and chemical characteristics will be realized outside a mixing zone of about 130 m^2, which is bounded by the 0.6°C ΔT isotherm. No perceptible impacts to the river ecosystem are foreseen from cooling water discharged to the R River.

There will be no direct releases of liquids or solids to the ground.

5.4.2.4 Radiological Effects

Doses to individuals in the vicinity of the FRP were calculated based on radionuclides released from the FRP (Table 5.4.2-2) after treatment in waste management facilities; exposure pathways, demography, and other parameters described for the reference environment in Appendix A; and mathematical models relating dose to man from radionuclide releases (Appendix B). For planned operation of the FRP, the only exposure pathway to man is via airborne effluents; there are no planned releases to ground or water.

The annual dose to individuals whose habits tend to maximize their dose ("maximum individual") are shown in Table 5.4.2-5. For perspective, the dose to an individual from naturally occurring radioactive sources averages about 0.1 rem/yr. Doses include the dose

received from leakage at the krypton storage facility and from release of residual ^{85}Kr at the end of the 50-year storage period.

TABLE 5.4.2-4. Water Quality Characteristics of Blowdown for a Cooling Tower Operating with Ten Cycles of Concentration of R River Water

	Concentration, mg/ℓ	
	Average	Extreme
Solids		
Total	1800	2200
Dissolved	1800	2100
Suspended	750	1800
Hardness (as $CaCO_3$)		
Total	1500	1700
Calcium	990	1200
Magnesium	480	580
Alkalinity (as $CaCO_3$)		
Total	1400	1600
Phenolphthalein	18	120
Gases		
Ammonia-nitrogen (N)	0.2	0.9
Anions		
Carbonate (CO_3)	21	140
Bicarbonate (HCO_3)	1700	2000
Hydroxide		
Chloride	14	50
Nitrate-nitrogen	2.6	5.5
Sulfate (SO_4)	95	140
Phosphorous soluble	0.30	0.57
Silica (SiO_2)	77	120
Cations		
Calcium	400	480
Magnesium	120	140
Sodium	50	64
Total iron	2.3	5.2
Biological oxygen demand	14	25
Dissolved oxygen	10	15

Note: The conductivity is 290 and 250 mhos for the average and extreme concentrations respectively. The pH is 8.2 and 8.6 for average and extreme concentrations respectively.

TABLE 5.4.2-5. Annual Doses to the Maximum Individual from Gaseous Effluents Released from the Reference FRP After Treatment (rem)

Pathway	Skin	Total Body	Thyroid (child)(a)	Thyroid(b)	Lung	Bone
		U Recycle, Pu in SHLW or PuO_2 Stored				
Air submersion	1.3×10^{-3}	1.3×10^{-5}	1.3×10^{-5}	1.3×10^{-5}	1.3×10^{-5}	1.3×10^{-5}
Inhalation		3.9×10^{-4}		3.9×10^{-4}	3.9×10^{-4}	8.4×10^{-6}
Ingestion		2.5×10^{-3}	1.6×10^{-3}	2.6×10^{-3}	2.5×10^{-3}	1.1×10^{-3}
Total	1.3×10^{-3}	2.9×10^{-3}	1.6×10^{-3}	3.1×10^{-3}	2.9×10^{-3}	1.1×10^{-3}
		U and Pu Recycle				
Air submersion	1.3×10^{-3}	1.2×10^{-5}	1.2×10^{-5}	1.2×10^{-5}	1.2×10^{-5}	1.2×10^{-5}
Inhalation		3.9×10^{-4}		3.9×10^{-4}	3.9×10^{-4}	7.9×10^{-6}
Ingestion		2.5×10^{-3}	1.5×10^{-3}	2.9×10^{-3}	2.4×10^{-3}	1.1×10^{-3}
Total	1.3×10^{-3}	2.9×10^{-3}	1.5×10^{-3}	3.3×10^{-3}	2.8×10^{-3}	1.1×10^{-3}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the highest annual average dispersion factor ($\bar{\chi}/Q'$) of 1.5×10^{-8} sec/m^3.

a. Thyroid dose is calculated for a 1-year-old child breathing air containing radioactive effluents and consuming 1 ℓ of milk per day from cows grazing 7 months/yr at the site boundary. Inhalation dose is <2% of total dose.

b. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

The combined dose from gaseous effluents to the population living within an 80-km radius of the plant was calculated using the projected year 2000 population data given in the reference environment. Table 5.4.2-6 summarizes the annual doses received by this population. The annual total-body population dose from naturally occurring sources to the approximately 2 million persons living within an 80-km radius of the plant in the year 2000 would be about 200,000 man-rem compared with the value of about 350 man-rem received from process sources as given in Table 5.4.2-7.

The annual total-body dose to the work force associated with the FRP waste management facilities was estimated based on permissible exposure limits and experience of operating plants. The annual dose was calculated to be 470 man-rem. Table 5.4.2-7 summarizes the annual total-body dose to the work force and the general population from process and naturally occurring sources in the year 2000.

The 70-year doses to the maximum individual and to the population within 80 km of the facility are given in Tables 5.4.2-8 and 5.4.2-9 respectively. Included are total doses received from 80 years of operation of the krypton storage facility. A summary of the 70-year total-body doses to the work force and the population is given in Table 5.4.2-10. For comparison, the population dose received from naturally occurring sources is also given for the year 2000 and amounts to about 14,000,000 man-rem compared with 11,000 man-rem received from the waste management facilities. All doses calculated include doses from routine releases and from minor accidents within each FRP waste management facility.

TABLE 5.4.2-6. Annual Doses to the Population (within 80 km) from Gaseous Effluents Released from the Reference FRP After Treatment (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
	U Recycle, Pu in SHLW or PuO_2 Stored			
Air submersion	3.1	3.1	3.1	3.1
Inhalation	8.3×10^{1}	8.3×10^{1}	9.6×10^{1}	2.0
Ingestion	2.2×10^{2}	2.3×10^{2}	2.2×10^{2}	1.3×10^{2}
Total	3.0×10^{2}	3.1×10^{2}	3.2×10^{2}	1.3×10^{2}
	U and Pu Recycle			
Air submersion	2.9	2.9	2.9	2.9
Inhalation	8.4×10^{1}	8.4×10^{1}	9.8×10^{1}	1.8
Ingestion	2.2×10^{2}	2.3×10^{2}	2.2×10^{2}	1.2×10^{2}
Total	3.0×10^{2}	3.1×10^{2}	3.2×10^{2}	1.2×10^{2}

TABLE 5.4.2-7. Summary of Annual Total-Body Doses Received from Operation of the Reference FRP and Naturally Occurring Sources

	Dose, man-rem
Reference FRP	
Process work force	470
Population (within 80 km)	300
Naturally occurring sources	
Population (within 80 km)	200,000

TABLE 5.4.2-8. 70-Year Doses to the Maximum Individual from Gaseous Effluents Released from the Reference FRP After Treatment (rem)

Pathway	Skin	Total Body	Thyroid[a]	Lung	Bone
	U Recycle, Pu in SHLW or PuO_2 Stored				
Air submersion	3.8×10^{-2}	4.0×10^{-4}	4.0×10^{-4}	4.0×10^{-4}	4.0×10^{-4}
Inhalation		1.1×10^{-2}	1.1×10^{-2}	1.3×10^{-2}	2.9×10^{-4}
Ingestion		8.0×10^{-2}	9.0×10^{-2}	7.9×10^{-2}	3.8×10^{-2}
First generation total	3.8×10^{-2}	9.1×10^{-2}	1.0×10^{-1}	9.2×10^{-2}	3.8×10^{-2}
Second generation total		6.4×10^{-4}	2.9×10^{-2}	5.5×10^{-4}	3.9×10^{-4}
Third generation total		6.3×10^{-4}	2.9×10^{-2}	5.5×10^{-4}	3.9×10^{-4}
	U and Pu Recycle[b]				
Air submersion	3.7×10^{-2}	3.7×10^{-4}	3.7×10^{-4}	3.7×10^{-4}	3.7×10^{-4}
Inhalation		1.1×10^{-2}	1.1×10^{-2}	1.4×10^{-2}	3.0×10^{-4}
Ingestion		7.9×10^{-2}	9.0×10^{-2}	7.9×10^{-2}	3.8×10^{-2}
First generation total	3.8×10^{-2}	9.0×10^{-2}	1.0×10^{-1}	9.3×10^{-2}	3.8×10^{-2}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the highest annual average dispersion factor ($\bar{\chi}/Q'$) of 1.5×10^{-8} sec/m^3.

a. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

b. Second and third generation doses are the same for both reprocessing options.

TABLE 5.4.2-9. 70-Year Doses to the Population (within 80 km) from Gaseous Effluents Released from the Reference FRP After Treatment (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
U Recycle, Pu in SHLW or PuO_2 Stored				
Air submersion	9.2×10^1	9.2×10^1	9.2×10^1	9.2×10^1
Inhalation	2.7×10^3	2.7×10^3	3.2×10^3	6.8×10^1
Ingestion	7.1×10^3	1.1×10^4	7.4×10^3	4.7×10^3
First generation total	1.0×10^4	1.4×10^4	1.1×10^4	4.8×10^3
Second generation total	9.1	1.4×10^2	9.8	3.5×10^1
Third generation total	8.6	1.4×10^2	9.4	3.5×10^1
U and Pu Recycle[a]				
Air submersion	8.7×10^1	8.7×10^1	8.7×10^1	8.7×10^1
Inhalation	2.7×10^3	2.7×10^3	2.7×10^3	7.1×10^1
Ingestion	7.3×10^3	1.1×10^4	7.3×10^3	4.3×10^3
First generation total	1.0×10^4	1.4×10^4	1.0×10^4	4.3×10^3

a. Second and third generation doses are the same for both reprocessing options.

TABLE 5.4.2-10. Summary of 70-Year Total-Body Doses Received from Operation of the Reference FRP and from Naturally Occurring Sources

	Dose, man-rem
Reference FRP	
Process work force (30 yr)	14,000
Population (within 80 km)	10,000
Naturally occurring sources	
Population (within 80 km)	14,000,000

In this report, 100 to 800 health effects are postulated to occur in the exposed population per million man-rem. On that basis the 70-year total body dose of 11,000 man-rem to the regional population suggests that one to 8 health effects would occur from waste management over the 30-year life of the reference FRP.

Total-body doses to the worldwide population from releases of ^3H, ^{14}C, and ^{85}Kr were also calculated. The world population was assumed to be 6.4 billion persons. The 1-year dose was calculated for the thirtieth year of operation of the FRP since it is expected to be the worst-case release period. One-year and 70-year total-body dose commitments to the worldwide population are shown in Table 5.4.2-11. Included in these 70-year dose commitments are doses for 80 years of operation of the krypton storage facility. For comparison, the worldwide dose from naturally occurring sources (0.1 rem/yr) would be 6.4×10^7 man-rem.

TABLE 5.4.2-11. Total-Body Dose Commitments to the Worldwide Population from Operation of the Reference FRP (man-rem)

Radionuclide	1-Year Dose	70-Year Dose
U Recycle, Pu in SHLW or PuO_2 Stored		
^{3}H	4.4×10^{3}	1.5×10^{5}
^{14}C	8.7×10^{2}	4.8×10^{4}
^{85}Kr	7.3×10^{2}	2.5×10^{4}
Total	6.0×10^{3}	2.2×10^{5}
U and Pu Recycle		
^{3}H	4.4×10^{3}	1.5×10^{5}
^{14}C	7.9×10^{2}	4.4×10^{4}
^{85}Kr	6.9×10^{2}	2.3×10^{4}
Total	5.9×10^{3}	2.2×10^{5}

Health effects to the worldwide population from the release of ^{3}H, ^{14}C, and ^{85}Kr were calculated to be from 22 to 180 over a 70-year period. Carbon-14 is the controlling radionuclide in terms of long-term worldwide dose. Second and third generation (70 years each) doses amount to 7.5×10^{5} man-rem. The eighth generation dose is 5.0×10^{4} man-rem and the 15th generation dose is also 5.0×10^{4} man-rem.

5.4.2.5 Ecological Effects

The release of about 1×10^{9} MJ per year (32 MW) of heat from waste management activities to the atmosphere via the FRP and solidified HLW storage cooling towers is not expected to have any ecological impact. Thermal discharges to the R River have a ΔT of only 17°C and will be further diluted by river flow. No perceptible impacts to the river ecosystem are foreseen from cooling water discharged. With proper intake structure design and placement in the river, the loss of aquatic organisms through intake screen impingement and entrainment in the cooling water is not expected to have a significant impact on the river ecosystem.

Since the concentrations of air pollutants are several orders of magnitude lower than the Federal air quality standards,[1] no impacts to the terrestrial ecosystem are expected. Chlorine concentrations in the cooling tower drift are discussed in Section 5.4.2.3. No toxic effects to native plant species in the reference environment are expected during the life of the reference FRP.

REFERENCES FOR SECTION 5.4.2

1. A. C. Stern, H. D. Wohlers, R. W. Boubel, and W. P. Lowery, Fundamentals of Air Pollution, Academic Press, New York, 1973.

5.4.3 Environmental Effects Related to Postulated Accidents

A number of minor, moderate and severe accidents were examined for each facility within the reference FRP. In cases where more than one minor, moderate, or severe accident was identified, one was chosen as representative. A list of these representative accidents is given in Table 5.4.3-1 along with the facility in which they occur and their expected frequencies. For waste management facilities where no accident was identified that would release radioactive material, no accident is listed.

TABLE 5.4.3-1. Representative Accidents at the Reference FRP Resulting in the Release of Radionuclides

Facility	Accident Number	Accident	Annual Frequency	DOE/ET-0028 Section
Waste vitrification	4.1.3	Canister spill caused by overfilling or other process irregularity (minor)	2	5.2.2.2
	4.1.8	Process off-gas filter or scrubber failure (moderate)	0.2	5.2.2.2
	Non-design	Calciner rupture; calciner damage from overheating	not calculated	5.2.2.1
Packaging of fuel residues	4.2.2	Zirconium fines fire (minor)	0.1	5.2.3
Combustible waste incineration	4.4.5	Incinerator explosion (moderate)	0.01	5.2.6.1
Degraded solvent incineration	4.4.5	Incinerator explosion (moderate)	0.01	5.2.4
Dissolver off-gas treatment	4.9.3	Process shutdown while dissolver is operating (moderate)		5.2.1
	4.9.14	Process shutdown with volatile venting for 30 days (moderate)		5.2.1
Krypton gas cylider storage	5.6.2	Krypton cylinder ruptured in storage facility (moderate)	0.05	5.3.8
Near-surface storage of fuel residues	5.2.1	Waste zirconium hulls canister breached by drop (moderate)	0.2	5.3.3
Outdoor surface storage of low-level transuranic waste	5.3.1	Mechanical breach of waste barrel (minor)	0.5	5.3.5
	5.3.6	Tornado strikes transuranic storage area stacking operation (moderate)		5.3.5
Outdoor subsurface storage of intermediate-level transuranic waste	5.3.1	Mechanical breach of waste barrel (minor)	0.5	5.3.4
	5.3.8	Canister drop from bridge crane (moderate)		5.3.4
Solidified high-level waste interim storage basin	5.4.13	Contamination of secondary cooling water (severe)	0.0001	5.3.2

Based on the anticipated releases of the minor accidents weighted by their expected frequency of occurrence, an average annual release was postulated. This minor accident contribution was included with the source term for planned annual releases of radioactive material from the FRP.

Source terms for the release of radioactive material from moderate and severe accidents with the greatest potential release are given in Table 5.4.3-2. The associated annual doses and 70-year dose commitments to the maximum individual from these accidents are given in Tables 5.4.2-3 and 5.4.2-4 respectively. The postulated worst-case moderate accident in the FRP would occur in the dissolver off-gas treatment system and result in 30 days of operation

TABLE 5.4.3-2. Radionuclides Released During Worst-Case Accidents at the Reference FRP

Radionuclide	Moderate Accident Release, Ci	Severe Accident Release, Ci
^{3}H	3.5×10^{4}	6.1×10^{-3}
^{14}C	1.2×10^{2}	
^{85}Kr	1.5×10^{6}	
^{90}Sr	1.1×10^{-7}	1.2×10^{1}
^{106}Ru		3.0×10^{1}
^{125m}Te		3.9×10^{-1}
^{127m}Te		7.5×10^{-2}
^{129}I	5.4×10^{-3}	3.0×10^{-8}
^{134}Cs		2.1×10^{1}
^{137}Cs	1.5×10^{-7}	1.6×10^{1}
^{144}Ce		4.5×10^{1}
^{239}Pu	4.8×10^{-10}	2.6×10^{-4}
^{241}Am		6.6×10^{-2}
^{242}Cm		6.2×10^{-1}
^{244}Cm		2.1×10^{-1}

TABLE 5.4.3-3. Annual Doses to the Maximum Individual from Worst-Case Accidents at the Reference FRP (rem)

TABLE 5.4.3-3. Annual Doses to the Maximum Individual from Worst-Case Accidents at the Reference FRP (rem)

Pathway	Skin	Total Body	Thyroid	Lung	Bone
		Moderate Accident			
Air submersion	2.8×10^{-2}	3.0×10^{-4}	3.0×10^{-4}	3.0×10^{-4}	3.0×10^{-4}
Inhalation		1.3×10^{-3}	1.3×10^{-3}	1.3×10^{-3}	2.9×10^{-5}
Total	2.8×10^{-2}	1.6×10^{-3}	1.6×10^{-3}	1.6×10^{-3}	3.3×10^{-5}
		Severe Accident			
Air submersion	4.2×10^{-3}	1.3×10^{-3}	1.3×10^{-3}	1.3×10^{-3}	1.3×10^{-3}
Inhalation		2.0×10^{-1}	1.1×10^{-2}	1.2×10^{1}	1.6
Total	4.2×10^{-3}	2.0×10^{-1}	1.2×10^{-2}	1.2×10^{1}	1.6

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the time-integrated atmospheric dispersion efficient (E/Q) of 1.5×10^{-8} sec/m^3.

TABLE 5.4.3-4. 70-Year Dose Commitments to the Maximum Individual from Worst-Case Accidents at the Reference FRP (rem)

Pathway	Skin	Total Body	Thyroid	Lung	Bone
		Moderate Accident			
Air submersion	2.8×10^{-2}	3.0×10^{-4}	3.0×10^{-4}	3.0×10^{-4}	3.0×10^{-4}
Inhalation		1.3×10^{-3}	1.3×10^{-3}	1.3×10^{-3}	2.9×10^{-5}
Total	2.8×10^{-2}	1.6×10^{-4}	1.6×10^{-3}	1.6×10^{-3}	3.3×10^{-4}
		Severe Accident			
Air submersion	4.2×10^{-3}	1.3×10^{-3}	1.3×10^{-3}	1.3×10^{-3}	1.3×10^{-3}
Inhalation		2.0	1.1×10^{-2}	1.9×10^{1}	1.4×10^{1}
Total	4.2×10^{-3}	2.0	1.2×10^{-2}	1.9×10^{1}	1.4×10^{1}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the time-integrated atmospheric dispersion efficient (E/Q) of 1.5×10^{-8} sec/m^3.

without off-gas treatment (Accident 4.8.14). The worst-case severe accident would occur in the solidified high-level waste interim storage basin and would result in contamination of secondary cooling water (Accident 5.4.13).

No accidents have been postulated that would cause significant ecological impacts. However, the accidental environmental release of transported or stored process chemicals (e.g., chlorine, acids, and caustics) could result in significant impacts to both terrestrial and aquatic ecosystems.

5.4.4 Socioeconomic Impacts of Construction and Operation of Waste Management Facilities at an FRP

Socioeconomic impacts associated with waste management facilities at an FRP depend largely on the numbers of persons who move into the county in which the FRP will be located. To analyze socioeconomic impacts, therefore, the size of the population influx was forecasted and estimates of the needs for local social services were determined. Specific economic impacts attributable to the reference waste management facilities will not be treated here because they are too dependent on local site characteristics to allow for generalization. Further information on socioeconomic impacts is provided in Appendix C.

Socioeconomic impacts also depend on site characteristics and the assumptions used in the forecasting model (Appendix C). Site characteristics that are especially important in influencing the size of the impacts forecasted include the availability of a local labor force having the required skills, secondary employment, proximity to a metropolitan area, and demographic diversity (population size, degree of urbanization, etc.) of counties in the commuting region. An additional factor in the generation of impacts is the time pattern of population change. For example, a large labor force buildup followed closely by rapidly declining project employment demand could cause serious economic and social disruptions near the site and elsewhere within the commuting region.

Impacts are estimated for three reference sites identified as Southeast, Midwest, and Southwest. These areas were chosen because siting of facilities in those regions is plausible, and they differ substantially in demographic characteristics, thus providing a reasonable range of socioeconomic impacts.

The socioeconomic model used in this analysis forecasts a regional population in five-year intervals in the absence of any project activities. This population forecast serves both as a comparative baseline and as a source for a portion of the postulated future project employment. The model takes account of both primary and secondary employment effects (such as additional retail store clerks) and incorporates as separate components spouses of members of the labor force and other dependents. Regional migrants associated with the project are distributed residentially to counties throughout the commuting region. The model accounts for separation and retirement from project employment and replacement by a new labor force. It also specifies the tendency of workers and their dependents to leave the region upon job separation.

In the following analysis, impacts are presented in terms of an expected level of impact as well as a maximum level of impact. The expected impact condition is based on the most likely value of model assumptions, whereas the maximum impact condition places an extreme but credible value on the model assumptions. The employment level for construction of the waste management facilities at the FRP is 1195 persons for the construction period from 1980 to 1984. The operating force from 1985 on is estimated at 275. Table 5.4.4-1 presents estimates of the cumulative project-related in-migrants for the facilities for the three reference sites over time. The forecasted values include primary and secondary employment and associated household dependents. Over time, some of the persons who separate from the facility will stay in the site county and some will leave. Those who stay are contained in the forecasted values until they leave the area. Thus, not all the forecasted populations are actually working on or directly associated with the project at each time period. Nevertheless, the presence of each of these persons was determined by the existence of the project, and they would not likely be present if the project had not occurred. The percentages associated with each population in these tables reflect the size of the in-migrant group relative to the baseline population in the respective sites. Since these baseline populations vary by site, the relative impact of a similar in-migrant group can vary greatly.

TABLE 5.4.4-1. Population Forecasts for Waste Management Facilities at the Reference FRP (persons)

Site	1980	1985	2000	2015
		Expected Impact Condition		
Southeast	192 (0.9%)	226 (1.0%)	264 (1.0%)	295 (1.0%)
Midwest	35 (0.1%)	436 (0.6%)	510 (0.6%)	575 (0.6%)
Southwest	3654 (7.6%)	2382 (4.9%)	2859 (5.4%)	3106 (5.4%)
		Maximum Impact Condition		
Southeast	2615 (11.0%)	2152 (8.5%)	2572 (8.9%)	2794 (8.9%)
Midwest	781 (1.3%)	1330 (1.8%)	1576 (1.7%)	1777 (1.8%)
Southwest	552 (11.1%)	4039 (8.1%)	4564 (8.8%)	5261 (8.8%)

Note: Numbers in parentheses denote percentage of the population influx based on the baseline population.

The total number of forecasted new in-migrants in the Southeast and Midwest sites does not exceed 1% of site county populations in the construction (1980 to 1985) or operation (1985 to 2015) phases. In-migration at this level is not likely to produce significant impacts. The effect of the facility is substantially different in the Southwest site. The number of in-migrants during construction is over three times the level of primary employment demand (3654 versus 1195). As a percent of projected baseline population size, the potential for significant impacts is much greater in the Southwest. It is important to note that there is a sharp drop in the size of the in-migrant population over the transition from construction to operation. This decline in population influx of about one-third sets the stage for a boom/bust type of effect in the Southwest reference site.

The maximum impact condition for the FRP (Table 5.4.4-1) produces substantially larger in-migrant flows for each site compared with the expected condition. Maximum impacts associated with waste management at the FRP in the Southwest reference site are the largest obtained for the FRP. The transition from construction to operation produces the same relative decline as was found under expected conditions but at a higher absolute level. This is reflected in the larger relative (to baseline) impacts, for example, 11.1% versus 7.6% in the Southwest case.

The translation of forecasted project-related in-migration into socioeconomic impacts is complex and imprecise. Estimates of the level of demand that will be placed on the community to provide social services to the new workers and their families were made by applying a set of factors (Appendix C) to the project in-migration values. The product of these factors indicates how many units of each social service would be "expected" by the in-migrants. The severity or significance of these impacts is primarily related to the capacity of the site county to meet these expectations. The calculated level of likely and maximum social services at the three reference sites is given for the year 2000 in Table 5.4.4-2.

5.4.5 Environmental Effects of Decommissioning an FRP (DOE/ET-0028 Sec. 8.5)

Two decommissioning modes were considered in detail for the FRP – 1) protective storage for 30 years followed by dismantlement (passive safe storage) and 2) entombment (hardened safe storage).

For dismantlement, the FRP is placed in protective storage immediately after shutdown and dismantled after 30 years when radioactive decay has reduced radiation levels in the facility. This permits the decommissioning to be carried out with less occupational exposure and at less cost than immediate dismantling.

Entombment involves preparation of the facility to be left in place until all radioactive material has decayed to innocuous levels. All radioactive material in the facility is consolidated in areas of relatively high contamination. Permanent physical barriers are erected between the material and the environment. A surveillance and environmental monitoring program is established to ensure the continued protection of the public and environment from the radioactive material in the entombed structure.

The analysis presented here assumes that facility shutdown activities have been completed when decommissioning begins. Activities assumed to have been carried out to shut down the facility include product recovery flushes; processing of all inventories of high-level,

TABLE 5.4.4-2. Selected Social Service Demands Associated with Local In-Migration Caused by FRP Construction and Operation

	Year 2000					
	Expected Demand			Maximum Demand		
Selected Social Services	Southeast Site	Midwest Site	Southwest Site	Southeast Site	Midwest Site	Southwest Site
Health						
Physicians	0	1	3	2	2	5
Nurses	1	3	7	8	8	13
Dentists	0	0	1	1	1	2
Hospital beds	1	3	10	10	9	16
Nursing care beds	1	3	6	5	8	10
Education						
Teachers (K-12)	3	6	37	33	18	63
Classroom space, m^2 (9-12)	420	880	4480	3950	2290	7500
Sanitation, m^3/day						
Water treatment	150	290	1620	1460	890	2760
Liquid waste	100	190	1080	970	600	1840
Safety						
Firemen	0	0	2	2	1	3
Policemen	1	1	6	5	3	10
Recreation						
Neighborhood parks, ha	0	0	1	2	2	3
Government						
Administrative staff	0	1	3	2	1	4
Other social impacts						
Crimes (7 crime index)	12	22	167	119	68	284

intermediate-level and low-level liquid wastes through the waste solidification and immobilization facilities; removal of all product materials from the facility; removal of all inventories of solidified high-level waste and packaged cladding residue; processing, packaging, and removal of all other radioactive wastes generated during plant operation or shutdown activities; removal from the site of bulk quantities of process chemicals; and completion of preparations to close out special nuclear material accountability requirements.

5.4.5.1 Protective Storage Followed by Dismantlement (Passive Safe Storage - DOE/ET-0028 Sec. 8.5.2)

Some aspects of protective storage followed by dismantlement of the reference FRP may have an effect on the environment and natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effects of dismantling activities.

Resource Commitments. The reference FRP site consists of a 2400-ha plot with a 40-ha exclusion area containing the FRP. Protective storage for 30 years followed by dismantlement requires that the 2400-ha site be maintained throughout the protective storage period. When delayed dismantling is completed the site may be released for other uses at the discretion of the owner.

Water used during chemical decontamination is estimated to be 2×10^3 m^3. Other than chemical decontamination water requirements will be limited to sanitary needs. Sanitary requirements will be less than that for facility operation for which withdrawal of water for operational needs from the R River (average flow of 1×10^7 m^3/day) was judged to be insignificant with respect to other downstream uses.

Materials committed for protective storage and dismantlement of the reference FRP are:

Steel	1600 MT
Paper, wood, plastic	130 MT
Equipment (mostly steel)	500 MT

Energy resources committed to protective storage and dismantlement are:

Electricity	25,000 kWh

Manpower requirements for protective storage and dismantlement of the reference FRP amount to 350 man-yr.

Process Effluents. A total of 1.8×10^4 m^3 of water with low-level radioactive contamination will be released to the environment during protective storage operations when the fuel storage basin and solidified high-level waste canister storage basin are drained. Routine radioactive effluents released from drainage of basins, chemical decontamination solutions, and atmospheric releases of gases and particulates are summarized in Table 5.4.5-1.

TABLE 5.4.5-1. Radionuclides Released to Biosphere During Protective Storage and Dismantlement of the Reference FRP

	Amount Released, Ci/yr				
	To Atmosphere			To Water	
Radionuclide	Protective Storage (2 yr)	Interim Care (30 yr)	Dismantlement (2 yr)	Basin Contents Capacity, (1.8×10^4 m^3 in 1 yr)	Decontamination Solutions (1000 m^3 in 1 yr)
^{54}Mn				1.1×10^{-3}	
^{55}Fe				2.3×10^{-2}	
^{58}Co				6.6×10^{-3}	
^{60}Co				1.5×10^{-2}	
^{89}Sr				9.4×10^{-4}	
^{90}Sr	5.2×10^{-4}	2.4×10^{-4}	1.0×10^{-4}	1.9×10^{-3}	2.6×10^{-4}
^{106}Ru					5.5×10^{-5}
^{125}Sb	9.2×10^{-6}		1.8×10^{-6}		4.6×10^{-6}
^{126}Sn					3.3×10^{-9}
^{127m}Te				4.3×10^{-4}	
^{129m}Te				4.6×10^{-5}	
^{129}I	4.2×10^{-11}	4.2×10^{-11}	8.4×10^{-12}		2.1×10^{-11}
^{134}Cs	1.4×10^{-4}		2.8×10^{-5}	1.1×10^{-1}	7.1×10^{-5}
^{137}Cs	8.0×10^{-4}	4.0×10^{-4}	1.6×10^{-4}	1.1×10^{-1}	4.0×10^{-4}
^{144}Ce					5.5×10^{-5}
^{154}Eu					2.0×10^{-5}
^{238}Pu		4.8×10^{-8}			3.0×10^{-5}
^{239}Pu	2.2×10^{-9}	4.4×10^{-9}	8.8×10^{-10}		2.2×10^{-6}
^{240}Pu					4.4×10^{-6}
^{241}Pu					5.6×10^{-4}
^{244}Am					2.0×10^{-5}
^{244}Cm					2.6×10^{-5}

Approximately 1000 m^3 of water containing concentrated chemical decontamination solutions and low-level radioactive contamination will be released to the R River during the dismantlement phase of the protective storage with deferred dismantlement option. Decontamination solutions used may include corrosive acids, detergents, and high-pressure water or steam. Used solutions will be processed through the waste treatment facility prior to release.

During demolition and site restoration in the dismantlement mode, fugitive dust will be generated. Effluents from the operation of heavy equipment will be produced during the six months required for these phases of decommissioning. The quantities of these materials discharged to the atmosphere are given in Table 5.4.5-2.

TABLE 5.4.5-2. Effluents Released from Operation of Heavy Equipment During Demolition and Site Restoration (also see footnote Table 5.4.1-1)

Pollutant	Construction and Vehicle Travel to Site, MT/yr	Air Concentrations	Standards,[a] $\mu g/m^3$
Carbon monoxide	2400	6900 $\mu g/m^3$, construction; 15,000 $\mu g/m^3$, vehicle travel	40,000 (1 hr standard)
Hydrocarbons	260	2.2% of ambient	
Nitrogen oxides	250	3.2% of ambient	
Sulfur dioxide	12	7 $\mu g/m^3$	80
Particulates	420	30 $\mu g/m^3$ (off site)	75

a. Source: A. C. Stern, H. C. Wohlers, R. W. Boubel, and W. P. Lowery, Fundamentals of Air Pollution, Academic Press, New York, 1973.

Physical and Chemical Effects. The impact of emissions given in Table 5.4.5-2 on the ambient air quality were predicted using an established modeling procedure.[1] Results of that effort[2] indicate that the maximum concentration of particulates off the immediate construction site during demolition and site restoration is 30 $\mu g/m^3$. The maximum areal extent of this impact occurs about 3 km from the site boundary to the southeast where an increase in particulate concentration of 5 $\mu g/m^3$ is predicted.

During the time when the reference FRP is being placed in protective storage, no noticeable effects on air quality are expected. The primary source of effluents during these periods will be from traffic, which is expected to be less than traffic present during normal plant operations and substantially less than that present during facility construction.

During the protective storage phase of decommissioning, about 25 m^3 of combustible materials will be generated after the waste treatment facilities have been shut down. In addition, about 20 m^3 of combustible waste may be generated during the 30-year protective storage period. These are low-level non-transuranic wastes and are not within the scope of this analysis.

Radiological Effects. Doses to individuals in the vicinity of the reference FRP during decommissioning were calculated based on the releases of radionuclides listed in Table 5.4.5-1; exposure pathways, demography, and other parameters described for the reference environment in

Appendix A; and mathematical models relating dose to man from radionuclide releases (Appendix B). Exposure pathways to man will exist for effluents released to the environment via air and water.

The annual doses to individuals whose habits tend to maximize their dose ("maximum individual") are shown in Table 5.4.5-3. For perspective, the dose to an individual from naturally occurring radioactive sources averages about 0.1 rem/yr.

TABLE 5.4.5-3. Annual Doses to the Maximum Individual Received During Protective Storage and Dismantlement of the Reference FRP (rem)

Pathway	Total Body	Thyroid (child)[a]	Thyroid[b]	Lung	Bone
		Protective Storage			
Air submersion	2.6×10^{-12}	2.6×10^{-12}	2.6×10^{-12}	2.6×10^{-12}	2.6×10^{-12}
External	1.2×10^{-6}		1.2×10^{-6}	1.2×10^{-6}	1.2×10^{-6}
Inhalation	4.9×10^{-10}		1.8×10^{-15}	5.5×10^{-8}	1.9×10^{-9}
Ingestion	8.2×10^{-5}	5.1×10^{-16}	2.0×10^{-9}	1.1×10^{-5}	5.5×10^{-5}
Subtotal	8.3×10^{-5}	5.1×10^{-16}	1.2×10^{-6}	1.2×10^{-5}	5.6×10^{-5}
		Dismantlement			
Air submersion	7.9×10^{-13}	7.9×10^{-13}	7.9×10^{-13}	7.9×10^{-13}	7.9×10^{-13}
External					
Inhalation	2.1×10^{-10}		8.4×10^{-16}	2.5×10^{-8}	7.8×10^{-10}
Ingestion	1.9×10^{-8}	5.1×10^{-16}	1.5×10^{-13}	2.6×10^{-9}	2.4×10^{-8}
Subtotal	1.9×10^{-8}	5.1×10^{-16}	1.2×10^{-13}	1.2×10^{-8}	5.6×10^{-8}
Total dose	8.3×10^{-5}	7.9×10^{-13}	1.2×10^{-6}	1.2×10^{-5}	5.6×10^{-5}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the highest annual average dispersion factor ($\bar{\chi}/Q'$) of 1.5×10^{-8} sec/m^3.

a. Thyroid dose is calculated for a 1-year-old child breathing air containing radioactive effluents and consuming 1 ℓ of milk per day from cows grazing 7 months/yr at the site boundary. Inhalation dose is <2% of total dose.

b. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

The combined dose to the population living within an 80-km radius of the plant was calculated using the projected year 2000 population data given in the reference environment (Appendix A). Table 5.4.5-4 summarizes the annual doses received by this population. The annual total-body population dose from naturally occurring sources to the approximately 2 million persons living within an 80-km radius of the plant in the year 2000 would be about 200,000 man-rem compared with a value of about 12 man-rem received from decommissioning sources.

TABLE 5.4.5-4. Annual Doses to the Population (within 80 km) Received During Protective Storage and Dismantlement of the Reference FRP (man-rem)

Pathway	Total Body	Thyroid[a]	Lung	Bone
		Protective Storage		
Air submersion	6.1×10^{-7}	6.1×10^{-7}	6.1×10^{-7}	6.1×10^{-7}
External	4.9×10^{-2}	4.9×10^{-2}	4.9×10^{-2}	4.9×10^{-2}
Inhalation	1.2×10^{-4}	4.2×10^{-10}	1.3×10^{-2}	4.4×10^{-4}
Ingestion	1.2×10^{1}	8.7×10^{-4}	1.5	7.8
Subtotal	1.2×10^{1}	5.0×10^{-2}	1.5	7.8
		Dismantlement		
Air submersion	1.9×10^{-7}	1.9×10^{-7}	1.9×10^{-7}	1.9×10^{-7}
Inhalation	5.0×10^{-5}	2.0×10^{-10}	5.8×10^{-3}	1.8×10^{-4}
Ingestion	3.4×10^{-3}	1.3×10^{-8}	5.1×10^{-4}	3.9×10^{-3}
Subtotal	3.5×10^{-3}	1.3×10^{-8}	6.3×10^{-3}	4.1×10^{-3}
Total dose	1.2×10^{1}	5.0×10^{-2}	1.5	7.8

a. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

The annual total-body dose to the work force associated with protective storage and dismantlement was estimated based on permissible exposure limits and experience of decommissioning plants. The annual occupational dose was calculated to be 300 man-rem. Table 5.4.5-5 summarizes the annual total-body dose to the work force and the general population from decommissioning and naturally occurring sources in the year 2000.

TABLE 5.4.5-5. Summary of Annual Total-Body Doses Received During Protective Storage and Dismantlement of the Reference FRP and from Naturally Occurring Sources

	Dose, man-rem
Reference FRP	
Decommissioning force	300
Population (within 80 km)	12
Naturally occurring sources	
Population (within 80 km)	200,000

The 70-year doses to the maximum individual and to the population within 80 km of the facility are given in Tables 5.4.5-6 and 5.4.5-7 respectively. A summary of the 70-year total-body doses to the work force and the population is given in Table 5.4.5-8.

In this report, 100 to 800 health effects are postulated to occur in the exposed population per million man-rem. Based on this frequency and the dose estimates in Table 5.4.5-8, no health effects would be expected to arise from decommissioning an FRP.

TABLE 5.4.5-6. 70-Year Doses to the Maximum Individual Received During Protective Storage and Dismantlement of the Reference FRP (rem)

Pathway	Total Body	Thyroid[a]	Lung	Bone
Air submersion	3.4×10^{-12}	3.4×10^{-12}	3.4×10^{-12}	3.4×10^{-12}
External	1.2×10^{-6}	1.2×10^{-6}	1.2×10^{-6}	1.2×10^{-6}
Inhalation	8.2×10^{-9}	2.8×10^{-15}	1.8×10^{-8}	3.4×10^{-8}
Ingestion	2.0×10^{-4}	3.8×10^{-9}	1.3×10^{-5}	9.2×10^{-5}
Total	2.0×10^{-4}	1.2×10^{-6}	1.4×10^{-5}	9.3×10^{-5}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 1.5×10^{-8} sec/m^3.

a. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

TABLE 5.4.5-7. 70-Year Doses to the Population (within 80 km) Received During Protective Storage and Dismantlement of the Reference FRP (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
Air submersion	8.0×10^{-7}	8.0×10^{-7}	8.0×10^{-7}	8.0×10^{-7}
External	5.0×10^{-2}	5.0×10^{-2}	5.0×10^{-2}	5.0×10^{-2}
Inhalation	1.9×10^{-3}	6.5×10^{-10}	4.1×10^{-3}	8.1×10^{-3}
Ingestion	1.1×10^{2}	3.4×10^{-3}	1.5×10^{1}	1.0×10^{2}
Total	1.1×10^{2}	5.3×10^{-2}	1.5×10^{1}	1.0×10^{2}

TABLE 5.4.5-8. Summary of 70-Year Total-Body Doses Received During Protective Storage and Dismantlement of the Reference FRP and from Naturally Occurring Sources

	Dose, man-rem
Reference FRP	
Decommissioning force	10,000
Population (within 80 km)	110
Naturally occurring sources	
Population (within 80 km)	14,000,000

Environmental Monitoring. During the 34-year period of protective storage and dismantlement, an environmental monitoring program will be maintained for the reference FRP. This environmental program will contain most of the characteristics of the program in force during plant operation. However, because of decreased potential for releases of radioactive material, the significant change will be the withdrawal of distant sampling points in favor of sampling points closer to the facility. There will be no significant reduction in the number of samples collected during these periods.

Ecological Effects. No adverse impacts are expected from the protective storage and dismantling mode of decommissioning the reference FRP. Chemicals used during decontamination that are potentially harmful to terrestrial plants and animals will be processed through the waste treatment facility. Approximately 1000 m^3 of these wastes will be treated and released to the R River. In addition, 18,000 m^3 of basin water will be treated and released.

The water requirements for decommissioning the FRP although not quantified is expected to be much less than that required during facility operation for which no significant impacts were predicted.

Nonradiological Accidents. The number of injuries and fatalities associated with nonradiological decommissioning accidents were calculated using an injury rate of 13.6 per million man-hours and a fatality rate of 0.17 per million man-hours (construction rates). For a total of 1.8 million man-hr worked, 25 injuries and no fatalities would be expected.

Radiological Accidents. Quantities of radioactive materials contained in facilities to be decommissioned will be several orders of magnitude less than those present during operation of the facility. The potential for significant releases of radioactive material to the biosphere during decommissioning would be small when compared with similar accidents occurring during operation of the facility. Therefore, no accident scenarios are included for facility decommissioning operations.

Accident scenarios associated with transportation of non-high-level transuranic wastes generated by decommissioning activities are included in Section 7.3.2.

5.4.5.2 Entombment (Hardened Safe Storage - DOE/ET-0028 Sec. 8.5.3)

Some aspects of entombing an FRP may have an effect on the environment and natural resources of the surrounding area. The information that follows is provided to form a basis for evaluating the effects of entombment.

Resource Commitments. The reference FRP site consists of a 2400-ha plot with a 40-ha exclusion area containing the FRP. Entombment requires that the 40-ha exclusion area of the facility site be occupied indefinitely by the entombed facility. The remaining portion of the 2400-ha site can be released for alternative uses at the discretion of the facility owner. Activities at the site may be restricted to ensure the continued integrity of the entombment structure.

Water used during entombment will be limited primarily to sanitary needs and will be less than that required for facility operation. Withdrawal of sanitary water from the R River (average flow of 1×10^7 m^3/day) is judged to be insignificant with respect to other downstream uses.

Materials committed for entombment of the reference FRP are:

Steel (shipping containers)	10 MT
Paper, wood, plastic	50 MT
Equipment (mostly steel)	100 MT

Energy resources committed to entombment are limited to 1×10^4 kWh of electricity.

Manpower requirements for entombment are 150 man-yr plus 0.3 man-yr/yr for interim care after entombment is complete. Estimated manpower for final decommissioning of the FRP at the end of the continuing care period is 160 man-yr.

Process Effluents. Approximately 1000 m^3 of water containing concentrated chemical decontamination solutions and low-level radioactive contamination will be released. Decontamination solutions used may include corrosive acids, detergents, and high-pressure water or steam. Used solutions will be processed through the waste treatment facility, which is the last facility to be shut down.

A total of 1.8×10^4 m^3 of water with low-level radioactive contamination will be released to the environment when the fuel storage basin and solidified high-level waste canister storage basin are drained. Routine radioactive effluents from drainage of basins, chemical decontamination solutions, and atmospheric releases of gases and particulates are summarized in Table 5.4.5-9.

TABLE 5.4.5-9. Radionuclides Released to Biosphere During Entombment of the Reference FRP

	Amount Released, Ci/yr		
	To Atmosphere	To Water	
Radionuclide	Entombment (2 yr)	Basin Contents (1.8×10^4 m^3 in 1 yr)	Decontamination Solutions (1000 m^3 in 1 yr)
^{54}Mn		1.1×10^{-3}	
^{55}Fe		2.3×10^{-2}	
^{58}Co		6.6×10^{-3}	
^{60}Co		1.5×10^{-2}	
^{89}Sr		9.4×10^{-4}	
^{90}Sr	1.0×10^{-4}	1.9×10^{-3}	2.6×10^{-4}
^{106}Ru			5.5×10^{-5}
^{125}Sb	1.8×10^{-6}		4.6×10^{-6}
^{126}Sn			3.3×10^{-9}
^{127m}Te		4.3×10^{-4}	
^{129m}Te		4.6×10^{-5}	
^{129}I	8.4×10^{-12}		2.1×10^{-11}
^{134}Cs	2.8×10^{-5}	1.1×10^{-1}	7.1×10^{-5}
^{137}Cs	1.6×10^{-4}	1.1×10^{-1}	4.0×10^{-4}
^{144}Ce			5.5×10^{-5}
^{154}Eu			2.0×10^{-5}
^{238}Pu			3.0×10^{-5}
^{239}Pu	8.8×10^{-10}		2.2×10^{-6}
^{240}Pu			4.4×10^{-6}
^{241}Pu			5.6×10^{-4}
^{241}Am			2.0×10^{-5}
^{244}Cm			2.6×10^{-5}

Physical and Chemical Effects. While the reference FRP is being entombed no noticeable effects to air quality are expected. The primary source of effluents during these periods will be from traffic, which is expected to be less than the traffic during normal plant operations.

Radioactive Wastes. If the entombment mode is chosen for decommissioning, 520 m^3 of wastes including 330 m^3 of transuranic wastes will be generated during the latter stages of the operation. Transuranic wastes generated after waste treatment facilities are shut down will be sent to an offsite waste treatment facility where they will be immobilized, packaged, and sent to the reference disposal site.

Radiological Effects. Doses to individuals in the vicinity of the reference FRP during entombment were calculated based on the releases of radionuclides listed in Table 5.4.5-9; exposure pathways, demography, and other parameters described for the reference environment in Appendix A; and mathematical models relating dose to man from radionuclide releases (Appendix B). Exposure pathways to man will exist for effluents released to the environment via air and water.

The annual doses to individuals whose habits tend to maximize their dose ("maximum individual") are shown in Table 5.4.5-10. For perspective, the dose to an individual from naturally occurring radioactive sources averages about 0.1 rem/yr.

TABLE 5.4.5-10. Annual Doses to the Maximum Individual from Entombment Operations of the Reference FRP (rem)

Pathway	Total Body	Thyroid (child)[a]	Thyroid[b]	Lung	Bone
Air submersion	5.2×10^{-13}	5.2×10^{-13}	5.2×10^{-13}	5.2×10^{-13}	5.2×10^{-13}
External	1.2×10^{-6}		1.2×10^{-6}	1.2×10^{-6}	1.2×10^{-6}
Inhalation	9.9×10^{-11}		3.6×10^{-16}	1.1×10^{-8}	3.8×10^{-10}
Ingestion	8.2×10^{-5}	1.0×10^{-16}	3.0×10^{-14}	1.3×10^{-9}	1.1×10^{-8}
Total	8.3×10^{-5}	5.2×10^{-13}	1.2×10^{-6}	1.2×10^{-6}	1.2×10^{-6}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the highest annual average dispersion factor ($\bar{\chi}/Q'$) of 1.5×10^{-8} sec/m^3.

a. Thyroid dose is calculated for a 1-year-old child breathing air containing radioactive effluents and consuming 1 ℓ of milk per day from cows grazing 7 months/yr at the site boundary. Inhalation dose is <2% of total dose.

b. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

The combined dose to the population living within an 80-km radius of the plant was calculated using the projected year 2000 population data given in the reference environment (Appendix A). Table 5.4.5-11 summarizes the annual doses received by this population. The annual total-body population dose from naturally occurring sources to the approximately 2 million persons living within an 80-km radius of the plant in the year 2000 would be about 200,000 man-rem compared with about 12 man-rem received from decommissioning sources.

TABLE 5.4.5-11. Annual Doses to the Population (within 80 km) from Entombment Operations at the Reference FRP (man-rem)

Pathway	Total Body	Thyroid[a]	Lung	Bone
Air submersion	1.2×10^{-7}	1.2×10^{-7}	1.2×10^{-7}	1.2×10^{-7}
External	4.9×10^{-2}	4.9×10^{-2}	4.9×10^{-2}	4.9×10^{-2}
Inhalation	2.3×10^{-5}	8.4×10^{-11}	2.6×10^{-3}	8.9×10^{-5}
Ingestion	1.2×10^{1}	8.7×10^{-4}	1.5	7.8
Total	1.2×10^{1}	5.0×10^{-2}	1.5	7.8

a. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

The annual total-body dose to the work force associated with decommissioning was estimated based on permissible exposure limits and experience of decommissioning plants. The annual occupational dose was calculated to be 80 man-rem for entombment. Table 5.4.5-12 summarizes the annual total-body dose to the work force and the general public from decommissioning and naturally occurring sources in the year 2000.

TABLE 5.4.5-12. Summary of Annual Total-Body Doses Received from Entombment Operations of the Reference FRP and from Naturally Occurring Sources

	Dose, man-rem
Reference FRP	
Decommissioning force	80
Population (within 80 km)	12
Naturally occurring sources	
Population (within 80 km)	200,000

The 70-year doses to the maximum individual and to the population within 80 km of the facility are given in Tables 5.4.5-13 and 5.4.5-14 respectively. A summary of the 70-year total-body doses to the work force and the population is given in Table 5.4.5-15.

TABLE 5.4.5-13. 70-Year Doses to the Maximum Individual from Entombment Operations of the Reference FRP (rem)

Pathway	Total Body	Thyroid[a]	Lung	Bone
Air submersion	5.2×10^{-13}	5.2×10^{-13}	5.2×10^{-13}	5.2×10^{-13}
External	1.2×10^{-6}	1.2×10^{-6}	1.2×10^{-6}	1.2×10^{-6}
Inhalation	1.1×10^{-9}	3.7×10^{-16}	2.6×10^{-9}	4.8×10^{-9}
Ingestion	2.0×10^{-4}	3.8×10^{-9}	1.3×10^{-5}	9.2×10^{-5}
Total	2.0×10^{-4}	4.2×10^{-6}	1.4×10^{-5}	9.3×10^{-5}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the highest annual average dispersion factor ($\overline{\chi}/Q'$) of 1.5×10^{-8} sec/m^3.

a. Thyroid dose is calculated for the adult inhalation pathway and consumption of 72 kg/yr of green leafy vegetables (growing season, 4 months/yr).

TABLE 5.4.5-14. 70-Year Doses to the Population (within 80 km) from Entombment Operations of the Reference FRP (man-rem)

Pathway	Total Body	Thyroid	Lung	Bone
Air submersion	1.2×10^{-7}	1.2×10^{-7}	1.2×10^{-7}	1.2×10^{-7}
External	5.0×10^{-2}	5.0×10^{-2}	5.0×10^{-2}	5.0×10^{-2}
Inhalation	2.0×10^{-4}	8.7×10^{-11}	6.0×10^{-4}	1.1×10^{-3}
Ingestion	1.1×10^{2}	3.4×10^{-3}	1.5×10^{1}	1.0×10^{2}
Total	1.1×10^{2}	5.3×10^{-2}	1.5×10^{1}	1.0×10^{2}

TABLE 5.4.5-15. Summary of 70-Year Total-Body Doses Received from Entombment Operations of the Reference FRP and from Naturally Occurring Sources

	Dose, man-rem
Reference FRP	
Decommissioning force	80
Population (within 80 km)	110
Naturally occurring sources	
Population (within 80 km)	14,000,000

In general doses at the individual process level are too small for a meaningful discussion of health effects. In this report, 100 to 800 health effects are postulated to occur in the exposed population per million man-rem.

Environmental Monitoring. During interim care after entombment an environmental monitoring program will be maintained for the reference FRP. This environmental program will contain most of the characteristics of the program in force during plant operation. The significant change will be the withdrawal of distant sampling points to points closer to the facility because of the decreased potential for significant environmental releases. There will be no significant reduction in the number of samples collected during the first few years. Although the environmental monitoring program is initially planned to be continued indefinitely, reduction in the sampling program can be accomplished as evidence of confinement of radioactive material is gathered.

Ecological Effects. No adverse impacts are expected from entombment of the reference FRP. Chemicals used during decontamination that are potentially harmful to terrestrial plants and animals will be processed through the waste treatment facility. Approximately 1000 m^3 of these wastes will be treated and released to the R River. In addition 18,000 m^3 of basin water will be treated and released.

The water required for decommissioning is much less than that needed for facility operation. Its withdrawal from the R River is judged to be insignificant with respect to other downstream uses and no effects are expected on aquatic ecosystems.

Nonradiological Accidents. The number of injuries and fatalities associated with nonradiological decommissioning accidents were calculated using an injury rate of 13.6 per million

man-hours and a fatality rate of 0.17 per million man-hours (construction rates). For a total of 1.3 million man-hours worked, 18 injuries and no fatalities would be expected.

Radiological Accidents. Quantities of radioactive materials contained in facilities to be decommissioned will be several orders of magnitude less than those present during operation of the facility. The potential for significant releases of radioactive material to the biosphere during decommissioning would be small when compared with similar accidents that could occur during operation of the facility. Therefore, no accident scenarios are included for facility decommissioning operations.

Accident scenarios associated with transportation of non-high-level transuranic wastes generated by decommissioning activities are included in Section 7.3.2.

5.4.5.3 Comparison of Environmental Effects Between Alternatives for Decommissioning the Reference FRP

Two modes of decommissioning the reference FRP have been considered: 1) protective storage with 30-year delayed dismantlement (Passive Safe Storage) and 2) entombment (Hardened Safe Storage). The dismantlement mode will result in total removal of the facility from the reference site 34 years after shutdown. The entombment mode will involve entombing contaminated equipment and structures onsite within existing structures. The 40-ha exclusion area that contains these structures is maintained under surveillance indefinitely. Selected aspects of decommissioning alternatives are presented in Tables 5.4.5-16 through 5.4.5-18.

TABLE 5.4.5-16. Resources Committed for Alternative Decommissioning Modes for the Reference FRP

Resource	Protective Storage with 30-Year Delayed Dismantlement (Passive Safe Storage)	Entombment (Hardened Safe Storage)
Land,[a] ha	0	40
Materials, MT		
Steel shipping containers	1,600	10
Paper, wood, plastic	130	50
Equipment (mostly steel)	500	100
Energy		
Electricity, kWh	25,000	10,000
Manpower, man-yr	350	150

a. Land commitment at FRP site after completion of decommissioning.
b. Plus 0.3 man-yr/yr for interim care up to period of 1000 years.

TABLE 5.4.5-17. Radionuclides Released to the Biosphere During Decommissioning of the Reference FRP

	Amount Released, Ci					
	To Atmosphere				To Water	
					Protective Storage or Entombment	
Radionuclide	Protective Storage (2 yr)	Interim Care (30 yr)	Dismantlement (2 yr)	Entombment (2 yr)	Basin Contents (1.8×10^4 m^3 in 1 yr)	Decontamination Solutions (1000 m^3 in 1 yr)
^{54}Mn					1.1×10^{-3}	
^{55}Fe					2.3×10^{-2}	
^{58}Co					6.6×10^{-3}	
^{60}Co					1.5×10^{-2}	
^{89}Sr					9.4×10^{-4}	
^{90}Sr	5.2×10^{-4}	2.4×10^{-4}	1.0×10^{-4}	1.0×10^{-4}	1.9×10^{-3}	2.6×10^{-4}
^{106}Ru						5.5×10^{-5}
^{125}Sb	9.2×10^{-6}		1.8×10^{-6}	1.8×10^{-6}		4.6×10^{-6}
^{126}Sn						3.3×10^{-9}
^{127m}Te					4.3×10^{-4}	
^{129m}Te					4.6×10^{-5}	
^{129}I	4.2×10^{-11}	4.2×10^{-11}	8.4×10^{-12}	8.4×10^{-12}		2.1×10^{-11}
^{134}Cs	1.4×10^{-4}		2.8×10^{-5}	2.8×10^{-5}	1.1×10^{-1}	7.1×10^{-5}
^{137}Cs	8.0×10^{-4}	4.0×10^{-4}	1.6×10^{-4}	1.6×10^{-4}	1.1×10^{-1}	4.0×10^{-4}
^{144}Ce						5.5×10^{-5}
^{154}Eu						2.0×10^{-5}
^{238}Pu		4.8×10^{-8}				3.0×10^{-5}
^{239}Pu	2.2×10^{-9}	4.4×10^{-9}	8.8×10^{-10}	8.8×10^{-10}		2.2×10^{-6}
^{240}Pu						4.4×10^{-6}
^{241}Pu						5.6×10^{-4}
^{241}Am						2.0×10^{-5}
^{244}Cm						2.6×10^{-5}

In terms of resource commitments, other than land use, dismantlement will require ten times more resource material for decommissioning than will entombment and will also generate a factor of 10 more transuranic wastes that must be sent to the repository. Fuel requirements for transportation of transuranic wastes to the reference repository will be 14 times greater for protective storage and dismantlement vs entombment. Although physical, chemical, and thermal effects will be greater when dismantlement is used, the effects can be easily mitigated or are insignificant for either decommissioning mode.

Comparisons of the radiological aspects during decommissioning indicate that the maximum individual and population doses for facility decommissioning are similar for both modes. The maximum individual and population doses received from transportation of transuranic wastes will be a factor of 10 higher when dismantlement is chosen. In either case doses from decommissioning or transportation of transuranic wastes will be less than 1% of the dose received from naturally occurring sources.

TABLE 5.4.5-18. Comparison of Radiological Aspects of Alternative Decommissioning Modes for the Reference FRP

	Dismantlement	Entombment
Dose to Maximum Individual with 70-Year Residency, rem		
Total body	2.0×10^{-4}	2.0×10^{-4}
Thyroid	1.2×10^{-6}	1.2×10^{-6}
Lung	1.4×10^{-5}	1.4×10^{-5}
Bone	9.3×10^{-5}	9.3×10^{-5}
Dose to Maximum Individual from Non-High-Level Transuranic Waste Shipments, rem		
Total body	9.3×10^{-5}	7×10^{-6}
(Dose from naturally occurring sources for same period, 7 rem)		
Dose to Regional Population (2×10^6 persons) within 80-km Radius with 70-Year Residency, man-rem		
Total body	1.1×10^{2}	1.1×10^{2}
Thyroid	5.3×10^{-2}	5.3×10^{-2}
Lung	1.5×10^{1}	1.5×10^{1}
Bone	1.0×10^{2}	1.0×10^{2}
Dose to Regional Population From Non-High-Level Transuranic Waste Shipments, rem		
Total body	1.5	1×10^{-1}
(Dose from naturally occurring sources for the same period, $\sim 1.4 \times 10^7$ man-rem)		
Dose to Work Force, man-rem		
Decommissioning and waste transportation	1.4×10^{2}	1.1×10^{1}
Maximum Individual 70-Year Dose Commitment from a Moderate Accident, rem		
Total body	1.4×10^{-3}	1.4×10^{-3}

Note: There is no release of ^{3}H, ^{14}C, or ^{85}Kr, therefore there is no worldwide dose. Doses received from minor accidents are negligible for either option. No severe accidents were postulated for either option.

Accident scenarios for both modes of decommissioning were determined to be the same and to involve transportation of transuranic wastes. Minor accidents postulated would not result in any radioactive releases to the environment. One moderate accident was postulated involving the subjection of a waste container to severe impact and fire with the subsequent release of 10^{-15} of the contained transuranic wastes in the form of respirable particles. No severe accidents were postulated.

In summary, differences between the two decommissioning modes are due mostly to the quantities of waste shipped to distant repositories. Dismantlement requires the commitment of ten times more resources. Population dose from transportation of transuranic wastes generated will be a factor of 10 higher for dismantlement. No significant differences in terms of manpower, ecological effects, or radiation doses to the population within an 80-km radius of the facility exist between the two modes of decommissioning.

REFERENCES FOR SECTION 5.4.5

1. Compilation of Air Pollutant Emission Factors, AP 42, Environmental Protection Agency, Research Triangle Park, NC, April 1973.

2. Air Quality Impacts Due to Construction of LWR Waste Management Facilities, URS 7043-01-01, URS Company, San Mateo, CA, June 1977.

5.4.6 Summary of Adverse Effects

Environmental effects for a single reference FRP constructed and operated with reference waste management facilities are summarized in Sections 5.4.1 through 5.4.5. The adverse environmental effects of note are the one construction fatality, exposure of the work force to 14,000 man-rem of radiation, consumption of about 270,000 m^3 of diesel and gasoline, and consumption of about 1,400,000 MWh of electrical energy.

The release of combustion products will result from the use of fuels. About 3500 MT of nitrogen oxides and 3500 MT of sulfur oxides will be released during the 70 years. One 1000-MWe coal-fired plant would release about 1,700,000 MT of nitrogen oxides during the same period.

Although dose to the population is often included as an adverse impact, the calculated dose of 1100 man-rem over 70 years is insignificant (0.008%) when compared with the dose of 4,000,000 man-rem to the same population from naturally occurring sources during the same period.

5.5 ALTERNATIVE REPROCESSING OPTIONS FOR A FUEL REPROCESSING PLANT: ANALYSIS OF ENVIRONMENTAL EFFECTS OF WASTE MANAGEMENT

5.5 ALTERNATIVE REPROCESSING OPTIONS FOR A FUEL REPROCESSING PLANT: ANALYSIS OF ENVIRONMENTAL EFFECTS OF WASTE MANAGEMENT

Environmental effects related to radioactive waste management at the reference FRP for the uranium and plutonium recycle option are discussed in detail in previous sections. Doses for uranium-only recycle options where differences from uranium and plutonium recycle exist are also presented. This section summarizes the differences in environmental effects for the uranium-only recycle option with respect to the uranium and plutonium recycle options.

5.5.1 Uranium Recycle with Plutonium in Solidified High-Level Waste

Radioactive waste management at the FRP for uranium recycle with plutonium in solidified high-level waste does not differ significantly from uranium and plutonium recycle in terms of facility construction and operation. Although the 70-year dose to the maximum individual from reprocessing both plutonium and uranium as fuel is less than 2% of the dose attributable to naturally occurring sources during the same period, that dose is three times higher than for uranium recycle only. The increase with plutonium recycle is a function of the buildup of actinides in the fuel as it is recycled for the second and third times.

Doses resulting from postulated accidental releases occurring within waste management facilities also tend to be higher when plutonium is recycled as fuel. In general terms total-body and thyroid doses to the maximum individual are similar while lung and bone doses are as much as a factor of 3 higher. All dose calculations assume fuel mixtures as postulated to exist in the year 2000.

5.5.2 Uranium Recycle with Plutonium Stored as Plutonium Oxide

Radioactive waste management at the FRP where uranium is to be recycled and plutonium is to be stored as the oxide does not differ significantly from the uranium and plutonium recycle options except for the addition of a storage facility for plutonium oxide at the FRP. As in the case of uranium only recycle with plutonium in solidified high-level waste, doses that depend on the quantity of actinides present will be less in this option than for plutonium recycle. Since doses from planned operations are by themselves marginally significant, this reduction appears unimportant.

Storage of plutonium oxide necessitates the addition of an interim plutonium oxide storage facility as a part of waste management at the FRP. The facility will have a storage capacity of 32 MT of plutonium oxide and a handling capacity of 320 kg/day. Selected aspects of construction and operation of the storage facility are compared with other waste management facility requirements in Tables 5.5.2-1 and 5.5.2-2 respectively.

Construction of the interim plutonium oxide storage facility will increase the resource commitments for FRP waste management facilities by approximately 10%. Physical, chemical, and ecological effects of construction of the storage facility will be indistinguishable from those of the FRP. The facility will not require additional transportation, and there are no site-specific requirements beyond those identified for the FRP.

TABLE 5.5.2-1. Comparison of Resource Commitments for Construction of the Interim Plutonium Oxide Storage Facility and Other Reference FRP Waste Management Facilities

Resource	Interim Plutonium Oxide Storage Facility	Other Waste Management Facilities
Concrete, m^3	6.7×10^3	7.5×10^4
Steel, MT	2.0×10^3	1.5×10^4
Copper, MT	3.6×10^1	2.3×10^2
Zinc, MT	9	1.9×10^2
Aluminum, MT	9	6
Lumber, m^3	3.6×10^2	5.1×10^3
Propane, m^3	1.1×10^2	1.4×10^3
Diesel fuel, m^3	1.1×10^3	1.4×10^4
Gasoline, m^3	7.2×10^2	9.3×10^3
Electricity, kW	5.9×10^5	5.7×10^6
Manpower, man-hr	9.4×10^5	5.2×10^6

TABLE 5.5.2-2. Comparison of Selected Resource Commitments for Operation of the Interim Plutonium Storage Facility and Other Reference FRP Waste Management Facilities

Resource	Interim Plutonium Oxide Storage Facility	Other Waste Management Facilities
Process water, m^3	1.6×10^5	4.6×10^5
Steam, kg	2×10^6	7.4×10^6
Electricity, kWh	4.6×10^6	4.7×10^7
Manpower, man-hr	9.4×10^1	2.6×10^4

The commitment of resources for operation of the interim plutonium oxide storage facility will not be significant in terms of total FRP waste management requirements. For planned operation there will be no release of radioactive material to air, water, or ground and no planned releases of nonradioactive liquid or solid wastes.

Construction of the interim plutonium storage facility at the FRP results in the postulation of two additional severe accidents that could release radioactive material to the environment. In the first accident, Accident 5.5.5,[1] it is assumed that a breach in one storage container results in the release of 200 g of plutonium oxide to HEPA filters over a period of 30 min. In the second accident, Accident 5.5.6,[1] it is assumed that a criticality event equal to 10^{19} fissions occurs and the resulting fission products are released to the atmospheric protection system filters over a period of 15 min.

The 70-year dose commitments to the maximum individual for each accident are presented in Tables 5.5.2-3 and 5.5.2-4. Calculated doses for the criticality accident are about 0.01 of those calculated for accidents involving storage of high-level liquid waste and solidified high-level waste and are similar to severe accidents postulated for other facilities within

TABLE 5.5.2-3. 70-Year Dose Commitment to the Maximum Individual from a Plutonium Spill Accident in the Interim Plutonium Oxide Storage Facility (rem)

Pathway	Skin	Total Body	Thyroid	Lung	Bone
Air submersion	1.3×10^{-17}	8.0×10^{-18}	8.0×10^{-18}	8.0×10^{-18}	8.0×10^{-18}
Inhalation		1.6×10^{-10}		9.4×10^{-10}	3.2×10^{-9}
Total	1.3×10^{-17}	1.6×10^{-10}	8.0×10^{-18}	9.4×10^{-10}	3.2×10^{-9}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the time-integrated atmospheric dispersion coefficient (E/Q) of 1.5×10^{-8} sec/m^3.

TABLE 5.5.2-4. 70-Year Dose Commitment to the Maximum Individual from a Criticality Accident at the Interim Plutonium Oxide Storage Facility (rem)

Pathway	Skin	Total Body	Thyroid	Lung	Bone
Air submersion	7.5×10^{-2}	4.9×10^{-2}	4.9×10^{-2}	4.9×10^{-2}	4.9×10^{-2}
Inhalation		3.0×10^{-4}	1.0×10^{-1}	3.2×10^{-3}	9.9×10^{-5}
Total	7.5×10^{-2}	4.9×10^{-2}	1.5×10^{-1}	5.2×10^{-2}	4.9×10^{-2}

Note: The maximum individual is defined as a permanent resident at a location 2800 m southeast of the stack with the time-integrated atmospheric dispersion coefficient (E/Q) of 1.5×10^{-8} sec/m^3.

the FRP. Doses to bone and lung resulting from accidents postulated within the waste management facilities tend to be a factor of 3 higher for uranium and plutonium recycle than for uranium recycle only. Differences in these doses (calculated assuming fuel mixtures in the year 2000) are due to the quantities of actinides in the reprocessed fuels. Doses to the total body and thyroid are essentially the same for either recycle mode.

REFERENCE FOR SECTION 5.5.2

1. Technology for Commercial Radioactive Waste Management, DOE/ET-0028, Department of Energy, Washington, DC, in press.

ACRONYMS LIST

ACRONYMS LIST

A-E	architect-engineer
AAPG	American Association of Petroleum Geologists
ACVSF	air-cooled vault storage facility
AEC	Atomic Energy Commission
AECL	Atomic Energy of Canada, Limited
AFR	away from reactor (spent fuel storage)
AGNS	Allied General Nuclear Services
ALARA	as low as reasonably achievable
AMAD	aerodynamic median activity diameter
AP	activation product
API	American Petroleum Institute
APS	atmospheric protection system
BFRSS	Barnwell Fuel Receiving and Storage Station
BIF	bitumen immobilization facility
BPPF	Barnwell Plutonium Product Facility
BTU	British thermal unit
BWR	boiling water reactor
CANDU	Canadian heavy water reactor
CDC	canister decontamination cell (cubicle)
CFR	Code of Federal Regulations
CIF	cement immobilization facility
CRWM	Committee on Radioactive Waste Management
CUP	cask unloading pool
CVCS	chemical and volume control system
CW	canistered waste
CWMS	Generic Environmental Impact Statement on Commercial Radioactive Waste Management, DOE-1559
CWTF	cask weld test facility
DCSF	dry caisson storage facility
DF	decontamination factor
DOE	Department of Energy
DOG	dissolver off-gas
DOP	dioctyphthalate
DOT	Department of Transportation
DTPA	diethylenetriamine pentaacetic acid
ECWS	essential cooling water system
EPC	engineering, procurement, and construction
ER	environmental report
ERDA	Energy Research and Development Administration
ESFS	engineered safety features systems
ESPS	essential spray pond system
FFTF	Fast Flux Test Facility
FP	fission product
FPF	fuel packaging facility
FRP	fuel reprocessing plant
FRPF	fuel residue packaging facility
FRSSF	fuel residue subsurface storage facility
FRVSF	fuel residue vault storage facility
FRW	fuel residue waste
FSA	fuel storage area
FSAR	Final Safety Analysis Report
FSB	fuel storage basin
FTF	fuel transfer facility
FTP	fuel transfer platform
GEIS	Generic Environmental Impact Statement
HCF	hulls compaction facility
HEPA	high-efficiency particulate air (filter)
HEU	highly enriched uranium
HLLW	high-level liquid waste
HLW	high-level waste
HM	heavy metal
HMA	hot maintenance area
HMF	hulls melting facility
HPF	hulls packaging facility
HTD	hulls transfer device
HTGR	high temperature gas-cooled reactor
HVAC	heating, ventilation, and air conditioning
IAEA	International Atomic Energy Agency
IBC	in-bed combustion
ICPP	Idaho Chemical Processing Plant
IFSF	independent fuel storage facility
IIPSF	independent interim plutonium oxide storage facility

ILLW	intermediate-level liquid waste
ILW	intermediate-level waste
INEL	Idaho National Engineering Laboratory
IPSF	interim plutonium oxide storage facility
ISFS	independent spent fuel storage
ISFSB	independent spent fuel storage basin
ISFSF	independent spent fuel storage facility
LAA	limited access area
LEU	low-enriched uranium
LHD	load-haul-dump
LLW	low-level waste
LN_2	liquid nitrogen
LSA	low specific activity
LWBR	light water breeder reactor
LWR	light water reactor
M&M	men and materials
MFBM	thousand board feet measure
MFRP	General Electric Company's Midwest Fuel Reprocessing Plant
MOX FFP	mixed oxide fuel fabrication plant
MP	mine production
MSRE	molten salt reactor
MTHM	metric ton heavy metal
NAA	normal access area
NAC	Nuclear Assurance Corporation
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NFS	Nuclear Fuel Services
NHLSW	non-high-level solid waste
NLI	National Lead Industries
NRC	Nuclear Regulatory Commission
NSSS	nuclear steam supply system
NWTS	National Waste Terminal Storage
ORIGEN	a computer program to calculate isotopic composition of irradiated nuclear fuel
ORNL	Oak Ridge National Laboratory
ONWI	Office of Nuclear Waste Isolation
OWI	Office of Waste Isolation
P-T	partioning and transmutation
PCWS	plant cooling water system
PFRF	packaged fuel receiving facility
PNL	Pacific Northwest Laboratory
POG	process off-gas
PSAR	preliminary safety analysis report
PWR	pressurized water reactor
R&D	research and development
RAA	restricted access area
RBOF	receiving basin for offsite fuel, Savannah River Plant
RCS	reactor coolant system
SCRA	storage cask receiving area
SCSF	surface cask storage facility
SF	spent fuel
SFPF	spent fuel packaging facility
SFRSS	spent fuel receiving and storage station
SFSF	spent fuel storage facility
SHLW	solidified high-level waste
SNM	special nuclear material, i.e., enriched uranium and plutonium
SRP	Savannah River Plant
SSC	sealed storage cask
SSCF	sealed storage cask facility
TBP	tributyl phosphate
TD	theoretical density
TN	Transnuclear Inc.
TRU	transuranic
TSA	transuranic storage area
TWCA	Teledyne Wahchang Albany
U-F	urea-formaldehyde
VE	ventilation exhaust
VOG	vessel off-gas
WBS	water basin storage
WBSF	water basin storage facility
WBSF-PF	water basin storage facility for packaged fuel
WCC	waste calcination cell (cubicle)
WCF	waste calcination facility
WIPP	Waste Isolation Pilot Plant
WTEB	waste tank equipment building
WVC	waste vitrification cell
WVF	waste vitrification facility

MEASUREMENT UNITS AND CONVERSIONS

MEASUREMENT UNITS AND CONVERSIONS

This report preferentially uses the metric system of measurements as defined by the International System of Units (SI). Common English units are often also included in parentheses. Prefixes used with the metric units are defined as follows:

Prefix	Abbreviation	Factor
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}

The following lists identify the symbols used in this report and the factors for converting between the SI and English units.

Symbols for metric units used in this report are:

Symbol	Name
°C[a]	degree Celsius
d[a]	day
g	gram
h (or hr)	hour
ha	hectare
kWh	Kilowatt-hour
J	joule
ℓ	liter
m	meter
min	minute
M	gram-mole/liter
MT	metric ton
MW-hr (or MWh)	megawatt-hour
s (or sec)	second
W	watt

a. Units which are not strictly SI but which are widely used.

Symbols for other units used in this report are:

Symbol	Name
atm	atmospheric pressure
BTU	British thermal unit
Ci	curie
°F	degree Fahrenheit
ft	feet
gal	gallon
in.	inch
lb	pound
MFBM	thousand board feet measure
psi	pounds/square inch
R	roentgen
rem	roentgen equivalent man
yd	yard
yr	year

To convert metric to English, multiply by:

Metric	English	Factor
°C	°F	(°C x 9/5) + 32
cm	inch	0.3937
ha	acre	2.47
kg	lb	2.205
km	mile	0.6214
ℓ	gal	0.2642
m	ft	3.281
m^2	ft^2	10.76
m^3	MFBM	0.424
m^3	ft^3	35.31
m^3	gal	264.2
m^3	yd^3	1.308
MT	ton	0.9070
W	BTU/hr	3.413
W-s/kg-°C	BTU/lb-°F	2.39×10^{-4}
W/m-°C	BTU/hr-ft-°F	0.576

To convert English to metric, multiply by:

English	Metric	Factor
acre	ha	0.405
BTU	W-hr	0.2931
BTU/lb-°F	W-s/kg-°C	4187
BTU/hr-ft-°F	W/m-°C	1.735
°F	°C	(°F-32) x 5/9
ft	m	0.3048
ft^2	m^2	0.0929
ft^3	m^3	0.0283
gal	ℓ	3.785
gal	m^3	3.785×10^{-3}
inches	cm	2.540
lb	kg	0.4536
mile	km	1.609
MFBM	m^3	2.360
ton	MT	1.103
yd^3	m^3	0.7646