APPENDIX I:

ENVIRONMENTAL IMPACTS OF OPTIONS FOR DISPOSAL OF OXIDE

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The following is a list of acronyms and abbreviations, including units of measure, used in this document. Some acronyms used only in tables are defined in those tables.

ACRONYMS AND ABBREVIATIONS

General

BEMR	*The 1996 Baseline Environmental Management Report*
CFR	*Code of Federal Regulations*
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
HEPA	high-efficiency particulate air (filter)
LCF	latent cancer fatality
LLMW	low-level mixed waste
LLNL	Lawrence Livermore National Laboratory
LLW	low-level radioactive waste
MCL	maximum contaminant level
MEI	maximally exposed individual
NEPA	*National Environmental Policy Act*
NRC	U.S. Nuclear Regulatory Commission
PEIS	programmatic environmental impact statement
PM_{10}	particulate matter with a mean diameter of 10 µm or less
Rf	retardation factor
WM PEIS	*Waste Management Programmatic Environmental Impact Statement for Managing Treatment, Storage, and Disposal of Radioactive and Hazardous Waste*

Chemicals

CO	carbon monoxide
HC	hydrocarbons
NO_x	nitrogen oxides
SO_x	sulfur oxides
UF_6	uranium hexafluoride
UO_2	uranium dioxide
$UO_3 \cdot H_2O$	schoepite (hydrous uranium oxide)
U_3O_8	triuranium octaoxide (uranyl uranate)

UNITS OF MEASURE

cm	centimeter(s)
d	day(s)
ft	foot (feet)
ft^3	cubic foot (feet)
g	gram(s)
gal	gallon(s)
gpm	gallon(s) per minute
ha	hectare(s)
in.	inch(es)
kg	kilogram(s)
km	kilometer(s)
km^2	square kilometer(s)
L	liter(s)
lb	pound(s)
µg	microgram(s)
µm	micrometer(s)
m	meter(s)
m^3	cubic meter(s)
mi^2	square mile(s)
min	minute(s)
mrem	millirem(s)
MWh	megawatt-hour(s)
pCi	picocurie(s)
ppm	part(s) per million
rad	radiation absorbed dose(s)
rem	roentgen equivalent man
s	second(s)
scf	standard cubic foot (feet)
ton(s)	short ton(s)
yd^3	cubic yard(s)
yr	year(s)

APPENDIX I:

ENVIRONMENTAL IMPACTS OF OPTIONS FOR DISPOSAL OF OXIDE

The U.S. Department of Energy (DOE) is proposing to develop a strategy for long-term management of the depleted uranium hexafluoride (UF_6) inventory currently stored at three DOE sites in Paducah, Kentucky; Portsmouth, Ohio; and Oak Ridge, Tennessee. This programmatic environmental impact statement (PEIS) describes alternative strategies that could be used for the long-term management of this material and analyzes the potential environmental consequences of implementing each strategy for the period 1999 through 2039. This appendix provides detailed information describing the disposal options considered in the PEIS. The discussion provides background information for these options, as well as a summary of the estimated environmental impacts associated with each option.

Disposal Options

Depleted uranium material would be disposed of as low-level radioactive waste. The disposal options assessed in the PEIS were defined on the basis of the chemical form of the uranium and the type of disposal facility. The following disposal options were considered:

Disposal as U_3O_8. Depleted uranium could be disposed of as U_3O_8, either ungrouted (bulk) or grouted U_3O_8, following conversion. The disposal facilities considered included shallow earthen structures, belowground vaults, and an underground mine.

Disposal as UO_2. Similar to U_3O_8, depleted uranium could be disposed of as UO_2 following conversion, either in ungrouted or grouted form. The disposal facilities considered were the same as those considered for U_3O_8: shallow earthen structures, belowground vaults, and an underground mine.

Disposal is defined as the emplacement of material in a manner designed to ensure its isolation for the foreseeable future. For the PEIS disposal options, depleted uranium was assumed to be disposed of belowground as low-level radioactive waste beginning in 2009. Compared with long-term storage, disposal is considered permanent, with no intent to retrieve the material for future use. In fact, considerable and deliberate effort would be required to regain access to the material following disposal. Low-level radioactive waste disposal in burial facilities has been practiced in the United States for over 50 years.

The disposal options considered in the PEIS are defined by the chemical form of the depleted uranium to be disposed of and by the type of disposal facility. Two chemical forms of uranium oxides were evaluated: triuranium octaoxide (U_3O_8) and uranium dioxide (UO_2). These forms were considered because of their chemical stability; UF_6 and uranium metal are not considered acceptable forms because they are chemically reactive (Lawrence Livermore National Laboratory [LLNL] 1997). Three types of disposal facilities were considered for each chemical form: (1) shallow earthen structures (engineered "trenches"), (2) vaults, and (3) an underground mine. The chemical forms and disposal options are summarized in Table I.1. Each type of disposal facility is described in Section I.2.

For each of the uranium oxides, two physical waste forms were considered in the PEIS, ungrouted and grouted. Ungrouted waste refers to U_3O_8 or UO_2 in the powder or pellet form produced during the conversion process. This bulk material would be disposed of in either 55-gal (208-L) drums for U_3O_8 or 30-gal (110-L) drums for UO_2. Grouted waste refers to the solid material obtained by mixing the uranium oxides with cement and repackaging it in drums. Grouting is intended to increase structural strength and stability of the waste, and reduce the leaching rate of the waste in water. However, because cement is added to the uranium oxide, grouting would increase the total volume requiring disposal. Grouting of waste was assumed to occur at the disposal facility.

In general, disposal facilities would be stand-alone, single-purpose facilities consisting of a central receiving building/warehouse (called the wasteform facility) and several disposal units. Depending on the option, the disposal units would be a series of shallow earthen structures, vaults, or underground mine tunnels (called drifts). Activities at the disposal facility would include receipt of containers of depleted uranium oxide by truck or railcar, inspection of the containers, grouting the material if necessary, and placement of the containers into the disposal units. The disposal unit would then be backfilled with soil, sand, gravel, or other material and covered with multiple layers of natural material (such as clay) designed to minimize infiltration of water for long periods of time. The disposal facilities would be designed to protect the waste from the environment and prevent potential releases of material to the environment. Following disposal of the last containers, the disposal facility would be closed and then monitored and maintained for a period of time consistent with regulatory and license requirements.

The potential environmental impacts from the disposal options were evaluated on the basis of information provided in the engineering analysis report (LLNL 1997). For each disposal option, the engineering analysis report provides preconceptual facility design data, including descriptions of facility layouts, resource requirements, estimates of effluents, wastes, and emissions, and

TABLE I.1 Summary of Depleted Uranium Chemical Forms and Disposal Options Considered

	Disposal Option Considered		
Physical/ Chemical Form	Shallow Earthen Structure	Vault	Mine
Grouted U_3O_8	Yes	Yes	Yes
Ungrouted U_3O_8	Yes	Yes	Yes
Grouted UO_2	Yes	Yes	Yes
Ungrouted UO_2	Yes	Yes	Yes

descriptions of potential accident scenarios. This report also contains additional discussion of issues related to low-level radioactive waste (LLW) disposal and discusses the results of previous assessments of the long-term impacts of uranium disposal.

The potential environmental impacts from disposal would differ from those for the other options considered in the PEIS. Whereas the impacts from the other options would generally occur during the operational period of the facilities considered (40 years or less), the impacts from disposal might occur hundreds to thousands of years after the facility had ceased operating. Thus, disposal impacts were estimated for two phases: (1) the operational phase, which includes construction of the facility and the period in which waste would be actively placed into disposal units, and (2) the post-closure phase, which considers hundreds of years in the future, beyond the time that any engineered disposal facilities would be expected to function as designed. The environmental impacts for the operational phase are presented in Section I.3, and those for the post-closure phase are presented in Section I.4.

Potential impacts during the operational phase, which would include construction activities and the handling of waste containers as they were placed into disposal units, would primarily affect workers. In addition, some potential impacts to the public would occur from air emissions during grouting of the waste. The potential impacts during the post-closure phase would affect only the public and would follow the eventual release of material from the disposal facility to the environment. For assessment purposes, all disposal facilities were assumed to fail, or release waste to the environment, at the end of an institutional control period (failure was assumed to occur around the year 2140, 100 years after site closure). Because of the infiltration of water, uranium would ultimately migrate through the soil, eventually contaminating the groundwater and potentially exposing members of the public. Post-closure impacts were estimated at 1,000 years after the disposal facilities were assumed to fail.

The potential environmental impacts from the disposal options were not determined on a site-specific basis because the location of a disposal facility would not be decided until sometime in the future. Instead, for assessment purposes, two generic environmental settings were defined, a generic dry setting and a generic wet setting. The conditions of the dry setting would be typical of a site in the arid western United States, and the conditions of the wet setting would be typical of a site in the eastern United States.

The estimated impacts associated with the disposal options are subject to a great deal of uncertainty, especially for the post-closure period. The degree of uncertainty in the disposal impacts is greater than that for the other categories of options in the PEIS, because disposal impacts consider an extremely long period of time and depend on predicting the behavior of the waste material as it interacts with soil and water in a complex and changing environment. Consequently, the estimated disposal impacts are very dependent on the assumptions made for the assessment, including such key factors as soil characteristics, water infiltration rates, depth to underlying groundwater table, chemistry of different uranium compounds, and locations of future human receptors. These factors could vary widely depending on site-specific conditions. Therefore, a range of these factors was selected for analysis to represent the range of actual conditions that could occur.

I.1 SUMMARY OF DISPOSAL OPTION IMPACTS

This section provides a summary of the potential environmental impacts associated with the disposal of depleted uranium oxides in shallow earthen structures, vaults, and a mine during two distinct phases: (1) the operational phase and (2) the post-closure phase. Analysis of the operational phase included facility construction and the time during which waste would be actively placed in disposal units (2009 through 2028). Analysis of the post-closure phase considered potential impacts 1,000 years after the disposal units fail (i.e., release uranium material to the environment). For each phase, impacts were estimated for both generic wet and dry environmental settings. Additional discussion and details related to the assessment methodologies and results for each area of impact are provided in Section I.3 for the operational phase and Section I.4 for the post-closure phase.

For the operational phase, the potential environmental impacts for disposal of U_3O_8 and UO_2 are summarized in Tables I.2 and I.3, respectively. Within each table, the potential impacts are presented first for the grouted form and then for the ungrouted form. The following is a general summary of potential environmental impacts during the operational phase:

- ***Potential Adverse Impacts.*** Potential adverse impacts during the operational phase would be small and generally similar for all options. Minor to moderate impacts would occur during construction activities, although these impacts would be temporary and easily mitigated by common engineering and construction practices. Impacts during waste emplacement activities also would be small and limited to involved and noninvolved workers.

- ***Wet or Dry Environmental Setting.*** In general, potential impacts would be similar for generic wet and dry environmental settings during the operational phase.

- ***U_3O_8 or UO_2.*** The potential disposal impacts tend to be slightly larger for U_3O_8 than for UO_2 because the volume of U_3O_8 would be greater and most environmental impacts tend to be proportional to the volume.

- ***Grouted or Ungrouted Waste.*** For both U_3O_8 and UO_2, the disposal of grouted waste would result in larger impacts than disposal of ungrouted waste during the operational phase for two reasons: (1) grouting increases the volume of waste requiring disposal (by about 50%) and (2) grouting operations result in small emissions of uranium material to the air and water.

TABLE I.2 Summary of Disposal Option Impacts for U_3O_8 during the Operational Phase[a]

A. Grouted

Impacts from Disposal as Grouted U_3O_8 in Shallow Earthen Structures	Impacts from Disposal as Grouted U_3O_8 in Vaults	Impacts from Disposal as Grouted U_3O_8 in a Mine
Human Health – Normal Operations: Radiological		
Involved Workers:	**Involved Workers:**	**Involved Workers:**
Total collective dose: 480 person-rem	Total collective dose: 520 person-rem	Total collective dose: 720 person-rem
Total number of LCFs: 0.2 LCF	Total number of LCFs: 0.2 LCF	Total number of LCFs: 0.3 LCF
Noninvolved Workers:	**Noninvolved Workers:**	**Noninvolved Workers:**
Annual dose to MEI : 0.0021 – 0.0088 mrem/yr	Annual dose to MEI : 0.0021 – 0.0088 mrem/yr	Annual dose to MEI : 0.00084 – 0.0085 mrem/yr
Annual cancer risk to MEI: 8×10^{-10} – 4×10^{-9} per year	Annual cancer risk to MEI: 8×10^{-10} – 4×10^{-9} per year	Annual cancer risk to MEI: 3×10^{-10} – 3×10^{-9} per year
Total collective dose: 0.00054 – 0.0035 person-rem	Total collective dose: 0.00059 – 0.0038 person-rem	Total collective dose: 0.00057 – 0.0036 person-rem
Total number of LCFs: 2×10^{-7} – 1×10^{-6} LCF	Total number of LCFs: 2×10^{-7} – 2×10^{-6} LCF	Total number of LCFs: 2×10^{-7} – 1×10^{-6} LCF
General Public:	**General Public:**	**General Public:**
Annual dose to MEI: 0.0061 – 0.026 mrem/yr	Annual dose to MEI: 0.0060 – 0.020 mrem/yr	Annual dose to MEI: 0.0061 – 0.026 mrem/yr
Annual cancer risk to MEI: 3×10^{-9} – 1×10^{-8} per year	Annual cancer risk to MEI: 3×10^{-9} – 1×10^{-8} per year	Annual cancer risk to MEI: 3×10^{-9} – 1×10^{-8} per year
Total collective dose to population within 50 miles: 0.037 – 0.11 person-rem	Total collective dose to population within 50 miles: 0.037 – 0.11 person-rem	Total collective dose to population within 50 miles: 0.037 – 0.11 person-rem
Total number of LCFs in population within 50 miles: 2×10^{-5} – 6×10^{-5} LCF	Total number of LCFs in population within 50 miles: 2×10^{-5} – 6×10^{-5} LCF	Total number of LCFs in population within 50 miles: 2×10^{-5} – 6×10^{-5} LCF
Human Health – Normal Operations: Chemical		
Noninvolved Workers: No impacts	**Noninvolved Workers:** No impacts	**Noninvolved Workers:** No impacts
General Public: No impacts	**General Public:** No impacts	**General Public:** No impacts

TABLE I.2 (Cont.)

Impacts from Disposal as Grouted U_3O_8 in Shallow Earthen Structures	Impacts from Disposal as Grouted U_3O_8 in Vaults	Impacts from Disposal as Grouted U_3O_8 in a Mine
Human Health – Accidents: Radiological		
Bounding accident frequency: 1 in 100 years to 1 in 10,000 years	Bounding accident frequency: 1 in 100 years to 1 in 10,000 years	Bounding accident frequency: 1 in 100 years to 1 in 10,000 years
Noninvolved Workers: Bounding accident consequences (per occurrence):	**Noninvolved Workers:** Bounding accident consequences (per occurrence):	**Noninvolved Workers:** Bounding accident consequences (per occurrence):
Dose to MEI: 140 rem	Dose to MEI: 140 rem	Dose to MEI: 140 rem
Risk of LCF to MEI: 0.06	Risk of LCF to MEI: 0.06	Risk of LCF to MEI: 0.06
Collective dose: 6.1 person-rem	Collective dose: 6.1 person-rem	Collective dose: 6.1 person-rem
Number of LCFs: 0.002	Number of LCFs: 0.002	Number of LCFs: 0.002
General Public: Bounding accident consequences (per occurrence):	**General Public:** Bounding accident consequences (per occurrence):	**General Public:** Bounding accident consequences (per occurrence):
Dose to MEI: 1.1 rem	Dose to MEI: 1.1 rem	Dose to MEI: 1.1 rem
Risk of LCF to MEI: 5×10^{-4}	Risk of LCF to MEI: 5×10^{-4}	Risk of LCF to MEI: 5×10^{-4}
Collective dose to population within 50 miles: 1.5 person-rem	Collective dose to population within 50 miles: 1.5 person-rem	Collective dose to population within 50 miles: 1.5 person-rem
Number of LCFs in population within 50 miles: 0.0007 LCF	Number of LCFs in population within 50 miles: 0.0007 LCF	Number of LCFs in population within 50 miles: 0.0007 LCF
Human Health – Accidents: Chemical		
Bounding accident frequency: 1 in 100 years to 1 in 10,000 years	Bounding accident frequency: 1 in 100 years to 1 in 10,000 years	Bounding accident frequency: 1 in 100 years to 1 in 10,000 years
Noninvolved Workers: Bounding accident consequences (per occurrence):	**Noninvolved Workers:** Bounding accident consequences (per occurrence):	**Noninvolved Workers:** Bounding accident consequences (per occurrence):
Number of persons with potential for adverse effects: 1 person	Number of persons with potential for adverse effects: 1 person	Number of persons with potential for adverse effects: 1 person
Number of persons with potential for irreversible adverse effects: 1 person	Number of persons with potential for irreversible adverse effects: 1 person	Number of persons with potential for irreversible adverse effects: 1 person
General Public: Bounding accident consequences (per occurrence):	**General Public:** Bounding accident consequences (per occurrence):	**General Public:** Bounding accident consequences (per occurrence):
Number of persons with potential for adverse effects: 0 persons	Number of persons with potential for adverse effects: 0 persons	Number of persons with potential for adverse effects: 0 persons
Number of persons with potential for irreversible adverse effects: 0 persons	Number of persons with potential for irreversible adverse effects: 0 persons	Number of persons with potential for irreversible adverse effects: 0 persons

TABLE I.2 (Cont.)

Impacts from Disposal as Grouted U_3O_8 in Shallow Earthen Structures	Impacts from Disposal as Grouted U_3O_8 in Vaults	Impacts from Disposal as Grouted U_3O_8 in a Mine
	Human Health — Accidents: Physical Hazards	
Construction and Operations: **All Workers:** Less than 1 (0.26) fatality, approximately 210 injuries	**Construction and Operations:** **All Workers:** Less than 1 (0.44) fatality, approximately 300 injuries	**Construction and Operations:** **All Workers** Approximately 1 fatality, approximately 450 injuries
	Air Quality	
Construction: Annual NO_x concentration potentially as large as 3% of standard; other criteria pollutant concentrations between 0.2 and 2% of respective standards	**Construction:** Annual NO_x concentration potentially as large as 13% of standard; other criteria pollutant concentration between 0.3 and 4% of respective standards	**Construction:** All pollutant concentrations below 0.1% of respective standards
Operations: Annual NO_x concentration potentially as large as 7% of standard; other criteria pollutant concentrations between 0.3 and 3% of respective standards	**Operations:** Annual NO_x concentration potentially as large as 37% of standard; other criteria pollutant concentrations between 0.8 and 10% of respective standards	**Operations:** All pollutant concentrations below 0.02% of respective standards
	***Water*[b]**	
Construction: Negligible impacts to surface water and groundwater	**Construction:** Negligible impacts to surface water and groundwater	**Construction:** Negligible impacts to surface water and groundwater
Operations: None to negligible impacts to surface water and groundwater	**Operations:** None to negligible impacts to surface water and groundwater	**Operations:** None to negligible impacts to surface water and groundwater
	***Soil*[b]**	
Construction: Negligible, but temporary, impacts	**Construction:** Moderate to large, but temporary, impacts	**Construction:** Moderate to large, but temporary, impacts
Operations: No impacts	**Operations:** No impacts	**Operations:** No impacts
	Socioeconomics	
Construction: Potential moderate impacts on employment and income	**Construction:** Potential moderate impacts on employment and income	**Construction:** Potential moderate impacts on employment and income
Operations: Potential moderate impacts on employment and income	**Operations:** Potential moderate impacts on employment and income	**Operations:** Potential moderate impacts on employment and income

TABLE I.2 (Cont.)

Impacts from Disposal as Grouted U_3O_8 in Shallow Earthen Structures	Impacts from Disposal as Grouted U_3O_8 in Vaults	Impacts from Disposal as Grouted U_3O_8 in a Mine
	Ecology	
Construction: Potential moderate impacts to vegetation and wildlife	**Construction:** Potential large impacts to vegetation and wildlife	**Construction:** Potential large impacts to vegetation and wildlife
Operations: Potential adverse impacts to aquatic biota	**Operations:** Potential adverse impacts to aquatic biota	**Operations:** Potential adverse impacts to aquatic biota
	Waste Management	
Negligible to low impacts on national waste management operations	Negligible to low impacts on national waste management operations	Negligible to low impacts on national waste management operations
	Resource Requirements	
No impacts from resource requirements (such as electricity or materials) on the local or national scale are expected	No impacts from resource requirements (such as electricity or materials) on the local or national scale are expected	No impacts from resource requirements on the local or national scale are expected; impacts of electrical requirements for mine excavation depend on site location
	Land Use	
Use of approximately 85 acres; potential moderate impacts	Use of approximately 149 acres; potential moderate impacts	Use of approximately 471 acres; potential large impacts, including impacts from disposal of excavated material and potential off-site traffic impacts during construction

B. Ungrouted

Impacts from Disposal as Ungrouted U_3O_8 in Shallow Earthen Structures	Impacts from Disposal as Ungrouted U_3O_8 in Vaults	Impacts from Disposal as Ungrouted U_3O_8 in a Mine
	Human Health – Normal Operations: Radiological	
Involved Workers: Total collective dose: 280 person-rem	**Involved Workers:** Total collective dose: 300 person-rem	**Involved Workers:** Total collective dose: 360 person-rem
Total number of LCFs: 0.1 LCF	Total number of LCFs: 0.1 LCF	Total number of LCFs: 0.1 LCF
Noninvolved Workers: No impacts	**Noninvolved Workers:** No impacts	**Noninvolved Workers:** No impacts
General Public: No impacts	**General Public:** No impacts	**General Public:** No impacts
	Human Health – Normal Operations: Chemical	
Noninvolved Workers: No impacts	**Noninvolved Workers:** No impacts	**Noninvolved Workers:** No impacts
General Public: No impacts	**General Public:** No impacts	**General Public:** No impacts

TABLE I.2 (Cont.)

Impacts from Disposal as Ungrouted U_3O_8 in Shallow Earthen Structures	Impacts from Disposal as Ungrouted U_3O_8 in Vaults	Impacts from Disposal as Ungrouted U_3O_8 in a Mine
	Human Health – Accidents: Radiological	
Bounding accident frequency: 1 in 100 years to 1 in 10,000 years	Bounding accident frequency: 1 in 100 years to 1 in 10,000 years	Bounding accident frequency: 1 in 100 years to 1 in 10,000 years
Noninvolved Workers: Bounding accident consequences (per occurrence):	**Noninvolved Workers:** Bounding accident consequences (per occurrence):	**Noninvolved Workers:** Bounding accident consequences (per occurrence):
Dose to MEI: 130 rem	Dose to MEI: 130 rem	Dose to MEI: 130 rem
Risk of LCF to MEI: 0.05	Risk of LCF to MEI: 0.05	Risk of LCF to MEI: 0.05
Collective dose: 5.6 person-rem	Collective dose: 5.6 person-rem	Collective dose: 5.6 person-rem
Number of LCFs: 0.002	Number of LCFs: 0.002	Number of LCFs: 0.002
General Public: Bounding accident consequences (per occurrence):	**General Public:** Bounding accident consequences (per occurrence):	**General Public:** Bounding accident consequences (per occurrence):
Dose to MEI: 1 rem	Dose to MEI: 1 rem	Dose to MEI: 1 rem
Risk of LCF to MEI: 5×10^{-4}	Risk of LCF to MEI: 5×10^{-4}	Risk of LCF to MEI: 5×10^{-4}
Collective dose to population within 50 miles: 1.3 person-rem	Collective dose to population within 50 miles: 1.3 person-rem	Collective dose to population within 50 miles: 1.3 person-rem
Number of LCFs in population within 50 miles: 0.0007 LCF	Number of LCFs in population within 50 miles: 0.0007 LCF	Number of LCFs in population within 50 miles: 0.0007 LCF
	Human Health – Accidents: Chemical	
Bounding accident frequency: 1 in 100 years to 1 in 10,000 years	Bounding accident frequency: 1 in 100 years to 1 in 10,000 years	Bounding accident frequency: 1 in 100 years to 1 in 10,000 years
Noninvolved Workers: Bounding accident consequences (per occurrence):	**Noninvolved Workers:** Bounding accident consequences (per occurrence):	**Noninvolved Workers:** Bounding accident consequences (per occurrence):
Number of persons with potential for adverse effects: 1 person	Number of persons with potential for adverse effects: 1 person	Number of persons with potential for adverse effects: 1 person
Number of persons with potential for irreversible adverse effects: 1 person	Number of persons with potential for irreversible adverse effects: 1 person	Number of persons with potential for irreversible adverse effects: 1 person
General Public: Bounding accident consequences (per occurrence):	**General Public:** Bounding accident consequences (per occurrence):	**General Public:** Bounding accident consequences (per occurrence):
Number of persons with potential for adverse effects: 0 persons	Number of persons with potential for adverse effects: 0 persons	Number of persons with potential for adverse effects: 0 persons
Number of persons with potential for irreversible adverse effects: 0 persons	Number of persons with potential for irreversible adverse effects: 0 persons	Number of persons with potential for irreversible adverse effects: 0 persons

TABLE I.2 (Cont.)

Impacts from Disposal as Ungrouted U_3O_8 in Shallow Earthen Structures	Impacts from Disposal as Ungrouted U_3O_8 in Vaults	Impacts from Disposal as Ungrouted U_3O_8 in a Mine
	Human Health — Accidents: Physical Hazards	
Construction and Operations: **All Workers:** Less than 1 (0.13) fatality, approximately 90 injuries	**Construction and Operations:** **All Workers:** Less than 1 (0.22) fatality, approximately 140 injuries	**Construction and Operations:** **All Workers:** Less than 1 (0.53) fatality, approximately 240 injuries
	Air Quality	
Construction: Annual NO_x concentration potentially as large as 1.3% of standard; all other criteria pollutant concentrations between 0.07 and 0.6% of respective standards	**Construction:** Annual NO_x concentration potentially as large as 3.5% of standard; all other criteria pollutant concentrations between 0.1 and 1% of respective standards	**Construction:** All pollutant concentrations below 0.1% of respective standards
Operations: Annual NO_x concentration potentially as large as 2.3% of standard; all other criteria pollutant concentrations between 0.1 and 1% of respective standards	**Operations:** Annual NO_x concentration potentially as large as 10% of standard; all other criteria pollutant concentrations between 0.3 and 3% of respective standards	**Operations:** All pollutant concentrations below 0.02% of respective standards
	Water[b]	
Construction: Negligible impacts to surface water and groundwater	**Construction:** Negligible impacts to surface water and groundwater	**Construction:** Negligible impacts to surface water and groundwater
Operations: None to negligible impacts to surface water and groundwater	**Operations:** None to negligible impacts to surface water and groundwater	**Operations:** None to negligible impacts to surface water and groundwater
	Soil[b]	
Construction: Negligible, but temporary, impacts	**Construction:** Moderate to large, but temporary, impacts	**Construction:** Moderate to large, but temporary, impacts
Operations: No impacts	**Operations:** No impacts	**Operations:** No impacts
	Socioeconomics	
Construction: Potential moderate impacts on employment and income	**Construction:** Potential moderate impacts on employment and income	**Construction:** Potential moderate impacts on employment and income
Operations: Potential moderate impacts on employment and income	**Operations:** Potential moderate impacts on employment and income	**Operations:** Potential moderate impacts on employment and income

TABLE I.2 (Cont.)

Impacts from Disposal as Ungrouted U_3O_8 in Shallow Earthen Structures	Impacts from Disposal as Ungrouted U_3O_8 in Vaults	Impacts from Disposal as Ungrouted U_3O_8 in a Mine
	Ecology	
Construction: Potential moderate impacts to vegetation and wildlife	**Construction:** Potential moderate impacts to vegetation and wildlife	**Construction:** Potential large impacts to vegetation and wildlife
Operations: Negligible impacts	**Operations:** Negligible impacts	**Operations:** Negligible impacts
	Waste Management	
Negligible to low impacts on national waste management operations	Negligible to low impacts on national waste management operations	Negligible to low impacts on national waste management operations
	Resource Requirements	
No impacts from resource requirements (such as electricity or materials) on the local or national scale are expected	No impacts from resource requirements (such as electricity or materials) on the local or national scale are expected	No impacts from resource requirements on the local or national scale are expected; impacts of electrical requirements for mine excavation depend on site location
	Land Use	
Use of approximately 46 acres; negligible impacts	Use of approximately 75 acres; potential moderate impacts	Use of approximately 232 acres; potential large impacts, including impacts from disposal of excavated material and potential off-site traffic impacts during construction

[a] Impacts presented in the table are for a generic wet setting (typical of the eastern United States). Potential impacts during the operational phase would be similar for a generic dry setting (typical of the western United States).

[b] Impacts are based on a site that would be large compared to the area of the facility, with a nearby river having a minimum flow that would be large compared to water use and discharge requirements.

Notation: LCF = latent cancer fatality; MEI = maximally exposed individual; NO_x = nitrogen oxides; ROI = region of influence.

TABLE I.3 Summary of Disposal Option Impacts for UO_2 during the Operational Phase[a]

A. Grouted

Impacts from Disposal as Grouted UO_2 in Shallow Earthen Structures	Impacts from Disposal as Grouted UO_2 in Vaults	Impacts from Disposal as Grouted UO_2 in a Mine
Human Health – Normal Operations: Radiological		
Involved Workers:	**Involved Workers:**	**Involved Workers:**
Total collective dose: 420 person-rem	Total collective dose: 440 person-rem	Total collective dose: 480 person-rem
Total number of LCFs: 0.2 LCF	Total number of LCFs: 0.2 LCF	Total number of LCFs: 0.2 LCF
Noninvolved Workers:	**Noninvolved Workers:**	**Noninvolved Workers:**
Annual dose to MEI : 0.0032 – 0.017 mrem/yr	Annual dose to MEI : 0.0037 – 0.017 mrem/yr	Annual dose to MEI : 0.0016 – 0.016 mrem/yr
Annual cancer risk to MEI: $1 \times 10^{-9} – 7 \times 10^{-9}$ per year	Annual cancer risk to MEI: $1 \times 10^{-9} – 7 \times 10^{-9}$ per year	Annual cancer risk to MEI: $6 \times 10^{-10} – 6 \times 10^{-9}$ per year
Total collective dose: 0.00055 – 0.0036 person-rem	Total collective dose: 0.00061 – 0.0040 person-rem	Total collective dose: 0.00055 – 0.0036 person-rem
Total number of LCFs: $2 \times 10^{-7} – 1 \times 10^{-6}$ LCF	Total number of LCFs: $2 \times 10^{-7} – 2 \times 10^{-6}$ LCF	Total number of LCFs: $2 \times 10^{-7} – 1 \times 10^{-6}$ LCF
General Public:	**General Public:**	**General Public:**
Annual dose to MEI: 0.012 – 0.050 mrem/yr	Annual dose to MEI: 0.012 – 0.050 mrem/yr	Annual dose to MEI: 0.012 – 0.050 mrem/yr
Annual cancer risk to MEI: $6 \times 10^{-9} – 2 \times 10^{-8}$ per year	Annual cancer risk to MEI: $6 \times 10^{-9} – 2 \times 10^{-8}$ per year	Annual cancer risk to MEI: $6 \times 10^{-9} – 2 \times 10^{-8}$ per year
Total collective dose to population within 50 miles: 0.071 – 0.21 person-rem	Total collective dose to population within 50 miles: 0.071 – 0.21 person-rem	Total collective dose to population within 50 miles: 0.071 – 0.21 person-rem
Total number of LCFs in population within 50 miles: $4 \times 10^{-5} – 1 \times 10^{-4}$ LCF	Total number of LCFs in population within 50 miles: $4 \times 10^{-5} – 1 \times 10^{-4}$ LCF	Total number of LCFs in population within 50 miles: $4 \times 10^{-5} – 1 \times 10^{-4}$ LCF
Human Health – Normal Operations: Chemical		
Noninvolved Workers: No impacts	**Noninvolved Workers:** No impacts	**Noninvolved Workers:** No impacts
General Public: No impacts	**General Public:** No impacts	**General Public:** No impacts

TABLE I.3 (Cont.)

Impacts from Disposal as Grouted UO_2 in Shallow Earthen Structures	Impacts from Disposal as Grouted UO_2 in Vaults	Impacts from Disposal as Grouted UO_2 in a Mine
	Human Health – Accidents: Radiological	
Bounding accident frequency: 1 in 100 years to 1 in 10,000 years	Bounding accident frequency: 1 in 100 years to 1 in 10,000 years	Bounding accident frequency: 1 in 100 years to 1 in 10,000 years
Noninvolved Workers: Bounding accident consequences (per occurrence):	**Noninvolved Workers:** Bounding accident consequences (per occurrence):	**Noninvolved Workers:** Bounding accident consequences (per occurrence):
Dose to MEI: 0.27 rem	Dose to MEI: 0.27 rem	Dose to MEI: 0.27 rem
Risk of LCF to MEI: 1×10^{-4}	Risk of LCF to MEI: 1×10^{-4}	Risk of LCF to MEI: 1×10^{-4}
Collective dose: 0.011 person-rem	Collective dose: 0.011 person-rem	Collective dose: 0.011 person-rem
Number of LCFs: 5×10^{-6}	Number of LCFs: 5×10^{-6}	Number of LCFs: 5×10^{-6}
General Public: Bounding accident consequences (per occurrence):	**General Public:** Bounding accident consequences (per occurrence):	**General Public:** Bounding accident consequences (per occurrence):
Dose to MEI: 0.0021 rem	Dose to MEI: 0.0021 rem	Dose to MEI: 0.0021 rem
Risk of LCF to MEI: 1×10^{-6}	Risk of LCF to MEI: 1×10^{-6}	Risk of LCF to MEI: 1×10^{-6}
Collective dose to population within 50 miles: 0.0027 person-rem	Collective dose to population within 50 miles: 0.0027 person-rem	Collective dose to population within 50 miles: 0.0027 person-rem
Number of LCFs in population within 50 miles: 1×10^{-6} LCF	Number of LCFs in population within 50 miles: 1×10^{-6} LCF	Number of LCFs in population within 50 miles: 1×10^{-6} LCF
	Human Health – Accidents: Chemical	
Bounding accident frequency: 1 in 100 years to 1 in 10,000 years	Bounding accident frequency: 1 in 100 years to 1 in 10,000 years	Bounding accident frequency: 1 in 100 years to 1 in 10,000 years
Noninvolved Workers: Bounding accident consequences (per occurrence):	**Noninvolved Workers:** Bounding accident consequences (per occurrence):	**Noninvolved Workers:** Bounding accident consequences (per occurrence):
Number of persons with potential for adverse effects: 0 persons	Number of persons with potential for adverse effects: 0 persons	Number of persons with potential for adverse effects: 0 persons
Number of persons with potential for irreversible adverse effects: 0 persons	Number of persons with potential for irreversible adverse effects: 0 persons	Number of persons with potential for irreversible adverse effects: 0 persons
General Public: Bounding accident consequences (per occurrence):	**General Public:** Bounding accident consequences (per occurrence):	**General Public:** Bounding accident consequences (per occurrence):
Number of persons with potential for adverse effects: 0 persons	Number of persons with potential for adverse effects: 0 persons	Number of persons with potential for adverse effects: 0 persons
Number of persons with potential for irreversible adverse effects: 0 persons	Number of persons with potential for irreversible adverse effects: 0 persons	Number of persons with potential for irreversible adverse effects: 0 persons

TABLE I.3 (Cont.)

Impacts from Disposal as Grouted UO_2 in Shallow Earthen Structures	Impacts from Disposal as Grouted UO_2 in Vaults	Impacts from Disposal as Grouted UO_2 in a Mine
	Human Health — Accidents: Physical Hazards	
Construction and Operations: **All Workers:** Less than 1 (0.23) fatality, approximately 180 injuries	**Construction and Operations:** **All Workers:** Less than 1 (0.26) fatality, approximately 190 injuries	**Construction and Operations:** **All Workers:** Less than 1 (0.50) fatality, approximately 280 injuries
	Air Quality	
Construction: Annual NO_x concentration potentially as large as 0.9% of standard; all other criteria pollutant concentrations between 0.05 and 0.6% of respective standards	**Construction:** Annual NO_x concentration potentially as large as 1% of standard; all other criteria pollutant concentrations between 0.04 and 0.4% of respective standards	**Construction:** All pollutant concentrations less than 10% of concentrations from shallow earthen structure construction
Operations: Annual NO_x concentration potentially as large as 1.8% of standard; all other criteria pollutant concentrations between 0.1 and 1.1% of respective standards	**Operations:** Annual NO_x concentration potentially as large as 5.6% of standard; all other criteria pollutant concentrations between 0.2 and 2% of respective standards	**Operations:** All pollutant concentrations about 10% of those from mine construction
	Water[b]	
Construction: Negligible impacts to surface water and groundwater	**Construction:** Negligible impacts to surface water and groundwater	**Construction:** Negligible impacts to surface water and groundwater
Operations: None to negligible impacts to surface water and groundwater	**Operations:** None to negligible impacts to surface water and groundwater	**Operations:** None to negligible impacts to surface water and groundwater
	Soil[b]	
Construction: Negligible, but temporary, impacts	**Construction:** Moderate to large, but temporary, impacts	**Construction:** Moderate to large, but temporary, impacts
Operations: No impacts	**Operations:** No impacts	**Operations:** No impacts
	Socioeconomics	
Construction: Potential moderate impacts on employment and income	**Construction:** Potential moderate impacts on employment and income	**Construction:** Potential moderate impacts on employment and income
Operations: Potential moderate impacts on employment and income	**Operations:** Potential moderate impacts on employment and income	**Operations:** Potential moderate impacts on employment and income

TABLE I.3 (Cont.)

Impacts from Disposal as Grouted UO_2 in Shallow Earthen Structures	Impacts from Disposal as Grouted UO_2 in Vaults	Impacts from Disposal as Grouted UO_2 in a Mine
	Ecology	
Construction: Potential moderate impacts to vegetation and wildlife	**Construction:** Potential moderate impacts to vegetation and wildlife	**Construction:** Potential large impacts to vegetation and wildlife
Operations: Potential adverse impacts to aquatic biota	**Operations:** Potential adverse impacts to aquatic biota	**Operations:** Potential adverse impacts to aquatic biota
	Waste Management	
Negligible to low impacts on national waste management operations	Negligible to low impacts on national waste management operations	Negligible to low impacts on national waste management operations
	Resource Requirements	
No impacts from resource requirements (such as electricity or materials) on the local or national scale are expected	No impacts from resource requirements (such as electricity or materials) on the local or national scale are expected	No impacts from resource requirements on the local or national scale are expected; impacts of electrical requirements for mine excavation depend on site location
	Land Use	
Use of approximately 39 acres; negligible impacts	Use of approximately 41 acres; negligible impacts	Use of approximately 149 acres; potential moderate impacts, including impacts from disposal of excavated material and potential off-site traffic impacts during construction

B. Ungrouted

Impacts from Disposal as Ungrouted UO_2 in Shallow Earthen Structures	Impacts from Disposal as Ungrouted UO_2 in Vaults	Impacts from Disposal as Ungrouted UO_2 in a Mine
	Human Health – Normal Operations: Radiological	
Involved Workers: Total collective dose: 170 person-rem	**Involved Workers:** Total collective dose: 220 person-rem	**Involved Workers:** Total collective dose: 240 person-rem
Total number of LCFs: 0.07 LCF	Total number of LCFs: 0.09 LCF	Total number of LCFs: 0.09 LCF
Noninvolved Workers: No impacts	**Noninvolved Workers:** No impacts	**Noninvolved Workers:** No impacts
General Public: No impacts	**General Public:** No impacts	**General Public:** No impacts
	Human Health – Normal Operations: Chemical	
Noninvolved Workers: No impacts	**Noninvolved Workers:** No impacts	**Noninvolved Workers:** No impacts
General Public: No impacts	**General Public:** No impacts	**General Public:** No impacts

TABLE I.3 (Cont.)

Impacts from Disposal as Ungrouted UO_2 in Shallow Earthen Structures	Impacts from Disposal as Ungrouted UO_2 in Vaults	Impacts from Disposal as Ungrouted UO_2 in a Mine
	Human Health – Accidents: Radiological	
Bounding accident frequency: 1 in 100 years to 1 in 100,000 years	Bounding accident frequency: 1 in 100 years to 1 in 100,000 years	Bounding accident frequency: 1 in 100 years to 1 in 100,000 years
Noninvolved Workers: Bounding accident consequences (per occurrence):	**Noninvolved Workers:** Bounding accident consequences (per occurrence):	**Noninvolved Workers:** Bounding accident consequences (per occurrence):
Dose to MEI: 0.22 rem	Dose to MEI: 0.22 rem	Dose to MEI: 0.22 rem
Risk of LCF to MEI: 9×10^{-5}	Risk of LCF to MEI: 9×10^{-5}	Risk of LCF to MEI: 9×10^{-5}
Collective dose: 12 person-rem	Collective dose: 12 person-rem	Collective dose: 12 person-rem
Number of LCFs: 0.005	Number of LCFs: 0.005	Number of LCFs: 0.005
General Public: Bounding accident consequences (per occurrence):	**General Public:** Bounding accident consequences (per occurrence):	**General Public:** Bounding accident consequences (per occurrence):
Dose to MEI: 0.0017 rem	Dose to MEI: 0.0017 rem	Dose to MEI: 0.0017 rem
Risk of LCF to MEI: 8×10^{-7}	Risk of LCF to MEI: 8×10^{-7}	Risk of LCF to MEI: 8×10^{-7}
Collective dose to population within 50 miles: 0.046 person-rem	Collective dose to population within 50 miles: 0.046 person-rem	Collective dose to population within 50 miles: 0.046 person-rem
Number of LCFs in population within 50 miles: 2×10^{-5} LCF	Number of LCFs in population within 50 miles: 2×10^{-5} LCF	Number of LCFs in population within 50 miles: 2×10^{-5} LCF
	Human Health – Accidents: Chemical	
Bounding accident frequency: 1 in 100 years to 1 in 100,000 years	Bounding accident frequency: 1 in 100 years to 1 in 100,000 years	Bounding accident frequency: 1 in 100 years to 1 in 100,000 years
Noninvolved Workers: Bounding accident consequences (per occurrence):	**Noninvolved Workers:** Bounding accident consequences (per occurrence):	**Noninvolved Workers:** Bounding accident consequences (per occurrence):
Number of persons with potential for adverse effects: 0 persons	Number of persons with potential for adverse effects: 0 persons	Number of persons with potential for adverse effects: 0 persons
Number of persons with potential for irreversible adverse effects: 0 persons	Number of persons with potential for irreversible adverse effects: 0 persons	Number of persons with potential for irreversible adverse effects: 0 persons
General Public: Bounding accident consequences (per occurrence):	**General Public:** Bounding accident consequences (per occurrence):	**General Public:** Bounding accident consequences (per occurrence):
Number of persons with potential for adverse effects: 0 persons	Number of persons with potential for adverse effects: 0 persons	Number of persons with potential for adverse effects: 0 persons
Number of persons with potential for irreversible adverse effects: 0 persons	Number of persons with potential for irreversible adverse effects: 0 persons	Number of persons with potential for irreversible adverse effects: 0 persons

TABLE I.3 (Cont.)

Impacts from Disposal as Ungrouted UO_2 in Shallow Earthen Structures	Impacts from Disposal as Ungrouted UO_2 in Vaults	Impacts from Disposal as Ungrouted UO_2 in a Mine
	Human Health — Accidents: Physical Hazards	
Construction and Operations: **All Workers:** Less than 1 (0.13) fatality, approximately 90 injuries	**Construction and Operations:** **All Workers:** Less than 1 (0.15) fatality, approximately 110 injuries	**Construction and Operations:** **All Workers:** Less than 1 (0.33) fatality, approximately 170 injuries
	Air Quality	
Construction: Annual NO_x concentration potentially as large as 0.6% of standard; all other criteria pollutant concentrations between 0.04 and 0.4% of respective standards	**Construction:** Annual NO_x concentration potentially as large as 0.6% of standard; all other criteria pollutant concentrations between 0.03 and 0.3% of respective standards	**Construction:** All pollutant concentrations less than 10% of concentration from shallow earthen structure construction
Operations: Annual NO_x concentration potentially as large as 1.3% of standard; all other criteria pollutant concentrations between 0.08 and 0.8% of respective standards	**Operations:** Annual NO_x concentration potentially as large as 3.3% of standard; all other criteria pollutant concentrations between 0.1 and 1.3% of respective standards	**Operations:** All pollutant concentrations about 10% of those from mine construction
	Water [b]	
Construction: Negligible impacts to surface water and groundwater	**Construction:** Negligible impacts to surface water and groundwater	**Construction:** Negligible impacts to surface water and groundwater
Operations: None to negligible impacts to surface water and groundwater	**Operations:** None to negligible impacts to surface water and groundwater	**Operations:** None to negligible impacts to surface water and groundwater
	Soil [b]	
Construction: Negligible, but temporary, impacts	**Construction:** Moderate to large, but temporary, impacts	**Construction:** Moderate to large, but temporary, impacts
Operations: No impacts	**Operations:** No impacts	**Operations:** No impacts
	Socioeconomics	
Potential moderate impacts on employment and income	Potential moderate impacts on employment and income	Potential moderate impacts on employment and income
	Ecology	
Construction: Potential moderate impacts to vegetation and wildlife	**Construction:** Potential moderate impacts to vegetation and wildlife	**Construction:** Potential large impacts to vegetation and wildlife
Operations: Negligible impacts	**Operations:** Negligible impacts	**Operations:** Negligible impacts

TABLE I.3 (Cont.)

Impacts from Disposal as Ungrouted UO_2 in Shallow Earthen Structures	Impacts from Disposal as Ungrouted UO_2 in Vaults	Impacts from Disposal as Ungrouted UO_2 in a Mine
	Waste Management	
Negligible to low impacts on national waste management operations	Negligible to low impacts on national waste management operations	Negligible to low impacts on national waste management operations
	Resource Requirements	
No impacts from resource requirements (such as electricity or materials) on the local or national scale are expected	No impacts from resource requirements (such as electricity or materials) on the local or national scale are expected	No impacts from resource requirements on the local or national scale are expected; impacts of electrical requirements for mine excavation depend on site location
	Land Use	
Use of approximately 28 acres; negligible impacts	Use of approximately 28 acres; negligible impacts	Use of approximately 102 acres; potential moderate impacts, including impacts from disposal of excavated material and potential off-site traffic impacts during construction

[a] Impacts presented in the table are for a generic wet setting (typical of the eastern United States). Potential impacts during the operational phase would be similar for a generic dry setting (typical of the western United States).

[b] Impacts are based on a site that would be large compared to the area of the facility, with a nearby river having a minimum flow that would be large compared to water use and discharge requirements.

Notation: LCF = latent cancer fatality; MEI = maximally exposed individual; NO_x = nitrogen oxides; ROI = region of influence.

- ***Shallow Earthen Structure, Vault, or Mine.*** The potential impacts are essentially similar for disposal in a shallow earthen structure, vault, or mine. However, disposal in a mine could create slightly larger potential impacts if excavation of the mine was required (use of an existing mine would minimize impacts).

For the post-closure phase, the potential environmental impacts for disposal of U_3O_8 and UO_2 are summarized in Tables I.4 and I.5, respectively. Impacts were calculated for a post-failure time of 1,000 years. The potential impacts estimated for the post-closure phase are subject to a great deal of uncertainty because of the extremely long time period considered and the dependence of predictions on the behavior of the waste material as it interacts with soil and water in a distant future environment. The post-closure impacts would depend greatly on the specific disposal facility design and site-specific characteristics. Because of these uncertainties, the assessment assumptions are generally selected to produce conservative estimates of impact, that is, they tend to overestimate the expected impact. Changes in key disposal assumptions could yield significantly different results (see Section I.4).

The following is presented as a general summary of potential environmental impacts during the post-closure phase (from information in Tables I.4 and I.5 and Section I.4):

- ***Potential Adverse Impacts.*** For all disposal options, potentially large impacts to human health and groundwater quality could occur within 1,000 years after failure of a facility in a wet setting, whereas essentially no impacts would occur for a dry setting in the same time frame. Potential impacts would result primarily from the contamination of groundwater. The maximum dose to an individual assumed to live at the edge of the disposal site and use the contaminated water was estimated to be about 110 mrem/yr, which would exceed the 25-mrem/yr limit specified in 10 *Code of Federal Regulations* [CFR] Part 61 and DOE Order 5820.2A. (For comparison, the average dose to an individual from background radiation is about 360 mrem/yr.) Possible exposures (on the order of 10 rem/yr) could occur for shallow earthen structures and vaults if the cover material were to erode and expose the uranium material; however, this would not occur until several thousand years later, and the exposure could be eliminated by adding new cover material to the top of the waste area.

- ***Wet or Dry Environmental Setting.*** The potential impacts would be significantly greater in a wet setting than a dry setting. Essentially no impacts would be expected in a dry setting for more than 1,000 years because of the low water infiltration rate and greater depth to the water table.

TABLE I.4 Summary of Disposal Option Impacts for U_3O_8 during the Post-Closure Phase[a,b]

A. Grouted

Impacts from Disposal as Grouted U_3O_8 in Shallow Earthen Structures	Impacts from Disposal as Grouted U_3O_8 in Vaults	Impacts from Disposal as Grouted U_3O_8 in a Mine
	Human Health: Radiological	
General Public:	**General Public:**	**General Public:**
Annual dose to MEI: 49 – 72 mrem/yr	Annual dose to MEI: 57 – 84 mrem/yr	Annual dose to MEI: 1 – 110 mrem/yr
Annual cancer risk to MEI: $2 \times 10^{-5} - 4 \times 10^{-5}$ per year	Annual cancer risk to MEI: $3 \times 10^{-5} - 4 \times 10^{-4}$ per year	Annual cancer risk to MEI: $4 \times 10^{-7} - 5 \times 10^{-5}$ per year
Collective dose to population within 50 miles: not determined	Collective dose to population within 50 miles: not determined	Collective dose to population within 50 miles: not determined
Number of LCFs in population within 50 miles: not determined	Number of LCFs in population within 50 miles: not determined	Number of LCFs in population within 50 miles: not determined
	Human Health: Chemical	
Potential impacts to MEI of the general public from groundwater	Potential impacts to MEI of the general public from groundwater	Potential impacts to MEI of the general public from groundwater
	Water	
Potential large impact to groundwater quality from uranium contamination	Potential large impact to groundwater quality from uranium contamination	Potential large impact to groundwater quality from uranium contamination
	Ecology	
Potential moderate impacts to wetlands and aquatic biota from surface water and groundwater contamination	Potential moderate impacts to wetlands and aquatic biota from surface water and groundwater contamination	Potential moderate impacts to wetlands and aquatic biota from surface water and groundwater contamination

B. Ungrouted

Impacts from Disposal as Ungrouted U_3O_8 in Shallow Earthen Structures	Impacts from Disposal as Ungrouted U_3O_8 in Vaults	Impacts from Disposal as Ungrouted U_3O_8 in a Mine
	Human Health: Radiological	
General Public:	**General Public:**	**General Public:**
Annual dose to MEI: 41 – 60 mrem/yr	Annual dose to MEI: 48 – 70 mrem/yr	Annual dose to MEI: 1 – 93 mrem/yr
Annual cancer risk to MEI: $2 \times 10^{-5} - 3 \times 10^{-5}$ per year	Annual cancer risk to MEI: $2 \times 10^{-5} - 4 \times 10^{-5}$ per year	Annual cancer risk to MEI: $4 \times 10^{-7} - 5 \times 10^{-5}$ per year
Collective dose to population within 50 miles: not determined	Collective dose to population within 50 miles: not determined	Collective dose to population within 50 miles: not determined
Number of LCFs in population within 50 miles: not determined	Number of LCFs in population within 50 miles: not determined	Number of LCFs in population within 50 miles: not determined

TABLE I.4 (Cont.)

Impacts from Disposal as Ungrouted U_3O_8 in Shallow Earthen Structures	Impacts from Disposal as Ungrouted U_3O_8 in Vaults	Impacts from Disposal as Ungrouted U_3O_8 in a Mine
	Human Health: Chemical	
Potential impacts to MEI of the general public from groundwater	Potential impacts to MEI of the general public from groundwater	Potential impacts to MEI of the general public from groundwater
	Water	
Potential large impact to groundwater quality from uranium contamination	Potential large impact to groundwater quality from uranium contamination	Potential large impact to groundwater quality from uranium contamination
	Ecology	
Potential moderate impacts to wetlands and aquatic biota from surface water and groundwater contamination	Potential moderate impacts to wetlands and aquatic biota from surface water and groundwater contamination	Potential moderate impacts to wetlands and aquatic biota from surface water and groundwater contamination

[a] Impacts for the post-closure phase were calculated for a time 1,000 years after each disposal facility was assumed to fail. Impacts are presented for a generic wet setting; no impacts would be expected within 1,000 years in a dry setting.

[b] All disposal facilities would be designed to contain the waste material for at least hundreds of years. Shallow earthen structures would be expected to last several hundred years before failure; vaults and mines would be expected to last several hundreds to thousands of years before failure.

Notation: LCF = latent cancer fatality; MEI = maximally exposed individual.

TABLE I.5 Summary of Disposal Option Impacts for UO_2 during the Post-Closure Phase[a,b]

A. Grouted

Impacts from Disposal as Grouted UO_2 in Shallow Earthen Structures	Impacts from Disposal as Grouted UO_2 in Vaults	Impacts from Disposal as Grouted UO_2 in a Mine
	Human Health: Radiological	
General Public: Annual dose to MEI: 37 – 54 mrem/yr	**General Public:** Annual dose to MEI: 38 – 56 mrem/yr	**General Public:** Annual dose to MEI: 1 – 84 mrem/yr
Annual cancer risk to MEI: $2 \times 10^{-5} – 3 \times 10^{-5}$ per year	Annual cancer risk to MEI: $2 \times 10^{-5} – 3 \times 10^{-5}$ per year	Annual cancer risk to MEI: $3 \times 10^{-7} – 4 \times 10^{-5}$ per year
Collective dose to population within 50 miles: not determined	Collective dose to population within 50 miles: not determined	Collective dose to population within 50 miles: not determined
Number of LCFs in population within 50 miles: not determined	Number of LCFs in population within 50 miles: not determined	Number of LCFs in population within 50 miles: not determined
	Human Health: Chemical	
Potential impacts to MEI of the general public from groundwater	Potential impacts to MEI of the general public from groundwater	Potential impacts to MEI of the general public from groundwater
	Water	
Potential large impact to groundwater quality from uranium contamination	Potential large impact to groundwater quality from uranium contamination	Potential large impact to groundwater quality from uranium contamination
	Ecology	
Potential moderate impacts to wetlands and aquatic biota from surface water and groundwater contamination	Potential moderate impacts to wetlands and aquatic biota from surface water and groundwater contamination	Potential moderate impacts to wetlands and aquatic biota from surface water and groundwater contamination

B. Ungrouted

Impacts from Disposal as Ungrouted UO_2 in Shallow Earthen Structures	Impacts from Disposal as Ungrouted UO_2 in Vaults	Impacts from Disposal as Ungrouted UO_2 in a Mine
	Human Health: Radiological	
General Public: Annual dose to MEI: 34 – 50 mrem/yr	**General Public:** Annual dose to MEI: 34 – 50 mrem/yr	**General Public:** Annual dose to MEI: 1 – 77 mrem/yr
Annual cancer risk to MEI: $2 \times 10^{-5} –3 \times 10^{-5}$ per year	Annual cancer risk to MEI: $2 \times 10^{-5} – 3 \times 10^{-5}$ per year	Annual cancer risk to MEI: $2 \times 10^{-7} – 4 \times 10^{-5}$ per year
Collective dose to population within 50 miles: not determined	Collective dose to population within 50 miles: not determined	Collective dose to population within 50 miles: not determined
Number of LCFs in population within 50 miles: not determined	Number of LCFs in population within 50 miles: not determined	Number of LCFs in population within 50 miles: not determined

TABLE I.5 (Cont.)

Impacts from Disposal as Ungrouted UO_2 in Shallow Earthen Structures	Impacts from Disposal as Ungrouted UO_2 in Vaults	Impacts from Disposal as Ungrouted UO_2 in a Mine
	Human Health: Chemical	
Potential impacts to MEI of the general public from groundwater	Potential impacts to MEI of the general public from groundwater	Potential impacts to MEI of the general public from groundwater
	Water	
Potential large impact to groundwater quality from uranium contamination	Potential large impact to groundwater quality from uranium contamination	Potential large impact to groundwater quality from uranium contamination
	Ecology	
Potential moderate impacts to wetlands and aquatic biota from surface water and groundwater contamination	Potential moderate impacts to wetlands and aquatic biota from surface water and groundwater contamination	Potential moderate impacts to wetlands and aquatic biota from surface water and groundwater contamination

[a] Impacts for the post-closure phase were calculated for a time 1,000 years after each disposal facility was assumed to fail. Impacts are presented for a generic wet setting; no impacts would be expected within 1,000 years in a dry setting.

[b] All disposal facilities would be designed to contain the waste material for at least hundreds of years. Shallow earthen structures would be expected to last several hundred years before failure; vaults and mines would be expected to last several hundreds to thousands of years before failure.

Notation: LCF = latent cancer fatality; MEI = maximally exposed individual.

- ***U_3O_8 or UO_2.*** Overall, the potential environmental impacts tend to be slightly larger for U_3O_8 than for UO_2 because the volume of U_3O_8 requiring disposal would be greater than that for UO_2. A larger volume essentially exposes a greater area of waste to infiltrating water.

- ***Grouted or Ungrouted Waste.*** For both U_3O_8 and UO_2, the disposal of grouted waste would have larger environmental impacts than disposal of ungrouted waste once the waste was exposed to the environment because grouting would increase the waste volume. However, further studies using site-specific soil characteristics are necessary to determine the effect of grouting on long-term waste mobility. Grouting might reduce the dissolution rate of the waste and subsequent leaching of uranium into the groundwater in the first several hundred years after failure. However, over longer periods the grouted form would be expected to deteriorate and, because of the long half-life of uranium, the performance of grouted and ungrouted waste would be essentially the same. Depending on soil properties and characteristics of the grout material, it is also possible that grouting could increase the solubility of the uranium material by providing a carbonate-rich environment.

- ***Shallow Earthen Structure, Vault, or Mine.*** Because of the long time periods considered and the fact that the calculations were performed for a time of 1,000 years *after* each facility was assumed to fail, the potential impacts are very similar for disposal in a shallow earthen structure, vault, or mine. However, shallow earthen structures would be expected to contain the waste material for a period of at least several hundred years before failure, whereas vaults and a mine would be expected to last even longer — from several hundred years to a thousand years or more. Therefore, vault and mine disposal would provide greater protection of waste in a wet environment. In addition, a vault and a mine would be expected to provide additional protection against erosion of the cover material (and possible surface exposure of the waste material) compared to shallow earthen structures. The exact time that any disposal facility would perform as designed would depend on the specific facility design and site characteristics.

I.2 DESCRIPTION OF OPTIONS

This section provides a brief summary of the different disposal options considered in the assessment of disposal impacts. The information is based on preconceptual design data provided in the engineering analysis report (LLNL 1997). The engineering analysis report includes much more detailed information, such as descriptions of facility layouts, resource requirements, estimates of effluents, wastes, and emissions, and descriptions of potential accident scenarios.

The three disposal options considered are (1) shallow earthen structures (engineered "trenches"), (2) vaults, and (3) an underground mine. For each option, the U_3O_8 and UO_2 would be packaged for disposal as follows:

- U_3O_8 would be disposed of in 55-gal (208-L) drums. If ungrouted, approximately 714,000 drums would be required; if grouted, approximately 1,500,000 drums would be required.

- UO_2 would be disposed of in 30-gal (110-L) drums. These small drums would be used because of the greater density of UO_2 — a filled 30-gal (110-L) drum would weigh about 2,350 lb (1,070 kg). If ungrouted, approximately 420,000 drums would be required; if grouted, approximately 630,000 drums would be required.

All disposal options would include a central wasteform facility where drums of uranium oxide would be received from the conversion facility and prepared for disposal. The wasteform facility would include an administration building, a receiving warehouse, and cementing/curing/short-term storage buildings (if necessary). Grouting of waste would be performed by mechanically mixing the uranium oxide with cement in large tanks and then pouring the mixture into drums. Once prepared for disposal (if necessary), drums would be moved into disposal units. For the grouted U_3O_8 option, the area of the wasteform facility would be approximately 9 acres (3.6 ha); for the grouted UO_2 option, the area would be about 6 acres (2.4 ha). For ungrouted disposal options, only about 4 acres (1.6 ha) would be required because the facilities for grouting, curing, and additional short-term storage would not be needed. The unique features of each disposal option are described in Sections I.2.1 through I.2.3.

I.2.1 Disposal in Shallow Earthen Structures

Shallow earthen structures, commonly referred to as engineered trenches, are among the most commonly used forms of low-level waste disposal, especially in dry climates. Shallow earthen structures would be excavated to a depth of about 26 ft (8 m), with the length and width determined by site conditions and the annual volume of waste to be disposed of. Disposal in shallow earthen structures would consist of placing waste on a stable structural pad with barrier walls constructed of compacted clay. Clay would be used because it prevents the walls from collapsing or caving in, and it presents a relatively impermeable barrier to waste migration. The waste containers (i.e., drums) would be tightly stacked three pallets high in the bottom of the structure with forklifts. Any open space between containers would be filled with earth, sand, gravel, or other similar material as each layer of drums was placed. After the structure was filled, a 6 ft (2 m) thick cap composed of engineered fill dirt and clay would be placed on top and compacted. The cap would be mounded at least 3 ft (1 m) above the local grade and sloped to minimize the potential for water infiltration. Disposal of ungrouted and grouted U_3O_8 would require about 42 acres (17 ha) and 76 acres (31 ha), respectively. Disposal of ungrouted and grouted UO_2 would require about 24 acres (10 ha) and 33 acres (14 ha), respectively.

I.2.2 Disposal in Vaults

Vaults for disposal would be similar to those described previously for the storage options (Appendix G, Section G.2.3), except that each vault would be divided into five sections, each section approximately 66 ft (20 m) long by 26 ft (8 m) wide and 13 ft (4 m) tall. As opposed to shallow earthen structures, the walls and floor of a vault would be constructed of reinforced concrete. A crane would be used to place drums within each section. Once a vault was full, any open space between containers would be filled with earth, sand, gravel, or other similar material. A permanent roof slab of reinforced concrete that completely covers the vault would be installed after all five sections were filled. A cap of engineered fill dirt and clay would be placed on top of the concrete cover and compacted. The cap would be mounded above the local grade and sloped to minimize the potential for water infiltration. Disposal of ungrouted and grouted U_3O_8 would require about 71 and 140 acres (28 and 56 ha), respectively. Disposal of ungrouted and grouted UO_2 would require about 24 and 35 acres (10 and 15 ha), respectively.

I.2.3 Disposal in a Mine

An underground mine disposal facility would be a repository for permanent deep geological disposal. A mined disposal facility could possibly use a previously existing mine, or be constructed for the sole purpose of waste disposal. For purposes of comparing alternatives, the conservative assumption of constructing a new mine was assessed for this PEIS. A mine disposal facility would consist of surface facilities that provide space for waste receiving and inspection (the wasteform facility), and shafts and ramps for access to and ventilation of the underground portion of the repository. The underground portion would consist of tunnels (called “drifts”) for the transport and disposal of waste underground. The dimensions of the drifts would be similar to those described previously for the storage options (Section G.2.4), except that each drift would have a width of 21 ft (6.5 m). Waste containers would be placed in drifts and backfilled. Disposal of ungrouted and grouted U_3O_8 would require about 228 acres (91 ha) and 462 acres (185 ha) of underground disposal space, respectively. Disposal of ungrouted and grouted UO_2 would require about 98 acres (39 ha) and 143 acres (57 ha), respectively.

I.2.4 Disposal Technologies and Chemical Forms Considered But Not Analyzed

Disposal of depleted uranium metal was not considered because uranium metal is not as chemically stable as U_3O_8 or UO_2. Uranium metal is subject to surface oxidation. Similarly, disposal of UF_6 and UF_4 were not considered because they react with water to form HF, which is a hazardous and corrosive chemical that would degrade the containment for the waste material. These characteristics are considered unacceptable for disposal.

I.3 IMPACTS OF OPTIONS — OPERATIONAL PHASE

Potential impacts analyzed for the operational phase of the disposal options included impacts occurring during facility construction and during the 20-year period when the waste material would be actively placed into disposal units. (The potential environmental impacts for the post-closure period, after the disposal facility ceased operations, are presented in Section I.4). The estimated impacts are discussed for each area of impact. Information related to the assessment methodologies is provided in Appendix C.

The environmental impacts from the operational phase were evaluated based on the information described in the engineering analysis report (LLNL 1997). The following general assumptions apply to the assessment of impacts:

- Impacts during the operational phase include those from preliminary facility construction and the 20-year period (2008 to 2028) when waste material (i.e., depleted uranium oxide from the DOE-generated inventory) would be actively placed into disposal units. Construction of disposal units would continue over the 20-year period while waste material was being received.

- Ungrouted U_3O_8 and ungrouted UO_2 would be disposed of directly without additional processing at the disposal facility. Consequently, no air or water emissions would be associated with normal (nonaccident) operations, except for exhaust emissions from equipment used during disposal.

- Grouting of U_3O_8 and UO_2 would occur at the disposal facility and consist of mixing the uranium material with cement and pouring it into drums. Grouting operations would result in the release of small amounts of uranium material to the air and water during normal operations.

- The potential impacts from disposal were analyzed for generic dry and wet environmental settings. The historical meteorological conditions for five actual "dry" locations in the southwestern United States and five actual "wet" locations in the central and southeastern United States were used to develop estimates for the generic sites. It was assumed that a disposal facility would not be located in an urban area. Therefore, analyses for both dry and wet environmental settings assumed a rural population density corresponding to 15 persons/mi^2 (6 persons/km^2).

The potential environmental impacts from the disposal options were not evaluated on a site-specific basis because the location of a disposal facility would not be chosen until sometime in the future (see Chapter 3). A more detailed assessment of site considerations would be addressed, as appropriate, as part of the Phase II reviews of the programmatic *National Environmental Policy Act* (NEPA) approach.

I.3.1 Human Health — Normal Operations

I.3.1.1 Radiological Impacts

Radiological impacts during normal operations of the facility were estimated for involved workers, noninvolved workers, and members of the general public. External radiation resulting from the handling and shipping of uranium materials would be the major source of exposure for involved workers. Because grouted waste would increase the total volume of waste substantially, thereby increasing the number of waste containers for handling and shipping, impacts to involved workers would be greater from grouted waste than ungrouted waste. Variations in exposures for the three disposal types considered (shallow earthen structures, vaults, or mine) would be caused by different practices for different technologies. Disposal in a mine would require transport of waste containers from the ground surface to the underground cavities, whereas disposal in shallow earthen structures and vaults would require filling and capping efforts to cover the waste containers with dirt, cement, and/or other engineering materials. In general, average radiation exposure of involved workers would be less than 630 mrem/yr.

Exposures for noninvolved workers and the general public would result from releases of uranium compounds from the grouting facility. Radiation doses from both airborne and waterborne pathways would be less than 0.05 mrem/yr and would tend to be similar between dry and wet environmental settings.

The estimated results for different disposal options are listed in Tables I.6 and I.7. Detailed discussions of the methodology used in the radiological impact analyses are provided in Appendix C and Cheng et al. (1997).

I.3.1.1.1 Disposal as U_3O_8

The total collective doses to involved workers from grouted waste would be nearly twice those from ungrouted waste, ranging from approximately 24 person-rem/yr for 85 workers for shallow earthen structures to 36 person-rem/yr for 87 workers for a mine. The corresponding collective cancer risks for grouted waste would be about 1×10^{-2} fatalities per year (1 additional latent cancer fatality [LCF] in 100 years). The estimated average individual doses to involved workers range from 210 mrem/yr (disposal in vaults) to 410 mrem/yr (disposal in a mine) for grouted

TABLE I.6 Radiological Doses from Disposal Options for Normal Operations

	Dose to Receptor					
	Involved Worker[b]		Noninvolved Worker[c]		General Public[d]	
Option/Location[a]	Average Dose (mrem/yr)	Collective Dose (person-rem/yr)	MEI Dose (mrem/yr)	Collective Dose (person-rem/yr)	MEI Dose (mrem/yr)	Collective Dose (person-rem/yr)
Disposal as Grouted U_3O_8						
Shallow earthen structure						
Dry	290	24	3.2×10^{-3}–5.1×10^{-3}	8.1×10^{-5}–1.2×10^{-4}	9.0×10^{-3}–1.6×10^{-2}	2.1×10^{-3}–3.9×10^{-3}
Wet	290	24	2.1×10^{-3}–8.8×10^{-3}	2.7×10^{-5}–1.7×10^{-4}	6.1×10^{-3}–2.6×10^{-2}	1.9×10^{-3}–5.4×10^{-3}
Vault						
Dry	210	26	3.2×10^{-3}–5.1×10^{-3}	8.9×10^{-5}–1.3×10^{-4}	4.7×10^{-3}–1.4×10^{-2}	2.1×10^{-3}–3.9×10^{-3}
Wet	210	26	2.1×10^{-3}–8.8×10^{-3}	3.0×10^{-5}–1.9×10^{-4}	6.0×10^{-3}–2.0×10^{-2}	1.9×10^{-3}–5.4×10^{-3}
Mine						
Dry	410	36	3.0×10^{-3}–4.7×10^{-3}	8.5×10^{-5}–1.3×10^{-4}	6.7×10^{-3}–1.6×10^{-2}	2.1×10^{-3}–3.9×10^{-3}
Wet	410	36	8.4×10^{-4}–8.5×10^{-3}	2.8×10^{-5}–1.8×10^{-4}	6.1×10^{-3}–2.6×10^{-2}	1.9×10^{-3}–5.4×10^{-3}
Disposal as Ungrouted U_3O_8						
Shallow earthen structure						
Dry	550	14	0	0	0	0
Wet	550	14	0	0	0	0
Vault						
Dry	330	15	0	0	0	0
Wet	330	15	0	0	0	0
Mine						
Dry	630	18	0	0	0	0
Wet	630	18	0	0	0	0

TABLE I.6 (Cont.)

	Dose to Receptor					
	Involved Worker[b]		Noninvolved Worker[c]		General Public[d]	
Option/Location[a]	Average Dose (mrem/yr)	Collective Dose (person-rem/yr)	MEI Dose (mrem/yr)	Collective Dose (person-rem/yr)	MEI Dose (mrem/yr)	Collective Dose (person-rem/yr)
Disposal as Grouted UO_2						
Shallow earthen structure						
Dry	300	21	6.0×10^{-3}– 9.8×10^{-3}	8.3×10^{-5}– 1.2×10^{-4}	1.7×10^{-2}– 3.0×10^{-2}	3.9×10^{-3} – 7.5×10^{-3}
Wet	300	21	3.2×10^{-3}– 1.7×10^{-2}	2.8×10^{-5}– 1.8×10^{-4}	1.2×10^{-2}– 5.0×10^{-2}	3.6×10^{-3}– 1.0×10^{-2}
Vault						
Dry	300	22	6.0×10^{-3}– 9.8×10^{-3}	9.1×10^{-5}– 1.4×10^{-4}	1.3×10^{-2}– 3.0×10^{-2}	3.9×10^{-3}– 7.5×10^{-3}
Wet	300	22	3.7×10^{-3}– 1.7×10^{-2}	3.0×10^{-5}– 2.0×10^{-4}	1.2×10^{-2}– 5.0×10^{-2}	3.6×10^{-3}– 1.0×10^{-2}
Mine						
Dry	330	24	5.7×10^{-3}– 8.9×10^{-3}	8.3×10^{-5}– 1.2×10^{-4}	1.3×10^{-2}– 3.0×10^{-2}	3.9×10^{-3}– 7.5×10^{-3}
Wet	330	24	1.6×10^{-3}– 1.6×10^{-2}	2.8×10^{-5}– 1.8×10^{-4}	1.2×10^{-2}– 5.0×10^{-2}	3.6×10^{-3}– 1.0×10^{-2}
Disposal as Ungrouted UO_2						
Shallow earthen structure						
Dry	360	8.3	0	0	0	0
Wet	360	8.3	0	0	0	0
Vault						
Dry	430	11	0	0	0	0
Wet	430	11	0	0	0	0
Mine						
Dry	470	12	0	0	0	0
Wet	470	12	0	0	0	0

[a] Two generic environmental settings were considered for each option, corresponding to a dry environment and wet environment, respectively.

[b] Involved workers are those workers directly involved with the handling of materials. Impacts are presented as average individual dose and collective dose for the worker population. Radiation doses to individual workers would be monitored by a dosimetry program and maintained below applicable standards, such as the DOE administrative control limit of 2,000 mrem/yr.

[c] Noninvolved workers are individuals who do not participate in material-handing activities, such as employees in the administration building. The number of noninvolved workers would be approximately 44.

[d] The off-site general public is defined as residents who live within a radius of 50 miles (80 km) around the disposal site. A rural environment with a population density of 6 persons/km^2 and a total population of 120,000 was assumed. Impacts to the MEI were assessed from both airborne and waterborne emissions; impacts to the total population were assessed from airborne emissions only.

TABLE I.7 Latent Cancer Risks from Disposal Options for Normal Operations

	Risk to Receptor					
	Involved Worker[b]		Noninvolved Worker[c]		General Public[d]	
Option/Location[a]	Average Risk (risk/yr)	Collective Risk (fatalities/yr)	MEI Risk (risk/yr)	Collective Risk (fatalities/yr)	MEI Risk (risk/yr)	Collective Risk (fatalities/yr)
Disposal as Grouted U_3O_8						
Shallow earthen structure						
Dry	1×10^{-4}	1×10^{-2}	1×10^{-9}– 2×10^{-9}	3×10^{-8}– 5×10^{-8}	4×10^{-9}– 8×10^{-9}	1×10^{-6}– 2×10^{-6}
Wet	1×10^{-4}	1×10^{-2}	8×10^{-10}– 4×10^{-9}	1×10^{-8}– 7×10^{-8}	3×10^{-9}– 1×10^{-8}	9×10^{-7}– 3×10^{-6}
Vault						
Dry	8×10^{-5}	1×10^{-2}	1×10^{-9}– 2×10^{-9}	4×10^{-8}– 5×10^{-8}	2×10^{-9}– 7×10^{-9}	1×10^{-6}– 2×10^{-6}
Wet	8×10^{-5}	1×10^{-2}	8×10^{-10}– 4×10^{-9}	1×10^{-8}– 8×10^{-8}	3×10^{-9}– 1×10^{-8}	9×10^{-7}– 3×10^{-6}
Mine						
Dry	2×10^{-4}	1×10^{-2}	1×10^{-9}– 2×10^{-9}	3×10^{-8}– 5×10^{-8}	3×10^{-9}– 8×10^{-9}	1×10^{-6}– 2×10^{-6}
Wet	2×10^{-4}	1×10^{-2}	3×10^{-10}– 3×10^{-9}	1×10^{-8}– 7×10^{-8}	3×10^{-9}– 1×10^{-8}	9×10^{-7}– 3×10^{-6}
Disposal as Ungrouted U_3O_8						
Shallow earthen structure						
Dry	2×10^{-4}	6×10^{-3}	0	0	0	0
Wet	2×10^{-4}	6×10^{-3}	0	0	0	0
Vault						
Dry	1×10^{-4}	6×10^{-3}	0	0	0	0
Wet	1×10^{-4}	6×10^{-3}	0	0	0	0
Mine						
Dry	3×10^{-4}	7×10^{-3}	0	0	0	0
Wet	3×10^{-4}	7×10^{-3}	0	0	0	0

TABLE I.7 (Cont.)

	Risk to Receptor					
	Involved Worker[b]		Noninvolved Worker[c]		General Public[d]	
Option/Location[a]	Average Risk (risk/yr)	Collective Risk (fatalities/yr)	MEI Risk (risk/yr)	Collective Risk (fatalities/yr)	MEI Risk (risk/yr)	Collective Risk (fatalities/yr)
Disposal as Grouted UO_2						
Shallow earthen structure						
Dry	1×10^{-4}	8×10^{-3}	2×10^{-9} 4×10^{-9}	3×10^{-8}– 5×10^{-8}	9×10^{-9}– 2×10^{-8}	2×10^{-6}– 4×10^{-6}
Wet	1×10^{-4}	8×10^{-3}	1×10^{-9}– 7×10^{-9}	1×10^{-8}– 7×10^{-8}	6×10^{-9}– 2×10^{-8}	2×10^{-6}– 5×10^{-6}
Vault						
Dry	1×10^{-4}	9×10^{-3}	2×10^{-9}– 4×10^{-9}	4×10^{-8}– 5×10^{-8}	6×10^{-9}– 2×10^{-8}	2×10^{-6}– 4×10^{-6}
Wet	1×10^{-4}	9×10^{-3}	1×10^{-9}– 7×10^{-9}	1×10^{-8}– 8×10^{-8}	6×10^{-9}– 2×10^{-8}	2×10^{-6}– 5×10^{-6}
Mine						
Dry	1×10^{-4}	1×10^{-2}	2×10^{-9}– 4×10^{-9}	3×10^{-8}– 5×10^{-8}	6×10^{-9}– 2×10^{-8}	2×10^{-6}– 4×10^{-6}
Wet	1×10^{-4}	1×10^{-2}	6×10^{-10}– 6×10^{-9}	1×10^{-8}– 7×10^{-8}	6×10^{-9}– 2×10^{-8}	2×10^{-6}– 5×10^{-6}
Disposal as Ungrouted UO_2						
Shallow earthen structure						
Dry	1×10^{-4}	3×10^{-3}	0	0	0	0
Wet	1×10^{-4}	3×10^{-3}	0	0	0	0
Vault						
Dry	2×10^{-4}	4×10^{-3}	0	0	0	0
Wet	2×10^{-4}	4×10^{-3}	0	0	0	0
Mine						
Dry	2×10^{-4}	5×10^{-3}	0	0	0	0
Wet	2×10^{-4}	5×10^{-3}	0	0	0	0

[a] Two generic environmental settings were considered for each option, corresponding to a dry environment and wet environment, respectively.

[b] Involved workers are those workers directly involved with the handling of materials. Impacts are presented as average individual risk and collective risk for the worker population.

[c] Noninvolved workers are individuals who do not participate in material-handling activities, such as employees in the administration building. The number of noninvolved workers would be approximately 44.

[d] The off-site general public is defined as residents who live within a radius of 50 miles (80 km) around the disposal site. A rural environment with a population density of 6 persons/km^2 and a total population of 120,000 was assumed. Impacts to the MEI were assessed from both airborne and waterborne emissions; impacts to the total population were assessed from airborne emissions only.

waste. Average worker doses for ungrouted waste range from 330 to 630 mrem/yr. Potential exposures of involved workers would be well below the radiation dose limit of 5,000 mrem/yr (10 CFR Part 835).

Radiation exposures of noninvolved workers would occur only for disposal of grouted waste. The radiation dose to the maximally exposed individual (MEI) would be less than 0.0088 mrem/yr, a small fraction of the dose limit of 10 mrem/yr from airborne emissions (10 CFR Part 61). The collective dose for noninvolved workers would be less than 0.0002 person-rem/yr for a total of approximately 43 workers.

The estimated maximum individual dose to the off-site general public is less than 0.026 mrem/yr for grouted waste, which corresponds to a cancer risk of 1 in 80 million per year. For a collective population of 120,000 persons within 50 miles (80 km) of the site, the estimated number of LCFs is less than 3×10^{-6} per year (1 fatality in 300,000 years).

I.3.1.1.2 Disposal as UO_2

Compared with the disposal of U_3O_8, disposal of UO_2 would result in less collective exposures of involved workers because of the smaller volume of waste involved. Grouted UO_2 would result in larger collective worker doses than ungrouted UO_2, with the collective dose ranging from 21 to 24 person-rem/yr for approximately 72 workers. The average individual dose to involved workers for grouted waste ranges from 300 to 330 mrem/yr. Although ungrouted waste would result in less collective exposure, the number of involved workers (about 25) would also be less. As a result, the average worker dose would be greater for ungrouted waste than grouted waste. The estimated average individual worker dose ranges from 360 mrem/yr to 470 mrem/yr. For all disposal types considered, the average radiation doses to involved workers would be well below the dose limit of 5,000 mrem/yr. The estimated maximum individual dose to noninvolved workers is less than 0.017 mrem/yr, and the estimated collective dose is less than 0.0002 person-rem/yr. The number of noninvolved workers would be approximately 44.

The maximum individual dose to the off-site general public would be less than 0.050 mrem/yr, which corresponds to a cancer risk of 1 in 40 million per year. For the assumed rural collective population of 120,000 persons within 50 miles (80 km) of the site, the number of LCFs would be less than 5×10^{-6} per year (1 fatality in 200,000 years of operation).

I.3.1.2 Chemical Impacts

Potential chemical impacts to human health from normal operations at the disposal facilities would result primarily from exposure to the insoluble uranium compounds, UO_2 and U_3O_8. Risks from normal operations were quantified on the basis of calculated hazard indices. Additional information on the exposure assumptions, health effects assumptions, reference doses used for uranium compounds, and calculational methods used in the chemical impact analysis are provided in Appendix C and Cheng et al. (1997).

Chemical impacts during the operational phase of the disposal facilities were calculated for noninvolved workers and the general public. Exposures of noninvolved workers and the general public to low levels of airborne emissions could occur from mixing uranium with cement and other grouting materials in the wasteform facility. Three disposal types (shallow earthen structures, vaults, and mines) were considered for U_3O_8 and UO_2 as both grouted and ungrouted wastes in generic dry and wet environmental settings.

Human health impacts from exposures to hazardous chemicals during normal operations of the U_3O_8 or UO_2 disposal facilities are summarized in Table I.8. Two waste forms were evaluated for U_3O_8 and UO_2: grouted and ungrouted. For grouted wastes, the range of chemical exposures to the noninvolved workers and general public would result primarily from differences between the locations and types of disposal facilities. The hazard indices for all disposal options are four orders of magnitude less than 1, the level for which potential adverse health effects could occur from normal operations. No impacts would occur for disposal of ungrouted U_3O_8 or UO_2 because airborne emissions would not be expected (LLNL 1997).

I.3.2 Human Health — Accident Conditions

A range of accidents covering the spectrum of high-frequency/low-consequence accidents to low-frequency/high-consequence accidents has been presented in the engineering analysis report (LLNL 1997). These accidents are listed in Table I.9. The following sections present the results for radiological and chemical health impacts of the highest consequence accident in each frequency category. Results for all accidents listed in Table I.9 are presented in Policastro et al. (1997). Detailed descriptions of the methodology and assumptions used in these calculations are also provided in Appendix C and Policastro et al. (1997).

I.3.2.1 Radiological Impacts

The radiological doses to various receptors for the accidents that give the highest dose from each frequency category are listed in Table I.10. The LCF risks for these accidents are given in Table I.11. The doses and the risks are presented as ranges (maximum and minimum) because two different meteorological conditions (wet and dry) were evaluated for each disposal option (see Appendix C). The doses and risks presented here were obtained by assuming that the accidents would occur. The probability of occurrence for each accident is indicated by the frequency category to which it belongs. For example, accidents in the extremely unlikely category have a probability of

TABLE I.8 Chemical Impacts to Human Health for the Disposal Options under Normal Operations

	Impacts to Receptor[a]			
	Noninvolved Workers[b]		General Public	
Option	Hazard Index for MEI[c]	Population Risk[d] (ind. at risk/yr)	Hazard Index for MEI[c]	Population Risk[d] (ind. at risk/yr)
Disposal as Grouted U_3O_8				
Shallow earthen structure				
Dry	3.9×10^{-7}– 6.3×10^{-7}	–	3.1×10^{-5}– 5.3×10^{-5}	–
Wet	2.5×10^{-7}– 1.1×10^{-6}	–	2.1×10^{-5}– 8.9×10^{-5}	–
Vault				
Dry	3.9×10^{-7}– 6.3×10^{-7}	–	1.6×10^{-5}– 3.8×10^{-5}	–
Wet	3.1×10^{-7}– 1.1×10^{-6}	–	2.0×10^{-5}– 6.6×10^{-5}	–
Mine				
Dry	3.6×10^{-7}– 5.4×10^{-7}	–	3.3×10^{-5}– 5.3×10^{-5}	–
Wet	1.0×10^{-7}– 1.1×10^{-6}	–	2.1×10^{-5}– 9.1×10^{-5}	–
Disposal as Ungrouted U_3O_8				
Shallow earthen structure				
Dry	~ 0	–	~ 0	–
Wet	~ 0	–	~ 0	–
Vault				
Dry	~ 0	–	~ 0	–
Wet	~ 0	–	~ 0	–
Mine				
Dry	~ 0	–	~ 0	–
Wet	~ 0	–	~ 0	–

TABLE I.8 (Cont.)

	Impacts to Receptor[a]			
	Noninvolved Workers[b]		General Public	
Option	Hazard Index for MEI[c]	Population Risk[d] (ind. at risk/yr)	Hazard Index for MEI[c]	Population Risk[d] (ind. at risk/yr)
Disposal as Grouted UO_2				
Shallow earthen structure				
Dry	7.2×10^{-7}– 1.2×10^{-6}	–	5.7×10^{-5}– 9.7×10^{-5}	–
Wet	3.8×10^{-7}– 2.0×10^{-6}	–	3.9×10^{-5}– 1.6×10^{-4}	–
Vault				
Dry	7.2×10^{-7}– 1.2×10^{-6}	–	6.0×10^{-5}– 9.7×10^{-5}	–
Wet	4.6×10^{-7}– 2.0×10^{-6}	–	3.9×10^{-5}– 1.7×10^{-4}	–
Mine				
Dry	6.5×10^{-7}– 9.9×10^{-7}	–	6.0×10^{-5}– 9.7×10^{-5}	–
Wet	1.9×10^{-7}– 1.8×10^{-6}	–	3.9×10^{-5}– 1.7×10^{-4}	–
Disposal as Ungrouted UO_2				
Shallow earthen structure				
Dry	~ 0	–	~ 0	–
Wet	~ 0	–	~ 0	–
Vault				
Dry	~ 0	–	~ 0	–
Wet	~ 0	–	~ 0	–
Mine				
Dry	~ 0	–	~ 0	–
Wet	~ 0	–	~ 0	–

[a] The range of impacts represent variations in meteorological conditions at the generic wet and dry environmental settings.

[b] Noninvolved workers are individuals who do not participate in material-handling activities, such as employees in the administration building.

[c] The hazard index is an indicator for potential health effects other than cancer; a hazard index greater than 1 indicates a potential for adverse health effects and a need for further evaluation.

[d] Calculation of population risk is not applicable when the corresponding hazard index for the MEI is less than 1.

TABLE I.9 Accidents Considered for the Disposal Options

Option/Accident Scenario	Accident Description	Chemical Form	Amount (lb)	Duration (min)	Release Level[a]
Disposal as Grouted U_3O_8					
Likely Accidents (frequency: 1 or more times in 100 years)					
Mishandling/drop of drum/ billet inside the product receiving area	A single U_3O_8 drum is damaged by a forklift and spills its contents onto the ground inside the product receiving area.	U_3O_8	0.00028	Puff	Stack
Mishandling/drop of drum/ billet outside	A single U_3O_8 drum is damaged by a forklift and spills its contents outside without HEPA filtration.	U_3O_8	0.000066	Puff	Ground
Unlikely Accidents (frequency: 1 in 100 years to 1 in 10,000 years)					
Earthquake	The product receiving area and cement mixing area are damaged during a design-basis earthquake, resulting in failure of the structure and confinement systems.	U_3O_8	400	Puff	Ground
Tornado	A major tornado and associated tornado missiles result in failure of the product receiving area and cement mixing area structures and confinement systems.	U_3O_8	770	Puff	Ground
Extremely Unlikely Accidents (frequency: 1 in 10,000 years to 1 in 1 million years)					
Fire/explosion inside the product mixing area	A fire or explosion within the product mixing area affects the contents of a single pallet of drums.	U_3O_8	0.0017	Puff	Stack
Incredible Accidents (frequency: less than 1 in 1 million years)					
Flood	The facility would be located at a site that would preclude severe flooding.	No release	NA	NA	NA
Disposal as Ungrouted U_3O_8					
Likely Accidents (frequency: 1 or more times in 100 years)					
Mishandling/drop of drum/ billet inside the product receiving area	A single U_3O_8 drum is damaged by a forklift and spills its contents onto the ground inside the product receiving area.	U_3O_8	0.00028	Puff	Stack
Unlikely Accidents (frequency: 1 in 100 years to 1 in 10,000 years)					
Earthquake	The product receiving area is damaged during a design-basis earthquake, resulting in failure of the structure and confinement systems.	U_3O_8	370	Puff	Ground
Tornado	A major tornado and associated tornado missiles result in failure of the product receiving structure and confinement systems.	U_3O_8	740	Puff	Ground
Incredible Accidents (frequency: less than 1 in 1 million years)					
Flood	The facility would be located at a site that would preclude severe flooding.	No release	NA	NA	NA

TABLE I.9 (Cont.)

Option/Accident Scenario	Accident Description	Chemical Form	Amount (lb)	Duration (min)	Release Level[a]
Disposal as Grouted UO_2					
Likely Accidents (frequency: 1 or more times in 100 years)					
Mishandling/drop of drum/ billet inside the product receiving area	A single UO_2 drum is damaged by a forklift and spills its contents onto the ground inside the product receiving area.	UO_2	0.00011	Puff	Stack
Mishandling/drop of drum/ billet outside	A single UO_2 drum is damaged by a forklift and spills its contents outside without HEPA filtration.	UO_2	0.00015	Puff	Stack
Unlikely Accidents (frequency: 1 in 100 years to 1 in 10,000 years)					
Earthquake	The product receiving area and cement mixing area are damaged during a design-basis earthquake, resulting in failure of the structure and confinement systems.	UO_2	0.73	Puff	Ground
Tornado	A major tornado and associated tornado missiles result in failure of the product receiving area and cement mixing area structures and confinement systems.	UO_2	2.1	Puff	Ground
Extremely Unlikely Accidents (frequency: 1 in 10,000 years to 1 in 1 million years)					
Fire/explosion inside the product mixing area	A fire or explosion within the product mixing area affects the contents of a single pallet of drums.	UO_2	0.00068	Puff	Stack
Incredible Accidents (frequency: less than 1 in 1 million years)					
Flood	The facility would be located at a site that would preclude severe flooding.	No release	NA	NA	NA
Disposal as Ungrouted UO_2					
Likely Accidents (frequency: 1 or more times in 100 years)					
Mishandling/drop of drum/ billet inside product receiving area	A single UO_2 drum is damaged by a forklift and spills its contents onto the ground inside the product receiving area.	UO_2	0.00011	Puff	Stack
Unlikely Accidents (frequency: 1 in 100 years to 1 in 10,000 years)					
Earthquake	The product receiving area is damaged during a design-basis earthquake, resulting in failure of the structure and confinement systems.	UO_2	0.59	Puff	Ground
Tornado	A major tornado and associated tornado missiles result in failure of the product receiving structure and confinement systems.	UO_2	1.2	Puff	Ground
Incredible Accidents (frequency: less than 1 in 1 million years)					
Flood	The facility would be located at a site that would preclude severe flooding.	No release	NA	NA	NA

[a] Ground-level releases were assumed to occur outdoors on concrete pads in the cylinder storage yards. To prevent contaminant migration, cleanup of residuals was assumed to begin immediately after the release was stopped.

Notation: HEPA = high-efficiency particulate air; NA = not applicable; UO_2 = uranium dioxide; U_3O_8 = triuranium octaoxide.

TABLE I.10 Estimated Radiological Doses per Accident Occurrence for the Disposal Options

		Maximum Dose[c]				Minimum Dose[c]			
		Noninvolved Workers		General Public		Noninvolved Workers		General Public	
Option/Accident[a]	Frequency Category[b]	MEI (rem)	Population (person-rem)	MEI (rem)	Population (person-rem)	MEI (rem)	Population (person-rem)	MEI (rem)	Population (person-rem)
Disposal as Grouted U_3O_8									
Mishandling/drop of drum/billet outside	L	4.1×10^{-7}	3.7×10^{-8}	1.3×10^{-8}	7.6×10^{-8}	4.1×10^{-7}	3.7×10^{-8}	1.0×10^{-8}	7.6×10^{-8}
Earthquake	U	1.4×10^{2}	6.1	1.1	1.5	1.3×10^{1}	1.1	2.9×10^{-1}	8.7×10^{-1}
Fire or explosion inside the product mixing area	EU	5.5×10^{-8}	1.1×10^{-7}	5.7×10^{-8}	2.2×10^{-6}	1.6×10^{-11}	3.1×10^{-11}	2.8×10^{-9}	1.0×10^{-6}
Disposal as Ungrouted U_3O_8									
Mishandling/drop of drum inside the product receiving area	L	9.0×10^{-9}	1.8×10^{-8}	9.3×10^{-9}	3.6×10^{-7}	2.7×10^{-12}	5.1×10^{-12}	4.6×10^{-10}	1.6×10^{-7}
Earthquake	U	1.3×10^{2}	5.6	1.0	1.3	1.2×10^{1}	9.8×10^{-1}	2.7×10^{-1}	8.0×10^{-1}
Disposal as Grouted UO_2									
Mishandling/drop of drum/billet outside	L	9.8×10^{-7}	8.7×10^{-8}	3.0×10^{-8}	1.8×10^{-7}	9.8×10^{-7}	8.7×10^{-8}	2.4×10^{-8}	1.8×10^{-7}
Earthquake	U	2.7×10^{-1}	1.1×10^{-2}	2.1×10^{-3}	2.7×10^{-3}	2.4×10^{-2}	2.0×10^{-3}	5.5×10^{-4}	1.6×10^{-3}
Fire or explosion inside the product mixing area	EU	2.3×10^{-8}	4.5×10^{-8}	2.4×10^{-8}	9.1×10^{-7}	6.8×10^{-12}	1.3×10^{-11}	1.2×10^{-9}	4.2×10^{-7}
Disposal as Ungrouted UO_2									
Mishandling/drop of drum inside the product receiving area	L	3.7×10^{-9}	7.3×10^{-9}	3.8×10^{-9}	1.5×10^{-7}	1.1×10^{-12}	2.1×10^{-12}	1.9×10^{-10}	6.7×10^{-8}
Earthquake	U	2.2×10^{-1}	9.3×10^{-3}	1.7×10^{-3}	2.2×10^{-3}	1.9×10^{-2}	1.6×10^{-3}	4.4×10^{-4}	1.3×10^{-3}

[a] The bounding accident chosen to represent each frequency category is the one that would result in the highest dose to the general public MEI. Health impacts in that row represent that accident only and not the range of impacts among accidents in that category. Absence of an accident in a certain frequency category indicates that the accident would not result in a release of radioactive material.

[b] Accident frequencies: likely (L), estimated to occur one or more times in 100 years of facility operations (> 10^{-2}/yr); unlikely (U), estimated to occur between once in 100 years and once in 10,000 years of facility operations (10^{-2} – 10^{-4}/yr); extremely unlikely (EU), estimated to occur between once in 10,000 years and once in 1 million years of facility operations (10^{-4} – 10^{-6}/yr).

[c] Maximum and minimum doses reflect differences in assumed sites, technologies, and meteorological conditions at the time of the accident. In general, maximum doses would occur under meteorological conditions of F stability with 1 m/s wind speed, whereas minimum doses would occur under D stability with 4 m/s wind speed.

TABLE I.11 Estimated Radiological Health Risks per Accident Occurrence for the Disposal Options[a]

		Maximum Risk[d] (LCFs)				Minimum Risk[d] (LCFs)			
		Noninvolved Workers		General Public		Noninvolved Workers		General Public	
Option/Accident[b]	Frequency Category[c]	MEI	Population	MEI	Population	MEI	Population	MEI	Population
Disposal as Grouted U_3O_8									
Mishandling/drop of drum/billet outside	L	2×10^{-10}	1×10^{-11}	6×10^{-12}	4×10^{-11}	2×10^{-10}	1×10^{-11}	5×10^{-12}	4×10^{-11}
Earthquake	U	6×10^{-2}	2×10^{-3}	5×10^{-4}	7×10^{-4}	5×10^{-3}	4×10^{-4}	1×10^{-4}	4×10^{-4}
Fire or explosion inside the product mixing area	EU	2×10^{-11}	4×10^{-11}	3×10^{-11}	1×10^{-9}	7×10^{-15}	1×10^{-14}	1×10^{-12}	5×10^{-10}
Disposal as Ungrouted U_3O_8									
Mishandling/drop of drum inside the product receiving area	L	4×10^{-12}	7×10^{-12}	5×10^{-12}	2×10^{-10}	1×10^{-15}	2×10^{-15}	2×10^{-13}	8×10^{-11}
Earthquake	U	5×10^{-2}	2×10^{-3}	5×10^{-4}	7×10^{-4}	5×10^{-3}	4×10^{-4}	1×10^{-4}	4×10^{-4}
Disposal as Grouted UO_2									
Mishandling/drop of drum/billet outside	L	4×10^{-10}	3×10^{-11}	1×10^{-11}	9×10^{-11}	4×10^{-10}	3×10^{-11}	1×10^{-11}	9×10^{-11}
Earthquake	U	1×10^{-4}	5×10^{-6}	1×10^{-6}	1×10^{-6}	1×10^{-5}	8×10^{-7}	3×10^{-7}	8×10^{-7}
Fire or explosion inside the product mixing area	EU	9×10^{-12}	2×10^{-11}	1×10^{-11}	5×10^{-10}	3×10^{-15}	5×10^{-15}	6×10^{-13}	2×10^{-10}
Disposal as Ungrouted UO_2									
Mishandling/drop of drum inside the product receiving area	L	1×10^{-12}	3×10^{-12}	2×10^{-12}	7×10^{-11}	4×10^{-16}	8×10^{-16}	9×10^{-14}	3×10^{-11}
Earthquake	U	9×10^{-5}	4×10^{-6}	8×10^{-7}	1×10^{-6}	8×10^{-6}	7×10^{-7}	2×10^{-7}	7×10^{-7}

[a] Values shown are the consequences if the accident did occur. The risk of an accident is the consequence (LCF) times the estimated frequency times 20 years of operations. The estimated frequencies are as follows: likely (L), 0.1; unlikely (U), 0.001; extremely unlikely (EU), 0.00001; incredible (I), 0.000001.

[b] The bounding accident chosen to represent each frequency category is the one that would result in the highest risk to the general public MEI. Health impacts in that row represent that accident only and not the range of impacts among accidents in that category. Absence of an accident in a certain frequency category indicates that the accident would not result in a release of radioactive material.

[c] Accident frequencies: likely (L), estimated to occur one or more times in 100 years of facility operations (> 10^{-2}/yr); unlikely (U), estimated to occur between once in 100 years and once in 10,000 years of facility operations (10^{-2} – 10^{-4}/yr); extremely unlikely (EU), estimated to occur between once in 10,000 years and once in 1 million years of facility operations (10^{-4} – 10^{-6}/yr).

[d] Maximum and minimum risks reflect differences in assumed sites, technologies, and meteorological conditions at the time of the accident. In general, maximum risks would occur under meteorological conditions of F stability with 1 m/s wind speed, whereas minimum risks would occur under D stability with 4 m/s wind speed.

occurrence between 1 in 10,000 and 1 in 1 million in any 1 year. The following conclusions may be drawn from the radiological health impact results:

- No cancer fatalities would be predicted from any of the accidents.

- Except for the impacts to a noninvolved worker MEI from an earthquake accident, the maximum radiological dose to noninvolved worker and general public MEIs (assuming an accident occurred) would be 1.1 rem. This dose is less than the 25-rem dose recommended for assessing the adequacy of protection of public health and safety from potential accidents by the U.S. Nuclear Regulatory Commission (NRC 1994).

- For an earthquake accident, the potential dose to the noninvolved worker MEI would range from 0.22 to 140 rem, depending on the option implemented for uranium disposal. The NRC recommendations are not directly applicable to workers but are used in this instance as a guideline to indicate potential for health effects. A dose of 140 rem could result in temporary adverse health effects to the MEI worker.

- The overall radiological risk to worker and general public MEI receptors (estimated by multiplying the risk per occurrence [Table I.11] by the annual probability of occurrence by the number of years of operations) would be less than 1 for all of the disposal accidents.

I.3.2.2 Chemical Impacts

The accidents assessed in this section are listed in Table I.9. The results of the accident consequence modeling in terms of chemical impacts are presented in Tables I.12 and I.13. Results are presented as (1) number of people with the potential for adverse effects and (2) number of people with the potential for irreversible adverse effects. The tables present the results for the accident within each frequency category that would affect the largest number of people (total of noninvolved workers and off-site population) (Policastro et al. 1997). The number of workers and members of the off-site public represent the impacts if the associated accident was assumed to occur. These impacts may be summarized as follows:

- If the accidents identified in Tables I.12 and I.13 did occur, the number of persons in the off-site population with potential for adverse effects and irreversible adverse effects would range from 0 to 1 (MEI), the maximum corresponding to an earthquake accident. The number of workers with potential for adverse effects and irreversible adverse effects would range from 0 to 1, the maximum also corresponding to the earthquake accident.

TABLE I.12 Number of Persons with Potential for Adverse Effects from Accidents under the Disposal Options[a]

Option/Accident[b]	Frequency Category[c]	Maximum Number of Persons[d]: Noninvolved Workers MEI[e]	Maximum Number of Persons[d]: Noninvolved Workers Population	Maximum Number of Persons[d]: General Public MEI[e]	Maximum Number of Persons[d]: General Public Population	Minimum Number of Persons[d]: Noninvolved Workers MEI[e]	Minimum Number of Persons[d]: Noninvolved Workers Population	Minimum Number of Persons[d]: General Public MEI[e]	Minimum Number of Persons[d]: General Public Population
Disposal as Grouted U_3O_8									
Mishandle/drop of drum/billet outside[f]	L	No	0	No	0	No	0	No	0
Earthquake	U	Yes	1	Yes[g]	0	Yes	1	No	0
Fire/explosion inside[f]	EU	No	0	No	0	No	0	No	0
Disposal as Grouted UO_2									
Mishandle/drop of drum/billet outside[f]	L	No	0	No	0	No	0	No	0
Earthquake[f]	U	No	0	No	0	No	0	No	0
Fire/explosion inside[f]	EU	No	0	No	0	No	0	No	0

[a] Values shown are the consequences if the accident did occur. The risk of an accident is the consequence (number of persons) times the estimated frequency times 20 years of operations. The estimated frequencies are as follows: likely (L), 0.1; unlikely (U), 0.001; extremely unlikely (EU), 0.00001; incredible (I), 0.000001.

[b] The bounding accident chosen to represent each frequency category is the one in which the largest number of people (noninvolved workers plus off-site people) would be affected. Health impacts in that row represent that accident only and not the range of impacts among accidents in that category.

[c] Accident frequencies: likely (L), estimated to occur one or more times in 100 years of facility operations ($> 10^{-2}$/yr); unlikely (U), estimated to occur between once in 100 years and once in 10,000 years of facility operations ($10^{-2} - 10^{-4}$/yr); extremely unlikely (EU), estimated to occur between once in 10,000 years and once in 1 million years of facility operations ($10^{-4} - 10^{-6}$/yr); incredible (I), estimated to occur less than one time in 1 million years of facility operations ($< 10^{-6}$/yr).

[d] Maximum and minimum risks reflect different meteorological conditions at the time of the accident. In general, maximum risks would occur under meteorological conditions of F stability with 1 m/s wind speed, whereas minimum risks would occur under D stability with 4 m/s wind speed.

[e] At the MEI location, the determination is either “Yes” or “No” for potential adverse effects to an individual.

[f] These accidents would result in the largest plume sizes, although no people would be affected.

[g] MEI locations were evaluated at 100 m from ground-level releases for noninvolved workers and at the location of highest off-site concentration for members of the general public; the population risks are 0 because generic worker and general public population distributions were used, which did not show receptors at the MEI locations.

TABLE I.13 Number of Persons with Potential for Irreversible Adverse Effects from Accidents under the Disposal Options[a]

Option/Accident[b]	Frequency Category[c]	Maximum Number of Persons[d]				Minimum Number of Persons[d]			
		Noninvolved Workers		General Public		Noninvolved Workers		General Public	
		MEI[e]	Population	MEI[e]	Population	MEI[e]	Population	MEI[e]	Population
Disposal as Grouted U_3O_8									
Mishandle/drop of drum/billet outside[f]	L	No	0	No	0	No	0	No	0
Earthquake	U	Yes	1	Yes[g]	0	No	0	No	0
Fire/explosion inside[f]	EU	No	0	No	0	No	0	No	0
Disposal as Grouted UO_2									
Mishandle/drop of drum/billet outside[f]	L	No	0	No	0	No	0	No	0
Earthquake[f]	U	No	0	No	0	No	0	No	0
Fire/explosion inside[f]	EU	No	0	No	0	No	0	No	0

[a] Values shown are the consequences if the accident did occur. The risk of an accident is the consequence (number of persons) times the estimated frequency times 20 years of operations. The estimated frequencies are as follows: likely (L), 0.1; unlikely (U), 0.001; extremely unlikely (EU), 0.00001; incredible (I), 0.000001.

[b] The bounding accident chosen to represent each frequency category is the one in which the largest number of people (noninvolved workers plus off-site people) would be affected. Health impacts in that row represent that accident only and not the range of impacts among accidents in that category.

[c] Accident frequencies: likely (L), estimated to occur one or more times in 100 years of facility operations (> 10^{-2}/yr); unlikely (U), estimated to occur between once in 100 years and once in 10,000 years of facility operations (10^{-2} – 10^{-4}/yr); extremely unlikely (EU), estimated to occur between once in 10,000 years and once in 1 million years of facility operations (10^{-4} – 10^{-6}/yr); incredible (I), estimated to occur less than one time in 1 million years of facility operations (< 10^{-6}/yr).

[d] Maximum and minimum risks reflect different meteorological conditions at the time of the accident. In general, maximum risks would occur under meteorological conditions of F stability with 1 m/s wind speed, whereas minimum risks would occur under D stability with 4 m/s wind speed.

[e] At the MEI location, the determination is either "Yes" or "No" for potential irreversible adverse effects to an individual.

[f] These accidents would result in the largest plume sizes, although no people would be affected.

[g] MEI locations were evaluated at 100 m from ground-level releases for noninvolved workers and at the location of highest off-site concentration for members of the general public; the population risks are 0 because generic worker and general public population distributions were used, which did not show receptors at the MEI locations.

- There would be no difference in accident consequences for disposal as UO_2 or U_3O_8 in shallow earthen structures, vaults, or a mine.

- The largest impacts would be caused by an earthquake in the product receiving and cement mixing areas. Accidents involving stack emissions would have very small impacts compared with accidents involving releases at ground level due to the large dilution (and lower source terms) involved with the stack emissions.

- For the earthquake accident, the noninvolved worker and the public MEIs could experience potential for both adverse effects and irreversible adverse effects. For all other accidents, the worker and general public MEIs would experience neither potential adverse effects nor potential irreversible adverse effects.

- The maximum risk was computed as the product of the consequence (number of people) times the frequency of occurrence (per year) times the number of years of operations (20 years, 2009 through 2028). The results indicated that the maximum risk values would be less than 1 for all accidents. These risk values are conservative because the numbers of people affected were based on assuming (1) meteorological conditions that would result in the maximum reasonably foreseeable plume size (i.e., F stability and 1 m/s wind speed) and (2) wind in the direction that would lead to maximum numbers of individuals exposed for workers or for the general population.

To aid in the interpretation of accident analysis results, the number of fatalities potentially associated with the estimated potential irreversible adverse effects was estimated. The bounding case accidents shown in Table I.13 would involve releases of uranium oxide and potential exposure to uranium compounds. If the accident occurred, exposures are estimated to result in death for 1% or fewer of the persons experiencing irreversible adverse effects (Policastro et al. 1997). Thus, for noninvolved workers and members of the general public experiencing a range of 0 to 1 irreversible adverse effects, 0 deaths would be expected.

I.3.2.3 Physical Hazards

The risk of on-the-job fatalities and injuries to all disposal facility workers is calculated using industry-specific statistics from the Bureau of Labor Statistics, as reported by the National Safety Council (1995). Construction and manufacturing annual fatality and injury rates were used, respectively, for the construction and operational components of the disposal facility activities.

One fatality due to accidental physical trauma would be predicted under the grouted U_3O_8 mine disposal option. The risk of a fatality for this option is almost twice as great as the risk for the other options; this difference is due mainly to the increased risk associated with construction of the large mine that would be needed for the entire inventory of grouted U_3O_8. Mitigation of risks from construction, loading, and closure of mines can be accomplished to a certain extent by instituting safety measures and by conducting thorough safety training programs for personnel.

Estimated fatalities range from 0.13 to 0.94, and injury incidences range from 90 to 450 (see Table I.14). Except for the grouted U_3O_8 mine disposal option discussed above, the other options are fairly comparable with respect to predicted fatalities and injuries due to physical trauma.

I.3.3 Air Quality

The methodology used to analyze air quality impacts from disposal options is provided in Appendix C and Tschanz (1997). The pollutant concentrations at several distances from the center of the facility were estimated because of uncertainty regarding the size and location of the generic disposal facility. Estimates at 2,460 ft (750 m) from the center of the disposal facilities are comparable to the estimates for options based on representative environmental settings (i.e., conversion and long-term storage options using the three current storage sites as representative of those settings). The shortest distances from the centers of the representative sites to their boundaries range from 2,300 to 2,600 ft (700 to 800 m).

Pollutant emissions would result from construction of the wasteform facility and construction of the disposal areas/facilities. The annual emissions of carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NO_x), sulfur oxides (SO_x), and particulate matter (PM_{10}), with a mean diameter of 10 µm or less) resulting from construction of the wasteform facility and from construction of disposal areas/facilities are shown in Table I.15 for disposal of grouted U_3O_8 in either shallow earthen structures or vaults. The criteria pollutant emissions from construction of facilities for the other disposal options and for operation of the facilities are related to those in Table I.15 by the scaling factors listed in Table I.16. For example, the CO emissions from operations for disposal of grouted UO_2 in shallow earthen structures would be 0.74 × 1.55 tons/yr, or 1.14 tons/yr (1.05 metric tons/yr). Operation of the wasteform facility would also produce 1.08 and 0.59 lb/yr (0.50 and 0.27 kg/yr) of uranium emissions for the grouted UO_2 and grouted U_3O_8 options, respectively.

The largest pollutant concentrations would result from the operation of vaults for disposal of grouted U_3O_8. The estimated NO_x concentrations for operation of this option are shown in the bottom half of Table I.17. The concentrations of CO, HC, SO_x, and PM_{10} are 0.21, 0.075, 0.065, and 0.070 times as large, respectively, as those for NO_x. The results show that the ranges of impacts would be larger for a wet environmental setting than for a dry setting, and in fact the ranges of dry setting impacts fall within those for the wet setting. At 2,460 ft (750 m), the maximum annual NO_x concentration during operations might be as large as 37% of the 100 $\mu g/m^3$ standard. The other

TABLE I.14 Potential Impacts to Human Health from Physical Hazards under Accident Conditions for the Disposal Options

	Impacts to All Disposal Facility Workers[a]					
	Fatality Incidence[b]			Injury Incidence[b]		
Option	Wasteform Facility	Disposal Facility	Total	Wasteform Facility	Disposal Facility	Total
Disposal as Grouted U_3O_8						
Shallow earthen structure	0.15	0.11	0.26	130	80	210
Vault	0.15	0.29	0.44	130	170	300
Mine	0.15	0.78	0.94	130	320	450
Disposal as Ungrouted U_3O_8						
Shallow earthen structure	0.06	0.08	0.13	50	40	90
Vault	0.06	0.17	0.22	50	90	140
Mine	0.06	0.47	0.53	50	190	240
Disposal as Grouted UO_2						
Shallow earthen structure	0.15	0.08	0.23	120	50	180
Vault	0.15	0.11	0.26	120	70	190
Mine	0.15	0.36	0.50	120	160	280
Disposal as Ungrouted UO_2						
Shallow earthen structure	0.06	0.07	0.13	50	40	90
Vault	0.06	0.10	0.15	50	60	110
Mine	0.06	0.27	0.33	50	120	170

[a] Values are rounded to two significant figures. All construction and operations workers at the disposal facilities were included in the physical hazard risk calculations.

[b] Fatality incidence and injury incidence were calculated as the number of full-time-equivalent employees times the annual fatality rate times the number of years. Only injuries involving lost workdays were included. Injury and fatality incidence rates used in the calculations were taken from National Safety Council (1995).

criteria pollutant concentrations are smaller fractions of their standards than is NO_x relative to its standard.

The NO_x concentrations for construction of the grouted U_3O_8 vault disposal option would be 0.35 times those for operation of the vaults and approximately the same as the estimated NO_x concentrations during operations for the disposal of grouted U_3O_8 in shallow earthen structures, shown in Table I.18. During operations for shallow earthen structure disposal of grouted U_3O_8, the CO, HC, SO_x, and PM_{10} impacts would be 0.22, 0.075, 0.066, and 0.070 times as large, respectively, as those for NO_x. The impacts of all of these other pollutants relative to their standards would be less than that of NO_x.

TABLE I.15 Pollutant Emissions from Construction Activities Associated with Disposal Facilities for Grouted U_3O_8[a]

	Pollutant Emissions from Construction Activities (tons/yr)		
Pollutant	Wasteform Facility	Shallow Earthen Structure	Vault
CO	2.11	1.55	2.62
HC	0.739	0.543	0.918
NO_x	9.79	7.18	12.2
SO_x	0.644	0.473	0.799
PM_{10}	0.688	0.505	0.854

[a] Represents emissions from construction of wasteform facility and from construction of either shallow earthen structures or vaults.

The NO_x concentrations from construction of the wasteform facility for grouted U_3O_8 disposal, shown in the upper half of Table I.17, would be slightly smaller than the NO_x concentrations for construction of vaults for grouted U_3O_8 disposal. However, construction of the wasteform facility would result in smaller ranges of impacts because the construction would take place only on a centrally located area; the ranges in this case reflect only the variability due to the different meteorological data sets used. For construction of the wasteform facility, the CO, HC, SO_x, and PM_{10} impacts relative to the NO_x impacts would be the same as those discussed for operation of the shallow earthen structure disposal of grouted U_3O_8.

Construction and operation would occur simultaneously for most of the operational phase. The combined construction and operations emissions might result in annual NO_x concentrations as large as 45 $\mu g/m^3$ at 2,460 ft (750 m) for the vault disposal of grouted U_3O_8, approaching 50% of the standard.

Operation of the wasteform facility would produce 0.6 lb/yr and 1.1 lb/yr of uranium emissions from the process stack for grouted U_3O_8 and grouted UO_2 suboptions, respectively, but no uranium emissions for the ungrouted suboptions. The impacts of uranium oxides emitted during operation of the wasteform facility for grouted disposal options are shown in Table I.19. Comparing the ranges of concentrations for the wet and dry settings indicates that the uranium emissions from the central point source would produce a slightly wider range of impacts for the dry setting than for the wet setting, in contrast to the wider wet setting impact ranges that would result for criteria pollutants from all the construction and operations area sources.

TABLE I.16 Scaling Factors for Criteria Pollutant Emissions from Construction and Operations for Disposal Options Relative to Emissions from Construction Activities Associated with Disposal Facilities for Grouted U_3O_8

	Scaling Factors	
Disposal Facility	Construction	Operations
Wasteform facility		
Grouted U_3O_8	1.00	0.62
Ungrouted U_3O_8	0.28	0.0041
Grouted UO_2	0.51	0.17
Ungrouted UO_2	0.17	0.0041
Shallow earthen structure		
Grouted U_3O_8	1.00	1.85
Ungrouted U_3O_8	0.51	0.87
Grouted UO_2	0.35	0.74
Ungrouted UO_2	0.26	0.56
Vault		
Grouted U_3O_8	1.00	2.87
Ungrouted U_3O_8	0.48	1.38
Grouted UO_2	0.21	1.12
Ungrouted UO_2	0.14	0.75

No quantitative estimate was made of the impacts on the ozone conditions. Ozone formation is a regional issue that would be affected by emissions for the entire area around a proposed disposal site. The pollutants most relevant to ozone formation that would result from the disposal of depleted uranium oxide are HC and NO_x. In later Phase II studies, when specific technologies and sites would be selected, the potential effects on ozone of releases of these pollutants at a proposed site could be evaluated by comparing those releases with the total emissions of HC and NO_x in the surrounding area. Small additional contributions to the regional totals would be unlikely to alter the ozone attainment status of the region.

I.3.4 Water and Soil

Tables I.20 through I.23 summarize the resource requirements for construction and operation of the wasteform facility, shallow earthen structure disposal facility, vault disposal facility, and mine disposal facility, respectively. Examination of these data indicates that the ranking of

TABLE I.17 Maximum NO_x Concentrations at Three Receptor Distances from Construction of the Wasteform Facility and Operation of Vaults for Disposal of Grouted U_3O_8

	Maximum NO_x Concentrations ($\mu g/m^3$)				
Site Environment/ Receptor Distance	1-Hour Average	3-Hour Average	8-Hour Average	24-Hour Average	Annual Average
Wasteform Facility: Construction					
Dry setting					
750 m	160 – 170	59 – 70	27 – 37	11 – 14	1.3 – 2.3
1,000 m	130 – 140	51 – 61	22 – 29	8.4 – 11	0.82 – 1.5
1,500 m	92 – 96	29 – 35	14 – 19	5.5 – 6.9	0.43 – 0.80
Wet setting					
750 m	150 – 250	57 – 110	25 – 57	10 – 25	1.1 – 2.7
1,000 m	120 – 220	49 – 96	20 – 45	7.8 – 20	0.67 – 1.7
1,500 m	84 – 150	27 – 57	13 – 29	5.1 – 13	0.35 – 0.92
Vault for Grouted U_3O_8: Operations					
Dry setting					
750 m	590 – 980	220 – 470	100 – 260	41 – 110	4.6 – 21
1,000 m	480 – 730	190 – 310	84 – 170	32 – 65	2.9 – 8.5
1,500 m	330 – 450	110 – 160	52 – 96	20 – 37	1.5 – 3.0
Wet setting					
750 m	540 – 1,500	210 – 790	95 – 410	38 – 200	3.8 – 37
1,000 m	440 – 1,100	180 – 530	77 – 270	29 – 120	2.4 – 15
1,500 m	310 – 690	110 – 280	48 – 160	19 – 67	1.3 – 5.2

facilities (largest to smallest) on the basis of resource requirements would be as follows: mine, vault, shallow earthen structure, and wasteform facility. For each facility, a secondary ranking indicates that the resource requirements would be consistently larger for disposal of U_3O_8, and grouted forms would require more resources than ungrouted.

Because the disposal option is based on a generic site without a specified location and detailed description, impacts could not be assessed on a site-specific basis; however, the impacts to surface water, groundwater, and soil would follow the same ranking as that for resource needs. For example, construction and operation of a mine disposal facility for U_3O_8 in a grouted form would produce the greatest impacts to the environment; the least impacts would result from construction and operation of the shallow earthen structure for disposal of ungrouted UO_2.

TABLE I.18 Maximum NO_x Concentrations at Three Receptor Distances from Operation of the Shallow Earthen Structure for Disposal of Grouted U_3O_8

	Maximum NO_x Concentrations ($\mu g/m^3$)				
Site Environment/ Receptor Distance	1-Hour Average	3-Hour Average	8-Hour Average	24-Hour Average	Annual Average
Dry setting					
750 m	220 – 330	93 – 160	44 – 89	17 – 37	1.3 – 3.9
1,000 m	170 – 240	67 – 110	32 – 62	12 – 23	0.82 – 1.8
1,500 m	110 – 140	38 – 60	18 – 34	6.7 – 12	0.38 – 0.81
Wet setting					
750 m	200 – 510	90 – 260	41 – 140	16 – 67	1.1 – 6.8
1,000 m	160 – 370	64 – 180	30 – 100	11 – 40	0.68 – 3.2
1,500 m	97 – 220	37 – 100	17 – 55	6.6 – 22	0.35 – 1.3

If the disposal facility was located on a site having an area that was large compared with the size of the facility, and if it was near a river having a minimum flow that was large compared with annual water use and wastewater discharge, impacts to surface water, groundwater, and soil would be negligible. Negligible impacts would occur because a large site and large river could provide sufficient resource buffering to mitigate the effects produced by construction and operation of the facility.

On the other hand, if the site or the minimum flow in the river were small relative to the resource requirements, impacts would be larger. For example, if the minimum flow in the river was 500 gpm, the net annual water withdrawal for operation of the wasteform facility for disposing of grouted U_3O_8 would be about 10% of the flow. The impact of this relative withdrawal could produce moderate impacts to existing floodplains. Similarly, if the mine disposal facility were located on a 500-acre (200-ha) site, paving 94 acres (38 ha) for disposing of depleted uranium as grouted U_3O_8 would permanently alter the soil structure of almost 20% of the land available. This disruption could produce moderate to large impacts to runoff at the site and moderate to large impacts to soil permeability and erosion potential.

More detailed calculations would be performed in the next tier of analyses if a disposal facility option were selected. In general, impacts could be minimized by constructing and operating a facility that would have the smallest resource requirements.

TABLE I.19 Maximum Annual Average Uranium Concentrations in Air during Operation of the Wasteform Facility for Disposal of Grouted Uranium Oxide

Site Environment/ Receptor Distance	Maximum Annual Average Uranium Concentration ($\mu g/m^3$)
Disposal as Grouted UO_2	
Dry setting	
750 m	$1.7 \times 10^{-5} – 3.0 \times 10^{-5}$
1,000 m	$1.2 \times 10^{-5} – 2.1 \times 10^{-5}$
1,500 m	$0.71 \times 10^{-5} – 1.3 \times 10^{-5}$
Wet setting	
750 m	$1.8 \times 10^{-5} – 2.7 \times 10^{-5}$
1,000 m	$1.2 \times 10^{-5} – 2.0 \times 10^{-5}$
1,500 m	$0.76 \times 10^{-5} – 1.3 \times 10^{-5}$
Disposal as Grouted U_3O_8	
Dry setting	
750 m	$0.94 \times 10^{-5} – 1.6 \times 10^{-5}$
1,000 m	$0.66 \times 10^{-5} – 1.2 \times 10^{-5}$
1,500 m	$0.39 \times 10^{-5} – 0.72 \times 10^{-5}$
Wet setting	
750 m	$0.96 \times 10^{-5} – 1.5 \times 10^{-5}$
1,000 m	$0.68 \times 10^{-5} – 1.1 \times 10^{-5}$
1,500 m	$0.42 \times 10^{-5} – 0.70 \times 10^{-5}$

I.3.5 Socioeconomics

The socioeconomic impacts of each disposal option were assessed for a generic site because the location of a disposal facility has not yet been determined. Impacts for each facility are presented for the peak construction year and the first year of operations. Discussion of the assessment methodology is presented in Appendix C and Allison and Folga (1997). Table I.24 shows construction-related impacts (engineering, construction, project management, and site preparation and restoration activities), and operations-related impacts (operation, emplacement and closure, surveillance, and maintenance activities). Impacts for each facility are presented separately. Because the wasteform facility would be utilized to process waste at the disposal site for each disposal option,

TABLE I.20 Summary of Environmental Parameters for the Wasteform Facility

		Disposal as U_3O_8		Disposal as UO_2	
Parameter	Unit	Grouted	Ungrouted	Grouted	Ungrouted
Land area	acres	9.3	4	6.1	4
Disturbed area	acres	9.3	4	6.1	4
Paved area	acres	1.8	1	1.2	1
Water					
Construction	million gal/yr	1.1	0.3	0.7	0.2
Operations	million gal/yr	19.4	0.1	8.2	0.1
Wastewater					
Construction	million gal/yr	0.2	0.1	0.2	0.1
Operations	million gal/yr	1.1	0.1	0.6	0.1
Excavated material	yd^3	32,300	0	21,000	0

TABLE I.21 Summary of Environmental Parameters for the Shallow Earthen Structure Disposal Facility

		Disposal as U_3O_8		Disposal as UO_2	
Parameter	Unit	Grouted	Ungrouted	Grouted	Ungrouted
Land area	acres	76	42	33	24
Disturbed area	acres	70	38	29	20
Paved area	acres	2.7	2.0	1.7	1.5
Water					
Construction	million gal/yr	0.005	0.005	0.003	0.003
Operations	million gal/yr	0.02	0.01	0.01	0.01
Wastewater					
Construction	million gal/yr	0.005	0.005	0.003	0.003
Operations	million gal/yr	0.005	0.005	0.003	0.003
Excavated material	million yd^3	2.6	1.4	1.0	0.7

TABLE I.22 Summary of Environmental Parameters for the Vault Disposal Facility

Parameter	Unit	Disposal as U_3O_8 Grouted	Disposal as U_3O_8 Ungrouted	Disposal as UO_2 Grouted	Disposal as UO_2 Ungrouted
Land area	acres	140	71	35	24
Disturbed area	acres	140	71	35	24
Paved area	acres	19	11	5	4
Water					
Construction	million gal/yr	1.7	0.8	0.4	0.2
Operations	million gal/yr	0.05	0.02	0.02	0.01
Wastewater					
Construction	million gal/yr	0.04	0.02	0.008	0.005
Operations	million gal/yr	0.05	0.02	0.02	0.01
Excavated material	million yd^3	1.7	0.8	0.4	0.3

TABLE I.23 Summary of Environmental Parameters for the Mine Disposal Facility

Parameter	Unit	Disposal as U_3O_8 Grouted	Disposal as U_3O_8 Ungrouted	Disposal as UO_2 Grouted	Disposal as UO_2 Ungrouted
Land area	acres	462	228	143	98
Disturbed area	acres	462	228	143	98
Paved area	acres	94	46	29	20
Water					
Construction	million gal/yr	0.7	0.5	0.4	0.3
Operations	million gal/yr	0.9	0.6	0.5	0.4
Wastewater					
Construction	million gal/yr	0.2	0.07	0.2	0.07
Operations	million gal/yr	0.2	0.1	0.08	0.07
Excavated material	million yd^3	2	1.2	0.9	0.4

the total impact of each option would be the summation of the impacts of the wasteform facility and the impact of each separate option.

I.3.5.1 Disposal as U_3O_8

The impacts of U_3O_8 disposal options in both grouted and ungrouted form on direct employment and income are shown in Table I.24. Construction of a wasteform facility for grouted U_3O_8 would create 360 direct jobs and $15 million in direct income during the peak year of construction in 2006. Operation of the grouted U_3O_8 wasteform facility would create 90 direct jobs and produce $13 million in direct income with the beginning of facility operations in 2009. Construction of a wasteform facility for ungrouted U_3O_8 would create 110 direct jobs and $4 million in direct income during the peak year of construction in 2006. Operation of the ungrouted U_3O_8 wasteform facility would create 40 direct jobs and produce $5 million in direct income annually with the beginning of facility operations in 2009.

Construction of a shallow earthen structure for grouted U_3O_8 would create 10 direct jobs and $1 million in direct income during the peak year of construction in 2008. Waste placement operations for a shallow earthen structure for grouted U_3O_8 would create 50 direct jobs and produce $3 million in direct income annually with the beginning of facility operations in 2009. Construction of a shallow earthen structure for ungrouted U_3O_8 would create less than 5 direct jobs and less than $500,000 in direct income during the peak year of construction in 2008. Operation of a shallow earthen structure for ungrouted U_3O_8 would create 30 direct jobs and produce $2 million in direct income annually with the beginning of facility operations in 2009.

Construction of a vault facility for grouted U_3O_8 would create 180 direct jobs and $8 million in direct income during the peak year of construction in 2008. Waste placement operations for a vault facility for grouted U_3O_8 would create 190 direct jobs and produce $5 million in direct income annually with the beginning of facility operations in 2009. Construction of a vault facility for ungrouted U_3O_8 would create 90 direct jobs and $4 million in direct income during the peak year of construction in 2008. Operation of a vault facility for ungrouted U_3O_8 would create 40 direct jobs and produce $3 million in direct income annually with the beginning of facility operations in 2009.

Construction of a mine facility for grouted U_3O_8 would create 410 direct jobs and $27 million in direct income during the peak year of construction in 2005. Waste placement operations for a mine facility for grouted U_3O_8 would create 190 direct jobs and produce $3 million in direct income annually with the beginning of facility operations in 2009. Construction of a mine facility for ungrouted U_3O_8 would create 300 direct jobs and $20 million in direct income during the peak year of construction in 2005. Operation of a mine facility for ungrouted U_3O_8 would create 30 direct jobs and produce $2 million in direct income with the beginning of facility operations in 2009.

TABLE I.24 Socioeconomic Impacts of U_3O_8 and UO_2 Disposal Facilities

	Disposal of Grouted Form		Disposal of Ungrouted Form	
Option/Location/Activity	Construction[a]	Operations[b]	Construction[a]	Operations[b]
U_3O_8 Disposal Facility				
Wasteform facility				
Direct employment	360	90	110	40
Direct income ($ million 1996)	15	13	4	5
Shallow earthen structure				
Direct employment	10	50	< 5	30
Direct income ($ million 1996)	1	3	< 0.5	2
Vault				
Direct employment	180	90	90	40
Direct income ($ million 1996)	8	5	4	3
Mine				
Direct employment	410	40	300	30
Direct income ($ million 1996)	27	3	20	2
UO_2 Disposal Facility				
Wasteform facility				
Direct employment	220	90	60	40
Direct income ($ million 1996)	9	12	3	5
Shallow earthen structure				
Direct employment	< 5	30	< 5	20
Direct income ($ million 1996)	< 0.5	1	< 0.5	1
Vault				
Direct employment	50	40	30	30
Direct income ($ million 1996)	2	2	1	2
Mine				
Direct employment	270	40	250	30
Direct income ($ million 1996)	18	2	16	2

[a] Impacts in the peak year of construction: 2007 for the wasteform facility; 2009 for the shallow earthen structure and the vault; and 2006 for the mine. Preoperations were assumed to occur from 1999 through 2008, with construction continuing concurrently with waste placement through 2028.

[b] Impacts are the annual average for operations for the period 2009–2028 (20 years).

I.3.5.2 Disposal as UO_2

The impacts of UO_2 disposal options in both grouted and ungrouted form on direct employment and income are shown in Table I.24. Construction of a wasteform facility for grouted UO_2 would create 220 direct jobs and $9 million in direct income during the peak year of construction in 2006. Operation of the grouted UO_2 wasteform facility would create 90 direct jobs and produce $12 million in direct income annually with the beginning of facility operations in 2009. Construction of a wasteform facility for ungrouted UO_2 would create 60 direct jobs and $3 million in direct income during the peak year of construction in 2006. Operation of the ungrouted UO_2 wasteform facility would create 40 direct jobs and produce $5 million in direct income annually with the beginning of facility operations in 2009.

Construction of a shallow earthen structure for grouted UO_2 would create less than 5 direct jobs and less than $500,000 in direct income during the peak year of construction in 2008. Waste placement operations for a shallow earthen structure for grouted UO_2 would create 30 direct jobs and produce $1 million in direct income annually with the beginning of facility operations in 2009. Construction of a shallow earthen structure for ungrouted UO_2 would create less than 5 direct jobs and less than $500,000 in direct income during the peak year of construction in 2008. Operation of a shallow earthen structure for ungrouted UO_2 would create 20 direct jobs and produce $1 million in direct income annually with the beginning of facility operations in 2009.

Construction of a vault facility for grouted UO_2 would create 50 direct jobs and $2 million in direct income during the peak year of construction in 2005. Waste placement operations for a vault facility for grouted UO_2 would create 40 direct jobs and produce $2 million in direct income annually with the beginning of facility operations in 2009. Construction of a vault facility for ungrouted UO_2 would create 30 direct jobs and $1 million in direct income during the peak year of construction in 2005. Operation of a vault facility for ungrouted UO_2 would create 30 direct jobs and produce $2 million in direct income with the beginning of facility operations in 2009.

Construction of a mine facility for grouted UO_2 would create 270 direct jobs and $18 million in direct income during the peak year of construction in 2005. Waste placement operations for a mine facility for grouted UO_2 would create 40 direct jobs and produce $2 million in direct income annually with the beginning of operations in 2009. Construction of a mine facility for ungrouted UO_2 would create 250 direct jobs and $16 million in direct income during the peak year of construction in 2005. Operation of a mine facility for ungrouted UO_2 would create 30 direct jobs and produce $2 million in direct income annually with the beginning of facility operations in 2009.

I.3.6 Ecology

Moderate to large impacts to ecological resources could result from construction of a facility for disposal of U_3O_8 or UO_2. Impacts could include mortality of individual organisms, habitat loss, or changes in biotic communities. Discussion of the methodology used to assess ecological impacts is presented in Appendix C.

I.3.6.1 Disposal as U_3O_8

I.3.6.1.1 Shallow Earthen Structure

Site preparation for the construction of a facility for the disposal of U_3O_8 in shallow earthen structures would require the elimination of approximately 46 acres (18 ha) of habitat for ungrouted U_3O_8 and 85 acres (34 ha) for grouted U_3O_8, including 3 acres (1.1 ha) that would be paved — including the areas required for construction of the wasteform facility, primarily structures and paved areas. Existing vegetation would be destroyed during land clearing activities. The vegetative communities that would be eliminated by site preparation would depend on the actual location of the facility. Although herbaceous vegetation could be reestablished relatively rapidly in a wet setting (with at least 40 in./yr [100 cm/yr] precipitation), such as in the eastern United States, a considerable period of time might be required in a dry setting (less than 10 in./yr [25 cm/yr] precipitation), such as in the western United States. The loss of 46 to 85 acres (18 to 34 ha) of undeveloped land would constitute a moderate adverse impact to vegetation. Erosion of exposed soil at construction sites could reduce the effectiveness of restoration efforts and create sedimentation downgradient of the site. The implementation of standard erosion control measures, installation of storm-water retention ponds, and immediate replanting of disturbed areas with native species would help minimize impacts to vegetation. Impacts due to facility construction are shown in Table I.25.

Wildlife would be disturbed by land clearing, noise, and human presence. Wildlife with restricted mobility, such as burrowing species or juveniles of nesting species, would be destroyed during land clearing activities. Mobile individuals would relocate to adjacent available areas with suitable habitat. Population densities and competition would increase in these areas, potentially reducing the chances of survival or reproductive capacity of displaced individuals. Some wildlife species would be expected to recolonize replanted areas near the disposal facility following completion of construction. However, habitat use in the vicinity of the facility might be reduced for some species due to the construction of a perimeter fence. Therefore, the loss of 85 acres (34 ha) of habitat for the construction of a facility for U_3O_8 disposal in shallow earthen structures would be considered a moderate adverse impact to wildlife.

Wetlands could potentially be impacted by filling or draining during construction. In addition, impacts to wetlands and aquatic habitats due to alteration of surface water runoff patterns, soil compaction, or groundwater flow could occur if the disposal facility was located adjacent to wetland or aquatic areas. However, impacts would be minimized by maintaining a buffer area around wetlands and aquatic habitats during construction of the facility. Unavoidable impacts to wetlands would require a *Clean Water Act* Section 404 permit, which might stipulate mitigative measures. Additional permitting might be required by state agencies. Depending on the facility location, water

TABLE I.25 Impacts to Ecological Resources from Disposal Facility Construction

Option/ Resource	Impacts from Disposal Facility Construction[a]		
	Shallow Earthen Structure	Vault	Mine
Disposal as U_3O_8			
Vegetation	Loss of 46 to 85 acres Moderate adverse impact	Loss of 75 to 149 acres Moderate to large adverse impact	Loss of 232 to 471 acres Large adverse impact
Wildlife	Loss of 46 to 85 acres Moderate adverse impact	Loss of 75 to 149 acres Moderate to large adverse impact	Loss of 232 to 471 acres Large adverse impact
Aquatic	Potential reduction in water quality, habitat	Potential reduction in water quality, habitat	Potential reduction in water quality, habitat
Wetlands	Potential loss, degradation	Potential loss, degradation	Potential loss, degradation
Protected species	Potential destruction, habitat loss	Potential destruction, habitat loss	Potential destruction, habitat loss
Disposal as UO_2			
Vegetation	Loss of 28 to 39 acres Moderate adverse impact	Loss of 28 to 41 acres Moderate adverse impact	Loss of 102 to 149 acres Large adverse impact
Wildlife	Loss of 28 to 39 acres Moderate adverse impact	Loss of 28 to 41 acres Moderate adverse impact	Loss of 102 to 149 acres Large adverse impact
Aquatic	Potential reduction in water quality, habitat	Potential reduction in water quality, habitat	Potential reduction in water quality, habitat
Wetlands	Potential loss, degradation	Potential loss, degradation	Potential loss, degradation
Protected species	Potential destruction, habitat loss	Potential destruction, habitat loss	Potential destruction, habitat loss

[a] All acreages include the wasteform facility.

withdrawal from surface waters or groundwater, as well as wastewater discharge, could potentially alter water levels (Section I.3.4), which could in turn affect aquatic ecosystems, including wetlands, especially those located along the periphery of these surface water bodies.

Prior to construction of a disposal facility, a survey for state and federally listed threatened, endangered, or candidate species, or species of special concern would be conducted so that, if possible, impacts to these species could be avoided. Where impacts were unavoidable, appropriate mitigation could be developed.

Ecological resources in the vicinity of the wasteform facility would be exposed to atmospheric emissions from facility operation; however, emission levels would be expected to be extremely low (Section I.3.3). At 230 ft (750 m) away, the highest annual average air concentration of U_3O_8 due to operation of the facility would be 1.6×10^{-5} µg/m^3. Resulting impacts to biota would be negligible.

Facility accidents, as discussed in Section I.3.2, could result in adverse impacts to ecological resources. The affected species and degree of impact would depend on a number of factors, such as location of the accident, season, and meteorological conditions.

I.3.6.1.2 Vault

The construction and operation of a facility for the disposal of U_3O_8 in vaults would generally result in impacts similar to those associated with shallow earthen structures. However, the size of the facility and area of disturbance for vault disposal would be larger. Disposal in vaults would require the disturbance of approximately 75 to 149 acres (30 to 60 ha) of habitat and 19 acres (8 ha) for paved areas, including the wasteform facility for grouted U_3O_8. This disposal option would also result in elevation of the soil surface by placement of excavated material and in reduction in soil permeability. The consequent decrease in soil moisture would make reestablishment of vegetation difficult and delay the establishment of native plant communities. This disposal option would result in a moderate to large adverse impact to existing vegetation and wildlife. Reestablishment of native vegetation over such a large area would be especially difficult in a dry environmental setting, and a considerable period of time might be required.

I.3.6.1.3 Mine

The construction and operation of a facility for the disposal of U_3O_8 in a mine would generally result in impacts similar to those associated with vaults. However, the mine option would require the disturbance of approximately 232 to 471 acres (93 to 188 ha), including 104 acres (42 ha) for buildings, paved areas, and the wasteform facility for grouted U_3O_8. This disposal option would result in elevation of the soil surface and in reduction in soil permeability. The excavated material would primarily consist of rock removed from the drifts and ramps. The consequent decrease in surface soil moisture would make reestablishment of vegetation difficult and delay the establishment of native plant communities. This disposal option would result in a large adverse impact to existing vegetation and wildlife. Reestablishment of native vegetation over such a large area would be especially difficult in a generic dry western environmental setting, and a considerable period of time might be required.

I.3.6.2 Disposal as UO_2

The construction and operation of a facility for the disposal of UO_2 would generally result in the types of impacts associated with the disposal of U_3O_8; however, the facility sizes would be smaller. A facility for disposal of UO_2 in shallow earthen structures would eliminate approximately 28 to 39 acres (11 to 16 ha) of habitat, including the wasteform facility for grouted UO_2. This habitat loss would result in a moderate adverse impact to vegetation and wildlife. A facility for the disposal of UO_2 in vaults would eliminate approximately 28 to 41 acres (11 to 16 ha) of habitat, including the wasteform facility for grouted UO_2. This loss would result in a moderate adverse impact to vegetation and wildlife. A mine disposal facility for UO_2 would result in disturbance of approximately 102 to 149 acres (41 to 60 ha) of habitat, including the wasteform facility for grouted UO_2. This habitat disturbance would constitute a large adverse impact to vegetation and wildlife.

Atmospheric emissions from wasteform facility operations would be expected to be slightly lower for grouted UO_2 disposal than for grouted U_3O_8 disposal (Section I.3.3). Emissions would be similar for ungrouted UO_2 and U_3O_8 disposal. The highest annual average air concentration of UO_2, due to operation of the facility, would be 0.00003 $\mu g/m^3$ at a distance of 230 ft (750 m) away from the facility. Resulting impacts to biota would be negligible.

I.3.7 Waste Management

Wastes would be generated during the construction of the wasteform facility. This facility would be used for the receipt of waste, grouting of the uranium oxide (if necessary), and storage of both the input and output from the facility. Waste generation would also occur during the construction of any of the three types of disposal facilities. No radioactive wastes would be generated during construction of the wasteform facility or any of the three possible disposal facilities because no radioactive materials would be used and the site would be uncontaminated. Table I.26 lists the various hazardous materials that would be generated in construction of the different types of disposal facilities. Only small differences are expected for the generation of waste for these different disposal options. The waste generated in the construction of any of these disposal facilities represents a negligible impact to DOE's waste management capabilities.

In grouting the converted uranium oxide, operation of the wasteform facility would generate two waste streams: the product (final form of uranium oxide grout) and minor amounts of secondary waste associated with making the final grout product of uranium. Table I.27 lists the volume throughputs of this facility as a function of the four different final form options for uranium. For the ungrouted wasteforms of U_3O_8 and UO_2, this facility would be used only as temporary storage between the conversion and disposal facilities. Consequently, no secondary waste streams would be generated at this facility for the ungrouted U_3O_8 and UO_2 final form options. Table I.28 lists the annual operational wastes from the wasteform facility for each of the four final waste form options (product waste) as well as the secondary waste streams expected from the two grouted waste options. The initial volumes of U_3O_8 and UO_2 listed under facility waste in Table I.28 are equivalent to the

TABLE I.26 Estimated Construction Wastes Generated under the Disposal Options

	U_3O_8 (m^3)		UO_2 (m^3)	
Facility/Waste Type	Grouted	Ungrouted	Grouted	Ungrouted
Wasteform Facility				
Hazardous liquids				
Paints	6.4	2.6	2.2	0.9
Phenol	1.6	0.6	0.6	0.2
Sulfuric acid	0.8	0.3	0.3	0.1
Total	8.8	3.5	3.1	1.2
Hazardous solids				
Mercury lamps	0.8	0.3	0.3	0.1
Lead batteries	0.2	0.1	0.1	0.05
Nonhazardous solids				
Conventional waste	600	240	210	90
Shallow Earthen Structure				
Hazardous liquids				
Paints	1.6	0.6	0.6	0.2
Phenol	0.4	0.2	0.1	0.05
Sulfuric acid	0.2	0.1	0.1	0.05
Total	2.2	0.9	0.8	0.3
Hazardous solids				
Mercury lamps	0.2	0.1	0.1	0.05
Lead batteries	0.05	0.03	0.02	0.01
Nonhazardous solids				
Conventional waste	150	60	60	30
Vault				
Hazardous liquids				
Paints	3.2	1.3	1.1	0.4
Phenol	0.8	0.3	0.3	0.1
Sulfuric acid	0.4	0.2	0.1	0.1
Total	4.4	1.8	1.5	0.6
Hazardous solids				
Mercury lamps	0.4	0.2	0.2	0.1
Lead batteries	0.1	0.04	0.03	0.01
Nonhazardous solids				
Conventional waste	300	120	110	50
Mine				
Hazardous liquids				
Paints	9.6	3.8	3.4	1.4
Phenol	2.4	1.0	0.8	0.3
Sulfuric acid	1.2	0.5	0.4	0.2
Total	13.2	5.3	4.6	1.9
Hazardous solids				
Mercury lamps	16.0	11.2	9.0	7.4
Lead batteries	0.4	0.3	0.2	0.15
Nonhazardous solids				
Conventional waste	900	640	500	420

TABLE I.27 Variations in Wasteform Facility Operations for the Different Final Forms of Uranium

Uranium Type	Throughput Quantity (m^3)	Containers	
		Number	Type
Grouted U_3O_8	312,000	1,560,000	55-gal
Ungrouted U_3O_8	148,800	714,000	55-gal
Grouted UO_2	72,000	630,000	30-gal
Ungrouted UO_2	47,600	420,000	30-gal

final waste volumes expected for the two ungrouted wasteforms because no waste processing would take place in this facility for these two options.

Estimates of the amount of LLW to be disposed of at DOE waste management disposal facilities depend critically upon the time frame under consideration and the types of waste to be included. The *Waste Management Programmatic Environmental Impact Statement* (WM PEIS) estimates that 1,060,000 m^3 of LLW will be disposed of during the time frame 1995-2014 (DOE 1997). This estimate does not include any LLW from environmental restoration activities or facility stabilization activities. A more appropriate value is reported in *The 1996 Baseline Environmental Management Report* (BEMR) (DOE 1996), which estimates the total amount of LLW for treatment at waste management facilities to be 3,400,000 m^3. This estimate is for the next 75 years and includes contributions from environmental restoration and facility stabilization programs.

The majority of environmental restoration wastes are expected to be generated between 2003 and 2033, approximately the correct time frame to compare with the depleted UF_6 program. For this reason, the BEMR estimate was used for comparison with the depleted UF_6 wastes. Adjustments must be made to the BEMR estimate to convert treatment volumes into disposal volumes. Both volume reductions and expansions would occur during waste treatment and grouting, depending on the relative amounts of the different types of waste. On the basis of the WM PEIS analysis (DOE 1997), the BEMR estimate was adjusted to 4,250,000 m^3 for the estimated disposal volume. The total LLW disposal volumes from disposal of depleted uranium, as either UO_2 or U_3O_8 (grouted or ungrouted), were compared with the total estimated disposal volume for LLW for all DOE waste management activities (including environmental restoration waste). Disposal volumes were compared as total volume (m^3) because disposal facilities would typically have no throughput limitations but rather would be limited by the total volume of waste that could be accepted.

For the case of grouted U_3O_8 with a waste volume of 15,600 m^3/yr, the total disposal volume would be [(15,600) × 20 years operation] = 312,000 m^3. This would add about 7.3% to the estimated total DOE LLW disposal volume of about 4,250,000 m^3. Using a similar approach for the other cases would add about 1.7% for grouted UO_2, 3.5% for ungrouted U_3O_8, and 1.1% for

TABLE I.28 Estimated Annual Radioactive Waste Streams from Wasteform Facility Operations

Waste Stream	Treatment	Initial Volume (m^3/yr) Ungrouted U_3O_8	Initial Volume (m^3/yr) Ungrouted UO_2	Final Volume (m^3/yr) Grouted U_3O_8	Final Volume (m^3/yr) Grouted UO_2	Uranium Content (kg)	Treatability Category
Facility waste (product)	Cement solidification	7,440	2,380	15,600	3,600	18,900,000[a]	Not applicable
HEPA filters	Drumming	24	24	24	24	5.7[b]	Noncombustible compactible solid (LLW)
Dry active waste	Dewater/Drum	57	24	24	5.5	760[b]	Combustible solid (LLW)
Inorganic spray solution used to clean drums	Neutralize	0.31	0.2	0.18	0.10	< 1	Low-level mixed waste
Cotton waste wipes used to clean drums[c]	Neutralize	NA	NA	0.0078 m^3 (5 kg)	0.0078 m^3 (5 kg)	< 1	Low-level mixed waste

[a] Uranium content determined by stoichiometry, given in the form of U_3O_8.

[b] Determined by analogy to production facilities.

[c] Final volume based on bulk density of 40 lb/ft^3.

ungrouted UO_2 to the total volume. The amount of low-level mixed waste (LLMW) from depleted UF_6 disposal added to total nationwide LLMW load would be negligible (less than 1%).

Although more secondary wastes would be generated in producing either of the grouted wasteforms of U_3O_8 and UO_2, compared with the ungrouted wasteforms, the differences are not significant. The choice of which wasteform would be used should be based on other factors such as long-term stability of the wasteform, leach rates of the radioactive contaminants, and cost.

Waste generation for the different disposal options is not expected to vary with wet or dry environments. The choice of which disposal option would be used in a wet or dry environment is based on considerations other than waste generation.

Overall, the disposal options would generate appreciable amounts of waste for disposal in DOE facilities. Within the context of the total amount of LLW undergoing disposal in DOE facilities, these wastes would have a low impact on DOE's total waste management disposal capabilities.

I.3.8 Resource Requirements

Resource requirements for the disposal options were estimated for construction and operations. The materials required for monitoring of the groundwater and disposal cell performance would be expected to be minor.

Materials and utilities required for construction and operation of the shallow earthen structure, vault, and mine options are presented in Table I.29. In general, the amount of resources is directly related to the volume of waste to be disposed, with the greatest resources required for the grouted U_3O_8 waste form and least with the ungrouted UO_2 waste form. A fixed facility for solidification is required for the two grouted waste forms, which results in greater construction requirements. During the operations phase, cement and sand are required for solidification of the uranium oxides. The total quantities of commonly used construction materials are not expected to be significant and would be comparable to construction of a multistory building. No specialty materials (e.g., Monel or Inconel) are projected to be needed for either construction or operations phases.

Significant quantities of electrical energy could be required during construction of the mine option because most of the construction equipment utilized in underground mines is powered by electricity to avoid polluting the air in the underground work area. Similarly, a relatively higher annual consumption of electricity is projected during underground operations, compared with the other disposal facility options.

TABLE I.29 Resource Requirements for Construction and Operation of Disposal Facilities

			Resource Requirements for Disposal Facility			
Facility/Activity	Resource	Unit	Grouted U_3O_8	Ungrouted U_3O_8	Grouted UO_2	Ungrouted UO_2
Shallow Earthen Structure						
Construction	Utilities					
	Electricity	MWh	7,700	4,000	3,100	2,300
	Solids					
	Concrete	yd^3	20,000	5,400	10,000	3,200
	Sand	yd^3	124,000	59,400	37,000	25,400
	Steel	tons	1,000	300	600	200
	Liquids					
	Diesel fuel	gal	530,000	260,000	200,000	130,000
Operations	Utilities					
	Electricity	MWh/yr	3,200	1,300	1,800	1,000
	Liquids					
	Diesel fuel	gal/yr	64,000	21,000	23,000	13,000
	Gases					
	Natural gas	million scf/yr	14	5.3	14	5.3
Vault						
Construction	Utilities					
	Electricity	MWh	3,100	1,400	1,000	590
	Solids					
	Concrete	yd^3	410,000	190,000	90,000	56,000
	Sand	yd^3	0	0	0	0
	Steel	tons	10,000	6,000	3,000	2,000
	Liquids					
	Diesel fuel	gal	860,000	400,000	200,000	120,000
Operations	Utilities					
	Electricity	MWh/yr	4,900	2,600	2,500	1,100
	Liquids					
	Diesel fuel	gal/yr	130,000	55,000	50,000	30,000
	Gases					
	Natural gas	million scf/yr	14	5.3	14	5.3

TABLE I.29 (Cont.)

			Resource Requirements for Disposal Facility			
Facility/Activity	Resource	Unit	Grouted U_3O_8	Ungrouted U_3O_8	Grouted UO_2	Ungrouted UO_2
Mine						
Construction	Utilities					
	Electricity	million MWh[a]	10	4.3	2.8	1.9
	Solids					
	Concrete	yd^3	180,000	102,000	83,000	62,000
	Sand	yd^3	0	0	0	0
	Steel	tons	42,000	17,000	18,000	8,900
	Liquids					
	Diesel fuel	gal	300,000	150,000	130,000	90,000
Operations	Utilities					
	Electricity	MWh/yr	110,900	6,600	5,900	4,300
	Liquids					
	Diesel fuel	gal/yr	23,000	2,000	8,000	2,000
	Gases					
	Natural gas	million scf/yr	14	5.3	14	5.3

[a] For the mine disposal facility, the unit of electricity is million MWh compared with MWh for the other disposal options.

I.3.9 Land Use

Land area requirements for each disposal option are presented in Table I.30. These data do not include acreage required for the construction phase for any of the disposal options because development of land would be incremental and space required for material excavation storage, equipment staging, and construction material laydown areas would be available on adjacent undeveloped parcels. Consequently, areal needs for construction would not be greater than those for operations.

Although no site has been chosen for facilities under each disposal option, selection of a site at or near a location that is already dedicated to similar use could result in reduced land-use impacts because immediate access to infrastructure and utility support would be possible with only minor disturbances to existing land use.

All disposal options would include a central wasteform facility where drums of uranium oxide would be received from the conversion facility and prepared for disposal. The facility would

TABLE I.30 Land Requirements and Excavated Material Volumes for Disposal Facilities

	Land Requirement[a] (acres)			
	Disposal as U_3O_8		Disposal as UO_2	
Facility	Grouted	Ungrouted	Grouted	Ungrouted
Shallow earthen structure	85	46	39	28
Vault	149	75	41	28
Mine	471	232	149	102

[a] Values include the wasteform facility areas, as follows: grouted U_3O_8 options, 9 acres, ungrouted U_3O_8 options, 4 acres; grouted UO_2 options, 6 acres; ungrouted UO_2 options, 4 acres.

Source: LLNL (1997).

include a grouting/cementing building, if necessary, which could affect the number of buildings erected for the wasteform facility. Impacts to land use from the wasteform facility would be very small and limited to clearing of required land, as well as potential minor and temporary disruptions to contiguous land parcels. No off-site impacts would be expected.

Land-use impacts resulting from the shallow earthen structure disposal option would be negligible to moderate and limited to clearing of required land and a potential slight increase in off-site vehicular traffic associated with construction activities. The shallow earthen structure option would require from 28 to 85 acres (11 to 34 ha) of land (including the wasteform facility) that would be cleared and developed incrementally. The rate of development would be determined by the selection of the wasteform. Up to 2.62 million yd^3 (2.0 million m^3) would be excavated. The large volume of excavated material that would remain on-site could, over time, result in topographical modifications of the site. Impacts of off-site disposal would be determined during the site-specific tier of NEPA documentation. Other than minor, temporary impacts associated with construction traffic, no other off-site impacts would be expected.

The vault option would require from 28 to 149 acres (11 to 60 ha) of land and would result in up to 1.62 million yd^3 (1.27 million m^3) of excavated material. Because the vault facility would be constructed incrementally (10 vault blocks per year), the amount of land disturbed during a given year would be limited. Impacts of off-site disposal would be determined during the site-specific tier of NEPA documentation.

Of all the disposal options, a mine would have the greatest potential for land-use impacts. A mine would require the largest amount of land, 102 to 471 acres (41 to 188 ha) (see Table I.30).

The construction associated with this option could result in potential land disturbance impacts for adjacent parcels. The large volume of excavated material (1.96 million yd^3 [1.5 million m^3]) would be disposed of on-site, probably resulting in topographical modifications of the site. The peak construction labor force could result in off-site land-use impacts, particularly if a remote site were chosen. Impacts could include pressure on existing commercial land and traffic congestion on local access roads and intersections.

I.3.10 Other Impacts Considered But Not Analyzed in Detail

Other impacts that could potentially occur if the disposal options considered in this PEIS were implemented include impacts to cultural resources and environmental justice, as well as impacts to the visual environment (e.g., aesthetics), recreational resources, and noise levels, and impacts associated with decontamination and decommissioning of the disposal facilities. These impacts, although considered, were not analyzed in detail for one or more of the following reasons:

- The impacts could not be determined at the programmatic level without consideration of specific sites. These impacts would be more appropriately addressed in the second-tier NEPA documentation when specific sites are considered.

- Consideration of these impacts would not contribute to differentiation among the alternatives and, therefore, would not affect the decisions to be made in the Record of Decision to be issued following publication of this PEIS.

I.4 IMPACTS OF OPTIONS — POST-CLOSURE PHASE

This section provides a summary of the potential environmental impacts associated with the post-closure phase of the disposal options. The post-closure phase considers the potential environmental impacts that could occur in the future, well beyond the time that any engineered disposal facility would be expected to function as designed. Post-closure impacts are evaluated because, no matter how well designed, all disposal facilities would be expected to release material to the environment eventually, a condition referred to as “failure.”

Disposal facility failure would generally occur hundreds to thousands of years in the future (assuming no sustained effort to maintain the facility). This failure would be caused by natural degradation of the disposal structures over time, primarily from physical processes such as the intrusion of water. Following failure, the release of uranium from the facility would occur very slowly as water moved through the disposed material. This water would carry dissolved uranium through the soil under the facility, eventually contaminating the groundwater. This process could continue for thousands to millions of years because of the large amount of uranium in the disposal facility and low solubility of that uranium.

In general, shallow earthen structures would be expected to contain the waste material for a period of at least several hundred years before failure. Vaults and a mine would be expected to last even longer, from many hundreds to thousands of years before failure. However, the exact time that a disposal facility would be expected to fail is extremely difficult to predict and would depend on the detailed facility design and site-specific conditions. Because of this difficulty, failure was assumed to occur at the end of a period of institutional control, 100 years after closure. The post-closure impacts were evaluated at 1,000 years after failure for all three disposal facility options.

Post-closure impacts were evaluated in three areas: (1) potential impacts to groundwater, (2) potential impacts to human health and safety, and (3) potential impacts to ecological resources. Impacts in other areas would be expected to be negligible. The following general assumptions apply to the assessment of post-closure impacts:

- All disposal facilities would fail at some time in the future. Failure is defined as the release of uranium material from the disposal facility to the surrounding soil. For consistency, failure was assumed to occur at the end of institutional control, 100 years after closure.

- The post-closure phase primarily considers impacts from the potential contamination of groundwater and surface water. Potential impacts from contamination of air and soil due to erosion of the disposal facility surface are also discussed.

- Impacts were evaluated at a time of 1,000 years after the facility failed and started to release uranium.

- Two generic environmental settings were assumed for the disposal facilities: a dry setting and a wet setting (see Section 3.4.4 for details).

- For analysis of groundwater impacts, assumptions were varied to assess a broad range of possibilities with respect to movement of the uranium through the soil to the groundwater aquifer.

The estimated impacts associated with the post-closure phase are subject to a great deal of uncertainty because the assessment considers an extremely long period of time and depends on predicting the behavior of the waste material as it interacts with soil and water in a complex and changing environment. Consequently, the estimated impacts are very dependent on the assessment assumptions. Key assumptions include such factors as soil characteristics, water infiltration rates, depth to the underlying groundwater table, chemistry of different uranium compounds, and the locations of future human receptors. These factors can vary widely depending on site-specific conditions. Because of these uncertainties, the assumptions were generally selected in a manner intended to produce conservative estimates of impact, that is, the assumptions tend to overestimate the expected impact. Changes in key disposal assumptions could yield significantly different estimates of impact.

I.4.1 Human Health — Normal Operations

I.4.1.1 Radiological Impacts

Radiation doses and cancer risks for the post-closure phase were assessed for a hypothetical individual who would live at or near the disposal site after the institutional control period of the site ended. This individual was assumed to drill a well at the edge of the disposal site and use the well water for drinking, household purposes, irrigating plant foods and fodder, and watering livestock. Because of leaching of uranium from the disposal area to the groundwater table, the hypothetical resident could be exposed to radiation through use of contaminated well water. Detailed discussions of the methodologies used in radiological impact analyses are provided in Cheng et al. (1997). Additional information on the methodology and assumptions used in the groundwater analyses is provided in Section I.4.2.

The estimated groundwater concentrations involve large degrees of uncertainty because of the preliminary nature of facility design and the various soil properties that depend on the location of the facility. The radiological impacts estimated by using the groundwater concentrations are subject to a large degree of uncertainty as well. The groundwater contamination would persist for millions of years once it occurred because of the large inventory of U_3O_8 and UO_2 in the disposal area. Because of the long decay half-lives of uranium isotopes and the continuous generation of decay products, the maximum radiation dose, which could be greater than 1 rem/yr from using contaminated groundwater, would not be observed until sometime after 10,000 years, a time frame well beyond that considered in this analysis. Table I.31 lists the calculated radiation doses and cancer risks for the maximally exposed individual (MEI) 1,000 years after the failure of engineering barriers and waste containers. Although impacts from using the contaminated groundwater at that time could reach 110 mrem/yr, they could be either minimized by treating the groundwater or eliminated by switching to a clean water source.

In addition to the possible exposures resulting from use of contaminated groundwater, radiological impacts could be caused by external radiation and inhalation of contaminated dust particles if all the cover materials above the disposal site were removed and if containers of U_3O_8 or UO_2 disintegrated. This scenario could be caused by natural forces of erosion over long periods of time or by human intervention (i.e., digging) to bring the waste to the surface. The associated external radiation dose could be as high as 10 rem/yr for an individual living on the disposal site. However, the exposure would not occur until several thousand years after closure of the shallow earthen structure or vault disposal facility and would be quite unlikely for mine disposal because a mine would be located at a depth of several hundred feet below the ground surface. Detailed analyses for this exposure scenario were not conducted because it is beyond the time frame considered in this

TABLE I.31 Human Health Impacts for the MEI from Disposal Options: Post-Closure Phase

	Radiological Impacts at 1,000 Years[b,c]				Chemical Impacts at 1,000 Years[b,c]	
	MEI Dose (mrem/yr)		MEI Risk (LCF/yr)		MEI Hazard Index[d]	
Option/ Location[a]	Grouted Oxide	Ungrouted Oxide	Grouted Oxide	Ungrouted Oxide	Grouted Oxide	Ungrouted Oxide
Disposal as U_3O_8						
Shallow earthen structure						
Dry	0	0	0	0	0	0
Wet	49 – 72	41 – 60	2×10^{-5} – 4×10^{-5}	2×10^{-5} – 3×10^{-5}	5.9 – 8.7	5.0 – 7.3
Vault						
Dry	0	0	0	0	0	0
Wet	57 – 84	48 – 70	3×10^{-5} – 4×10^{-5}	2×10^{-5} – 4×10^{-5}	6.9 – 10	5.8 – 8.5
Mine						
Dry	0	0	0	0	0	0
Wet	0.88 – 110	0.72 – 93	4×10^{-7} – 6×10^{-5}	4×10^{-7} – 5×10^{-5}	0.1 – 14	0.1 – 11
Disposal as UO_2						
Shallow earthen structure						
Dry	0	0	0	0	0	0
Wet	37 – 54	34 – 50	2×10^{-5} – 3×10^{-5}	2×10^{-5} – 3×10^{-5}	4.5 – 6.6	4.1 – 6.0
Vault						
Dry	0	0	0	0	0	0
Wet	38 – 56	34 – 50	2×10^{-5} – 3×10^{-5}	2×10^{-5} – 3×10^{-5}	4.6 – 6.7	4.2 – 6.1
Mine						
Dry	0	0	0	0	0	0
Wet	0.64 – 84	0.59 – 77	3×10^{-7} – 4×10^{-5}	2×10^{-7} – 4×10^{-5}	0.1 – 10	0.1 – 9.3

[a] Two generic environmental settings were considered for each option, corresponding to dry and wet environments, respectively.

[b] Impacts are reported as ranges, which result from different transport speeds of radionuclides in the unsaturated and saturated zones. Retardation factors of 5 and 50 were used to represent relatively mobile and immobile transport situations, respectively. Values correspond to estimated impacts 1,000 years after failure of the engineering barriers and containers.

[c] The maximally exposed individual was assumed to live at the edge of the disposal site and use contaminated groundwater for drinking, irrigating plant foods and fodder, and feeding livestock. The exposure pathways considered were ingestion of drinking water, plant foods, meat, and milk; and, for radiological exposures, inhalation of radon emanating from household water.

[d] The hazard index is an indicator for potential adverse health effects other than cancer; a hazard index of greater than 1 indicates a potential for adverse health effects and a need for further evaluation.

analysis. If any exposure occurred, the radiation dose could be eliminated by adding new cover materials to the top of the waste area.

I.4.1.1.1 Disposal as U_3O_8

Radiological impacts are presented in Table I.31 for a scenario in which an individual uses contaminated groundwater. In a dry setting, it would take more than 10,000 years for uranium and its decay products to reach the groundwater because of the low water infiltration rate. Therefore, no radiation exposure would occur before 1,000 years in a dry environment, the time frame considered in this analysis.

In a wet setting, the required time for uranium and decay products to reach the groundwater table could be less than 1,000 years after the failure of the disposal facility. The groundwater concentrations would vary from site to site, depending on the specific soil properties (which determine whether the uranium and decay products travel rapidly or slowly in soil). As a result, at 1,000 years after failure of the disposal facility, the radiation dose from using groundwater could range from 41 to 72 mrem/yr for disposal in shallow earthen structures, 48 to 84 mrem/yr for disposal in vaults, and 0.72 to 110 mrem/yr for disposal in a mine. With no remediation effort, the radiation dose could exceed the dose limit of 25 mrem/yr set for low-level waste disposal (10 CFR Part 61). Variation of radiation doses among different disposal types is related to the size of the disposal facility. More discussions are provided in Section I.4.2 regarding the effect of facility dimensions on groundwater concentrations.

I.4.1.1.2 Disposal as UO_2

Variations in disposal settings and disposal types have the same effects on the groundwater concentrations for UO_2 disposal as they do on the groundwater concentrations for U_3O_8 disposal. The time required for uranium and decay products to reach the groundwater table would be greater than 10,000 years for a dry setting, so no impacts would be expected within 1,000 years. The radiation doses estimated for a wet setting for disposal of UO_2 tend to be smaller than those for disposal of U_3O_8 because the waste volume of UO_2 would be less than the volume of U_3O_8 and would require a smaller disposal facility. The doses estimated for use of groundwater range from 34 to 54 mrem/yr for disposal in shallow earthen structures, 34 to 56 mrem/yr for disposal in vaults, and 0.59 to 84 mrem/yr for disposal in a mine at 1,000 years after failure of the disposal facility. With no remediation effort, the exposure could exceed the dose limit of 25 mrem/yr set for low-level waste disposal.

I.4.1.2 Chemical Impacts

Chemical impacts during the post-closure phase are assessed for a hypothetical individual who lives at the border of the disposal site after the institutional control period is over. As for the radiological assessment, potential chemical impacts to human health were evaluated for a scenario involving a hypothetical individual who drills a well at the edge of the disposal site and uses the well water for drinking, irrigating plant foods and fodder, and watering livestock. Leaching of uranium from the disposal area to the groundwater table could potentially result in the hypothetical resident being exposed to uranium from ingestion of drinking water, plant foods, meat, and milk. Risks are estimated on the basis of calculated hazard indices. Information on the exposure assumptions, health effects assumptions, reference doses used for uranium compounds, and calculational methods used in the chemical impact analysis are provided in Appendix C and Cheng et al. (1997).

I.4.1.2.1 Disposal as U_3O_8

Potential health impacts to the general public MEI from exposures to hazardous chemicals due to use of groundwater are presented in Table I.31. Two disposal options are evaluated: disposal as grouted U_3O_8 and ungrouted U_3O_8. The hazard indices for chemical impacts in a dry environment are always zero because the time required for the uranium to reach the groundwater would be greater than 10,000 years due to the low water infiltration rate. In a wet environmental setting, the time to reach groundwater would be less than 1,000 years, but would be dependent on the soil properties (i.e., retardation factor). A retardation factor of 5 results in the uranium reaching the groundwater more quickly and consequently producing greater chemical exposures at 1,000 years than would occur with a retardation factor of 50.

The range of hazard indices for all types of disposal facilities in a wet setting is about 0.1 to 14, exceeding the threshold of 1 for potential adverse health effects. The highest values are for mines, which would require the largest disposal area; and the lowest values are for shallow earthen structures, which would require the smallest disposal area. On the basis of maximum hazard indices, potential chemical impacts are greater for disposal as grouted waste than as ungrouted waste because of the larger waste volume that would be required. Among the groundwater-related exposure pathways that were analyzed, ingestion of drinking water is responsible for more than 80% of the total uranium exposure.

I.4.1.2.2 Disposal as UO_2

Potential human health impacts to the general public MEI from exposures to hazardous chemicals due to groundwater use are presented in Table I.31. Two disposal options were evaluated: disposal as grouted UO_2 and ungrouted UO_2. Differences in environmental settings and types of disposal facilities result in the same variations in groundwater concentrations for UO_2 disposal as they do in the groundwater concentrations for U_3O_8 disposal. Because the waste volume of UO_2

would be less than the volume of U_3O_8, the estimated maximum chemical exposures for UO_2 disposal are consistently less than those for U_3O_8 disposal.

The range of hazard indices for all types of UO_2 disposal facilities in a wet setting is about 0.1 to 10, exceeding the threshold of 1 for potential adverse health effects. The highest values are for mines, which would require the largest disposal area; and the lowest values are for shallow earthen structures, which would require the smallest disposal area. Based on maximum hazard indices, potential chemical impacts are greater for disposal as grouted waste because of the larger waste volume that would be required compared with disposal as ungrouted waste.

I.4.2 Groundwater

Potential impacts to groundwater for the three disposal options during the post-closure phase only include changes in groundwater quality. There would be no impacts to effective recharge, depth to groundwater, or the direction of groundwater flow.

I.4.2.1 Shallow Earthen Structure

During the post-closure period, the only potential impacts to groundwater would be to water quality. With time, the roof material would and allow water to infiltrate the disposal facility. This water could corrode the drums and permit leaching of their contents. Although both forms of the disposed material (U_3O_8 and UO_2) are essentially insoluble in water (LLNL 1997), a conservative estimate of dissolution was obtained by assuming that schoepite ($UO_3{\cdot}H_2O$) would form under the aerobic conditions present in the structure.

With additional time (several hundred to thousands of years), the facility would fail completely, and dissolved schoepite would infiltrate the soil beneath the structure and interact with soil water present in the unsaturated zone. For the shallow earthen structure, this soil water would have a nearly neutral pH (about 7). For the ungrouted case, this interaction would have no impact, and the dissolved schoepite would move vertically downward toward the water table. Transport of the schoepite would be influenced by advection, dispersion, adsorption, and decay (Tomasko 1997).

For the grouted wastes, schoepite was again assumed to form at a concentration equal to its equilibrium value, although carbonates might also form, depending on the type of grout used and site-specific conditions. Because schoepite is about two million times more soluble under the high pH conditions that would occur for the grouted forms of the waste (pH between 10 and 12), the disposed material would dissolve at greatly different rates. However, once the schoepite reached the groundwater, its concentration would be oversaturated relative to the soil water, and it would precipitate and then slowly redissolve. After redissolving, it would be transported vertically downward through the unsaturated zone in the same way that transport would occur for the ungrouted case (Tomasko 1997).

At the water table, schoepite would mix with initially clean water in the uppermost groundwater aquifer and be diluted. After mixing and dilution, the contaminants would be transported in a direction consistent with natural flow. Advection, dispersion, adsorption, and decay would again influence the transport process (Tomasko 1997).

Uranium concentrations and activities at the water table for a wet environmental setting are summarized in Table I.32 for 1,000 years after failure. Values are shown for lateral distances of 0 and 1,000 ft (300 m) downgradient of the facility. For a dry setting, the concentrations would be very small (nearly zero) and are not shown. Additional details on the calculations for the dry location are presented in Tomasko (1997).

The highest uranium groundwater concentrations (270 pCi/L; 1,100 µg/L) would result from a grouted U_3O_8 wasteform; the lowest concentrations (188 pCi/L; 760 µg/L) would result from ungrouted UO_2 (see Table I.32). All of the predicted concentrations would exceed the U.S. Environmental Protection Agency (EPA) proposed maximum contaminant level (MCL) of 20 µg/L (EPA 1996) used for comparison. In all cases, concentrations from grouted wasteforms would be higher than those from ungrouted forms over the long term. This result occurs because a larger facility would be required for the grouted wastes, which would, in turn, reduce the amount of subsequent dilution when the leachate mixes with water in the underlying aquifer. Impacts to groundwater quality could be reduced by decreasing the size of the facility in a direction parallel to the direction of groundwater flow, thereby increasing dilution. The relative concentrations for the decay products formed during transport are reported in Tomasko (1997).

Varying the distance to the receptor from 0 to 1,000 ft (300 m) would have no effect on concentrations if the uranium was relatively mobile in the soil (a retardation of 5 [Table I.32]). This result occurs because of hydrological conditions present in the soil beneath the facility in the wet environment (Tomasko 1997). If the uranium was less mobile and had a retardation coefficient of 50, the concentration at 1,000 years at a lateral distance of 1,000 ft (300 m) would be about 100 times less than the concentration directly below the edge of the facility (0 ft) (Table I.32).

I.4.2.2 Vault

The disposal vault would be located in a dry or wet environment. Because of the design of the facility with a concrete slab roof and other engineered barriers (LLNL 1997), the vault would be expected to have an effective life ranging from several hundred years to tens of thousands of years. Failure of this facility would parallel the failure process described for the shallow earthen structure, and the only impacts to groundwater would be changes in quality once the facility failed completely.

Uranium concentrations in groundwater at 1,000 years for distances of 0 and 1,000 ft (300 m) from the edge of the vault are given in Table I.32. As for the shallow earthen structure, concentrations in the dry environment would be nearly zero, and are not presented here. At 1,000 years, uranium concentrations for a relatively mobile uranium species (retardation coefficient

TABLE I.32 Uranium Activity and Schoepite Concentration in Groundwater for the Disposal Options at 1,000 Years in a Wet Environmental Setting: Retardation Factor = 5 or 50[a]

	Uranium Activity (pCi/L) at Two Distances from Edge of Disposal Facility			
	X = 0 ft		X = 1,000 ft	
Option/Uranium Oxide	Rf = 5	Rf = 50	Rf = 5	Rf = 50
Shallow earthen structure				
Grouted U_3O_8	270	184	270	2.4
Ungrouted U_3O_8	226	154	226	2.0
Grouted UO_2	204	139	204	1.8
Ungrouted UO_2	188	128	188	1.7
Vault				
Grouted U_3O_8	315	214	315	2.8
Ungrouted U_3O_8	264	180	264	2.4
Grouted UO_2	209	142	209	1.9
Ungrouted UO_2	189	129	189	1.7
Mine				
Grouted U_3O_8	425	3.3	425	0
Ungrouted U_3O_8	350	2.7	350	0
Grouted UO_2	316	2.4	316	0
Ungrouted UO_2	289	2.2	289	0

	Schoepite ($UO_3 \cdot 2H_2O$) Concentration (µg/L) at Two Distances from Edge of Disposal Facility			
	X = 0 ft		X = 1,000 ft	
Option/Uranium Oxide	Rf = 5	Rf = 50	Rf = 5	Rf = 50
Shallow earthen structure				
Grouted U_3O_8	1,100	740	1,100	9.7
Ungrouted U_3O_8	910	620	910	8.1
Grouted UO_2	820	560	820	7.3
Ungrouted UO_2	760	520	760	6.9
Vault				
Grouted U_3O_8	1,300	860	1,300	11
Ungrouted U_3O_8	1,100	730	1,100	9.7
Grouted UO_2	840	570	840	7.7
Ungrouted UO_2	760	520	760	6.9
Mine				
Grouted U_3O_8	1,700	13	1,700	0
Ungrouted U_3O_8	1,400	11	1,400	0
Grouted UO_2	1,300	9.7	1,300	0
Ungrouted UO_2	1,200	8.9	1,200	0

[a] The retardation factor (Rf) describes how readily a contaminant such as uranium moves through the soil to the groundwater. An Rf of 5 represents a case in which the uranium moves relatively rapidly through the soil, whereas an Rf of 50 represents a case in which the uranium moves very slowly through the soil.

of 5) would be the same at 0 and 1,000 ft (300 m) downstream of the facility because of the hydrological characteristics of the saturated zone (Tomasko 1997). The maximum concentration of uranium would be 315 pCi/L (1,300 µg/L) for grouted U_3O_8, and the minimum concentration (189 pCi/L; 760 µg/L) would occur for ungrouted UO_2 (Table I.32). These values would exceed the proposed EPA MCL of 20 µg/L (EPA 1996) used for comparison. The differences in concentrations between the different wasteforms primarily results from differences in the size of the facility. That is, the larger the facility, the greater the concentration because of decreased dilution. Impacts to groundwater quality could be reduced by decreasing the size of the facility in a direction parallel to the direction of groundwater flow, thereby increasing dilution (Tomasko 1997).

If the uranium were less mobile in the saturated zone and had a retardation coefficient of 50, uranium concentrations at 1,000 ft (300 m) would be about 100 times less than the concentration directly below the edge of the facility. Because of design considerations (size of the facility), the concentrations from the vault would be greater than those from the shallow earthen structure by about a factor of 1.2 (Tomasko 1997).

I.4.2.3 Mine

For disposal in a mine, waste would be placed in a mine hundreds of feet below the ground surface to minimize intrusion and potential erosion of a surface cap. The effective life of the mine would be expected to be thousands of years. As with the shallow earthen structure and vault, the only impacts to groundwater would be to quality once the facility failed completely.

If the disposal site were located in a dry environment, all of the resulting uranium concentrations at 1,000 years would be nearly zero (Tomasko 1997). In a wet climate, the uranium concentrations would all greatly exceed the proposed EPA MCL if the uranium was mobile (retardation coefficient of 5) (Table I.32) because the distance from the bottom of the mine to the top of the next lower aquifer was assumed to be small (100 ft). If the schoepite was less mobile (retardation coefficient of 50), uranium concentrations in groundwater after 1,000 years would be much less than the EPA proposed MCL and would be the smallest of all the disposal options considered (Table I.32) because the mine was assumed to be located at a distance of 100 ft (30 m) from the water table, whereas the shallow earthen structure and vault were assumed to be 30 ft (9.1 m) from the underlying aquifer. Impacts to groundwater quality could be reduced by decreasing the size of the facility in a direction parallel to the direction of groundwater flow, thereby increasing dilution (Tomasko 1997).

I.4.3 Ecology

Predicted concentrations of contaminants in groundwater were compared to benchmark values of toxic and radiological effects to assess impacts to biota. Discussion of assessment methodology is presented in Appendix C.

I.4.3.1 Disposal as U_3O_8

The disposal facilities considered would be expected to adequately prevent the release of their contents for considerable periods of time. Impacts to ecological resources due to the presence of the facility would not be expected to occur prior to facility failure. Failure of facility integrity would result in contamination of groundwater if the facility was located in a wet environmental setting (typical of the eastern United States, with at least 40 in./yr [100 cm/yr] precipitation). Groundwater could discharge to the surface (such as in wetland areas) near the facility, thus exposing biota to contaminants. Groundwater concentrations of schoepite ($UO_3 \cdot 2H_2O$) were calculated for 1,000 years after facility failure (Section I.4.2). Schoepite concentrations would be nearly zero throughout the time period analyzed for a disposal facility located in a dry environmental setting (typical of the western United States, with less than 10 in./yr [25 cm/yr] precipitation). Ecological impacts are summarized in Table I.33.

Failure of a shallow earthen structure disposal facility would result in groundwater concentrations of schoepite near the facility ranging from 3.1×10^{-6} to 1.1×10^{-3} g/L (0.003 to 1.5 ppm). Soluble uranium compounds can produce toxic effects in aquatic biota at concentrations as low as 1.5×10^{-4} g/L (0.15 ppm). An organism continuously exposed to the undiluted groundwater could therefore be adversely impacted by the toxic effects of uranium. Uranium activity would range from 2.0 to 270 pCi/L (Section I.4.2). Resulting dose rates to maximally exposed organisms would be less than 0.015 rad/d, less than 2% of the dose limit of 1 rad/d for aquatic organisms specified in DOE Order 5400.5.

Failure of a facility for disposal in vaults would result in groundwater concentrations of schoepite ranging from 9.7×10^{-6} to 1.3×10^{-3} g/L (0.01 to 1.3 ppm). Therefore an organism continuously exposed to this undiluted groundwater could be adversely impacted by the toxic effects of uranium. Uranium activity would range from 2.4 to 315 pCi/L (Section I.4.2). Resulting dose rates to maximally exposed organisms would be less than 0.015 rad/d, less than 2% of the dose limit of 1 rad/d.

Failure of a mine disposal facility would result in groundwater concentrations ranging from 0 to 1.7×10^{-3} g/L (1.7 ppm). Adverse impacts to aquatic biota could result from exposure to soluble uranium compounds within this concentration range. Uranium activity would range from 0 to 425 pCi/L (Section I.4.2). Resulting dose rates to maximally exposed organisms would be less than 0.015 rad/d, less than 2% of the dose limit of 1 rad/d.

I.4.3.2 Disposal as UO_2

Groundwater schoepite concentrations resulting from the failure of a facility for disposal of UO_2 would also be nearly zero at 1,000 years for a facility in a dry environmental setting. Groundwater concentrations for disposal of UO_2 in a wet environmental setting would be similar to those for disposal of U_3O_8.

TABLE I.33 Potential Radiological and Chemical Impacts to Aquatic Biota due to Failure of a Disposal Facility

Option/Contaminant	Maximum Exposure	Effect
Disposal as U_3O_8		
Shallow earthen structure		
Uranium in groundwater	2.0 to 270 pCi/L	Negligible
Uranium in groundwater	3.1×10^{-6} to 1.1×10^{-3} g/L	Moderate
Vault		
Uranium in groundwater	2.4 to 315 pCi/L	Negligible
Uranium in groundwater	9.7×10^{-6} to 1.3×10^{-3} g/L	Moderate
Mine		
Uranium in groundwater	0 to 425 pCi/L	Negligible
Uranium in groundwater	0 to 1.7×10^{-3} g/L	Negligible to moderate
Disposal as UO_2		
Shallow earthen structure		
Uranium in groundwater	1.7 to 204 pCi/L	Negligible
Uranium in groundwater	6.9×10^{-6} to 8.2×10^{-4} g/L	Moderate
Vault		
Uranium in groundwater	1.7 to 209 pCi/L	Negligible
Uranium in groundwater	6.9×10^{-6} to 8.4×10^{-4} g/L	Moderate
Mine		
Uranium in groundwater	0 to 316 pCi/L	Negligible
Uranium in groundwater	0 to 1.3×10^{-3} g/L	Negligible to moderate

Failure of a shallow earthen structure facility would result in groundwater concentrations of schoepite near the facility ranging from 6.9×10^{-6} to 8.2×10^{-4} g/L (0.007 to 0.82 ppm). Soluble uranium compounds can produce toxic effects in aquatic biota at concentrations as low as 1.5×10^{-4} g/L (0.15 ppm). An organism continuously exposed to the undiluted groundwater could be adversely impacted by the toxic effects of uranium. Uranium activity would range from 1.7 to 204 pCi/L (Section I.4.2). Resulting dose rates to maximally exposed organisms would be less than 0.015 rad/d, less than 2% of the dose limit of 1 rad/d.

Failure of a facility for disposal in vaults would result in groundwater concentrations of schoepite ranging from 6.9×10^{-6} to 8.4×10^{-4} g/L (0.007 to 0.84 ppm). Therefore, an organism continuously exposed to this undiluted groundwater could be adversely impacted by the toxic effects of uranium. Uranium activity would range from 1.7 to 209 pCi/L (Section I.4.2). Resulting dose rates to maximally exposed organisms would be less than 0.015 rad/d, less than 2% of the dose limit of 1 rad/d.

Failure of a mined cavity disposal facility would result in groundwater schoepite concentrations ranging from 0 to 1.3×10^{-3} g/L (1.3 ppm). Adverse impacts to aquatic biota could result from exposure to soluble uranium compounds within this concentration range. Uranium activity would range from 0 to 316 pCi/L (Section I.4.2). Resulting dose rates to maximally exposed organisms would be considerably lower than the dose limit of 1 rad/d.

I.5 REFERENCES FOR APPENDIX I

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