D. PALMROSE STAFF EXHIBIT 2

NIRS/PC EC-4

DOE/EIS-0269

FINAL PROGRAMMATIC ENVIRONMENTAL IMPACT STATEMENT FOR ALTERNATIVE STRATEGIES FOR THE LONG-TERM MANAGEMENT AND USE OF DEPLETED URANIUM HEXAFLUORIDE

Volume 2: Appendices

April 1999

U.S. Department of Energy
Office of Nuclear Energy, Science and Technology

APPENDIX F:

ENVIRONMENTAL IMPACTS OF OPTIONS FOR CONVERSION OF UF_6 TO OXIDE OR METAL

CONTENTS (APPENDIX F)

CONTENTS (Cont.)

TABLES

TABLES (Cont.)

TABLES (Cont.)

FIGURE

NOTATION (APPENDIX F)

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

CFR	*Code of Federal Regulations*
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
LCF	latent cancer fatality
LLMW	low-level mixed waste
LLNL	Lawrence Livermore National Laboratory
LLW	low-level radioactive waste
MEI	maximally exposed individual
NEPA	*National Environmental Policy Act*
NPDES	National Pollutant Discharge Elimination System
NRC	U.S. Nuclear Regulatory Commission
PEIS	programmatic environmental impact statement
PM_{10}	particulate matter with a mean diameter of 10 μm or less
ROI	region of influence

Chemicals

AlF_3	aluminum trifluoride
CaF_2	calcium fluoride
CO	carbon monoxide
Fe	iron
HC	hydrocarbons
HF	hydrogen fluoride
HNO_3	nitric acid
Mg	magnesium
MgF_2	magnesium fluoride
NO_2	nitrogen dioxide
NO_x	nitrogen oxides
TCE	trichloroethylene
SO_2	sulfur dioxide
UF_4	uranium tetrafluoride
UF_6	uranium hexafluoride

UO_2	uranium dioxide
UO_2F_2	uranyl fluoride
U_3O_8	triuranium octaoxide (uranyl uranate)

UNITS OF MEASURE

°F	degree(s) Fahrenheit	μg	microgram(s)
Ci	curie(s)	m	meter(s)
cm	centimeter(s)	m^3	cubic meter(s)
cm^3	cubic centimeter(s)	mg	milligram(s)
d	day(s)	min	minute(s)
ft	foot (feet)	mrem	millirem(s)
ft^2	square foot (feet)	MW	megawatt(s)
g	gram(s)	MWh	megawatt hour(s)
gal	gallon(s)	pCi	picocurie(s)
gpm	gallon(s) per minute	ppm	part(s) per million
GWh	gigawatt hour(s)	psia	pound(s) per square inch absolute
ha	hectare(s)	rad	radiation absorbed dose(s)
in.	inch(es)	rem	roentgen equivalent man
kg	kilogram(s)	s	second(s)
km	kilometer(s)	scf	standard cubic foot (feet)
L	liter(s)	ton(s)	short ton(s)
lb	pound(s)	yr	year(s)

APPENDIX F:

ENVIRONMENTAL IMPACTS OF OPTIONS FOR CONVERSION OF UF_6 TO OXIDE OR METAL

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 conversion options considered in the PEIS. The discussion provides background information for the conversion options, as well as a summary of the estimated environmental impacts associated with each option.

Conversion Options

Conversion of depleted UF_6 to another chemical form is required for a number of storage, use, and disposal management alternatives. The principal conversion options considered in the PEIS are as follows:

Conversion to U_3O_8. This chemical form is a stable, low-solubility oxide considered for storage and disposal. Two different technologies were considered for conversion to U_3O_8.

Conversion to UO_2. This stable, low-solubility oxide is considered for storage, disposal, and potential use as shielding material. Three different technologies were considered for conversion to UO_2.

Conversion to Metal. Metallic depleted uranium is considered for use as shielding material. Two different technologies were considered for conversion to metal.

Conversion of depleted UF_6 to another chemical form is required for most alternative management strategies. Three different conversion options have been considered in the PEIS: (1) conversion to triuranium octaoxide (U_3O_8), (2) conversion to uranium dioxide (UO_2), and (3) conversion to uranium metal. The specific conversion option considered under each of the alternatives is shown in Table F.1. Because of their high chemical stability and low solubility, uranium oxides (i.e., U_3O_8 and UO_2) are considered for the storage and disposal alternatives. High-density UO_2 and uranium metal are considered for the use alternatives (e.g., spent nuclear fuel radiation shielding applications). Other details concerning the characteristics of the different chemical forms of uranium are given in Appendix A.

Conversion of depleted UF_6 to another chemical form would take place at a stand-alone industrial plant dedicated to the conversion process. A representative conversion plant layout is shown in Figure F.1; the actual plant layout would depend on the specific conversion option and technology selected, as well as on certain site characteristics. In general, the plant would be capable of receiving depleted UF_6 cylinders on trucks or railcars, temporarily storing a small inventory of

TABLE F.1 Summary of the Conversion Options Considered for Each Programmatic Management Alternative

	Option Considered for Management Alternative[a]					
		Long-Term Storage		Use		
Option	No Action	UF_6	Oxide	Uranium Oxide	Uranium Metal	Disposal
Conversion to U_3O_8	–	–	X	–	–	X
Conversion to UO_2	–	–	X	X	–	X
Conversion to metal	–	–	–	–	X	–

[a] X = option considered; – = option not considered.

full cylinders, processing the depleted UF_6 to another chemical form, and storing the converted uranium product and any other products until shipment off-site. The empty cylinders would be stored until transfer to a cylinder treatment facility, which is assumed to be located at the conversion plant site. It is estimated that a typical conversion plant would cover an area of approximately 20 acres (8 ha) (Lawrence Livermore National Laboratory [LLNL] 1997).

In general, potential environmental impacts would occur (1) during construction of a conversion facility, (2) during operations of the facility, and (3) during postulated accidents. The potential impacts associated with facility construction would result from typical land-clearing and construction activities. Potential impacts during operations would occur primarily to workers during handling operations and to the public as a result of routine releases of small amounts of contaminants through exhaust stacks and treated liquid effluent discharges. In addition, potential impacts to workers and the public from processing or storage might occur as a result of accidents that release hazardous materials.

The environmental impacts from the conversion options were evaluated based on the information described in the engineering analysis report (LLNL 1997). For each of the three conversion options (conversion to U_3O_8, UO_2, or metal), the engineering analysis report provides preconceptual facility design data, including descriptions of facility layouts; resource requirements; estimates of effluents, wastes, and emissions; and estimates of potential accident scenarios. Within each conversion option, several technologies or chemical processes that could be used to produce the same uranium end product are described (two are considered for conversion to U_3O_8, three for conversion to UO_2, and two for conversion to metal). Some of these technologies have not been demonstrated on a commercial scale but were considered to provide an estimate of the range of the

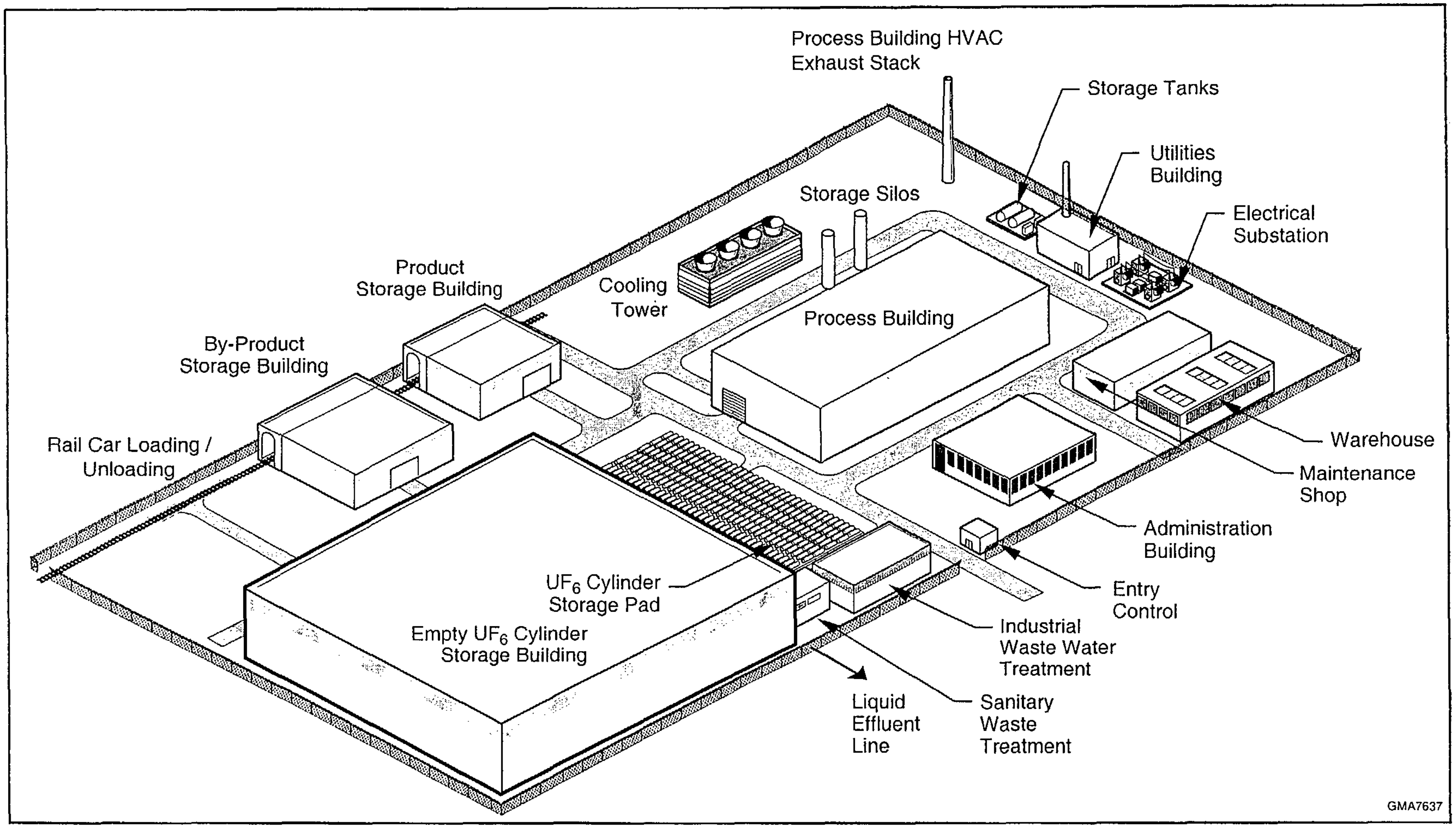

FIGURE F.1 Representative Site Layout for a Conversion Facility

environmental impacts that might be associated with each of the conversion options. All facility designs were based on a single plant sized to process the entire inventory of DOE-generated depleted UF_6 cylinders over a 20-year period (approximately 2,300 cylinders per year).

F.1 SUMMARY OF CONVERSION OPTION IMPACTS

A summary of the potential environmental impacts associated with the conversion options is provided in this section. These potential impacts are not site-specific because the location of a conversion facility, if required at all, would not be decided until some time in the future. For assessment purposes, the environmental impacts were determined for a range of environmental conditions represented by those at the three current depleted UF_6 storage sites.

The potential environmental impacts for the three conversion options are compared in Table F.2. For each conversion option, the potential environmental impacts are presented as a range within each area of impact. This range is intended to provide a reasonable estimate of the magnitude of impacts, taking into account the uncertainty relative to the specific technologies and sites that could ultimately be selected for conversion. The range of impacts results from two factors: (1) fundamental differences among the technologies within each conversion option; and (2) differences in the conditions at the three representative sites that were evaluated. A more detailed assessment of specific technologies and site conditions will be conducted, as appropriate, as part of the second phase (tier) of the programmatic *National Environmental Policy Act* (NEPA) approach. Additional discussion and details related to the assessment methodologies and results for individual areas of impact are provided in the remaining sections of this appendix.

F.2 DESCRIPTION OF OPTIONS

This section provides a brief summary of the different conversion options considered in the assessment of conversion impacts (Table F.3). 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 estimates of potential accident scenarios.

All of the conversion options would involve the removal of depleted UF_6 from the storage cylinders, resulting in a large number of empty cylinders. These empty cylinders would contain approximately 22 lb (10 kg) of depleted UF_6 (Charles et al. 1991), called "heels." For assessment purposes, it has been assumed that a cylinder treatment facility would be constructed to wash the empty cylinders. This facility has been assumed to be an independent, or "stand-alone," facility, although it could be integrated directly into the design of the conversion plant. The facility would be co-located with the conversion plant.

TABLE F.2 Summary of Conversion Option Impacts

Impacts from Conversion to U_3O_8	Impacts from Conversion to UO_2	Impacts from Conversion to Metal	Impacts from Cylinder Treatment[a]
	Human Health – Normal Operations: Radiological		
Involved Workers: Total collective dose: 820 person-rem	**Involved Workers:** Total collective dose: 980 – 1,100 person-rem	**Involved Workers:** Total collective dose: 650 – 1,300 person-rem	**Involved Workers:** Total collective dose: 320 person-rem
Total number of LCFs: 0.3 LCF	Total number of LCFs: 0.4 LCF	Total number of LCFs: 0.3 – 0.5 LCF	Total number of LCFs: 0.1 LCF
Noninvolved Workers: Annual dose to MEI: $1.6 \times 10^{-3} - 5.8 \times 10^{-3}$ mrem/yr	**Noninvolved Workers:** Annual dose to MEI: $3.2 \times 10^{-3} - 2.2 \times 10^{-2}$ mrem/yr	**Noninvolved Workers:** Annual dose to MEI: $6.8 \times 10^{-4} - 1.7 \times 10^{-2}$ mrem/yr	**Noninvolved Workers:** Annual dose to MEI: $4.9 \times 10^{-6} - 1.8 \times 10^{-5}$ mrem/yr
Annual cancer risk to MEI: $6 \times 10^{-10} - 2 \times 10^{-9}$ per year	Annual cancer risk to MEI: $1 \times 10^{-9} - 9 \times 10^{-9}$ per year	Annual cancer risk to MEI: $3 \times 10^{-10} - 7 \times 10^{-9}$ per year	Annual cancer risk to MEI: $2 \times 10^{-12} - 7 \times 10^{-12}$ per year
Total collective dose: 0.043 – 0.09 person-rem	Total collective dose: 0.084 – 0.34 person-rem	Total collective dose: 0.018 – 0.27 person-rem	Total collective dose: $1.3 \times 10^{-4} - 2.7 \times 10^{-4}$ person-rem
Total number of LCFs: $2 \times 10^{-5} - 4 \times 10^{-5}$ LCF	Total number of LCFs: $3 \times 10^{-5} - 1 \times 10^{-4}$ LCF	Total number of LCFs: $7 \times 10^{-6} - 1 \times 10^{-4}$ LCF	Total number of LCFs: $5 \times 10^{-8} - 1 \times 10^{-7}$ LCF
General Public: Annual dose to MEI: $4.9 \times 10^{-3} - 8.8 \times 10^{-3}$ mrem/yr	**General Public:** Annual dose to MEI: $9.7 \times 10^{-3} - 3.3 \times 10^{-2}$ mrem/yr	**General Public:** Annual dose to MEI: $2.1 \times 10^{-3} - 2.6 \times 10^{-2}$ mrem/yr	**General Public:** Annual dose to MEI: $1.5 \times 10^{-5} - 2.7 \times 10^{-5}$ mrem/yr
Annual cancer risk to MEI: $2 \times 10^{-9} - 4 \times 10^{-9}$ per year	Annual cancer risk to MEI: $5 \times 10^{-9} - 2 \times 10^{-8}$ per year	Annual cancer risk to MEI: $1 \times 10^{-9} - 1 \times 10^{-8}$ per year	Annual cancer risk to MEI: $8 \times 10^{-12} - 1 \times 10^{-11}$ per year
Total collective dose to population within 50 miles: 0.79 – 2.7 person-rem	Total collective dose to population within 50 miles: 1.6 – 10 person-rem	Total collective dose to population within 50 miles: 0.34 – 8.0 person-rem	Total collective dose to population within 50 miles: 0.0024 – 0.0082 person-rem
Total number of LCFs in population within 50 miles: 0.0004 – 0.001 LCF	Total number of LCFs in population within 50 miles: 0.0008 – 0.005 LCF	Total number of LCFs in population within 50 miles: 0.0002 – 0.004 LCF	Total number of LCFs in population within 50 miles: $1 \times 10^{-6} - 4 \times 10^{-6}$ LCF

TABLE F.2 (Cont.)

Impacts from Conversion to U_3O_8	Impacts from Conversion to UO_2	Impacts from Conversion to Metal	Impacts from Cylinder Treatment[a]
	Human Health – Normal Operations: Chemical		
Noninvolved Workers: No impacts	**Noninvolved Workers:** No impacts	**Noninvolved Workers:** No impacts	**Noninvolved Workers:** No impacts
General Public: No impacts	**General Public:** No impacts	**General Public:** No impacts	**General Public:** No impacts
	Human Health – Accidents: Radiological		
Bounding accident frequency: 1 in 10,000 years to 1 in 1 million years	Bounding accident frequency: 1 in 10,000 years to 1 in 1 million years	Bounding accident frequency: 1 in 10,000 years to 1 in 1 million years	Bounding accident frequency: 1 in 10,000 years to 1 in 1 million years
Noninvolved Workers: Bounding accident consequences (per occurrence): Dose to MEI: 9.2 rem Risk of LCF to MEI: 4×10^{-3} Collective dose: 840 person-rem Number of LCFs: 0.3	**Noninvolved Workers:** Bounding accident consequences (per occurrence): Dose to MEI: 2.3 rem Risk of LCF to MEI: 9×10^{-4} Collective dose: 210 person-rem Number of LCFs: 0.08	**Noninvolved Workers:** Bounding accident consequences (per occurrence): Dose to MEI: 0.02 rem Risk of LCF to MEI: 8×10^{-6} Collective dose: 7.5 person-rem Number of LCFs: 3×10^{-3}	**Noninvolved Workers:** Bounding accident consequences (per occurrence): Dose to MEI: 0.43 rem Risk of LCF to MEI: 2×10^{-4} Collective dose: 38 person-rem Number of LCFs: 0.02
General Public: Bounding accident consequences (per occurrence): Dose to MEI: 0.27 rem Risk of LCF to MEI: 1×10^{-4} Collective dose to population within 50 miles: 20 person-rem Number of LCFs in population within 50 miles: 0.01 LCF	**General Public:** Bounding accident consequences (per occurrence): Dose to MEI: 0.068 rem Risk of LCF to MEI: 3×10^{-5} Collective dose to population within 50 miles: 5.1 person-rem Number of LCFs in population within 50 miles: 0.003 LCF	**General Public:** Bounding accident consequences (per occurrence): Dose to MEI: 0.015 rem Risk of LCF to MEI: 7×10^{-6} Collective dose to population within 50 miles: 56 person-rem Number of LCFs in population within 50 miles: 0.03 LCF	**General Public:** Bounding accident consequences (per occurrence): Dose to MEI: 0.013 rem Risk of LCF to MEI: 7×10^{-6} Collective dose to population within 50 miles: 2.5 person-rem Number of LCFs in population within 50 miles: 0.001 LCF

TABLE F.2 (Cont.)

Impacts from Conversion to U_3O_8	Impacts from Conversion to UO_2	Impacts from Conversion to Metal	Impacts from Cylinder Treatment[a]
	Human Health – Accidents: Chemical		
Bounding accident frequency: less than once in 1 million years	Bounding accident frequency: less than once in 1 million years	Bounding accident frequency: less than once in 1 million years	Bounding accident frequency: 1 in 10,000 years to 1 in 1 million years
Noninvolved Workers: Bounding accident consequences (per occurrence):	**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: 1,100 persons	Number of persons with potential for adverse effects: 1,100 persons	Number of persons with potential for adverse effects: 1,100 persons	Number of persons with potential for adverse effects: 1 person
Number of persons with potential for irreversible adverse effects (bounding accident frequency: 1 in 10,000 years to 1 in 1 million years): 440 persons	Number of persons with potential for irreversible adverse effects (bounding accident frequency: 1 in 10,000 years to 1 in 1 million years): 440 persons	Number of persons with potential for irreversible adverse effects (bounding accident frequency: 1 in 10,000 years to 1 in 1 million years): 440 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):	**General Public:** Bounding accident consequences (per occurrence):
Number of persons with potential for adverse effects: 41,000 persons	Number of persons with potential for adverse effects: 41,000 persons	Number of persons with potential for adverse effects: 41,000 persons	Number of persons with potential for adverse effects: 0 persons
Number of persons with potential for irreversible adverse effects: 1,700 persons	Number of persons with potential for irreversible adverse effects: 1,700 persons	Number of persons with potential for irreversible adverse effects: 1,700 persons	Number of persons with potential for irreversible adverse effects: 0 persons
	Human Health — Accidents: Physical Hazards		
Construction and Operations: **All Workers:** Less than 1 (0.35) fatality, approximately 290 injuries	**Construction and Operations:** **All Workers:** Less than 1 (0.59) fatality, approximately 490 injuries	**Construction and Operations:** **All Workers:** Less than 1 (0.55) fatality, approximately 490 injuries	**Construction and Operations:** **All Workers:** Less than 1 (0.19) fatality, approximately 170 injuries

TABLE F.2 (Cont.)

Impacts from Conversion to U_3O_8	Impacts from Conversion to UO_2	Impacts from Conversion to Metal	Impacts from Cylinder Treatment[a]
		Air Quality	
Construction: 24-hour PM_{10} concentration potentially as large as 65% of standard. Concentrations of other criteria pollutants all below 15% of respective standards.	**Construction:** 24-hour PM_{10} concentration potentially as large as 90% of standard. Concentrations of other criteria pollutants all below 30% of respective standards.	**Construction:** 24-hour PM_{10} concentration potentially as large as 90% of standard. Concentrations of other criteria pollutants all below 20% of respective standards.	**Construction:** 24-hour PM_{10} concentration potentially as large as 25% of standard. Concentrations of other criteria pollutants all below 10% of respective standards.
Operations: 8-hour CO concentration potentially as large as 3% of standard.	**Operations:** 8-hour CO concentration potentially as large as 5% of standard.	**Operations:** 8-hour CO concentration potentially as large as 5% of standard.	**Operations:** Concentrations of all criteria pollutants below 0.06% of respective standards.
		Water	
Construction: None to negligible physical impacts; concentrations less than applicable standards	**Construction:** None to negligible physical impacts; concentrations less than applicable standards	**Construction:** None to negligible physical impacts; concentrations less than applicable standards	**Construction:** None to negligible physical impacts; concentrations less than applicable standards
Operations: None to negligible physical impacts to surface water and groundwater; concentrations less than applicable standards	**Operations:** None to negligible physical impacts to surface water and groundwater; concentrations less than applicable standards	**Operations:** None to negligible physical impacts to surface water and groundwater; concentrations less than applicable standards	**Operations:** None to negligible physical impacts to surface water and groundwater; concentrations less than applicable standards
		Soil	
Construction: None to negligible impacts	**Construction:** None to negligible impacts	**Construction:** None to negligible impacts	**Construction:** None to negligible impacts
Operations: None to negligible physical impacts; concentrations less than applicable guidelines	**Operations:** None to negligible physical impacts; concentrations less than applicable guidelines	**Operations:** None to negligible physical impacts; concentrations less than applicable guidelines	**Operations:** None to negligible physical impacts; concentrations less than applicable guidelines

TABLE F.2 (Cont.)

Impacts from Conversion to U_3O_8	Impacts from Conversion to UO_2	Impacts from Conversion to Metal	Impacts from Cylinder Treatment[a]
	Socioeconomics		
Construction: Negligible to low impacts to ROI employment and population growth rates, vacant housing, and public finances	**Construction:** Negligible to low impacts to ROI employment and population growth rates and to public finances; potential moderate impacts to vacant housing	**Construction:** Negligible to low impacts to ROI employment and population growth rates, vacant housing, and public finances.	**Construction:** Negligible to low impacts to ROI employment and population growth rates, vacant housing, and public finances.
Operations: Negligible to low impacts to ROI employment and population growth rates, vacant housing, and public finances	**Operations:** Negligible to low impacts to ROI employment and population growth rates and to public finances; potential moderate impacts to vacant housing	**Operations:** Negligible to low impacts to ROI employment and population growth rates, vacant housing, and public finances.	**Operations:** Negligible to low impacts to ROI employment and population growth rates, vacant housing, and public finances.
	Ecology		
Construction: Potential moderate impacts to vegetation and wildlife	**Construction:** Potential moderate impacts to vegetation and wildlife	**Construction:** Potential moderate impacts to vegetation and wildlife	**Construction:** Potential moderate impacts to vegetation and wildlife
Operations: Negligible impacts	**Operations:** Negligible impacts	**Operations:** Negligible impacts	**Operations:** Negligible impacts
	Waste Management		
Potential moderate impacts to site, regional, or national waste management operations	Potential moderate impacts to site, regional, or national waste management operations	Potential moderate impacts to site, regional, or national waste management operations	Potential moderate impacts to national waste management operations

TABLE F.2 (Cont.)

Impacts from Conversion to U_3O_8	Impacts from Conversion to UO_2	Impacts from Conversion to Metal	Impacts from Cylinder Treatment[a]
		Resource Requirements	
No impacts from resource requirements (such as electricity or materials) on the local or national scale	No impacts from resource requirements (such as electricity or materials) on the local or national scale	No impacts from resource requirements (such as electricity or materials) on the local or national scale	No impacts from resource requirements (such as electricity or materials) on the local or national scale
		Land Use[b]	
Construction: Use of approximately 20 acres; negligible impacts	**Construction:** Use of approximately 22 to 31 acres; negligible impacts	**Construction:** Use of approximately 23 to 26 acres; negligible impacts	**Construction:** Use of approximately 9 acres; negligible impacts
Operations: Use of approximately 13 acres; negligible impacts	**Operations:** Use of approximately 14 to 20 acres; negligible impacts	**Operations:** Use of approximately 15 to 16 acres; negligible impacts	**Operations:** Use of approximately 5 acres; negligible impacts

[a] These impacts must be added to those for each of the conversion options.

[b] Land-use acreages given as maximum for a single site or facility. Conversion facilities would also need to establish protective action distances encompassing about 960 acres around the facility.

Notation: CO = carbon monoxide; LCF = latent cancer fatality; MEI = maximally exposed individual; PM_{10} = particulate matter with a mean diameter of 10 μm or less; ROI = region of influence.

TABLE F.3 Summary of Technologies Considered under Each Conversion Option

Conversion Option	Technologies
Conversion to U_3O_8	- Defluorination with anhydrous HF production - Defluorination with HF neutralization
Conversion to UO_2	- Dry process with anhydrous HF production - Dry process with HF neutralization - Gelation process
Conversion to metal	- Batch metallothermic reduction - Continuous metallothermic reduction

Following removal of the depleted UF_6, the emptied cylinders containing "heels" would be stored for about 3 months to allow the level of radioactivity associated with the decay products of uranium that remained after UF_6 withdrawal to decrease to acceptable levels. Subsequently, in the proposed cylinder treatment facility, the emptied cylinders are first washed with water and the resulting aqueous wash solution is evaporated and converted to solid U_3O_8 and hydrogen fluoride (HF). The U_3O_8 would be packaged and sent either for disposal or storage. The HF would be neutralized to calcium fluoride (CaF_2) and separately packaged for disposal or sale.

It was assumed that the treated cylinders with a very low residual radiation level would become part of the DOE scrap metal inventory. A report by Nieves et al. (1997) analyzed the potential health and cost impacts associated with various options for the empty cylinders after treatment, including recycle into low-level radioactive waste (LLW) disposal containers, reuse as LLW containers, free release for remelting, and disposal (i.e., burial) as LLW. Health endpoints assessed included chemical risks, radiation risks, and trauma risks. The estimated total health risks over 20 years of processing ranged from 0.1 to 0.8 total fatality for the various options. The potential health impacts were similar for each of the options; however, the disposal option was considered to have the greatest adverse environmental impacts because it would require land allocations and removal of the metal mass from any further usefulness.

F.2.1 Conversion to U_3O_8

A "dry" process, referred to as defluorination, is well established and currently used by industry. It is also practiced on a large-scale industrial basis by Cogema in France. In this process, UF_6 is chemically decomposed with steam and heat to produce U_3O_8 and concentrated HF. The U_3O_8 would then be compacted to achieve a bulk density of about 3 g/cm^3 prior to storage or disposal.

Two technologies were considered for management of the HF following conversion of UF_6 to U_3O_8. The first process would upgrade the concentrated HF to anhydrous HF for sale. Anhydrous HF is a valuable product; one potential use for HF is in the production of UF_6 from natural uranium ore for feedstock to the gaseous diffusion process. The second process would neutralize the HF to CaF_2 for disposal or sale, depending on whether the CaF_2 with trace amounts of uranium could be marketed.

Because of the considerable market for anhydrous HF, the technology of defluorination with anhydrous HF production would minimize waste and increase product value. However, the handling, storage, and transportation of large quantities of anhydrous HF pose a potential hazard to both workers and the public. During the conversion process, the HF would be upgraded to anhydrous HF by distillation, a common industrial process. Based on historical experience, it is anticipated that the anhydrous HF would contain only trace amounts of depleted uranium (less than 1 ppm, or 0.4 pCi/g) (LLNL 1997). Thus, it was assumed that the anhydrous HF could be sold commercially for unrestricted use.

The process of HF neutralization with lime would convert the concentrated HF to CaF_2 for disposal or possible sale. This step would avoid the potential hazards associated with the processing, general handling, storage, and transportation of large quantities of anhydrous HF. However, the value of CaF_2 is significantly less than that of anhydrous HF, and large quantities of lime are required for neutralization, which would add to the cost of the neutralization option. It is also unknown whether the CaF_2 produced would be sold, disposed of as nonhazardous solid waste, or disposed of as LLW. If disposal were required, there could be moderate impacts to waste management (see Section F.3.7).

F.2.2 Conversion to UO_2

The conversion of UF_6 to UO_2 is used in the nuclear fuel fabrication industry. The UF_6 is converted to a low-density UO_2 powder by either a "wet" or "dry" process. "Wet" processes are based upon separation of solid UO_2 from an aqueous solution, whereas "dry" processes are based upon decomposing and reducing the UF_6. The resulting powder is pressed into a pellet under high pressure, and the pellet is sintered (agglomerated) at high temperatures to yield a dense solid. Depending on the shape, size, and size distribution, the bulk density of UO_2 will generally be 6 to 9 g/cm^3.

Three technologies were considered for the conversion of UF_6 to UO_2. A generic industrial dry process with conversion to produce centimeter-sized pellets is the basis for the first two technologies. The first process would upgrade the concentrated HF to anhydrous HF for sale, similar to the U_3O_8 process. The second process would neutralize the HF to CaF_2 for disposal or sale. The third process is a "wet" process, based on pilot-scale studies, and is referred to as the gelation process.

In the dry process, gaseous UF_6 would be chemically reacted with steam to produce solid uranyl fluoride (UO_2F_2) and HF. The UO_2F_2 would then be converted to UO_2 powder through a combination of chemical reactions. Using standard physical treatment operations (milling, compacting, and screening) and the addition of a dry lubricant, the UO_2 powder would be pressed into dense pellets with a bulk density of about 6 g/cm^3. The HF would be upgraded to anhydrous HF for commercial resale, as described in Section F.2.1. In the other dry process, the HF would be neutralized to CaF_2 rather than upgraded to anhydrous HF.

In the gelation process, small, dense spheres of UO_2 would be produced through a combination of chemical processes beginning with the conversion of UF_6 to UO_2F_2 and anhydrous HF. The solid UO_2F_2 would then be reacted with steam to produce U_3O_8 and additional anhydrous HF. The U_3O_8 would be dissolved in nitric acid, mixed with other chemicals, and chilled to form a feed broth. This broth would be formed into droplets and fed into a column of hot chlorinated hydrocarbon liquid. Once these droplets formed into spheres, they would be removed from the hot liquid and washed. The droplets would then be dried and converted by heating to dense uranium oxide. The final sintered uranium dioxide spheres are expected to have a density of about 95% or greater of the theoretical maximum density of uranium dioxide, resulting in a bulk density of about 9 g/cm^3. The gelation process has not been demonstrated on a commercial scale.

F.2.3 Conversion to Metal

The conversion of UF_6 to uranium metal would use a commercial process called metallothermic reduction. During this process, UF_6 would react with both hydrogen and magnesium metal to produce uranium metal, anhydrous HF, and magnesium fluoride ($MgFl_2$; slag). Two technologies were considered: a batch reduction process, which is the method used to date, and a continuous reduction process, which is under development and has not been demonstrated on a commercial scale.

In the batch metallothermic reduction process, the UF_6 would be mixed with hydrogen gas in a vertical reaction vessel to form uranium tetrafluoride (UF_4) and HF. The anhydrous HF would be recovered and stored for sale. The UF_4 powder and an excess of magnesium would be contained in a sealed metal vessel and preheated. Once initiated, the reaction would produce molten uranium metal (collecting at the bottom of the reactor) and less dense molten MgF_2 slag. The cycle time per batch (about 12 hours total) would be dominated by the heating and cooling periods. A large number of reactors would be required because of the long cycle time. The slag would be ground, screened, and prepared for disposal. Any metal pellets would be recovered for recycle.

In the continuous metallothermic reduction process, the UF_6 would be mixed with hydrogen gas in a vertical reaction vessel to form UF_4 and HF. The anhydrous HF would be recovered and stored for sale. A mixture of UF_4, magnesium (Mg), iron (Fe), and salt would be continuously fed into the top of a heated reactor. The more dense molten uranium/iron compound would settle to the bottom of the reactor where it would be continuously withdrawn. The lower density MgF_2/salt mixture would float on top and be separately withdrawn. The molten uranium/iron compound would then be cast into ingots or the end-product form if the manufacturing function was integrated into the conversion facility. The molten salt mixture would be cooled and ground and the water-soluble salt dissolved. After evaporation and drying, the salt would be recycled to the reactor. The insoluble MgF_2 would be drummed for disposal. The annual throughput of the continuous metallothermic reduction reactor would be greater than a batch reactor, requiring fewer reactors.

Neutralization of HF to CaF_2 was not explicitly analyzed in the engineering analysis report for the conversion to metal options (LLNL 1997). However, the process could be implemented and would produce approximately one-third as much CaF_2 as would be produced under the conversion to oxide with neutralization options.

F.2.4 Conversion Technologies and Chemical Forms Considered But Not Analyzed in Detail

The conversion technologies analyzed in the engineering analysis report (LLNL 1997) and the PEIS are those with a sufficient technical basis to carry out preconceptual designs. A number of other promising conversion technologies were considered, but, with minor exceptions, these are in the early stages of conceptualization or development. These options are also discussed in the engineering analysis report (LLNL 1997).

For conversion to an oxide form, technologies considered but not analyzed in detail include a molten metal catalyzed process; the Cameco process (patent pending), which uses a different chemical process than steam hydrolysis/pyrolysis; a conversion process that produces a by-product of aluminum trifluoride (AlF_3); and a defluorination process that results in the production of hydrofluorocarbons. For conversion to metal, a plasma dissociation process was considered but not analyzed in detail.

F.3 IMPACTS OF OPTIONS

This section provides a summary of the potential environmental impacts associated with the conversion options, including impacts from construction and facility operations. For each area of impact, a description of the assessment methodology (including models) is provided in Appendix C.

The environmental impacts from the conversion options were evaluated based on the information described in the engineering analysis report (LLNL 1997). The following general assumptions apply to all conversion facility operations:

- All facility designs were based on a single conversion plant sized to process the entire inventory of DOE-generated depleted UF_6 cylinders over a 20-year period (approximately 2,300 cylinders per year).
- The conversion plant was assumed to operate 24 hours per day, 7 days per week, 52 weeks per year, with 20% down-time.
- A "stand-alone" cylinder treatment facility (for empty cylinders) is collocated with the conversion plant.

The location of a conversion facility at one of the three current storage sites, if required at all, would not be decided until some time in the future. Instead, for each conversion option, the environmental impacts were calculated separately for a single hypothetical facility located at each of the three current depleted UF_6 storage sites. The three current storage sites were used to provide a reasonable range of environmental conditions. A more detailed assessment of site considerations would be addressed, as appropriate, as part of the second phase (tier) of the programmatic NEPA approach.

For each conversion option, the potential environmental impacts are presented as a range within each area of impact. This range is intended to provide a reasonable estimate of the magnitude of impacts, taking into account the uncertainty relative to the specific technologies and sites that would ultimately be selected for conversion. The range of impacts results from two factors: (1) fundamental differences among the technologies within each conversion option and (2) differences in the site conditions.

F.3.1 Human Health — Normal Operations

F.3.1.1 Radiological Impacts

Radiological impacts to involved workers during normal operations at conversion facilities would result primarily from external radiation from the handling of depleted uranium materials. Impacts to noninvolved workers and members of the public would result primarily from trace amounts of uranium compounds released to the environment. Detailed discussions of the methodologies used in radiological impact analysis are provided in Appendix C and in Cheng et al. (1997).

F.3.1.1.1 Conversion to U_3O_8

Conversion to U_3O_8 would result in average radiation exposure of about 300 mrem/yr to involved workers and less than 0.01 mrem/yr to noninvolved workers and members of the public. Radiation doses and cancer risks associated with normal operations of the U_3O_8 conversion facilities are listed in Tables F.4 and F.5, respectively. The two conversion technologies evaluated are described in Section F.2.1. Due to the similarity of the conversion processes, the airborne emission rates of uranium compounds and the material handling activities are expected to vary only slightly from each other, resulting in similar radiological impacts.

Involved Workers. Radiation exposures for the involved workers are estimated according to the descriptions of material handling activities provided in the engineering analysis report (LLNL 1997). Due to the preliminary nature of each facility design, the estimated radiation doses are subject to a large degree of uncertainty. The results presented in this appendix should be used only for purposes of comparison among different technologies. Radiation exposure of involved workers would be monitored by a dosimetry program and maintained below regulatory limits.

The collective dose for involved workers is estimated to be about 41 person-rem/yr for 135 workers for the U_3O_8 conversion processes. This would result in about 0.02 excess latent cancer fatalities (LCFs) per year (or about 2 LCFs over a 100-year period) among the involved workers. If evenly distributed among involved workers, the average individual dose would be approximately 300 mrem/yr, well below the regulatory limit of 5,000 mrem/yr for workers (10 *Code of Federal Regulations* [CFR] Part 835). This corresponds to an average cancer risk of about 1×10^{-4} per year (1 chance in 10,000 of developing 1 LCF per year).

Noninvolved Workers. Estimated doses and health risks are much lower for noninvolved workers than for involved workers. Inhalation of U_3O_8 particulates accounts for more than 99.9% of the radiological exposures for noninvolved workers. The radiation dose (risk of an LCF) to a maximally exposed noninvolved worker would range from 1.6×10^{-3} mrem/yr (6×10^{-10} per year) to 5.8×10^{-3} mrem/yr (2×10^{-9} per year), which is a very small fraction (less than 1 in 1,000) of the maximally allowable dose limit (10 mrem/yr) from airborne emissions (40 CFR Part 61). The population of noninvolved workers would vary from site to site. For representative noninvolved worker population sizes ranging from 2,000 to 3,500, the resulting collective dose would range from 0.0021 to 0.0045 person-rem/yr.

General Public. The locations of the maximally exposed individual (MEI) for the general public are either at or near the site boundary. Although other exposure pathways are also considered, inhalation exposure accounts for more than 95% of the total dose. The radiation dose for the MEI would be negligible, ranging from 0.0049 to 0.0088 mrem/yr, compared with the dose limit of 10 mrem/yr from airborne emissions. The potential radiation dose resulting from drinking

TABLE F.4 Radiological Doses from Conversion/Treatment Options under Normal Operations[a]

	Dose to Receptor					
	Involved Workers[b]		Noninvolved Workers[c]		General Public	
Option	Average Dose (mrem/yr)	Collective Dose (person-rem/yr)	MEI Dose[d] (mrem/yr)	Collective Dose (person-rem/yr)	MEI Dose[e] (mrem/yr)	Collective Dose[f] (person-rem/yr)
Conversion to U_3O_8	300	41	1.6×10^{-3} – 5.8×10^{-3}	2.1×10^{-3} – 4.5×10^{-3}	4.9×10^{-3} – 8.8×10^{-3}	3.9×10^{-2} – 1.4×10^{-1}
Conversion to UO_2	180 – 340	49 – 54	3.2×10^{-3} – 2.2×10^{-2}	4.2×10^{-3} – 1.7×10^{-2}	9.7×10^{-3} – 3.3×10^{-2}	7.8×10^{-2} – 5.1×10^{-1}
Conversion to metal	230 – 240	33 – 67	6.8×10^{-4} – 1.7×10^{-2}	9.0×10^{-4} – 1.3×10^{-2}	2.1×10^{-3} – 2.6×10^{-2}	1.7×10^{-2} – 4.0×10^{-1}
Cylinder treatment	160	16	4.9×10^{-6} – 1.8×10^{-5}	6.5×10^{-6} – 1.4×10^{-5}	1.5×10^{-5} – 2.7×10^{-5}	1.2×10^{-4} – 4.1×10^{-4}

[a] Impacts are reported as ranges, which result from variations in the three representative facility locations and the different conversion technologies within each option.

[b] Involved workers are those workers directly involved with the handling of radioactive materials. Calculation results 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 include individuals who work at the facility but are not directly involved in handling materials and individuals who work on-site but not within the facility. The population size of noninvolved workers ranges from 2,000 to 3,500 for all options.

[d] The MEI for the noninvolved workers was assumed to be located on-site 100 m or more from the release point at the location that would result in the largest dose, which includes doses from inhalation, external radiation, and incidental soil ingestion.

[e] The MEI for the general public was assumed to be located off-site at the point that would result in the largest dose from exposures through inhalation, external radiation, and ingestion of plant foods, meat, milk, soil, and drinking water.

[f] Collective dose was estimated for the populations (ranging from 500,000 to 880,000 persons) within a radius of 50 miles (80 km) around the three representative sites. The exposure pathways considered are inhalation, external radiation, and ingestion of plant foods, meat, milk, and soil.

TABLE F.5 Latent Cancer Risks from Conversion/Treatment Options under Normal Operations[a]

	Latent Cancer Risk to Receptor					
	Involved Workers[b]		Noninvolved Workers[c]		General Public	
Option	Average Risk (risk/yr)	Collective Risk (fatalities/yr)	MEI Risk[d] (risk/yr)	Collective Risk (fatalities/yr)	MEI Risk[e] (risk/yr)	Collective Risk[f] (fatalities/yr)
Conversion to U_3O_8	1×10^{-4}	2×10^{-2}	6×10^{-10} – 2×10^{-9}	9×10^{-7} – 2×10^{-6}	2×10^{-9} – 4×10^{-9}	2×10^{-5} – 7×10^{-5}
Conversion to UO_2	7×10^{-5} – 1×10^{-4}	2×10^{-2}	1×10^{-9} – 9×10^{-9}	2×10^{-6} – 7×10^{-6}	5×10^{-9} – 2×10^{-8}	4×10^{-5} – 3×10^{-4}
Conversion to metal	9×10^{-5} – 1×10^{-4}	1×10^{-2} – 3×10^{-2}	3×10^{-10} – 7×10^{-9}	4×10^{-7} – 5×10^{-6}	1×10^{-9} – 1×10^{-8}	9×10^{-6} – 2×10^{-4}
Cylinder treatment	6×10^{-5}	6×10^{-3}	2×10^{-12} – 7×10^{-12}	3×10^{-9} – 5×10^{-9}	8×10^{-12} – 1×10^{-11}	6×10^{-8} – 2×10^{-7}

[a] Impacts are reported as ranges, which result from variations in the three representative facility locations and the different conversion technologies within each option.

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

[c] Noninvolved workers include individuals who work at the facility but are not directly involved in handling materials and individuals who work on-site but not within the facility. The population size of noninvolved workers ranges from 2,000 to 3,500 for all options.

[d] The MEI for the noninvolved workers was assumed to be located on-site 100 m or more from the release point at the location that would result in the largest risk, which includes risks from inhalation, external radiation, and incidental soil ingestion.

[e] The MEI for the general public was assumed to be located off-site at the point that would result in the largest risk from exposures through inhalation, external radiation, and ingestion of plant foods, meat, milk, soil, and drinking water.

[f] Collective risk was estimated for the populations (ranging from 500,000 to 880,000 persons) within a radius of 50 miles (80 km) around the three representative sites. The exposure pathways considered are inhalation, external radiation, and ingestion of plant foods, meat, milk, and soil.

contaminated surface water would be two orders of magnitude less than that from exposure to airborne emissions.

For a location with an off-site population ranging from 500,000 to 880,000 persons within a 50-mile (80-km) distance from the site boundary, the collective dose would range from 0.039 to 0.14 person-rem/yr, which corresponds to about 2×10^{-5} to 7×10^{-5} LCF per year (less than 1 chance in 10,000 of 1 LCF per year in the population).

F.3.1.1.2 Conversion to UO_2

Conversion to UO_2 would result in average radiation exposure of less than 340 mrem/yr to involved workers and less than 0.04 mrem/yr to noninvolved workers and members of the public, similar to those for conversion to U_3O_8. The radiation doses and cancer risks associated with normal operations of the UO_2 conversion facilities are listed in Tables F.4 and F.5, respectively.

Involved Workers. The estimated collective dose for involved workers ranges from 49 to 54 person-rem/yr, slightly greater than conversion to U_3O_8. This would result in approximately 0.02 excess cancer fatality per year (2 LCFs over a 100-year period). If evenly distributed among involved workers (about 160 to 270 workers), the average individual dose would range from about 180 to 340 mrem/yr, well below the annual worker dose limit of 5,000 mrem/yr. This corresponds to an average cancer risk of 7×10^{-5} to 1×10^{-4} per year (less than 1 chance in 10,000 of developing 1 LCF per year).

Noninvolved Workers. The doses to noninvolved workers are similar to but slightly higher than those for conversion to U_3O_8. The dose to the MEI would range from 0.0032 to 0.022 mrem/yr, which is negligible compared with the dose limit of 10 mrem/yr for airborne emissions. For representative population sizes ranging from 2,000 to 3,500, the collective dose would range from 0.0042 to 0.017 person-rem/yr. The estimated number of potential LCFs would be less than 0.00001 per year.

General Public. The estimated radiation dose to the MEI for the general public would be slightly higher than that from conversion to U_3O_8, ranging from 0.0097 to 0.033 mrem/yr. These values are well below the radiation dose limit of 10 mrem/yr set for airborne emissions. The radiation dose from drinking contaminated surface water would be very small compared with the dose from airborne emissions. The collective dose for a population of 500,000 to 880,000 persons would range from 0.078 to 0.51 person-rem/yr. This would correspond to 4×10^{-5} to 3×10^{-4} LCF per year among the population (less than 1 chance in 3,000 of 1 LCF per year).

F.3.1.1.3 Conversion to Metal

Conversion to uranium metal would result in average exposure of less than 240 mrem/yr to involved workers and less than 0.03 mrem/yr to noninvolved workers and members of the public. The radiological impacts and cancer risks from operations of the metal conversion facilities are shown in Tables F.4 and F.5, respectively.

Involved Workers. The collective dose to involved workers would range from 33 to 67 person-rem/yr, similar to conversion to U_3O_8 and conversion to UO_2. The corresponding number of LCFs would range from 0.01 to 0.03 per year (1 to 3 LCFs over a 100-year period) among a worker population of approximately 140 to 270. If evenly distributed among workers, the average annual worker dose would be about 240 mrem/yr, which is well below the regulatory limit of 5,000 mrem/yr. The corresponding cancer risk is 0.0001 per year (less than 1 chance in 10,000 of developing 1 LCF per year).

Noninvolved Workers. The radiation dose to noninvolved workers would be similar to those for conversion to U_3O_8 and conversion to UO_2 and would be negligible compared with the regulatory dose limit of 10 mrem/yr. The collective dose would range from 0.0009 to 0.013 person-rem/yr for 2,000 to 3,500 workers.

General Public. The radiation dose for the MEI of the general public would range from 0.0021 to 0.026 mrem/yr, which corresponds to a cancer risk of 1×10^{-9} to 1×10^{-8} per year (less than 1 chance in 100 million of developing 1 LCF per year). The radiation dose from drinking contaminated surface water would be very small compared with the dose from airborne emissions. The collective dose for the population of 500,000 to 880,000 people living within 50 miles (80 km) of the site would range from 0.017 to 0.4 person-rem/yr. This corresponds to about 9×10^{-6} to 2×10^{-4} LCF per year within the exposed population.

F.3.1.1.4 Cylinder Treatment Facility

The empty UF_6 cylinders from the conversion facilities would be decontaminated at a cylinder treatment facility before reuse or final disposal. Average radiological exposure incurred by involved workers would be less than 200 mrem/yr, and maximum exposures incurred by noninvolved workers and the off-site public would be less than 3×10^{-5} mrem/yr. The estimated radiological impacts and cancer risks from cylinder treatment operations are presented in Tables F.4 and F.5, respectively.

Involved Workers. The average annual dose received by involved workers would be approximately 160 mrem/yr, which was calculated by evenly distributing the estimated collective dose of 16 person-rem/yr to a worker population of approximately 100. The average dose is a small fraction of the dose limit of 5,000 mrem/yr and corresponds to a cancer risk of 6×10^{-5} per year (1 chance in 16,000 of developing 1 LCF per year). The collective number of LCFs among the involved workers would be 6×10^{-3} per year.

Noninvolved Workers. Only a small amount of U_3O_8 (0.01 lb/yr) would be released to the atmosphere from the cylinder treatment facility. Radiological exposure to the noninvolved worker MEI would be negligible (less than 1.8×10^{-5} mrem/yr). The collective dose would range from 6.5×10^{-6} to 1.4×10^{-5} person-rem/yr for a population of 2,000 to 3,500.

General Public. The radiation exposure of the general public MEI from normal operations at the treatment facility would be negligible (less than 2.7×10^{-5} mrem/yr). The collective dose to the off-site population of 500,000 to 880,000 people would be less than 4.1×10^{-4} person-rem/yr.

F.3.1.2 Chemical Impacts

Potential chemical impacts to human health from normal operations at the conversion facilities would result primarily from exposure to trace amounts of insoluble uranium compounds (i.e., UO_2, U_3O_8, and UF_4) and HF released from process exhaust stacks. Risks from normal operations were quantified on the basis of calculated hazard indices. Information on the exposure assumptions, health effects assumptions, reference doses used for uranium compounds and HF, and calculational methods used in the chemical impact analysis are provided in Appendix C and Cheng et al. (1997).

Conversion to U_3O_8, UO_2, or metal would result in very low-level exposures to hazardous chemicals. No adverse health effects would be expected during normal operations. Hazardous chemical human health impacts resulting from normal operations of the conversion facilities are summarized in Table F.6. The hazard indices for all conversion processes are more than 5,000 times lower than the hazard index of 1, which is the level at which adverse health effects might be expected to occur in some exposed individuals. The range of chemical exposures to the noninvolved workers and general public results primarily from the assumed locations of the representative conversion facilities.

One of the UO_2 conversion options, the gelation process, would also generate emissions of the chemical trichloroethylene from the process stack. The estimated increased lifetime carcinogenic risk of cancer incidence for noninvolved workers and members of the general public from exposure to trichloroethylene would be less than 1×10^{-8}, a very small increased risk that would not be considered an adverse impact.

TABLE F.6 Chemical Impacts to Human Health for Conversion/Treatment Options under Normal Operations[a]

	Impacts to Receptor			
	Noninvolved Workers[b]		General Public	
Option	Hazard Index for MEI[c,d]	Population Risk[e] (persons at risk/yr)	Hazard Index for MEI[c,f]	Population Risk[e] (persons at risk/yr)
Conversion to U_3O_8	3.9×10^{-7} – 1.5×10^{-6}	–	3.4×10^{-5} – 1.2×10^{-4}	–
Conversion to UO_2	7.5×10^{-7} – 3.1×10^{-6}	–	6.2×10^{-5} – 1.9×10^{-4}	–
Conversion to metal	4.8×10^{-7} – 3.0×10^{-6}	–	4.1×10^{-5} – 1.5×10^{-4}	–
Cylinder treatment	4.2×10^{-10} – 1.5×10^{-9}	–	3.5×10^{-8} – 7.1×10^{-8}	–

[a] Impacts are reported as ranges, which result from variations in the three representative facility locations and the different conversion technologies within each option.

[b] Noninvolved workers include individuals who work at the facility but are not directly involved in handling hazardous materials and individuals who work on-site but not within the facility.

[c] The hazard index is an indicator for potential adverse health effects other than cancer; a hazard index greater than 1 indicates a potential for adverse health effects and a need for further evaluation. Hazard indices were calculated for combined exposures to uranium compounds and HF.

[d] The MEI for the noninvolved workers was assumed to be located on-site 100 m or more from the release point at the location that would result in the largest exposure from airborne emissions, including inhalation and incidental ingestion of contaminated soil.

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

[f] The MEI for the general public was assumed to be located off-site at the location that would result in the largest exposures through inhalation and ingestion of soil and drinking water.

The empty UF_6 cylinders from the conversion facilities would be decontaminated at a cylinder treatment facility prior to final disposal. Estimates of the hazardous chemical impacts to human health resulting from cylinder treatment operations are also summarized in Table F.6. The hazard indices from the cylinder treatment facility would be hundreds of times lower than those predicted for the conversion options, for which no adverse human health impacts were predicted.

F.3.2 Human Health — Accident Conditions

A range of accidents covering the spectrum from 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 F.7. 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 F.7 are presented in Policastro et al. (1997). A detailed description of the methodology and assumptions used in the calculations is also provided in Appendix C and Policastro et al. (1997).

F.3.2.1 Radiological Impacts

Table F.8 lists the radiological doses to various receptors for the accidents that give the highest dose from each frequency category. The LCF risks for these accidents are given in Table F.9. The doses and the risks are presented as ranges (maximum and minimum) because two different meteorological conditions, three representative sites, and two or three technologies were considered for each conversion 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 occurrence of between 1 in 10,000 and 1 in 1 million per year. The following conclusions may be drawn from the radiological health impact results:

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

- The maximum radiological dose to noninvolved worker and general public MEIs (assuming that an accident occurred) would be 9.2 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).

- The overall radiological risk to noninvolved worker and general public MEI receptors (estimated by multiplying the risk per occurrence [Table F.9] by the annual probability of occurrence by the number of years of operations) would be less than 1 for all of the conversion facility accidents.

F.3.2.2 Chemical Impacts

The accidents considered in this section are listed in Table F.7. The results of the accident consequence modeling in terms of chemical impacts are presented in Tables F.10 and F.11. The results are presented as (1) number of people with potential for adverse effects and (2) number of

TABLE F.7 Accidents Considered for the Conversion Options

Option/Accident Scenario	Accident Description	Chemical Form	Amount (lb)	Duration (min)	Release Level[a]
Conversion to U_3O_8					
Likely Accidents (frequency: 1 or more times in 100 years)					
Corroded cylinder spill, dry conditions	A 1-ft hole results during handling, with solid UF_6 forming a 4-ft^2 area on the dry ground.	UF_6	24	60 (continuous)	Ground
Cylinder valve shear	A single UF_6 cylinder is mishandled, etc., resulting in the shearing of the cylinder valve and loss of solid UF_6 from the valve onto the ground.	UF_6	0.25	120 (continuous)	Ground
HF system leak during upgrading of HF to anhydrous HF	An HF absorber column line leaks 5% of its flowing contents due to potential vessel, pump, or pipe leakage.	HF	216	15	Stack
HF system leak during HF neutralization	An HF distillation column line leaks 5% of its flowing contents due to potential vessel, pump, or pipe leakage.	HF	10	15	Stack
Loss of cooling water during upgrading of HF to anhydrous HF	Cooling water is lost to the HF distillation column condenser, and HF vapor is removed by a limestone bed before reaching the environment.	HF	22	2	Stack
Loss of cooling water during HF neutralization	Cooling water is lost to the absorption column coolers, and HF vapor is released to the atmosphere.	HF	19	2	Stack
Loss of off-site electrical power	Off-site electrical power is lost, which halts facility operations but does not result in significant releases to the environment.	No release	NA[b]	NA	NA
U_3O_8 drum spill	A single U_3O_8 drum is damaged by a forklift and spills its contents onto the floor inside the storage facility.	U_3O_8	0.00014	30	Stack
Unlikely Accidents (frequency: 1 in 100 years to 1 in 10,000 years)					
Ammonia release	An ammonia fill line is momentarily disconnected, and ammonia is released at grade.	Ammonia	255	1	Ground
Corroded cylinder spill, wet conditions – rain	A 1-ft hole results during handling, with solid UF_6 forming a 4-ft^2 area on the wet ground.	HF	96	60 (continuous)	Ground
HF pipeline rupture	An earthquake ruptures an underground pipeline transporting HFs, releasing it to the ground.	HF	500	10	Soil
HF storage tank overflow	An HF storage tank overflows during filling, spilling onto the floor; the pool of HF evaporates and is released through the building stack.	HF	45	15	Stack

TABLE F.7 (Cont.)

Accident Scenario	Accident Description	Chemical Form	Amount (lb)	Duration (min)	Release Level[a]
Conversion to U_3O_8 (Cont.)					
Extremely Unlikely Accidents (frequency: 1 in 10,000 years to 1 in 1 million years)					
Corroded cylinder spill, wet conditions – water pool	A 1-ft hole results during handling, with solid UF_6 forming a 4-ft^2 area into a 0.25-in.-deep water pool.	HF	150	60 (continuous)	Ground
Earthquake	The U_3O_8 storage building is damaged during a design-basis earthquake, and 10% of the stored drums are breached.	U_3O_8	41	30	Ground
Hydrogen explosion	Due to equipment malfunction, hydrogen that accumulated in the conversion reactor ignites and causes the reactor to rupture.	U_3O_8 HF	0.27 7	30	Stack
Tornado	A windblown missile from a design-basis tornado pierces a single U_3O_8 drum in the U_3O_8 storage building.	U_3O_8	69	0.5	Ground
Vehicle-induced fire, 3 full 48G cylinders	Three full 48G UF_6 cylinders hydraulically rupture during a fire resulting from the ignition of fuel and/or hydraulic fluid from the transport vehicle, etc.	UF_6	0 11,500 8,930 3,580	0 to 12 12 12 to 30 30 to 121	Ground
Incredible Accidents (frequency: less than 1 in 1 million years)					
Anhydrous HF tank rupture	Large seismic or beyond-design-basis event causes rupture of a filled anhydrous HF storage tank.	HF	7,920	120	Ground
Ammonia tank rupture	Large seismic or beyond-design-basis event causes rupture of a filled ammonia storage tank.	Ammonia	118,000	20	Ground
Flood	The facility would be located at a site that would preclude severe flooding.	No release	NA	NA	NA
Small plane crash, 2 full 48G cylinders	A small plane crash affects two full 48G UF_6 cylinders. One cylinder hydraulically ruptures during a fire resulting from the ignition of aviation fuel.	UF_6	0 3,840 2,980 1,190	0 to 12 12 12 to 30 30 to 121	Ground
	The second cylinder is initially breached due to impact with aircraft debris, followed by sublimation due to fire.	UF_6	4,240 1,190	0 to 30 30 to 121	Ground

TABLE F.7 (Cont.)

Accident Scenario	Accident Description	Chemical Form	Amount (lb)	Duration (min)	Release Level[a]
Conversion to UO_2					
Likely Accidents (frequency: 1 or more times in 100 years)					
Ammonia stripper overpressure	Cooling water is lost to the ammonia stripping column, and ammonia vapor is released to the atmosphere.	Ammonia	15	1	Ground
Corroded cylinder spill, dry conditions	A 1-ft² hole results during handling, with solid UF_6 forming a 4-ft² area on the dry ground.	UF_6	24	60 (continuous)	Ground
Cylinder valve shear	A single UF_6 cylinder is mishandled, etc., resulting in shearing of the cylinder valve and loss of solid UF_6 from the valve onto the ground.	UF_6	0.25	120 (continuous)	Ground
HF system leak during upgrading of HF to anhydrous HF	An HF absorber line leaks 5% of its flowing contents due to potential vessel, pump, or pipe leakage.	HF	216	15	Stack
HF system leak during HF neutralization	An HF distillation column line leaks 5% of its flowing contents due to potential vessel, pump, or pipe leakage.	HF	10	15	Stack
Loss of cooling water during upgrading of HF to anhydrous HF	Cooling water is lost to the HF distillation column condenser, and HF vapor is removed by a limestone bed before reaching the environment.	HF	22	2	Stack
Loss of cooling water during HF neutralization	Cooling water is lost to the absorption column coolers, and HF vapor is released to the atmosphere.	HF	19	2	Stack
Loss of off-site electrical power	Off-site electrical power is lost, which halts facility operations but does not result in significant releases to the environment.	No release	NA	NA	NA
Trichloroethylene (TCE) spill	A TCE storage tank spills onto the floor during operations, and the pool of TCE evaporates and is released to the environment.	TCE	120	120	Stack
Trichloroethylene vapor leak	The exhaust line from the gel sphere dryers leaks 5% of its flowing contents due to potential pipe leakage.	TCE	20	60	Stack
UO_2 drum spill	A single UO_2 drum is damaged by a forklift and spills its contents onto the floor inside the storage facility.	UO_2	0.000056	~30	Stack

TABLE F.7 (Cont.)

Accident Scenario	Accident Description	Chemical Form	Amount (lb)	Duration (min)	Release Level[a]
Conversion to UO_2 (Cont.)					
Unlikely Accidents (frequency: 1 in 100 years to 1 in 10,000 years)					
Ammonia release	An ammonia fill line is momentarily disconnected, and ammonia is released at grade.	Ammonia	255	1	Ground
Corroded cylinder spill, wet conditions – rain	A 1-ft^2 hole results during handling, with solid UF_6 forming a 4-ft^2 area on the wet ground.	HF	96	60 (continuous)	Ground
HF pipeline rupture	An earthquake ruptures an underground pipeline transporting HF, releasing it to the ground.	HF	500	10	Soil
HF storage tank overflow	An HF storage tank overflows during filling, spilling onto the floor; the pool of HF evaporates and is released to the indoor air of the process building.	HF	45	15	Stack
Extremely Unlikely Accidents (frequency: 1 in 10,000 years to 1 in 1 million years)					
Corroded cylinder spill, wet conditions – water pool	A 1-ft^2 hole results during handling, with solid UF_6 forming a 4-ft^2 area into a 0.25-in.-deep water pool.	HF	147	60 (continuous)	Ground
Earthquake	The UO_2 storage building is damaged during a design-basis earthquake, and 10% of the stored drums are breached.	UO_2	9.8	30	Ground
Hydrogen explosion	Due to equipment malfunction, hydrogen that accumulated in the ceramic UO_2 conversion reactor ignites and causes the reactor to rupture.	UO_2 HF	0.25 7	30	Stack
Hydrogen explosion	Due to equipment malfunction, hydrogen that accumulated in the gelation conversion reactor ignites and causes the reactor to rupture.	UO_2	0.017	30	Stack
Tornado	A windblown missile from a design-basis tornado pierces a single ceramic UO_2 drum in the UO_2 storage building.	UO_2	3.7	0.5	Ground
Tornado	A windblown missile from a design-basis tornado pierces a single UO_2 drum produced by gelation in the UO_2 storage building.	UO_2	5.6	0.5	Ground
Vehicle-induced fire, 3 full 48G cylinders	Three full 48G UF_6 cylinders hydraulically rupture during a fire resulting from the ignition of fuel and/or hydraulic fluid from the transport vehicle, etc.	UF_6	0 11,500 8,930 3,580	0 to 12 12 12 to 30 30 to 121	Ground

TABLE F.7 (Cont.)

Accident Scenario	Accident Description	Chemical Form	Amount (lb)	Duration (min)	Release Level[a]
Conversion to UO_2 (Cont.)					
Incredible Accidents (frequency: less than 1 in 1 million years)					
Anhydrous HF tank rupture	Large seismic or beyond-design-basis event causes rupture of a filled anhydrous HF storage tank.	HF	7,920	120	Ground
Ammonia tank rupture	Large seismic or beyond-design-basis event causes rupture of a filled ammonia storage tank.	Ammonia	117,920	20	Ground
Flood	The facility would be located at a site that would preclude severe flooding.	No release	NA	NA	NA
Small plane crash, 2 full 48G cylinders	A small plane crash affects two full 48G UF_6 cylinders. One cylinder hydraulically ruptures during a fire resulting from the ignition of aviation fuel.	UF_6	0 3,840 2,980 1,190	0 to 12 12 12 to 30 30 to 121	Ground
	The second cylinder is initially breached due to impact with aircraft debris, followed by sublimation due to fire.	UF_6	4,240 1,190	0 to 30 30 to 121	Ground
Conversion to Metal					
Likely Accidents (frequency: 1 or more times in 100 years)					
Corroded cylinder spill, dry conditions	A 1-ft hole results during handling, with solid UF_6 forming a 4-ft^2 area on the dry ground.	UF_6	24	60 (continuous)	Ground
Cylinder valve shear	A single UF_6 cylinder is mishandled, etc., resulting in shearing of the cylinder valve and loss of solid UF_6 from the valve onto the ground.	UF_6	0.25	120 (continuous)	Ground
HF system leak	An off-gas line from the conversion reactor to the condenser leaks 5% of its flowing contents due to potential vessel, pump, or pipe leakage.	HF	3.6	15	Stack
Loss of cooling water	Cooling water is lost to the reactor HF coolers, and HF vapor is released to the atmosphere.	HF	17	2	Stack
Loss of off-site electrical power	Off-site electrical power is lost, which halts facility operations but does not result in significant releases to the environment.	No release	NA	NA	NA
UF_4 drum spill	A single UF_4 drum is damaged by a forklift and spills its contents onto the floor of the process building.	UF_4	0.00015	30	Stack

TABLE F.7 (Cont.)

Accident Scenario	Accident Description	Chemical Form	Amount (lb)	Duration (min)	Release Level[a]
Conversion to Metal (Cont.)					
Unlikely Accidents (frequency: 1 in 100 years to 1 in 10,000 years)					
Ammonia release	An ammonia fill line is momentarily disconnected, and ammonia is released at grade.	Ammonia	255	1	Ground
Corroded cylinder spill, wet conditions – rain	A 1-ft hole results during handling, with solid UF_6 forming a 4-ft^2 area on the wet ground.	HF	96	60 (continuous)	Ground
HF pipeline rupture	An earthquake ruptures an underground pipeline transporting HF and releasing it to the ground.	HF	500	10	Soil
HF storage tank overflow	An HF storage tank overflows during filling, spilling onto the floor; the pool of HF evaporates and is released to the indoor air of the process building.	HF	45	15	Stack
Nitric acid (HNO_3) release	Due to equipment failure, hot HNO_3 flows through a relief valve.	HNO_3	6	2	Stack
Uranium metal fire	The wooden boxes containing the uranium metal product burn, affecting a total of 34 uranium derbies.	U_3O_8	0.058	30	Stack
Extremely Unlikely Accidents (frequency: 1 in 10,000 years to 1 in 1 million years)					
Corroded cylinder spill, wet conditions – water pool	A 1-ft hole results during handling, with solid UF_6 forming a 4-ft^2 area into a 0.25-in.-deep water pool.	HF	147	60 (continuous)	Ground
Earthquake	The uranium product storage building is damaged during a design-basis earthquake, and some of the boxes containing uranium metal are breached.	U_3O_8	0.058	30	Ground
Hydrogen explosion	Due to equipment malfunction, hydrogen that accumulated in the conversion reactor ignites and causes the reactor to rupture.	UF_4 HF	0.05 2	30	Stack
Reactor rupture	A reactor containing molten uranium metal is damaged or breached, releasing hot molten uranium metal as airborne particles.	U_3O_8	0.0026	15	Stack
Tornado	A design-basis tornado does not result in significant releases because uranium is in metal form.	No release	NA	NA	NA
Vehicle-induced fire, 3 full 48G cylinders	Three full 48G UF_6 cylinders hydraulically rupture during a fire resulting from the ignition of fuel and/or hydraulic fluid from the transport vehicle, etc.	UF_6	0 11,500 8,930 3,580	0 to 12 12 12 to 30 30 to 121	Ground

TABLE F.7 (Cont.)

Accident Scenario	Accident Description	Chemical Form	Amount (lb)	Duration (min)	Release Level[a]
Conversion to Metal (Cont.)					
Incredible Accidents (frequency: less than 1 in 1 million years)					
Anhydrous HF tank rupture	Large seismic or beyond-design-basis event causes rupture of a filled anhydrous HF storage tank.	HF	7,920	120	Ground
Ammonia tank rupture	Large seismic or beyond-design-basis event causes rupture of a filled ammonia storage tank.	Ammonia	118,000	20	Ground
Flood	The facility would be located at a site that would preclude severe flooding.	No release	NA	NA	NA
Small plane crash, 2 full 48G cylinders	A small plane crash affects two full 48G UF_6 cylinders. One cylinder hydraulically ruptures during a fire resulting from the ignition of aviation fuel.	UF_6	0 3,840 2,980 1,190	0 to 12 12 12 to 30 30 to 121	Ground
	The second cylinder is initially breached due to impact with aircraft debris, followed by sublimation due to fire.	UF_6	4,240 1,190	0 to 30 30 to 121	Ground
Cylinder Treatment Facility					
Likely Accidents (frequency: 1 or more times in 100 years)					
Loss of off-site electrical power	Off-site electrical power is lost, which halts facility operations but does not result in significant releases to the environment.	No release	NA	NA	NA
U_3O_8 drum spill	A single U_3O_8 drum is damaged by a forklift and spills its contents onto the ground outside the storage facility.	U_3O_8	0.138	30	Ground
Unlikely Accidents (frequency: 1 in 100 years to 1 in 10,000 years)					
Loss of scrubber water	Water is lost to both HF scrubbers, and HF is released with the off gas.	HF	26	30	Stack
Extremely Unlikely Accidents (frequency: 1 in 10,000 years to 1 in 1 million years)					
Depleted UF_6 cylinder rupture	A truck crashes into the depleted UF_6 heel storage pad, damaging two cylinders; the fuel from the truck ignites and releases all of the depleted UF_6.	UO_2F_2 HF	38.5 10	30	Ground
Earthquake	The solids product building is damaged during a design-basis earthquake, and 50% of the stored drums are breached.	U_3O_8	1.9	30	Ground
HF aqueous tank rupture	The evaporator tank fails, releasing its entire contents of HF to the floor; the pool of aqueous HF evaporates and is released to the indoor air of the process building.	HF	3.4	60	Stack
Tornado	A windblown missile from a design-basis tornado pierces a single U_3O_8 drum in the solids product building.	U_3O_8	69	0.5	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.

[b] NA = not applicable.

TABLE F.8 Estimated Radiological Doses per Accident Occurrence for the Conversion 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)
Conversion to U_3O_8									
Corroded cylinder spill, dry conditions	L	7.7×10^{-2}	7.1	2.3×10^{-3}	3.0×10^{-1}	3.3×10^{-3}	8.1×10^{-2}	7.8×10^{-5}	7.4×10^{-3}
Earthquake	EU	9.2	8.4×10^{2}	2.7×10^{-1}	2.0×10^{1}	3.9×10^{-1}	9.6	9.2×10^{-3}	8.0×10^{-1}
Small plane crash, 2 full 48G cylinders	I	6.6×10^{-3}	2.5	4.9×10^{-3}	2.7×10^{-1}	8.7×10^{-4}	2.2×10^{-1}	6.2×10^{-4}	2.5×10^{-2}
Conversion to UO_2									
Corroded cylinder spill, dry conditions	L	7.7×10^{-2}	7.1	2.3×10^{-3}	3.0×10^{-1}	3.3×10^{-3}	8.1×10^{-2}	7.8×10^{-5}	7.4×10^{-3}
Earthquake	EU	2.3	2.1×10^{2}	6.8×10^{-2}	5.1	9.6×10^{-2}	2.4	2.3×10^{-3}	2.0×10^{-1}
Small plane crash, 2 full 48G cylinders	I	6.6×10^{-3}	2.5	4.9×10^{-3}	2.7×10^{-1}	8.7×10^{-4}	2.2×10^{-1}	6.2×10^{-4}	2.5×10^{-2}
Conversion to metal									
Corroded cylinder spill, dry conditions	L	7.7×10^{-2}	7.1	2.3×10^{-3}	3.0×10^{-1}	3.3×10^{-3}	8.1×10^{-2}	7.8×10^{-5}	7.4×10^{-3}
Uranium metal fire	U	2.4×10^{-6}	1.2×10^{-3}	2.6×10^{-6}	2.0×10^{-2}	4.9×10^{-7}	2.4×10^{-11}	2.0×10^{-6}	1.1×10^{-3}
Vehicle-induced fire, 3 full 48G cylinders	EU	2.0×10^{-2}	7.5	1.5×10^{-2}	5.6×10^{1}	3.7×10^{-3}	5.2×10^{-1}	1.9×10^{-3}	5.2×10^{-1}
Small plane crash, 2 full 48G cylinders	I	6.6×10^{-3}	2.5	4.9×10^{-3}	2.7×10^{-1}	8.7×10^{-4}	2.2×10^{-1}	6.2×10^{-4}	2.5×10^{-2}
Cylinder treatment									
U_3O_8 drum spill	L	3.1×10^{-2}	2.8	9.2×10^{-4}	6.9×10^{-2}	1.3×10^{-3}	3.2×10^{-2}	3.1×10^{-5}	2.7×10^{-3}
Tornado[d]	EU	4.3×10^{-1}	3.8×10^{1}	1.3×10^{-2}	2.5	4.3×10^{-1}	1.1×10^{1}	1.0×10^{-2}	4.5×10^{-1}

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); incredible (I), estimated to occur less than one time in 1 million years of facility operations (< 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.

d Meteorological conditions analyzed for the tornado were D stability with 20 m/s wind speed.

TABLE F.9 Estimated Radiological Health Risks per Accident Occurrence for the Conversion Options[a]

Option/Accident[b]	Frequency Category[c]	Maximum Risk[d] (LCFs): Noninvolved Workers MEI	Maximum Risk[d] (LCFs): Noninvolved Workers Population	Maximum Risk[d] (LCFs): General Public MEI	Maximum Risk[d] (LCFs): General Public Population	Minimum Risk[d] (LCFs): Noninvolved Workers MEI	Minimum Risk[d] (LCFs): Noninvolved Workers Population	Minimum Risk[d] (LCFs): General Public MEI	Minimum Risk[d] (LCFs): General Public Population
Conversion to U_3O_8									
Corroded cylinder spill, dry conditions	L	3×10^{-5}	3×10^{-3}	1×10^{-6}	2×10^{-4}	1×10^{-6}	3×10^{-5}	4×10^{-8}	4×10^{-6}
Earthquake	EU	4×10^{-3}	3×10^{-1}	1×10^{-4}	1×10^{-2}	2×10^{-4}	4×10^{-3}	5×10^{-6}	4×10^{-4}
Small plane crash, 2 full 48G cylinders	I	3×10^{-6}	1×10^{-3}	2×10^{-6}	1×10^{-4}	3×10^{-7}	9×10^{-5}	3×10^{-7}	1×10^{-5}
Conversion to UO_2									
Corroded cylinder spill, dry conditions	L	3×10^{-5}	3×10^{-3}	1×10^{-6}	2×10^{-4}	1×10^{-6}	3×10^{-5}	4×10^{-8}	4×10^{-6}
Earthquake	EU	9×10^{-4}	8×10^{-2}	3×10^{-5}	3×10^{-3}	4×10^{-5}	1×10^{-3}	1×10^{-6}	1×10^{-4}
Small plane crash, 2 full 48G cylinders	I	3×10^{-6}	1×10^{-3}	2×10^{-6}	1×10^{-4}	3×10^{-7}	9×10^{-5}	3×10^{-7}	1×10^{-5}
Conversion to metal									
Corroded cylinder spill, dry conditions	L	3×10^{-5}	3×10^{-3}	1×10^{-6}	2×10^{-4}	1×10^{-6}	3×10^{-5}	4×10^{-8}	4×10^{-6}
Uranium metal fire	U	1×10^{-9}	5×10^{-7}	1×10^{-9}	1×10^{-5}	2×10^{-10}	1×10^{-14}	1×10^{-9}	6×10^{-7}
Vehicle-induced fire, 3 full 48G cylinders	EU	8×10^{-6}	3×10^{-3}	7×10^{-6}	3×10^{-2}	1×10^{-6}	2×10^{-4}	1×10^{-6}	3×10^{-4}
Small plane crash, 2 full 48G cylinders	I	3×10^{-6}	1×10^{-3}	2×10^{-6}	1×10^{-4}	3×10^{-7}	9×10^{-5}	3×10^{-7}	1×10^{-5}
Cylinder treatment									
U_3O_8 drum spill	L	1×10^{-5}	1×10^{-3}	5×10^{-7}	3×10^{-5}	5×10^{-7}	1×10^{-5}	2×10^{-8}	1×10^{-6}
Tornado[e]	EU	2×10^{-4}	2×10^{-2}	7×10^{-6}	1×10^{-3}	2×10^{-4}	4×10^{-3}	5×10^{-6}	2×10^{-4}

a Values shown are the consequences if the accident did occur. The risk of an accident is the consequence (LCFs) 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 risks 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); 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 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.

e Meteorological conditions analyzed for the tornado were D stability with 20 m/s wind speed.

TABLE F.10 Number of Persons with Potential for Adverse Effects from Accidents under the Conversion Options[a]

		Maximum Number of Persons[d]				Minimum Number of Persons[d]			
		Noninvolved Workers		General Public		Noninvolved Workers		General Public	
Option/Accident[b]	Frequency Category[c]	MEI[e]	Population	MEI[e]	Population	MEI[e]	Population	MEI[e]	Population
Conversion to U_3O_8									
Corroded cylinder spill, dry conditions	L	Yes	240	No	0	Yes	2	No	0
Corroded cylinder spill, wet conditions – rain	U	Yes	520	Yes	10	Yes	52	No	0
Vehicle-induced fire, 3 full 48G cylinders	EU	Yes	310	Yes	2,500	Yes[f]	0	Yes	3
HF tank rupture	I	Yes	1,100	Yes	41,000	Yes	770	Yes	18
Conversion to UO_2									
Corroded cylinder spill, dry conditions	L	Yes	240	No	0	Yes	2	No	0
Corroded cylinder spill, wet conditions – rain	U	Yes	520	Yes	10	Yes	52	No	0
Vehicle-induced fire, 3 full 48G cylinders	EU	Yes	310	Yes	2,500	Yes[f]	0	Yes	3
HF tank rupture	I	Yes	1,100	Yes	41,000	Yes	770	Yes	18
Conversion to metal									
Corroded cylinder spill, dry conditions	L	Yes	240	No	0	Yes	2	No	0
Corroded cylinder spill, wet conditions – rain	U	Yes	520	Yes	10	Yes	52	No	0
Vehicle-induced fire, 3 full 48G cylinders	EU	Yes	310	Yes	2,500	Yes[f]	0	Yes	3
HF tank rupture	I	Yes	1,100	Yes	41,000	Yes	770	Yes	18
Cylinder treatment									
U_3O_8 drum spill[g]	L	No	0	No	0	No	0	No	0
Loss of scrubber water[g]	U	No	0	No	0	No	0	No	0
Tornado[h]	EU	Yes	1	No	0	NA[i]	NA	NA	NA

[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 (workers plus off-site population) 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 values reflect differences in assumed meteorological conditions at the time of the accident. In general, the maximum risks would occur under meteorological conditions of F stability with 1 m/s wind speed, whereas the 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] MEI locations were evaluated at 100 m from ground-level releases for workers and at the location of highest off-site concentration for members of the general public; the population risks are 0 because the worker and general public population distributions for the representative sites were used, which did not show receptors at the MEI locations.

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

[h] Meteorological conditions analyzed for the tornado were D stability with 20 m/s wind speed.

[i] NA = not applicable.

TABLE F.11 Number of Persons with Potential for Irreversible Adverse Effects from Accidents under the Conversion 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
Conversion to U_3O_8									
Corroded cylinder spill, dry conditions	L	Yes	5	No	0	No	0	No	0
Corroded cylinder spill, wet conditions – rain	U	Yes	370	Yes	0	Yes	3	No	0
Corroded cylinder spill, wet conditions – water pool	EU	Yes	440	Yes[f]	0	Yes	4	No	0
Ammonia tank rupture	I	Yes	420	Yes	1,700	Yes	180	Yes	8
Conversion to UO_2									
Ammonia stripper overpressure	L	Yes	40	No	0	No	0	No	0
Corroded cylinder spill, wet conditions – rain	U	Yes	370	Yes	0	Yes	3	No	0
Corroded cylinder spill, wet conditions – water pool	EU	Yes	440	Yes[f]	0	Yes	4	No	0
Ammonia tank rupture	I	Yes	420	Yes	1,700	Yes	180	Yes	8
Conversion to metal									
Corroded cylinder spill, dry conditions	L	Yes	5	No	0	No	0	No	0
Corroded cylinder spill, wet conditions – rain	U	Yes	370	Yes	0	Yes	3	No	0
Corroded cylinder spill, wet conditions – water pool	EU	Yes	440	Yes[f]	0	Yes	4	No	0
Ammonia tank rupture	I	Yes	420	Yes	1,700	Yes	180	Yes	8
Cylinder treatment									
U_3O_8 drum spill[g]	L	No	0	No	0	No	0	No	0
Loss of scrubber water[g]	U	No	0	No	0	No	0	No	0
Tornado[h]	EU	Yes[f]	0	No	0	NA[i]	NA	NA	NA

[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 (workers plus off-site population) 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 values reflect different meteorological conditions at the time of the accident. In general, the maximum risks would occur under meteorological conditions of F stability with 1 m/s wind speed, whereas the minimum risks would occur under D stability with 4 m/s wind speed. An exception is worker impacts for the ammonia tank rupture, for which maximum 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 affects to an individual.

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

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

[h] Meteorological conditions analyzed for the tornado were D stability with 20 m/s wind speed.

[i] NA = not applicable.

people with 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 workers and off-site population) (Policastro et al. 1997). The numbers of noninvolved workers and members of the off-site public represent the impacts if the associated accident was assumed to occur. The accidents listed in Tables F.10 and F.11 are not identical because an accident with the largest impacts for adverse effects might not lead to the largest impacts for irreversible adverse effects. The impacts may be summarized as follows:

- If the accidents identified in Tables F.10 and F.11 did occur, the number of persons in the off-site population with potential for adverse effects would range from 0 to 41,000 (maximum corresponding to HF tank rupture), and the number of off-site persons with potential for irreversible adverse effects would range from 0 to 1,700 (maximum corresponding to ammonia tank rupture).

- If the accidents identified in Tables F.10 and F.11 were to occur, the number of noninvolved workers with potential for adverse effects would range from 0 to 1,100 (maximum corresponding to HF tank rupture), and the number of noninvolved workers with potential for irreversible adverse effects would range from 0 to 440 (maximum corresponding to corroded cylinder spill, wet conditions — water pool).

- The largest impacts would be caused by HF tank rupture; corroded cylinder spill, wet conditions – rain; ammonia tank rupture; and vehicle-induced fire involving three full 48G cylinders. 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 due to filtration and deposition) involved with the stack emissions.

- The bounding accidents for the conversion options (conversion to U_3O_8, UO_2, and metal) would have nearly identical impacts.

- For the most severe accidents in each frequency category, the noninvolved worker MEI and the public MEI would have the potential for both adverse effects and irreversible adverse effects. The likely accidents for each conversion option (frequency of more than one chance in 100 per year) would result in no potential adverse or irreversible adverse effects for the general public. The generally reduced impacts to the public MEI compared with the noninvolved worker MEI are related to dispersion of the chemical release with downwind distance (except for UF_6 cylinder fire with plume rise).

- 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 indicate that the maximum risk values would be less than 1 for all accidents except the following:

- *Potential Adverse Effects:*

  Corroded cylinder spill, dry conditions (L, likely): Workers
  Corroded cylinder spill, wet conditions – rain (U, unlikely): Workers

- *Potential Irreversible Adverse Effects:*

  Corroded cylinder spill, dry conditions (L, likely): Workers
  Ammonia stripper overpressure (L, likely): Workers
  Corroded cylinder spill, wet conditions – rain (U, unlikely): Workers

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 noninvolved workers or for the general population.

To aid in the interpretation of accident analysis results, the number of fatalities potentially associated with the estimated irreversible adverse effects was calculated. For the worker and general public accidents involving UF_6 releases shown in Table F.10, exposure to HF and uranium compounds could be high enough to result in death for 1% or less of the persons experiencing irreversible adverse effects (Policastro et al. 1997). Thus, for the corroded cylinder spill accidents having a range of 0 to 440 irreversible adverse effects for noninvolved workers, approximately 0 to 4 worker deaths would be expected; no deaths would be expected for members of the general public from such accidents. For the ammonia tank rupture accident caused by an earthquake, exposure to ammonia would result in death for about 2% of the persons experiencing irreversible adverse effects. This would correspond to about 4 to 8 deaths among noninvolved workers and 0 to 34 deaths for the general public. These are the maximum potential consequences of the accidents; the upper ends of the ranges result from assuming worst-case weather conditions, with the wind blowing in the direction where the highest number of people would be exposed.

F.3.2.3 Physical Hazards

The risk of on-the-job fatalities and injuries to all conversion facility workers was calculated using industry-specific statistics from the U.S. Bureau of Labor Statistics, as reported by the National Safety Council (1995). Annual fatality and injury rates for construction and manufacturing, respectively, were used for the construction and operational phases of the conversion facility lifetime.

No on-the-job fatalities are predicted for any of the options analyzed, but a range of about 300 to 500 injuries is predicted during the conversion facility lifetimes. Overall, the largest impacts are predicted for conversion to UO_2 through gelation and for conversion to metal through batch reduction because these options require larger numbers of employees. All other conversion options would result in similar impacts; fewer impacts are predicted for the cylinder treatment facility (i.e., approximately 170 injuries).

Because the conversion technologies analyzed for conversion of U_3O_8 would employ almost the same number of workers, there are essentially no differences between them. There would be a probability of about 0.35 of an on-the-job fatality (sum of 0.18 for the construction phase and 0.17 for the operations phase) for the U_3O_8 conversion options (Table F.12). The predicted injury incidence would be about 285 injuries over the lifetime of the facility.

The predicted probability of worker fatalities for conversion to UO_2 ranges from 0.4 to 0.59 (Table F.12). The predicted injury incidence ranges from about 320 to 492 injuries over the lifetime of the UO_2 conversion facility. The upper ends of the ranges result from the larger number of workers required for operation of the gelation facility.

The predicted probability of worker fatalities for conversion to metal ranges from about 0.4 to 0.55 (Table F.12). The predicted injury incidence ranges from about 300 to 490 injuries over the lifetime of the metal conversion facility. The upper ends of the ranges result from the larger number of workers required for operation of the batch reduction facility.

For the cylinder treatment facility option, the probability of an on-the-job fatality is about 0.19 (sum of 0.08 for the construction phase and 0.11 for the operations phase) (Table F.12). The estimated injury incidence would be about 170 over the lifetime of the facility.

F.3.3 Air Quality

Additional details regarding the analysis of air quality impacts for the conversion option are presented in Tschanz (1997).

F.3.3.1 Construction

The annual emissions of sulfur dioxide (SO_2), nitrogen dioxide (NO_2), hydrocarbons (HC), carbon monoxide (CO), and particulate matter (PM_{10}) expected during conversion plant construction are listed in Table F.13. The estimated 1-hour maximum pollutant concentrations at the facility boundary during construction are shown in Table F.14. Additional estimates were made for the conversion technology that had the highest estimated 1-hour maximum pollutant concentrations (i.e., gelation); these estimated concentrations are given in Table F.15). Although all of these pollutant concentrations would be much higher than those for plant operations, they remain below

TABLE F.12 Potential Impacts to Human Health from Physical Hazards under Accident Conditions for the Conversion Options[a]

	Impacts to Conversion Facility Workers[b]			
	Incidence of Fatalities		Incidence of Injuries	
Option	Construction	Operations	Construction	Operations
Conversion to U_3O_8	0.18	0.16–0.17	66	215–219
Conversion to UO_2	0.22–0.30	0.18–0.29	79–108	243–384
Conversion to metal	0.22–0.25	0.17–0.30	79–92	222–395
Cylinder treatment	0.08	0.11	30	140

[a] Impacts are reported as ranges, which result from variations in the employment requirements for the different conversion technologies for each option.

[b] Potential hazards were estimated for all conversion facility workers.

Source: Injury and fatality rates used in calculations taken from National Safety Council (1995).

TABLE F.13 Emissions to the Atmosphere from Construction of a Depleted UF_6 Conversion Plant during the Peak Year

	Emissions to Atmosphere (tons/yr)				
Option	SO_2	NO_2	HC	CO	PM_{10}
Conversion to U_3O_8	2	28	8	190	40–50
Conversion to UO_2	2–3	30–46	8–13	200–320	50–60
Conversion to metal	2–3	30–40	8–12	200–270	50–60

Source: LLNL (1997).

ambient air quality standards. One possible exception is PM_{10}, for which concentrations were estimated to be 90% of the 24-hour standard of 150 $\mu g/m^3$. Some fugitive dust control measures would be necessary to mitigate this potentially high concentration. Construction of the conversion plant in a region of already high, even if compliant, ambient pollutant concentrations might require consideration of changes and/or controls for the emission of the other pollutants as well.

Estimated emissions from the cylinder treatment facility for all aspects of construction and operations are of the same order of magnitude (generally about 0.4 to 0.7 times as large) as those associated with the baseline cylinder transfer facility (see Appendix E), and the cylinder treatment facility area would be about half as large as the baseline cylinder transfer facility area. Except for the

TABLE F.14 Maximum 1-Hour Average Pollutant Concentrations at the Nearest Point on the Facility Boundary from Construction of a Conversion Facility[a]

	Pollutant ($\mu g/m^3$)				
Option	SO_2	NO_2	HC	CO	PM_{10}
Conversion to U_3O_8	26	360	100	2,400	520
Conversion to UO_2	25–37	380–570	100–160	2,400–3,900	620–740
Conversion to metal	25–36	360–480	100–140	2,500–3,200	610–720

[a] The ranges shown for some pollutants include results from the various technologies used for the conversion option and the differences in representative sites used for analysis.

TABLE F.15 Maximum Air Quality Impacts from Conversion Facility Construction[a]

	Estimated Pollutant Emissions[b]							
	1-Hour Average		8-Hour Average		24-Hour Average		Annual Average	
Pollutant	Concentration[c] ($\mu g/m^3$)	Fraction of Standard[d]	Concentration[c] ($\mu g/m^3$)	Fraction of Standard[d]	Concentration[c] ($\mu g/m^3$)	Fraction of Standard[d]	Concentration[c] ($\mu g/m^3$)	Fraction of Standard[d]
CO	3,810	0.1	3,100	0.30	–	–	–	–
NO_x	–	–	–	–	–	–	16	0.17
SO_2	–	–	–	–	5.8	0.02	0.9	0.01
PM_{10}	–	–	–	–	136	0.90	21	0.42

[a] Estimated pollutant emissions are given for the conversion to UO_2 gelation option, which would have the highest emissions.

[b] Values are listed only for pollutant/averaging time period combinations that have applicable air quality standards.

[c] Concentrations are the second highest values estimated for one entire year. Short-term standards are not to be exceeded more than once per year.

[d] Ratio of the concentration to the respective air quality standard. A ratio of less than 1 indicates that the standard would not be exceeded.

1-hour average results, the analytical results shown in Table F.16 for the cylinder treatment facility are about 0.2 to 0.4 times as large as those shown in Appendix E, Tables E.9-E.11, for the cylinder transfer facility. The 1-hour average impacts of construction of a cylinder treatment facility would be essentially the same as those for cylinder transfer facility construction.

F.3.3.2 Operations

Hourly emission rates during operations were determined from annual emission rates given in the engineering analysis report (LLNL 1997); these rates are shown in Table F.17. The methods used to analyze the impacts of pollutant emissions are described in Appendix C. All air pollutant concentrations during operations would be well below applicable ambient air quality standards for all conversion options. The maximum ground-level atmospheric concentrations at the representative facility boundaries from the boiler stack's emissions are listed in Tables F.18 through F.20. At the upper ends of the ranges, the nearest any of the criteria pollutant concentrations would come to a corresponding air quality standard is the annual nitrogen oxides (NO_x) concentration, which would be between 0.0007 and 0.002 of the annual NO_x standard.

Maximum air quality impacts from the process stacks are also listed in Tables F.18 through F.20. State HF standards in Tennessee and Kentucky have been used for comparative purposes. The estimated 24-hour maximum HF concentrations at representative facility boundaries for the conversion to U_3O_8 with anhydrous HF are about 2% of the respective state standards. The batch conversion to uranium metal is the only case for which NO_2 would be emitted from the process stack, and the NO_2 emission rate from the process stack in that case would be about eight times larger than from the boiler stack. Nevertheless, the estimated maximum annual NO_2 concentrations at the representative facility boundaries are less than 1% of the respective state standards.

TABLE F.16 Air Quality Impacts from Construction of the Cylinder Treatment Facility

	Estimated Pollutant Emissions							
	1-Hour Average		8-Hour Average		24-Hour Average		Annual Average	
Pollutant	Range[a] ($\mu g/m^3$)	Fraction of Standard[b]	Range[a] ($\mu g/m^3$)	Fraction of Standard[b]	Range[a] ($\mu g/m^3$)	Fraction of Standard[b]	Range[a] ($\mu g/m^3$)	Fraction of Standard[b]
CO	1,800 – 3,500	0.088	310 – 450	0.045	120 – 180	–	7.2 – 13	–
NO_x	280 – 520	–	47 – 69	–	19 – 27	–	1.1 – 2.0	0.02
PM_{10}	390 – 720	–	65 – 95	–	26 – 37	0.25	1.5 – 2.6	0.052

[a] Concentrations are the second highest values estimated for one entire year. Short-term standards are not to be exceeded more than once per year.

[b] Ratio of the upper end of the concentration range to the respective air quality standard. A ratio of less than 1 indicates that the standard is not exceeded. Pollutant/averaging time period combinations for which no air quality standard exists are noted with a dash (–).

TABLE F.17 Emissions to the Atmosphere from Operation of a Depleted UF_6 Conversion Plant

	Emissions to Atmosphere (lb/yr)						
Option/Source	SO_2	NO_2	HC	CO	PM_{10}	HF	Uranium Compounds
Conversion to U_3O_8							
Boiler stack	60–80	8,300–10,000	180–200	4,100–5,000	310–400	–	–
Process stack	–	–	–	–	–	300–900	3.3 U_3O_8
Generator stack	60	400	400	2,300	80	–	–
Conversion to UO_2							
Boiler stack	23–820	3,800–110,000	170–2,300	800–55,000	290–4,100	–	–
Process stack	–	–	–	–	–	300–900	2.5–12 UO_2
Generator stack	54–80	400–720	400–690	2,300–3,700	20–140	–	–
Conversion to metal							
Boiler stack	60–100	8,200–14,000	170–290	4,000–6,700	300–500	–	–
Process stack	–	117,000	–	–	–	300	1.2–9.6 U_3O_8; 3.8 UF_4
Generator stack	54–60	460–600	410–490	2,700–3,600	90–120	–	–

Source: LLNL (1997).

Each emergency generator would operate for 300 hours or less during 1 year. When it was operating, however, an emergency generator would produce higher concentrations of criteria pollutants at the facility boundaries than would the boiler. The estimated pollutant concentrations from the generator are listed in Tables F.18 through F.20. Compared with the air quality standards, the estimated concentrations are no more than 5% of allowed values.

The boiler stack parameters are identical for the cylinder treatment facility and the baseline cylinder transfer facility (see Appendix E). Given the similarities in the input data, the results of the air quality analyses for the two facilities should be expected to be comparable. Although not presented explicitly here, the same can be said of the impacts for operations. In summary, all of the criteria pollutant impacts of the cylinder treatment facility would not differ substantially from those of the cylinder transfer facility; all of the impacts not explicitly noted here are considered to be negligible. The only pollutant of concern emitted by the cylinder treatment facility process stack would be HF, and it, too, would be comparable for the two facilities. The cylinder treatment facility process stack would produce maximum annual average HF concentrations of 1.6×10^{-6} $\mu g/m^3$. This concentration is several orders of magnitude smaller than any applicable HF air quality standard.

No quantitative estimate was made of the impacts on the criterion pollutant ozone. Ozone formation is a regional issue that would be affected by emissions data for the entire area around a proposed conversion site. The pollutants most related to ozone formation that would result from the

TABLE F.18 Air Quality Impacts from Operations for Conversion to U_3O_8

	Estimated Pollutant Emissions[a]							
	1-Hour Average		8-Hour Average		24-Hour Average		Annual Average	
Option/ Stack/ Pollutant	Range[b] ($\mu g/m^3$)	Fraction of Standard[c]	Range[b] ($\mu g/m^3$)	Fraction of Standard[c]	Range[b] ($\mu g/m^3$)	Fraction of Standard[c]	Range[b] ($\mu g/m^3$)	Fraction of Standard[c]
Conversion to U_3O_8 with Anhydrous HF								
Boiler stack								
CO	0.92 – 1.01	3×10^{-5}	0.37 – 0.63	6×10^{-5}	–	–	–	–
NO_x	–	–	–	–	–	–	0.054 – 0.090	0.0009
Generator stack								
CO	320 – 440	0.011	64 – 270	0.027	–	–	Not calculated	
NO_x	–	–	–	–	–	–	Not calculated	
Process stack								
HF	–	–	–	–	0.025 – 0.069	0.02	0.0040 – 0.0073	2×10^{-5}
U_3O_8	–	–	–	–	–	–	1.4×10^{-5} – 2.6×10^{-5}	NS[d]
Conversion to U_3O_8 with HF Neutralization								
Boiler stack								
CO	0.81 – 0.89	2×10^{-5}	0.31 – 0.57	6×10^{-5}	–	–	–	–
NO_x	–	–	–	–	–	–	0.046 – 0.077	0.0008
Generator stack								
CO	320 – 440	0.011	64 – 270	0.027	–	–	Not calculated	
NO_x	–	–	–	–	–	–	Not calculated	
Process stack								
HF	–	–	–	–	0.0091 – 0.022	0.006	0.0012 – 0.0023	6×10^{-6}
U_3O_8	–	–	–	–	–	–	0.000013 – 0.000026	NS

[a] Values are listed only for pollutant/averaging time period combinations with air quality standards.

[b] Concentrations are the second highest values estimated for one entire year. Short-term standards are not to be exceeded more than once per year.

[c] Ratio of the upper end of the concentration range to the respective air quality standard. A ratio of less than 1 indicates that the standard is not exceeded.

[d] NS = No annual average air quality standard is available for U_3O_8.

TABLE F.19 Air Quality Impacts from Operations for Conversion to UO_2

Option/ Stack/ Pollutant	Estimated Pollutant Emissions[a]							
	1-Hour Average		8-Hour Average		24-Hour Average		Annual Average	
	Range[b] ($\mu g/m^3$)	Fraction of Standard[c]	Range[b] ($\mu g/m^3$)	Fraction of Standard[c]	Range[b] ($\mu g/m^3$)	Fraction of Standard[c]	Range[b] ($\mu g/m^3$)	Fraction of Standard[c]
Conversion to UO_2 with Anhydrous HF								
Boiler stack								
CO	0.77 – 0.82	2×10^{-5}	0.31 – 0.51	5×10^{-5}	–	–	–	–
NO_x	–	–	–	–	–	–	0.045 – 0.079	0.0008
Generator stack								
CO	550 – 690	0.017	120 – 440	0.044	–	–	Not calculated	
NO_x	–	–	–	–	–	–	Not calculated	
Process stack								
HF	–	–	–	–	0.020 – 0.052	0.015	0.0030 – 0.0064	2×10^{-5}
U_3O_8	–	–	–	–	–	–	4×10^{-5} – 8.5×10^{-5}	NS[d]
Conversion to UO_2 with HF Neutralization								
Boiler stack								
CO	0.71 – 0.77	2×10^{-5}	0.28 – 0.47	5×10^{-5}	–	–	–	–
NO_x	–	–	–	–	–	–	0.041 – 0.070	0.0007
Generator stack								
CO	550 – 690	0.017	120 – 440	0.044	–	–	Not calculated	
NO_x	–	–	–	–	–	–	Not calculated	
Process stack								
HF	–	–	–	–	0.0067 – 0.017	0.005	0.00099 – 0.0021	5×10^{-6}
U_3O_8	–	–	–	–	–	–	4.0×10^{-5} – 8.4×10^{-5}	NS[d]
Conversion to UO_2 with Gelation Process								
Boiler stack								
CO	1.7 – 1.8	5×10^{-5}	0.71 – 1.3	1×10^{-4}	–	–	–	–
NO_x	–	–	–	–	–	–	0.058 – 0.17	0.002
Generator stack								
CO	NA[e]	NA	NA	NA	NA	NA	NA	NA
NO_x	NA	NA	NA	NA	NA	NA	NA	NA
Process stack								
HF	–	–	–	–	0.016 – 0.029	0.01	0.0022 – 0.0040	1×10^{-5}
U_3O_8	–	–	–	–	–	–	1.0×10^{-5} – 1.7×10^{-5}	NS[d]

[a] Values are listed only for pollutant/averaging time period combinations with air quality standards.

[b] Concentrations are the second highest values estimated for one entire year. Short-term standards are not to be exceeded more than once per year.

[c] Ratio of the upper end of the concentration range to the respective air quality standard. A ratio of less than 1 indicates that the standard is not exceeded.

[d] NS = No annual average air quality standard is available for U_3O_8.

[e] NA = Data not available.

TABLE F.20 Air Quality Impacts from Operations for Conversion to Uranium Metal

Option/ Stack/ Pollutant	Estimated Pollutant Emissions[a]							
	1-Hour Average		8-Hour Average		24-Hour Average		Annual Average	
	Range[b] ($\mu g/m^3$)	Fraction of Standard[c]	Range[b] ($\mu g/m^3$)	Fraction of Standard[c]	Range[b] ($\mu g/m^3$)	Fraction of Standard[c]	Range[b] ($\mu g/m^3$)	Fraction of Standard[c]
Batch Process								
Boiler stack								
CO	0.88 – 0.90	2×10^{-5}	0.35 – 0.56	6×10^{-5}	–	–	–	–
NO_x	–	–	–	–	–	–	0.049 – 0.101	0.0010
Generator stack								
CO	580 – 720	0.018	120 – 460	0.046	–	–	Not calculated	
NO_x	–	–	–	–	–	–	Not calculated	
Process stack								
HF	–	–	–	–	0.0061 – 0.0125	0.004	0.00083 – 0.0019	5×10^{-6}
UF_4	–	–	–	–	–	–	1.0×10^{-5} – 2.4×10^{-5}	NS[d]
U_3O_8	–	–	–	–	–	–	2.6×10^{-5} – 6.1×10^{-5}	NS
NO_2	–	–	–	–	–	–	0.32 – 0.74	0.007
Continuous Process								
Boiler stack								
CO	0.71 – 0.77	2×10^{-5}	0.28 – 0.47	5×10^{-5}	–	–	–	–
NO_x	–	–	–	–	–	–	0.042 – 0.072	0.0007
Generator stack								
CO	550 – 690	0.017	120 – 440	0.044	–	–	Not calculated	
NO_x	–	–	–	–	–	–	Not calculated	
Process stack								
HF	–	–	–	–	0.0068 – 0.0172	0.005	0.0010 – 0.0021	5×10^{-6}
UF_4	–	–	–	–	–	–	1.3×10^{-5} – 2.7×10^{-5}	NS
U_3O_8	–	–	–	–	–	–	4.1×10^{-5} – 8.6×10^{-5}	NS

[a] Values are listed only for pollutant/averaging time period combinations with air quality standards.

[b] Concentrations are the second highest values estimated for one entire year. Short-term standards are not to be exceeded more than once per year.

[c] Ratio of the upper end of the concentration range to the respective air quality standard. A ratio of less than 1 indicates that the standard is not exceeded.

[d] NS = No annual average air quality standard is available for this pollutant.

conversion of depleted UF_6 are HC and NO_x. In later Phase II studies, when specific technologies and sites would be selected, the potential effects on ozone of these pollutants at a proposed site could be put in perspective by comparing them with the total emissions of HC and NO_x in the surrounding area. Small additional contributions to the totals would be unlikely to alter the ozone attainment status of the region.

F.3.4 Water and Soil

This section discusses impacts of the conversion options on surface water, groundwater, and soils. The impacts are evaluated over a range of conditions present at the representative sites and are also relevant for a similarly sized generic site located in the vicinity of a river that could be used to supply water for construction and normal operations and to receive liquid waste discharges. The major conversion option parameters are summarized in Table F.21.

F.3.4.1 Surface Water

The methodology used to determine potential impacts to surface water for each conversion technology is described in Appendix C and Tomasko (1997).

F.3.4.1.1 Conversion to U_3O_8

Construction. Construction of a U_3O_8 conversion facility would produce increased runoff to nearby surface waters because of replacing soil and vegetation with either buildings or paved areas, approximately 13 acres (5.3 ha) (LLNL 1997). The amount of increased runoff would be negligible compared with the assumed existing area for runoff (0.3 to 0.8% of the representative site areas). None of the construction activities would measurably affect floodplains.

Table F.21 shows the quantity of water that would be used during construction of the U_3O_8 conversion facility (about 8 million gal/yr). This water would be withdrawn from nearby rivers or pumped from underlying aquifers. If the rate of water consumption were constant, the average rate of withdrawal would be about 15 gpm. This rate of withdrawal would be negligible compared to average flows in the adjacent rivers (less than 0.0001%). If the water were obtained from aquifers, there would be no impacts to the surface waters. Construction impacts would, therefore, range from none to negligible.

For construction, the net volume of water disposed of would be about 4 million gal/yr (7.6 gpm) (Table F.21). The primary contaminants of concern would be construction chemicals, organics, and some suspended solids. The wastewater would be discharged to nearby surface waters under a National Pollutant Discharge Elimination System (NPDES) permit, or to an appropriate

TABLE F.21 Summary of Conversion Option Parameters Affecting Water Quality and Soil[a]

Option	Disturbed Land Area (acres)	Operations Area (acres)	Construction Water (million gal/yr)	Operations Water (million gal/yr)
Conversion to U_3O_8	20	13	Raw = 8 Waste = 4	Raw = 34 – 47 Waste = 15 – 23 Sanitary = 1.2
Conversion to UO_2	22 – 31	14 – 20	Raw = 4 – 12 Waste = 5 – 6	Raw = 41 – 285 Waste = 9.7 – 135 Sanitary = 0.7 – 2.3
Conversion to metal	23 – 26	15 – 16	Raw = 10 – 12 Waste = 5 – 6	Raw = 55 Waste = 25 – 26 Sanitary = 1.4 – 2.3

Option	Accident Scenario	Radioactive Release to Surface Water[a] (Ci/yr)	Radioactive Effluent Concentration[b] (pCi/L)	Dilution Factor[c]	Surface Water Concentration (pCi/L)
Conversion to U_3O_8	HF pipeline break	0.001	12 – 17	47,000 – 4,200,000	4.1×10^{-6} – 2.6×10^{-4}
Conversion to UO_2	HF pipeline break	0.002 – 0.003	6 – 21	42,000 – 500,000	1.2×10^{-5} – 5.0×10^{-4}
Conversion to metal	HF pipeline break	0.001 – 0.002	10 – 21	42,000 – 2,600,000	4.0×10^{-6} – 4.9×10^{-4}

[a] Data from engineering analysis report (LLNL 1997).

[b] Concentration derived from estimated annual radioactive release and annual wastewater discharge.

[c] Dilution factor based on average flow conditions in receiving rivers.

wastewater sewer. By following good engineering practices (e.g., stockpiling materials away from surface water drainages, covering construction piles with tarps to prevent erosion by precipitation, and cleaning up small chemical spills as soon as they occur), concentrations in the wastewater would be small (well below any drinking water criteria).

Once in the surface water, mixing and dilution of the pollutants would occur. This dilution would be greater than 270,000:1 for average flow conditions in nearby rivers. This amount of dilution would reduce any contamination present to concentrations well below regulatory standards. Because the concentration of contamination in the water would be very low, impacts to sediment in the streams would also be negligible.

Operations. For normal operations, no impacts would occur to surface runoff, and there would be no measurable impacts on floodplains (effluent discharges to surface waters less than 0.001% of the average flows). As indicated in Table F.21, normal operation of the U_3O_8 conversion facility would require at most 47 million gal/yr (approximately 89 gpm) of raw water. If this water were obtained from nearby rivers, impacts would be negligible, less than 0.004% of the average flows. If the raw water were obtained from wells, there would be no impacts to surface waters.

A maximum of 23 million gal/yr of wastewater would be generated during operations, including cooling tower blowdown, process water, and industrial waste water. Another 1.2 million gal/yr of sanitary wastewater would be produced (Table F.21). For constant rates of discharge, about 44 gpm of wastewater and 2.3 gpm of sanitary water would be released to the environment at approved NPDES locations.

The primary contaminants of concern for the wastewater would be uranium and chemicals used to inhibit rust, reduce friction, and enhance heat exchange (e.g., copolymers, phosphates, phosphonates, calcium, magnesium, nitrates, sodium, and potassium). As discussed in the engineering analysis report (LLNL 1997), approximately 0.001 Ci/yr of uranium with an activity of 4×10^{-7} Ci/g would be released in the discharge water. For a waste volume of 23 million gal/yr (Table F.21), the uranium concentration in the effluent would be about 30 μg/L. After dilution in nearby surface water, the concentration would be much less than the proposed U.S. Environmental Protection Agency (EPA) drinking water standard for uranium of 20 μg/L, used here for comparison. Concentrations of the other chemicals released would also be expected to be very low and within the guidelines of an NPDES permit.

Accident Scenarios. Most of the accidents analyzed would involve outdoor releases on impermeable concrete pads in the cylinder yards; such releases could be cleaned up with little loss of the contaminated material to the soil. The only postulated accident that would release contaminated water to the environment is an HF pipeline break produced by an earthquake (Table F.21). Anhydrous HF would be pumped from the process building to the HF storage building through an underground pipeline that would carry liquid HF at a rate of 10 gpm (0.63 L/s) through 200 ft (61 m) of 1-in. (2.5-cm) pipe. For this accident scenario, 100% of the HF would drain into the ground at a point 3 ft (0.91 m) below grade during a 10-minute period. Approximately 500 lb (227 kg) of liquid HF (60 gal [227 L]) would be released. After 48 hours, the contaminated soil was assumed to be removed. Because of the rapid response to the accident, the HF would have little time to travel into the soil. For a silty sand, the travel distance would be about 2 ft (6.1 m) (Tomasko 1997). Removal of the contaminated soil and soil water would prevent any contamination problems to the groundwater and would prevent any cross contamination with surface waters. Therefore, there would be no net impact from this accident. Because this accident scenario would not affect surface runoff or existing floodplains, impacts to these parameters would also be nonexistent.

F.3.4.1.2 Conversion to UO_2

The environmental parameters associated with the UO_2 conversion alternatives are similar to those for U_3O_8 conversion (Table F.21), except for raw water use, which would be about five times larger for normal operations. If water were withdrawn from a nearby river, impacts would be negligible and would be less than 0.03% of the average flows. If it were withdrawn from wells, there would be no surface water impacts. Because of this option's similarities to the U_3O_8 conversion option, impacts to surface water produced by UO_2 conversion would be essentially the same as those for U_3O_8 conversion (i.e., none to negligible).

As was the case for the conversion to U_3O_8 option, discharge waters would receive from 0.002 to 0.003 Ci/yr. For the water discharges listed in Table F.21, the equivalent concentrations would range from 6 to 76 pCi/L (30 to 400 μg/L). After dilution in nearby surface waters, concentrations would be much less than the EPA proposed drinking water standard for uranium, used here for comparison.

F.3.4.1.3 Conversion to Metal

The environmental parameters associated with conversion to metal are very similar to those for U_3O_8 conversion (Table F.21); however, raw water usage for construction and normal operation would be about 50% higher. If the construction water was obtained from a nearby river, the rate of withdrawal would be negligible compared to average flows (less than 0.001%). For normal operations, the increased rate of withdrawal would produce an impact less than 0.005% of the average flows. If the construction water and water for normal operations were obtained from wells, there would be no impacts on surface water.

As was the case for the conversion to U_3O_8 and UO_2 options, discharge waters would receive either 0.001 or 0.002 Ci/yr. For the water discharges listed in Table F.21, the equivalent concentrations would range from 25 to 53 μg/L. After dilution in nearby surface waters, the concentrations would be much less than the EPA proposed drinking water standard for uranium, used here for comparison.

F.3.4.1.4 Cylinder Treatment

Construction and operation of the cylinder treatment facility would use less land and water and produce less wastewater than the construction and operation of conversion facilities, as shown in Table F.22. Thus, potential impacts would be smaller. There are no postulated accidents that would directly release contaminants to surface water (LLNL 1997).

TABLE F.22 Summary of Environmental Parameters for the Cylinder Treatment Facility

Parameter	Unit	Construction	Operations	Accidents
Land area	acres	8.7	–	None
Disturbed land	acres	4.5	–	None
Water	million gal/yr	3.6	3.4	None
Wastewater[a]	million gal/yr	1.3	2.3	None

[a] Includes sanitary wastewater, cooling tower blowdown, industrial water, and process water.

F.3.4.2 Groundwater

The methodology for assessing impacts to groundwater for each conversion technology is described in detail in Appendix C and Tomasko (1997).

F.3.4.2.1 Conversion to U_3O_8

Potential impacts to groundwater could occur during construction, normal operations, and postulated accident scenarios. These impacts include the following: changes in effective recharge to underlying aquifers; changes in the depth to groundwater; changes in the direction of groundwater flow; and changes in groundwater quality.

If construction water were supplied from underlying aquifers, approximately 15 gpm would be withdrawn. This withdrawal represents a maximum 0.1% increase in extraction over that at representative facilities and would produce a negligible impact on the groundwater system. If the construction water were obtained from surface water, there would be no groundwater impacts. Groundwater quality could also be impacted by construction activities. For example, exposed chemicals could be mobilized by precipitation and infiltrate the surficial aquifers. By following good engineering and construction practices (e.g., covering chemicals to prevent interaction with rainfall, promptly cleaning up any chemical spills, and providing retention basins to catch and hold any contaminated runoff), groundwater concentrations would be less than the EPA guidelines.

Normal operations of the conversion facility would require about 65 gpm of raw water (Table F.21). If pumped from wells in the surficial aquifers, the impact would be negligible (0.5% increase in extraction). If withdrawn from nearby surface water, there would be no impact on groundwater. Because discharges to groundwater are not planned for normal operations, there would be no direct impacts to groundwater quality. Potential impacts could be derived from interaction with surface water; however, because impacts to surface water are negligible, impacts to groundwater via a surface water pathway would be even less.

As discussed in Section F.3.4.1.1, only one accident scenario, the HF pipeline break, would potentially release contaminants to the groundwater (Table F.21). Because of rapid mitigation and the small volume of HF in the release, this scenario would have a negligible impact on groundwater quality and would not affect recharge, depth to groundwater, or direction of flow.

F.3.4.2.2 Conversion to UO_2

The environmental parameters associated with the UO_2 conversion alternatives are very similar to those for U_3O_8 conversion (Table F.21), except for raw water use during normal operations (about five times larger). If water were obtained from underlying aquifers, pumping would represent an increase of about 5% of the current groundwater use. These impacts would be negligible.

F.3.4.2.3 Conversion to Metal

The environmental parameters associated with the metal conversion alternatives are very similar to those for U_3O_8 conversion (Table F.21), except for a 50% increase in raw water use during construction and normal operations. If the water for construction and normal operations was obtained from underlying aquifers, pumping would increase by 0.15% above current usage during construction, and by 0.8% of the current use for normal operations. These impacts would be negligible. If the water needed for construction and operations was obtained from surface water, there would be no impacts to groundwater.

During construction, groundwater concentrations would be kept below EPA guidelines (EPA 1996) by following good engineering practices. During normal operations, there would be no impacts to groundwater quality because direct discharges to groundwater are not planned.

F.3.4.2.4 Cylinder Treatment Facility

For the cylinder treatment facility, there would be no direct impacts to groundwater during normal operations because groundwater would not be used to supply the water required (Table F.22) and there would be no discharges of wastewater to the ground. Impacts to groundwater during construction of the cylinder treatment facility include changes in effective recharge, changes in the depth to the water table, changes in the direction of groundwater flow, and changes in quality.

Construction of the cylinder treatment facility would decrease the permeability of about 4.5 acres (1.8 ha) of land because of paving and building. This loss of permeable land would reduce recharge, increase the depth to the water table, and change the direction of groundwater flow; however, because the area affected would be small (about 0.1 to 0.3% of the land area available), these impacts would be negligible and limited to small, local regions in the immediate vicinity of the paved lots and building footprints.

During construction, groundwater quality would also be impacted. For example, stockpiled chemicals could be mobilized by precipitation and infiltrate the surficial aquifers. By following good engineering and construction practices (e.g., covering chemicals to prevent interaction with rain, promptly cleaning up any chemical spills, and providing retention basins to catch and hold any contaminated runoff), groundwater concentrations would be less than the EPA guidelines.

F.3.4.3 Soil

The methodology for estimating potential impacts to soil is described in detail in Appendix C and Tomasko (1997).

F.3.4.3.1 Conversion to U_3O_8

Potential impacts to soil could occur during construction, normal operations, and postulated accident scenarios. These impacts include changes in topography, permeability, quality, and erosion potential. The impacts are evaluated over a range of conditions present at the representative sites and are also applicable for a similarly sized generic site located in the vicinity of a major river.

Paving and construction would alter about 13 acres (5.3 ha) and potentially disturb up to 20 acres (8.1 ha) (LLNL 1997). Soil beneath the buildings and paved areas may be altered permanently. Although the alteration of these lands might be permanent, the net impact would be negligible in comparison to the representative land areas involved (ranging from 0.3 to 0.8% of the land area available). A larger range of values is associated with the potential land area disturbed (ranging from 0.5 to 1.2% of the land area available). These impacts could include increased permeability, modification of the local topography, changes in the soil chemistry, and increases in the potential for soil erosion. These impacts would, however, be insignificant on a sitewide scale. In addition, impacts to these areas would be mitigated with time (e.g., disturbed soil would be regraded to natural contours and seeded with natural vegetation, thereby returning the soils to their original condition).

By following good engineering practices (e.g., disturbing as little soil as possible, contouring and reseeding disturbed lands, scheduling construction activities to minimize land disturbance, controlling runoff, using tarps to prevent chemical/precipitation interactions, and cleaning up any spills as soon as they occurred), negligible impacts to soils should occur.

Because normal operations would not affect soil, there would be no soil impacts. The only accident identified that could potentially impact the soil is an HF pipeline rupture (Table F.21), discussed in Section F.3.4.1.1. Because of rapid mitigation (any contaminated soil would be cleaned up within 48 hours of the rupture) and the small release volume (60 gal of HF), impacts to the soil would be negligible.

F.3.4.3.2 Conversion to UO_2

The environmental parameters associated with the UO_2 conversion alternatives are very similar to those for U_3O_8 conversion (Table F.21). Because of these similarities, impacts to soil for UO_2 conversion would be negligible.

F.3.4.3.3 Conversion to Metal

The environmental parameters associated with the metal conversion alternatives are very similar to those for U_3O_8 conversion (Table F.21). Because of these similarities, impacts to soils would be essentially the same as those previously presented, i.e., none to negligible.

F.3.4.3.4 Cylinder Treatment Facility

For the cylinder treatment facility, the only impacts would occur during construction. There would be no discharges to the ground under normal operations, and there are no accidents identified in LLNL (1997) that would lead to direct contamination of the soil. Impacts from construction would include changes in topography, permeability, quality, and erosion potential. By following good engineering and construction practices (e.g., covering chemicals with tarps, cleaning up chemical spills as soon as they occur, and providing retention basins to catch and hold any contaminated surface runoff), impacts to soil quality would be negligible.

F.3.5 Socioeconomics

The impact of each conversion option on socioeconomic activity was estimated for a region of influence (ROI) at the three representative sites. The assessment methodology is discussed in Appendix C and Allison and Folga (1997).

Each of the conversion options is likely to have a small impact on socioeconomic conditions in the ROIs surrounding the three representative sites described in Chapter 3, Sections 3.1.8, 3.2.8, and 3.3.8. This is largely because a major proportion of the expenditures associated with procurement for the construction and operation of each technology option flows outside the ROI to other locations in the United States, reducing the concentration of local economic effects of each conversion option.

Slight changes in employment and income would occur in each ROI as a result of local spending of personal consumption expenditures derived from employee wages and salaries, local procurement of goods and services required to construct and operate each conversion option, and other local investment associated with construction and operation. In addition to creating new (direct) jobs at each site, each conversion option would also create indirect employment and income in the ROI as a result of jobs and procurement expenditures at each site. Jobs and income created directly by each conversion option, together with indirect activity in the ROI, would contribute slightly to reduction in unemployment in the ROI surrounding each site. Minimal impacts are expected on local population growth, and consequently on local housing markets and local fiscal conditions.

The effects of constructing and operating each conversion technology on regional economic activity (measured in terms of employment and personal income) and on population, housing, and local public revenues and expenditures are described in Sections F.3.5.1 through F.3.5.4. Impacts are presented as ranges to include impacts that would occur with each conversion option and for the cylinder treatment facility at each of the representative sites. Impacts for the three sites are presented for the peak year of construction (assumed to be 2006) and the first year of operations (assumed to be 2009). The potential impacts for each conversion option and for the cylinder treatment facility are presented in Table F.23.

F.3.5.1 Conversion to U_3O_8

During the peak year of construction of a U_3O_8 conversion facility, between 240 and 250 direct jobs would be created at the site and 170 to 330 additional jobs would be created indirectly in the site ROI (Table F.23) as a result of the spending of employee wages and salaries and procurement-related expenditures. Overall, 410 to 580 jobs would be created. Construction activity would also produce direct and indirect income in the ROI surrounding the site, with total income ranging from $14 million to $17 million during the peak year. During the first year of operations of the U_3O_8 conversion facility, 440 to 510 direct and indirect jobs would be created. Direct and indirect income would also be produced in the ROIs, with total income ranging from $14 million to $15 million. Construction and operation of the conversion facility would result in an increase in the projected baseline compound annual average growth rate in ROI employment of 0.01 to 0.05 percentage points from 1999 through 2028.

Construction of the U_3O_8 conversion facility would be expected to generate direct in-migration of 330 to 340 people in the peak year of construction at the site. Additional indirect job in-migration would also be expected in the site ROIs, bringing the total number of in-migrants to between 410 and 470 in the peak year (Table F.23). Operation of the U_3O_8 conversion facility would be expected to generate direct and indirect job in-migration of 220 to 340 in the first year of

TABLE F.23 Potential Socioeconomic Impacts of the Conversion Options

	Conversion to U_3O_8		Conversion to UO_2	
	Construction[a]	Operations[b]	Construction[a]	Operations[b]
Economic activity in the ROI				
Direct jobs	240 – 250	200 – 210	330 – 630	230 – 360
Indirect jobs	170 – 330	240 – 300	230 – 730	310 – 920
Total jobs	410 – 580	440 – 510	560 – 1,400	500 – 1,300
Income ($ million)				
Direct income	11	10	15 – 28	11 – 18
Total income	14 – 17	14 – 15	19 – 42	16 – 28
Population in-migration into the ROI	410 – 470	220 – 340	570 – 1,200	210 – 1,100
Housing demand				
Number of units in the ROI	150 – 170	80 – 130	210 – 440	80 – 390
Public finances				
Change in ROI fiscal balance (%)	0.1 – 0.3	<0.1 – 0.2	0.1 – 0.7	<0.1 – 0.6

	Conversion to Uranium Metal		Cylinder Treatment Facility	
	Construction[a]	Operations[b]	Construction[a]	Operations[b]
Economic activity in the ROI				
Direct jobs	380 – 440	210 – 370	100	130
Indirect jobs	230 – 470	310 – 520	40 – 80	130 – 180
Total jobs	610 – 910	520 – 890	150 – 180	260 – 310
Income ($ million)				
Direct income	12 – 16	10 – 18	5	10
Total income	15 – 25	15 – 27	5 – 6	13 – 14
Population in-migration into the ROI	650 – 790	240 – 630	160 – 180	240 – 300
Housing demand				
Number of units in the ROI	240 – 290	90 – 230	60 – 70	90 – 110
Public finances				
Change in ROI fiscal balance (%)	0.1 – 0.5	<0.1 – 0.4	<0.0 – 0.1	<0.0 – 0.2

[a] Impacts are for the peak year of construction, 2007. Socioeconomic impacts were assessed for 1999 through 2008.

[b] Impacts are the annual averages for operations for the period 2009 through 2028.

operations. Construction and operation of the facility would result in an increase in the projected baseline compound annual average growth rate in ROI population of less than 0.01 to 0.04 percentage points from 1998 through 2028.

A U_3O_8 conversion facility would generate a demand for 150 to 170 additional rental housing units during the peak year of construction (Table F.23), representing an impact of 2.7-11% on the projected number of vacant rental housing units in the representative site ROIs. A demand for 80 to 130 additional owner-occupied housing units would be expected in the first year of operations, representing an impact of 0.7 to 2.7% on the number of vacant owner-occupied housing units in the ROIs.

During the peak year of construction, 410 to 470 people would be expected to in-migrate into the ROI at the site, leading to increases of between 0.1 and 0.3% over forecasted baseline revenues and expenditures in the representative site ROI (Table F.23). In the first year of operations, 220 to 340 in-migrants would be expected, leading to increases of less than 0.1 to 0.2% in local revenues and expenditures.

F.3.5.2 Conversion to UO_2

During the peak year of construction of a UO_2 conversion facility, 330 to 630 direct jobs would be created at the site and 230 to 730 additional jobs indirectly in the site ROI (Table F.23) as a result of the spending of employee wages and salaries and procurement-related expenditures. Overall, 560 to 1,400 jobs would be created. Construction activity would also produce direct and indirect income in the ROI surrounding the site, with total income ranging from $19 million to $42 million during the peak year. During the first year of operations of the UO_2 conversion facility, 540 to 1,200 direct and indirect jobs would be created. Direct and indirect income would also be produced in the ROI, with total income ranging from $16 million to $28 million. Construction and operation of the conversion facility would result in an increase in the projected baseline compound annual average growth rate in ROI employment of 0.01 to 0.1 percentage points from 1999 through 2028.

Construction of the UO_2 conversion facility would be expected to generate direct in-migration of 460 to 860 people in the peak year of construction at the site. Additional indirect job in-migration would also be expected in the site ROIs, bringing the total number of in-migrants to between 570 and 1,200 in the peak year (Table F.23). Operation of the UO_2 conversion facility would be expected to generate direct and indirect job in-migration of 210 to 1,100 in the first year of operations. Construction and operation of the facility would result in an increase in the projected baseline compound annual average growth rate in ROI population of less than 0.01 to 0.06 percentage points from 1999 through 2028.

The UO_2 conversion facility would generate a demand for 210 to 440 additional rental housing units during the peak year of construction, representing an impact of 3.8 to 28% on the projected number of vacant rental housing units in the representative site ROIs (Table F.23). A demand for 80 to 390 additional owner-occupied housing units would be expected in the first year of operations, representing an impact of 0.7 to 8.2% on the number of vacant owner-occupied housing units in the ROIs.

During the peak year of construction, 570 to 1,200 people would be expected to in-migrate into the ROI at the site, leading to increases of 0.1 to 0.7% over forecasted baseline revenues and expenditures in the representative site ROIs (Table F.23). In the first year of operations, 210 to 1,100 in-migrants would be expected, leading to increases of less than 0.1 to 0.6% in local revenues and expenditures.

F.3.5.3 Conversion to Metal

During the peak year of construction of a metal conversion facility, 380 to 440 direct jobs would be created at the site and 230 to 470 additional jobs indirectly in the site ROI (Table F.23) as a result of the spending of employee wages and salaries and procurement-related expenditures. Overall, 610 to 910 jobs would be created. Construction activity would also produce direct and indirect income in the ROI surrounding the site, with total income ranging from \$15 million to \$25 million during the peak year. During the first year of operations of the metal conversion facility, 520 to 890 direct and indirect jobs would be created. Direct and indirect income would also be produced in the ROI, with total income ranging from \$15 million to \$27 million. Construction and operation of the conversion facility would result in an increase in the projected baseline compound annual average growth rate in ROI employment of 0.01 to 0.09 percentage points from 1999 through 2028.

Construction of the metal conversion facility would be expected to generate direct in-migration of 520 to 600 people in the peak year of construction at the site. Additional indirect job in-migration would also be expected in the site ROI, bringing the total number of in-migrants to between 650 and 790 in the peak year (Table F.23). Operation of the metal conversion facility would be expected to generate direct and indirect job in-migration of 240 to 630 in the first year of operations. Construction and operation of the facility would result in an increase in the projected baseline compound annual average growth rate in ROI population of 0.01 to 0.08 percentage points from 1999 through 2028.

The metal conversion facility would generate a demand for 240 to 290 additional rental housing units during the peak year of construction, representing an impact of 4.3 to 18.5% on the projected number of vacant rental housing units in the representative site ROIs (Table F.23). A demand for 90 to 230 additional owner-occupied housing units would be expected in the first year of operations, representing an impact of 0.8 to 4.9% on the number of vacant owner-occupied housing units in the ROI.

During the peak year of construction, 650 to 790 people would be expected to in-migrate into the ROI surrounding the site, leading to increases of 0.1 to 0.5% over forecasted baseline revenues and expenditures in the representative site ROIs (Table F.23). In the first year of operations, 240 to 630 in-migrants would be expected, leading to increases of less than 0.1 to 0.4% in local revenues and expenditures.

F.3.5.4 Cylinder Treatment Facility

During the peak year of construction of a cylinder treatment facility, approximately 100 direct jobs would be created at the site and 40 to 80 additional jobs indirectly in the site ROI (Table F.23) as a result of the spending of employee wages and salaries and procurement-related expenditures. Overall, 150 to 180 jobs would be created. Construction activity would also produce direct and indirect income in the ROI surrounding the site, with total income ranging from $5 million to $6 million during the peak year. During the first year of operations of the cylinder treatment facility, 260 to 310 direct and indirect jobs would be created. Direct and indirect income would also be produced in the ROI, with total income ranging from $13 million to $14 million. Construction and operation of the facility would result in an increase in the projected baseline compound annual average growth rate in ROI employment of 0.01 to 0.03 percentage points from 1999 through 2028.

Construction of the cylinder treatment facility would be expected to generate direct in-migration of 140 people in the peak year of construction at the site. Additional indirect job in-migration would also be expected in the site ROI, bringing the total number of in-migrants to between 160 and 180 in the peak year (Table F.23). Operation of the cylinder treatment facility would be expected to generate direct and indirect job in-migration of 240 to 300 in the first year of operations. Construction and operation of the facility would result in an increase in the projected baseline compound annual average growth rate in ROI population of less than 0.01 to 0.02 percentage points from 1999 through 2028.

The cylinder treatment facility would generate a demand for 60 to 70 additional rental housing units during the peak year of construction, representing an impact of 1.1 to 4.4% on the projected number of vacant rental housing units in the representative site ROIs (Table F.23). A demand for 90 to 110 additional owner-occupied housing units would be expected in the first year of operations, representing an impact of 0.8 to 2.3% on the number of vacant owner-occupied housing units in the ROI.

During the peak year of construction, 160 to 180 people would be expected to in-migrate into the ROI surrounding the site, leading to increases of 0.0 to 0.1% over forecasted baseline revenues and expenditures in the representative site ROIs (Table F.23). In the first year of operations, 240 to 300 in-migrants would be expected, leading to increases of less than 0.1 to 0.2% in local revenues and expenditures.

F.3.6 Ecology

Moderate impacts to ecological resources could result from construction of a conversion facility. Impacts could include mortality of individual organisms, habitat loss, or changes in biotic communities. Impacts due to operation of a conversion facility would be negligible. Potential impacts to vegetation, wildlife, wetlands, and threatened and endangered species were assessed. The methodology used in the ecological impact analysis is discussed in Appendix C.

F.3.6.1 Conversion to U_3O_8

Site preparation for the construction of a facility to convert UF_6 to U_3O_8 would require the disturbance of approximately 20 acres (8 ha), including the permanent replacement of approximately 13 acres (5.3 ha) with structures and paved areas. Existing vegetation would be destroyed during land clearing activities. Determination of the vegetation communities that would be eliminated by site preparation would depend on the future location of the facility. Communities occurring on undeveloped land at the three representative sites are relatively common and well represented in the vicinity of the sites. Impacts to high-quality native plant communities may occur if facility construction requires disturbance to vegetation communities outside of the currently fenced areas (see Section F.3.9 for a discussion of land use). Construction of the conversion facility would not be expected to threaten the local population of any species. The loss of up to 20 acres (8 ha) of undeveloped land would constitute a moderate adverse impact. 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 F.24.

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. More mobile individuals would relocate to adjacent available areas with suitable habitat. Population densities, and thus competition for food and nesting sites, would increase in these areas, potentially reducing the survivability or reproductive capacity of displaced individuals. Many wildlife species would be expected to quickly recolonize replanted areas near the conversion facility following completion of construction. The permanent loss of up to 13 acres (5.3 ha) of habitat would not be expected to threaten the local population of any wildlife species because similar habitat would be available in the vicinity of the sites. Therefore, construction of a conversion facility for U_3O_8 production would be considered a moderate adverse impact to wildlife.

Impacts to surface water and groundwater quality during construction are expected to be negligible (Section F.3.4). Thus, construction-derived impacts to aquatic biota would also be expected to be negligible. Wetlands could potentially be impacted by filling or draining during construction. Impacts to wetlands due to alteration of surface water runoff patterns, soil compaction, or groundwater flow could occur if the conversion facility were located immediately adjacent to

TABLE F.24 Impacts to Ecological Resources from Construction of a Conversion Facility and Cylinder Treatment Facility

Option/Resource	Type of Impact	Degree of Impact
Conversion to U_3O_8		
Vegetation	Loss of 20 acres	Moderate adverse impact
Wildlife	Loss of 13 to 20 acres	Minor to moderate adverse impact
Wetlands	Loss, degradation	Potential adverse impact
Aquatic species	Water quality, habitat reduction	Negligible impact
Protected species	Destruction, habitat loss	Potential adverse impact
Conversion to UO_2		
Vegetation	Loss of 22 to 31 acres	Moderate adverse impact
Wildlife	Loss of 14 to 31 acres	Moderate adverse impact
Wetlands	Loss, degradation	Potential adverse impact
Aquatic species	Water quality, habitat reduction	Negligible impact
Protected species	Destruction, habitat loss	Potential adverse impact
Conversion to metal		
Vegetation	Loss of 23 to 26 acres	Moderate adverse impact
Wildlife	Loss of 15 to 26 acres	Moderate adverse impact
Wetlands	Loss, degradation	Potential adverse impact
Aquatic species	Water quality, habitat reduction	Negligible impact
Protected species	Destruction, habitat loss	Potential adverse impact
Cylinder treatment facility		
Vegetation	Loss of 9 acres	Moderate adverse impact
Wildlife	Loss of 5 to 9 acres	Moderate adverse impact
Wetlands	Loss, degradation	Potential adverse impact
Aquatic species	Water quality, habitat reduction	Negligible impact
Protected species	Destruction, habitat loss	Potential adverse impact

wetland areas. However, impacts to wetlands would be minimized by maintaining a buffer area around wetlands 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.

Critical habitat has not been designated for any state or federally listed threatened or endangered species at any of the representative sites. Prior to construction of a conversion facility, a site-specific survey for federal- and state-listed threatened, endangered, or candidate species or species of special concern would be conducted. Impacts to these species could thus be avoided or, where impacts were unavoidable, appropriate mitigation could be developed.

During operations, ecological resources in the vicinity of the conversion facility would be exposed to atmospheric emissions from the boiler stack and process stack; however, emission levels would be expected to be extremely low (Section F.3.3.2). The highest annual average air concentration of U_3O_8 at a representative site boundary would be less than 2.6×10^{-5} $\mu g/m^3$. This would result in a radiation exposure to the general public (nearly 100% due to inhalation) of less than 0.009 mrem/yr (Section F.3.1.1), well below the DOE guidelines of 100 mrem/yr (0.00027 rad/d). Wildlife species are less sensitive to radiation than humans (proposed DOE guidelines would require an absorbed dose limit to terrestrial animals of 0.1 rad/d). Therefore, impacts to wildlife due to radiation effects would be expected to be negligible. Toxic effects of chronic inhalation of U_3O_8 are minor at a concentration of 17 mg/m^3 for tested animal species. This is many orders of magnitude greater than expected emissions. Therefore, toxic effects to wildlife due to U_3O_8 inhalation would also be expected to be negligible. See Appendix C for further discussion.

The maximum annual average air concentration of hydrogen fluoride at a site boundary, due to operation of a conversion facility, would be less than 0.0073 $\mu g/m^3$ (Section F.3.3.2). Chronic exposure to HF gas produces only mild effects in tested animal species at concentrations as high as 7 mg/m^3, considerably higher than expected emissions. Therefore, toxic effects to wildlife from HF emissions would be expected to be negligible.

A portion of the U_3O_8 released from the process stack of a conversion facility would become deposited on the soils surrounding the site. Uptake of uranium-containing compounds can cause adverse effects to vegetation. Deposition of U_3O_8 on soils, resulting from atmospheric emissions, would result in soil uranium concentrations considerably below the lowest concentration known to produce toxic effects in plants. Therefore, toxic effects on vegetation due to U_3O_8 uptake would be expected to be negligible.

Effluent discharges to surface waters would result in a uranium concentration of about 12 pCi/L (0.03 mg/L) as uranyl nitrate (Section F.3.4.1). Resulting dose rates to maximally exposed organisms would be considerably lower than the dose limit of 1 rad/d for aquatic organisms, which is required by DOE Order 5400.5. Uranyl nitrate concentrations in the effluent also would be considerably lower than 0.15 mg/L, the lowest concentration known to cause toxic effects in aquatic biota. Mixing of the effluent with surface water downstream of the outfall would result in a dilution factor of more than 50,000. Therefore, impacts to aquatic biota would be considered to be negligible.

For the U_3O_8 conversion process, water withdrawal from surface waters or groundwater, as well as wastewater discharge, could potentially alter water levels which could in turn affect aquatic ecosystems including wetlands (including wetlands located along the periphery of these surface water bodies). However, water level changes due to process water withdrawal and wastewater discharge would be negligible (Section F.3.4.1). Therefore, impacts to wetlands would be expected to be negligible.

A potential release of contaminants due to the occurrence of an earthquake was analyzed. The subsequent rupture of an HF pipeline would potentially release anhydrous HF into the surrounding soil, surface water, or groundwater. Due to the brief duration of the release, the small volume involved, and rapid mitigation, the expected impacts to surface water, groundwater, and soil would be negligible (Section F.3.4). Therefore, impacts to ecological resources from such an accident would also be expected to be negligible. Facility accidents, as discussed in Section F.3.2, could result in adverse impacts to ecological resources. The affected species and the degree of impact would depend on a number of factors such as location of the accident, season, and meteorological conditions.

F.3.6.2 Conversion to UO_2

The construction of a facility to convert depleted UF_6 to UO_2 would generally result in the types of impacts associated with conversion to U_3O_8. Site preparation for the construction of a facility to convert depleted UF_6 to UO_2 would require the disturbance of approximately 22 to 31 acres (8.9 to 12.5 ha), including the permanent replacement of approximately 14 to 19 acres (5.5 to 7.8 ha) with structures and paved areas. The loss of 22 to 31 acres (8.9 to 12.5 ha) of undeveloped land would constitute a moderate adverse impact to vegetation. The permanent loss of up to 19 acres (7.8 ha) of habitat would not be expected to threaten the local population of any wildlife species because similar habitat would be available in the vicinity of the representative sites. However, habitat use in the vicinity of the facility might be greatly reduced for many species due to the construction of a perimeter fence. Consequently, the construction of a conversion facility for UO_2 production is considered a moderate adverse impact to wildlife.

Impacts to surface water and groundwater quality during construction would be expected to be negligible (Section F.3.4). Thus, construction-derived impacts to aquatic biota would also be expected to be negligible. Impacts to wetlands and protected species due to facility construction would be similar to impacts associated with conversion to U_3O_8.

During operations, exposures to contaminants from conversion to UO_2 would generally be slightly larger than for conversion to U_3O_8, but all exposures would be well below levels that might produce adverse effects. All impacts would therefore be negligible. Impacts to ecological resources from accident scenarios would be as discussed for conversion to U_3O_8 (Section F.3.6.1).

F.3.6.3 Conversion to Metal

Construction of a facility to convert depleted UF_6 to uranium metal would generally result in the types of impacts associated with conversion to U_3O_8. Site preparation would require the disturbance of approximately 23 to 26 acres (9.4 to 11 ha), including the permanent replacement of about 15 to 16 acres (6.2 to 6.5 ha) with structures and paved areas. The loss of 23 to 26 acres (9.4

to 11 ha) of undeveloped land would constitute a moderate adverse impact to vegetation and wildlife. Impacts due to facility construction are shown in Table F.24.

During operation of the metal conversion facility, exposure to contaminants would be considerably below levels known to cause toxic effects in biota. The resulting impacts would therefore be negligible. Impacts to ecological resources from accidents would be as discussed for conversion to U_3O_8 (Section F.3.6.1).

Construction of a cylinder treatment facility would generally result in the types of impacts associated with construction of a conversion facility; however, the area affected would be smaller (Table F.24). Site preparation for constructing a cylinder treatment facility would require the disturbance of approximately 9 acres (4 ha). About 5 acres (2 ha) would be permanently replaced with structures, paved areas, and landscaping. The loss of 9 acres (4 ha) of undeveloped land would constitute a moderate adverse impact to vegetation and wildlife. Exposure to contaminants resulting from operation of a cylinder treatment facility would be considerably below levels known to result in toxic effects to biota. The resulting impacts would therefore be negligible.

F.3.7 Waste Management

Impacts on waste management from wastes generated during construction and normal operations at the depleted UF_6 conversion facilities would be caused by the potential overload of waste treatment and/or disposal capabilities either at a site or on a regional/national scale. The types of wastes that are expected to be generated by the depleted UF_6 conversion include low-level radioactive waste (LLW), low-level mixed waste (LLMW), hazardous waste, nonhazardous solid waste, and nonhazardous wastewater. Currently, there are numerous DOE and commercial facilities that treat and/or dispose of LLW, hazardous waste, nonhazardous solid waste, and wastewaters. The treatment/disposal of LLMW is limited by regulatory and technological restrictions.

F.3.7.1 Conversion to U_3O_8

Construction of a facility to convert UF_6 into U_3O_8 would generate both hazardous and nonhazardous wastes. Approximately 115 m^3 of hazardous waste, 700 m^3 of nonhazardous solid waste, and 15,000 m^3 of wastewater would be generated during construction (see Table F.25). This compares with existing contributions for hazardous waste ranging from approximately 80 m^3/yr to 1,000 m^3/yr, solid waste loads for the representative sites of 2,100 to 28,000 m^3/yr, and wastewater loads of 500,000 to 880,000 m^3 annually for the representative sites (see Appendix C, Table C.3). No radioactive waste would be generated during the construction phase of the facility. Overall, only minimal waste management impacts would result from construction-generated wastes.

Operations at the facility to convert UF_6 into U_3O_8 would generate radioactive, hazardous, and nonhazardous wastes (Table F.25). The conversion facility would generate 140 to 600 m^3/yr of

TABLE F.25 Wastes Generated from Construction and Operations Activities for Depleted UF_6 Conversion[a]

Activity/ Waste Category	Volume Ranges for the Options		
	Conversion to U_3O_8	Conversion to UO_2	Conversion to Metal
Construction[a] (m^3)			
Low-level waste	–	–	–
Low-level mixed waste	–	–	–
Hazardous waste	115	140 – 200	140 – 180
Nonhazardous waste			
Solids	700	1,300	860 – 1,130
Wastewater	3,800	7,600	5,700 – 7,580
Sanitary wastewater	11,400	17,000	13,200 – 15,200
Operations (m^3/yr)			
Low-level waste			
Combustible waste	76.5	88.0 – 136	76.5 – 420
Noncombustible	62 – 68.2	82.0 – 140	112 – 470
Grouted	0 – 466	0 – 466	0 – 997
Total	140 – 600	170 – 740	190 – 1,890
Low-level mixed waste	1.1	1.1 – 8.8	1.1
Hazardous waste	7.32	7.32 – 17	7.32 – 9.5
Nonhazardous waste			
Solids	380 – 11,000[b]	520 – 30,600[b]	6,580 – 6,840[c]
Wastewater	58,000 – 87,100	74,900 – 510,000	94,000 – 96,500
Sanitary wastewater	4,540 – 4,920	5,680 – 8,700	5,300 – 8,700

[a] Total waste generated during construction period of 4 years.

[b] Includes 240 to 10,630 m^3 of CaF_2.

[c] Includes 67 m^3 of CaF_2 and 5,850 to 6,110 m^3 of MgF_2.

LLW, which, at the upper end, represents approximately 7 to 27% of the representative site LLW loads (see Appendix C, Table C.3). The U_3O_8 conversion facility waste input would represent less than 1% of DOE LLW generation. The U_3O_8 conversion facility would generate approximately 1.1 m^3/yr of LLMW, which is less than 1% of the LLMW generation at the representative sites (ranging from 100 to 5,000 m^3/yr LLMW) (see Appendix C, Table C.3). The U_3O_8 conversion facility would generate approximately 7 m^3/yr of hazardous waste, which would result in an increase of about 1 to 10% of the hazardous waste loads at the representative sites; and about 60,000 to

90,000 m^3/yr of wastewater, representing between 9 and 17% of the current loads for wastewater at the representative sites.

The CaF_2 potentially produced in the U_3O_8 conversion process was assumed to have a uranium content of less than 1 ppm (LLNL 1997). It is currently unknown whether this CaF_2 could be sold (e.g., as feedstock for commercial production of anhydrous HF) or whether the low uranium content would require disposal as either a nonhazardous solid waste or as LLW. The nonhazardous solid waste generation estimates for conversion to U_3O_8 and UO_2, as shown in Table F.25, are based on the assumption that CaF_2 would be disposed of as nonhazardous solid waste, generating approximately 380 to 11,000 m^3/yr of nonhazardous solid waste (from 18 to 500% of the current nonhazardous solid waste loads at the representative sites, depending on the conversion technology chosen). If CaF_2 were considered to be LLW, it would represent an additional 3 to 480% of the current LLW loads at the representative sites. The upper end of the range of nonhazardous and LLW volume increases (which correspond to the HF neutralization process) would constitute a potentially large impact to either nonhazardous or LLW management activities at an actual site. Disposal as LLW might require the CaF_2 to be grouted, generating up to 21,300 m^3/yr of grouted waste. The maximum volume of LLW generated would still represent less than 10.4% of the projected DOE complexwide LLW disposal volume, constituting a moderate impact with respect to complexwide LLW management. It is also unknown whether CaF_2 LLW would be considered DOE waste if the conversion were conducted by a private commercial enterprise. If CaF_2 could be sold, the nonhazardous solid waste or LLW management impacts would be reduced to a low level for U_3O_8 conversion technologies.

The impacts from normal operation of the U_3O_8 conversion facility would range from negligible to large, depending upon the choice of technology and the ultimate generation volumes and disposition of CaF_2 for the facility. Overall, the waste input resulting from normal operations at the U_3O_8 conversion facility would be expected to have a moderate impact on waste management. If CaF_2 were disposed of as nonhazardous solid waste, the increased input could be managed by expanding the capacity of the nonhazardous solid waste disposal facilities at the actual site.

F.3.7.2 Conversion to UO_2

Construction of a facility to convert UF_6 into UO_2 would generate approximately the same quantity of hazardous wastes as conversion to U_3O_8. Construction would generate approximately 1,300 m^3 of solid nonhazardous wastes and up to 24,000 m^3 of wastewater (see Table F.25). These waste loads are well below the representative site waste inputs for comparable wastes. No radioactive waste would be generated during the construction phase of the facility. Overall, only minimal waste management impacts would result from construction-generated wastes.

Operations at the facility to convert UF_6 into UO_2 would generate radioactive, hazardous, and nonhazardous wastes (Table F.25). The conversion facility would generate about 9 to 33% of the representative site LLW loads (see Appendix C, Table C.3). The UO_2 conversion facility would generate up to 465 m^3/yr of a solid, grouted LLW that would require off-site disposal. The conversion facility LLW input would represent less than 1% of the projected annual DOE LLW treatment volume. The UO_2 conversion facility would generate from 1 to 9% of the LLMW generation for the representative sites (see Appendix C, Table C.3). The UO_2 conversion facility would generate 7 to 17 m^3/yr of hazardous waste, which would result in a minor increase to the hazardous waste load from routine operations at the representative site. The UO_2 conversion facility would add 520 to 30,600 m^3/yr of nonhazardous solid waste and about 80,000 to 500,000 m^3/yr of wastewater (see Table F.25).

As in the U_3O_8 conversion option, it is currently unknown whether CaF_2 generated in the conversion to UO_2 option could be sold or whether the low uranium content (less than 1 ppm) would require disposal as either a nonhazardous solid waste or as LLW. The nonhazardous solid waste generation estimates for conversion to UO_2 shown in Table F.25 are based on the assumption that CaF_2 would be disposed of as nonhazardous solid waste, generating about 240 to 11,000 m^3/yr of nonhazardous solid waste (up to 500% of the current nonhazardous solid waste loads at the representative sites, depending on the conversion technology chosen). If CaF_2 were considered to be LLW, it would represent up to 480% of the current LLW loads at the representative sites. The upper end of the range of nonhazardous and LLW volume increases (which correspond to the HF neutralization process) would constitute a potentially large impact to either nonhazardous or LLW management activities at an actual site. Disposal as a LLW might require the CaF_2 to be grouted, generating up to 21,300 m^3/yr of grouted waste. However, the maximum volume of LLW generated would still represent less than 10.4% of the projected DOE complexwide LLW disposal volume, constituting a moderate impact with respect to complexwide LLW management, if the CAF_2 were considered DOE waste. If CaF_2 could be sold, the nonhazardous solid waste or LLW management impacts would be reduced to a low level for UO_2 conversion technologies.

The large range in the expected volume of nonhazardous solid waste and wastewater is also a result of differences in UO_2 conversion technologies. The gelation technology would result in the highest nonhazardous waste generation volumes. The range of 520 to 30,600 m^3/yr for nonhazardous solid wastes represents an approximate range of 2 to 1,500% (15 times) the annual nonhazardous solid waste production at the representative sites. The estimated range for wastewater generation represents a range of about 13 to 115% of the annual wastewater generation at the representative sites.

The impacts from normal operation of the UO_2 conversion facility would range from negligible to large, depending upon the choice of technology for this facility. Overall, the waste input resulting from normal operations at the UO_2 conversion facility would be expected to have a moderate impact on waste management. The increased solid waste input could be managed by expanding the capacity of the solid nonhazardous waste disposal facilities at the sites. The increased wastewater input would be handled by existing site wastewater capabilities of the representative sites.

F.3.7.3 Conversion to Metal

Construction of the facility to convert UF_6 into uranium metal would generate approximately the same quantity of hazardous and nonhazardous wastes as conversion to U_3O_8 or UO_2 (Table F.25). No radioactive waste would be generated during the construction phase of the facility. Overall, only minimal waste management impacts would result from construction-generated wastes.

Operations at the facility to convert UF_6 into uranium metal would generate radioactive, hazardous, and nonhazardous wastes (Table F.25). The conversion facility would generate about 23 to 85% of the representative site LLW loads (see Appendix C, Table C.3). A metal conversion facility LLW input would represent less than 3% of the projected annual DOE LLW treatment volume. The metal conversion facility would generate less than 1% of the LLMW generation at the representative sites (see Appendix C, Table C.3) and less than 12% of the hazardous waste load from routine operations at the three representative sites. The metal conversion facility would add from 25 to 325% of the existing representative site solid waste load and from 12 to 20% of the load for wastewater. The increased solid waste input could be managed by expanding the disposal capacity of the solid nonhazardous waste disposal facilities at the actual site.

It is possible that the MgF_2 waste generated in the conversion to metal option would be sufficiently contaminated with uranium to require disposal as LLW rather than as solid nonhazardous waste. The uranium level in the MgF_2 is estimated to be about 90 ppm (LLNL 1997). Such disposal might require the MgF_2 waste to be grouted, generating about 6,150 to 12,300 m^3/yr of grouted waste for LLW disposal. This volume range represents about 72 to 560% of the current LLW generation for the representative three sites (see Appendix C, Table C.3). However, it would represent less than 6% of the projected DOE complexwide LLW disposal volume, constituting a low impact with respect to complexwide LLW management, if the MgF_2 were considered a DOE waste.

Neutralization of HF to CaF_2 was not explicitly analyzed in the engineering analysis report for the conversion to metal options (LLNL 1997). However, the process could be implemented and would produce approximately one-third as much CaF_2 as would be produced under the conversion to oxide with neutralization options (i.e., approximately 3,500 m^3/yr of CaF_2). If this CaF_2 waste were disposed of as LLW, it would constitute less than 3% of the DOE complexwide LLW disposal volume, representing a low impact with respect to complexwide LLW management.

Overall, the waste input resulting from normal operations at the uranium metal conversion facility would have a moderate impact on waste management.

F.3.7.4 Cylinder Treatment Facility

All of the conversion options would require the removal of depleted UF_6 from the storage cylinders, resulting in a large number of empty cylinders. These empty UF_6 cylinders from the conversion facility would be decontaminated at the cylinder treatment facility and then prepared for disposal as scrap metal. It was assumed for this assessment that the cylinder treatment facility would be washing the empty cylinders with water to remove the "heels" of depleted UF_6. The resulting aqueous wash solution would be evaporated and converted to solid U_3O_8 and HF. The U_3O_8 would be packaged and sent for disposal. The HF would be neutralized to CaF_2 and separately packaged for either disposal or sale.

Construction of the cylinder treatment facility would generate both hazardous and nonhazardous wastes. These waste quantities — hazardous, 18 m^3; solid nonhazardous, 300 m^3; and sanitary and other nonhazardous liquids, 28,000 m^3 — all represent only minimal waste management impacts at any of the three potential sites. No radioactive waste would be generated during construction of this facility.

The amounts of waste generated annually during operation of the cylinder treatment facility are given in Table F.26. Included are crushed old cylinders and wastes obtained (U_3O_8 and CaF_2) from disposal of the "heels." All of these wastes, except the crushed old cylinders, represent only negligible impacts to the waste management system. Over 20 years of operations, the crushed old cylinders (2,322 cylinders/yr) would generate about 125,000 m^3 (6,190 m^3/yr × 20 years) of waste volume for disposal. It was assumed that the treated cylinders with a very low residual radiation level

TABLE F.26 Annual Waste Generation during Operation of the Cylinder Treatment Facility

Waste Category	Volume (m^3/yr)
Low-level waste	
Combustible solids	31
Contaminated metal and other noncombustible solids	11
U_3O_8	6.3
Low-level mixed waste	0.2
Hazardous waste	2
Nonhazardous waste	
Solids	100
Wastewater	6,400
CaF_2	14
Sanitary waste	2,300
Crushed cylinders	6,190

would become part of the DOE scrap metal inventory. If a disposal decision were made, the treated cylinders would be disposed of as LLW, representing a 3% addition to the projected DOE complexwide LLW disposal volume.

F.3.7.5 Summary

The impacts from the uranium metal conversion facility would be greater than the waste management impacts resulting from operations of U_3O_8 conversion, unless CaF_2 required disposal as a waste. In the latter case, the impacts to waste management facilities for U_3O_8 conversion would probably exceed those for uranium metal conversion. The largest waste volumes would result from conversion to UO_2.

F.3.8 Resource Requirements

Utilities and materials required for constructing the conversion facility for UF_6 to U_3O_8, UO_2, or uranium metal are listed in Table F.27. The equipment for conversion processes would be purchased from equipment vendors. The total quantities of commonly used materials of construction (e.g, carbon steel, stainless steel) for equipment would be minor compared to the quantities required for facility construction, as listed in Table F.27. The primary specialty materials required for fabricating process equipment include Monel and Inconel (LLNL 1997). Utilities and materials required for operating the three conversion facilities are shown in Table F.28.

F.3.9 Land Use

F.3.9.1 Conversion to U_3O_8

Impacts to land use from the construction and operation of a U_3O_8 conversion facility would be negligible. Such impacts would be limited to the clearing of required land, minor and temporary disruptions to contiguous land parcels, and a slight increase in vehicular traffic. Under this conversion option, a conversion facility would require approximately 20 acres (8 ha) for construction and about 13 acres (5 ha) for operation (see Table F.29). The construction phase requires more land because space is needed for material excavation storage, equipment staging, and construction material laydown areas.

The amount of land required for this conversion option would not be great enough to require major land modification. However, it should be noted that siting a conversion facility at a location that is already dedicated to similar use could result in fewer land-use impacts because immediate access to infrastructure and utility support would be possible with only minor disturbances to existing land use.

TABLE F.27 Resource Requirements for Constructing a Conversion Facility

Utilities/Materials	Unit	Total Consumption: Conversion to U_3O_8	Conversion to UO_2	Conversion to Metal
Utilities				
Electricity[a]	MWh	30,000	35,000	35,000 – 45,000
Solids				
Concrete	yd^3	15,000 – 18,000	21,000 – 44,300	20,000 – 23,000
Steel (carbon or mild)	ton	6,000 – 7,000	8,000 – 8,800	9,000 – 10,000
Liquids				
Diesel fuel	million gal	0.75	0.45 – 0.80	0.80 – 1.0
Gasoline	million gal	0.75	0.40 – 0.80	0.80 – 1.0
Gases				
Industrial gases (propane)	gal	4,000	4,400	4,400 – 5,500
Specialty materials				
Monel	ton	15 – 30	25 – 88	20 – 100
Inconel	ton	10	10 – 88	0 – 4
Titanium	ton	NA[b]	0 – 33	0 – 10

[a] The peak electricity demand during any hour would be as follows: conversion to U_3O_8, about 1.5 MW; conversion to UO_2, about 1.5 MW; conversion to metal, from 1.5 to 2.5 MW.

[b] NA = not applicable.

Source: LLNL (1997).

Impacts to land use outside the boundaries of a conversion facility would include negligible and temporary traffic impacts associated with project construction peaks. Also, because of the handling of UF_6 at the facility, NUREG-1140 (McGuire 1985) suggests that a 1-mile protective action distance be established around such a facility, which would cover an area of about 960 acres. The protective action distance is the recommended distance for which emergency planning would be appropriate to mitigate off-site exposure to accidental releases.

F.3.9.2 Conversion to UO_2

Impacts to land use from the UO_2 conversion option would be only slightly greater than those associated with other conversion options. The areal requirements for this option range from

TABLE F.28 Resource Requirements for Operating a Conversion Facility

		Average Annual Requirement		
Utilities/Materials	Unit	Conversion to U_3O_8	Conversion to UO_2	Conversion to Metal
Utilities				
Electricity[a]	GWh	11.0	24 – 29	25 – 44
Liquid fuel	gal	6,000	3,040 – 7,000	6,500 – 9,500
Natural gas	million scf[b]	102 – 118	38 – 116	100 – 167
Solids				
Calcium hydroxide (hydrated lime)	million lb	0.388 – 1.27	0.388 – 1.27	0.247
Calcium oxide (quicklime)	million lb	0 – 29	0 – 29	NA[c]
Cement	lb	0 – 862,000	0 – 862,000	0 – 940,000
Detergent	lb	500	600	600 – 700
Iron	million lb	NA	NA	0 – 1.3
Magnesium	million lb	NA	NA	8.4 – 8.6
Sodium chloride	lb	NA	NA	0 – 514,000
Pelletizing lubricant	lb	NA	236,000	NA
Liquids				
Ammonia	million lb	0 – 0.662	2.9	2.4
Hydrochloric acid	lb	11,100 – 18,200	8,900 – 13,600	5,300 – 9,500
Nitric acid	lb	NA	NA	0 – 230,000
Sodium hydroxide	lb	8,800 – 14,400	7,000 – 10,700	4,200 – 7,500

a Peak electricity demand during any hour would be as follows: conversion to U_3O_8, about 1.5 MW; conversion to UO_2, from 3.2 to 4.0 MW; conversion to metal, from 3.3 to 6.0 MW.

b scf = standard cubic feet measured at 14.7 psia and 60°F.

c NA = not applicable.

Source: LLNL (1997).

22 to 31 acres (9 to 13 ha) for construction and from 14 to 20 acres (5.5 to 8 ha) for operations (Table F.29). Siting a conversion facility at a location that is already dedicated to similar use could result in fewer land-use impacts because immediate access to infrastructure and utility support would be possible with only minor disturbances to existing land use.

Impacts to local traffic patterns outside potential UO_2 conversion plant sites could be greater than those expected under the conversion to U_3O_8 option due to the potential for increased traffic volume associated with greater construction workforce demands. However, such impacts would be temporary and would be expected to diminish during the operations phase. The protective

TABLE F.29 Land Requirements for the Conversion Options

	Land Requirement (acres)[a]	
Option	Construction	Operation
Conversion to U_3O_8	20	13
Conversion UO_2	22 – 31	14 – 20
Conversion to metal	23 – 26	15 – 16

[a] NUREG-1140 (McGuire 1985) suggests that each conversion facility establish a protective action distance for emergency planning, which would incorporate an area of about 960 acres around each facility.

Source: LLNL (1997).

action distance described in Section F.3.9.1 would be applicable to an area of about 960 acres around the facility.

F.3.9.3 Conversion to Metal

Land-use impacts from the conversion to uranium metal option would be minimal. Land requirements (Table F.29) would be similar to those discussed for the conversion to UO_2 option, and impacts related to construction traffic outside the conversion plant sites would be negligible. The protective action distance would be applicable to an area of about 960 acres around the facility.

F.3.9.4 Cylinder Treatment Facility

Impacts to land use from the construction and operation of a cylinder treatment facility would be negligible and of a lesser magnitude than those generated under any of the conversion options. Although the cylinder treatment facility could be a stand-alone facility, it is likely to be integrated into a depleted UF_6 conversion facility. If the cylinder treatment facility were incorporated into a conversion facility, it would require less than 1 acre (0.4 ha) of land, regardless of the conversion option. Such a small areal requirement would account for much less than 1% of the land available for development at the representative sites. If construction of a cylinder treatment facility and conversion facility occurred simultaneously, the peak construction labor force of 230 for the cylinder treatment facility could slightly increase the magnitude (expected to be negligible) of off-site traffic impacts associated with the conversion facility construction.

As a stand-alone facility, the cylinder treatment facility would require 8.7 acres (3.5 ha) of land for construction and 4.5 acres (2 ha) for operations. The areal requirement would probably not be large enough to result in land-use impacts, particularly if the facility were sited at a location already dedicated to a similar industrial-type use.

F.3.10 Other Impacts Considered But Not Analyzed in Detail

Other impacts that could potentially occur if the conversion 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 conversion facilities. These impacts, although considered, were not analyzed in detail for one or both of the following reasons:

- The impacts could not be determined at the programmatic level without consideration of specific sites (e.g., impacts on cultural resources, threatened and endangered species, wetlands, and environmental justice). 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.

F.4 REFERENCES FOR APPENDIX F

Allison, T., and S. Folga, 1997, *Socioeconomic Impact Analyses in Support of the Depleted Uranium Hexafluoride Programmatic Environmental Impact Statement*, attachment to memorandum from T. Allison (Argonne National Laboratory, Argonne, Ill.) to H.I. Avci (Argonne National Laboratory, Argonne, Ill.), May 21.

Charles, L.D., et al., 1991, *Cost Study for the D&D of the GDPs: Depleted Uranium Management and Conversion,* K/D-5940-F, Martin Marietta Energy Systems, Oak Ridge, Tenn.

Cheng, J.-J., et al., 1997, *Human Health Impact Analyses for Normal Operations in Support of the Depleted Uranium Hexafluoride Programmatic Environmental Impact Statement*, attachment to memorandum from J.-J. Cheng (Argonne National Laboratory, Argonne, Ill.) to H.I. Avci (Argonne National Laboratory, Argonne, Ill.), May 21.

EPA: see U.S. Environmental Protection Agency.

Lawrence Livermore National Laboratory, 1997, *Depleted Uranium Hexafluoride Management Program; the Engineering Analysis Report for the Long-Term Management of Depleted Uranium Hexafluoride*, UCRL-AR-124080, Volumes I and II, prepared by Lawrence Livermore National Laboratory, Science Applications International Corporation, Bechtel, and Lockheed Martin Energy Systems for U.S. Department of Energy.

LLNL: see Lawrence Livermore National Laboratory.

McGuire, S.A., 1985, *A Regulatory Analysis on Emergency Preparedness for Fuel Cycle and Other Radioactive Material Licensees*, NUREG-1140, Draft Report for Comment, U.S. Nuclear Regulatory Commission, Washington, D.C., June.

National Safety Council, 1995, *Accident Facts*, 1995 Edition, Itasca, Ill.

Nieves, L.A., et al., 1997, *Analysis of Options for Disposition of Empty Depleted UF_6 Cylinders*, attachment to memorandum from L.A. Nieves et al. (Argonne National Laboratory, Argonne, Ill.) to H.I. Avci (Argonne National Laboratory, Argonne, Ill.), May 21.

NRC: see U.S. Nuclear Regulatory Commission.

Policastro, A.J., et al., 1997, *Facility Accident Impact Analyses in Support of the Depleted Uranium Hexafluoride Programmatic Environmental Impact Statement*, attachment to memorandum from A.J. Policastro (Argonne National Laboratory, Argonne, Ill.) to H.I. Avci (Argonne National Laboratory, Argonne, Ill.), June 15.

Tomasko, D., 1997, *Water and Soil Impact Analyses in Support of the Depleted Uranium Hexafluoride Programmatic Environmental Impact Statement*, attachment to memorandum from D. Tomasko (Argonne National Laboratory, Argonne, Ill.), to H.I. Avci (Argonne National Laboratory, Argonne, Ill.), May 21.

Tschanz, J., 1997, *Air Impact Analyses in Support of the Depleted Uranium Hexafluoride Programmatic Environmental Impact Statement*, attachment to memorandum from J. Tschanz (Argonne National Laboratory, Argonne, Ill.) to H.I. Avci (Argonne National Laboratory, Argonne, Ill.), May 21.

U.S. Environmental Protection Agency, 1996, *Drinking Water Regulations and Health Advisories*, EPA 882-B-96-002, Office of Water, Washington, D.C., Oct., pp. 1-11.

U.S. Nuclear Regulatory Commission, 1994, "10 CFR Part 19, et al., Certification of Gaseous Diffusion Plants; Final Rule," discussion on Section 76.85, "Assessment of Accidents," *Federal Register* 59(184):48954-48955, Sept. 23.

APPENDIX J:

ENVIRONMENTAL IMPACTS OF TRANSPORTATION OF UF_6 CYLINDERS, URANIUM OXIDE, URANIUM METAL, AND ASSOCIATED MATERIALS

CONTENTS (APPENDIX J)

TABLES

TABLES (Cont.)

TABLES (Cont.)

NOTATION (APPENDIX J)

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

CFR	*Code of Federal Regulations*
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
ICRP	International Commission on Radiological Protection
LCF	latent cancer fatality
LLNL	Lawrence Livermore National Laboratory
LLMW	low-level mixed waste
LLW	low-level radioactive waste
MEI	maximally exposed individual
NEPA	*National Environmental Policy Act*
PEIS	programmatic environmental impact statement

Chemicals

CaF_2	calcium fluoride
HF	hydrogen fluoride; hydrofluoric acid
MgF_2	magnesium fluoride
NH_3	ammonia
UF_6	uranium hexafluoride
UO_2	uranium dioxide
U_3O_8	triuranium octaoxide (uranyl uranate)

UNITS OF MEASURE

ft	foot (feet)
h	hour(s)
kg	kilogram(s)
km	kilometer(s)
lb	pound(s)
m	meter(s)
mrem	millirem(s)

APPENDIX J:

ENVIRONMENTAL IMPACTS OF TRANSPORTATION OF UF_6 CYLINDERS, URANIUM OXIDE, URANIUM METAL, AND ASSOCIATED MATERIALS

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 from 1999 through 2039. This appendix provides detailed information describing the transportation of radioactive and other hazardous materials associated with the options considered in the PEIS. The discussion provides background information, as well as a summary of the estimated environmental impacts associated with transportation.

> **Transportation**
>
> The transportation of hazardous and radioactive materials was assessed for all alternative strategies considered in the PEIS for management of the depleted UF_6 inventory currently stored at three DOE sites. For purposes of analysis, it was assumed that all long-term storage, conversion, disposal, and manufacture and use facilities would be located at different sites, thus requiring the transportation of materials between sites. The PEIS transportation assessment considered the impacts from all shipments associated with each category of the options that make up the alternatives. The materials considered include depleted UF_6 cylinders, uranium conversion products, chemicals required for or produced during processing (such as hydrogen fluoride and hydrochloric acid), as well as any low-level radioactive, low-level mixed radioactive, and hazardous waste generated during operations. The analysis considered both truck and rail shipment options.

All of the PEIS alternatives would involve some transportation of radioactive and hazardous materials. For purposes of the PEIS analysis, it was assumed that all long-term storage, conversion, disposal, and manufacture and use facilities would be located at different locations. Thus, transportation would form the links between the options that make up each of the PEIS alternatives, as shown graphically in Chapter 2, Figures 2.2 through 2.6. In reality, the transportation activities actually required by an alternative would depend on the locations of the facilities involved — if facilities were colocated, the transportation of materials, and any associated impacts, would be minimized or eliminated.

The transportation assessment considered all shipments associated with the categories of options that make up each of the PEIS alternatives. The primary uranium materials transported under these alternatives include depleted UF_6 cylinders, uranium oxide (uranium dioxide [UO_2] or triuranium octaoxide [U_3O_8]), uranium metal, and uranium oxide and uranium metal storage casks (see Table J.1). Also, each alternative would involve transportation of chemicals required for or

TABLE J.1 Primary Uranium Materials Transported under Each Management Alternative

	Primary Material Transported[a]				
PEIS Alternative	Depleted UF_6 Cylinders	Oxide (UO_2 or U_3O_8)	Uranium Metal	Uranium Oxide Casks	Uranium Metal Casks
No action	–	–	–	–	–
Long-term storage as UF_6	X[b]	–	–	–	–
Long-term storage as oxide	X	X	–	–	–
Use as uranium oxide	X	X	–	X	–
Use as uranium metal	X	–	X	–	X
Disposal	X	X	–	–	–

[a] In addition to the uranium materials listed, each alternative would also involve the transportation of chemicals required for or produced during processing, as well as LLW and LLMW.

[b] X indicates that the material was assumed to be transported under that PEIS alternative.

produced during processing (such as hydrogen fluoride [HF]), as well as any low-level radioactive waste (LLW), low-level mixed waste (LLMW), and hazardous chemical waste generated during operations.

Impacts from the on-site transportation of the various materials at the different facilities (conversion, storage, manufacture, and disposal) were not computed. On-site transportation impacts are expected to be negligible when compared with the impacts associated with the off-site transportation between facilities. On-site shipments of over 19 miles (30 km) were assessed for the Hanford site for comparison with off-site shipments analyzed in the *Waste Management Programmatic Environmental Impact Statement* (DOE 1997). The on-site impacts were found to be more than 100 times smaller than the off-site impacts, primarily because of the much shorter shipment distances involved (Biwer et al. 1996). For the depleted UF_6 PEIS, shorter on-site distances are likely; therefore, the on-site transportation impacts are also expected to be more than 100 times smaller than the off-site impacts. The decisions to be made based on this PEIS would not be affected by on-site transportation impacts. In addition, transportation impacts would be much smaller for on-site shipments than off-site shipments and would also be smaller than the impacts associated with loading and unloading shipments for off-site shipments, which were included in the involved worker doses estimated for facility operations.

Additional details regarding the methodology used to assess transportation impacts are provided in Biwer et al. (1997).

J.1 SUMMARY OF TRANSPORTATION OPTION IMPACTS

The potential environmental impacts associated with transportation activities for the PEIS alternatives are summarized in Table J.2. For purposes of comparison in Table J.2, the analysis was based on the assumption that all shipments would be transported a distance of 620 miles (1,000 km), regardless of the type of material. (Transportation impacts were evaluated for distances ranging from 155 to 3,100 mi [250 to 5,000 km] in Section J.3.) The assessment considered impacts on human health that would result from the radioactive and hazardous chemical characteristics of the materials shipped, as well as the impacts that would result from operation of the transportation vehicles. Additional discussion and details related to the results for individual areas of impact are provided in Section J.3.

Various options were considered for each alternative, including the following transportation-related steps:

- ***No Action Alternative.*** No off-site transportation is expected under the no action alternative, except for a few LLW and LLMW shipments. Minor amounts of LLW and LLMW may be generated during monitoring and maintenance activities associated with the storage of the depleted UF_6 cylinders at their current locations. Fewer than one shipment per year to a disposal site would be expected for the waste generated, and no fatalities would be anticipated from waste shipments. Shipment impacts are expected to be negligible, similar to LLW and LLMW shipments from the cylinder treatment facility or the cylinder transfer facility as considered under other alternatives.

- ***Long-Term Storage as UF_6.*** Long-term storage as UF_6 would involve transportation of the depleted UF_6 cylinders from the three existing storage sites to a long-term storage facility. The cylinders might be shipped in overcontainers. If a transfer facility were used to alleviate the problem of substandard cylinders before shipment of the UF_6, shipment of LLW and LLMW from the transfer facility would be required.

- ***Long-Term Storage as Oxide.*** Long-term storage as oxide (UO_2 or U_3O_8) would involve transportation of the depleted UF_6 cylinders to an oxide conversion plant. The conversion facility would also require inbound shipments of ammonia and outbound shipments of HF and waste. Cleaning of the empty cylinders at a cylinder treatment facility colocated with the conversion facility would require outbound shipments of U_3O_8 and waste. The final transportation step would be shipment of the oxide to the long-term storage facility.

TABLE J.2 Summary of Transportation Impacts by Alternative[a]

Impacts from Long-Term Storage as UF_6	Impacts from Long-Term Storage as Oxide	Impacts from Use as Uranium Oxide Cask	Impacts from Use as Uranium Metal Cask	Impacts from Disposal
Total Shipments: LLW (cylinder transfer): 460 – 580 LLMW (cylinder transfer): 60 Cylinders: 11,606 – 46,666	**Total Shipments:** LLW (cylinder transfer): 460 – 580 LLMW (cylinder transfer): 60 Cylinders: 11,606 – 46,666 HF: 0 – 4,860 NH_3: 0 – 1,120 LLW (oxide conversion): 320 – 1,680 LLMW (oxide conversion): 20 – 40 CaF_2: 180 – 19,760 Oxide: 8,480 – 26,800	**Total Shipments:** LLW (cylinder transfer): 460 – 580 LLMW (cylinder transfer): 60 Cylinders: 11,606 – 46,666 HF: 0 – 4,860 NH_3: 0 – 1,120 LLW (UO_2 conversion): 360 – 1,680 LLMW (UO_2 conversion): 20 – 40 CaF_2: 180 – 19,760 Oxide: 8,480 – 26,800 LLW (cask manufacture): 300 LLMW (cask manufacture): 20 Uranium oxide casks: 9,600	**Total Shipments:** LLW (cylinder transfer): 460 – 580 LLMW (cylinder transfer): 60 Cylinders: 11,606 – 46,666 HF: 1,640 NH_3: 920 LLW (metal conversion): 360 – 3,840 LLMW (metal conversion): 20 MgF_2: 3,800 – 10,780 Metal: 7,360 – 21,500 LLW (cask manufacture): 1,540 LLMW (cask manufacture): 20 Uranium metal casks: 9,060	**Total Shipments:** LLW (cylinder transfer): 460 – 580 LLMW (cylinder transfer): 60 Cylinders: 11,606 – 46,666 HF: 0 – 4,860 NH_3: 0 – 1,120 LLW (oxide conversion): 320 – 1,680 LLMW (oxide conversion): 20 – 40 CaF_2: 180 – 19,760 Oxide: 8,480 – 26,800
Human Health – Normal Operations: Radiological[b]				
Workers and Public: Total number of LCFs: 0.1 Maximum risk of LCF to MEI member of general public (resident along route): $9 \times 10^{-15} - 8 \times 10^{-12}$	**Workers and Public:** Total number of LCFs: 0.1 – 0.3 Maximum risk of LCF to MEI member of general public (resident along route): $9 \times 10^{-15} - 8 \times 10^{-12}$	**Workers and Public:** Total number of LCFs: 0.1 – 0.3 Maximum risk of LCF to MEI member of general public (resident along route): $9 \times 10^{-15} - 8 \times 10^{-12}$	**Workers and Public:** Total number of LCFs: 0.1 – 0.2 Maximum risk of LCF to MEI member of general public (resident along route): $9 \times 10^{-15} - 8 \times 10^{-12}$	**Workers and Public:** Total number of LCFs: 0.1 – 0.3 Maximum risk of LCF to MEI member of general public (resident along route): $9 \times 10^{-15} - 8 \times 10^{-12}$
Human Health – Normal Operations: Chemical				
Workers and Public: Fatalities from vehicle exhaust emissions: 0.04 – 0.2	**Workers and Public:** Fatalities from vehicle exhaust emissions: 0.08 – 0.4	**Workers and Public:** Fatalities from vehicle exhaust emissions: 0.1 – 0.5	**Workers and Public:** Fatalities from vehicle exhaust emissions: 0.08 – 0.4	**Workers and Public:** Fatalities from vehicle exhaust emissions: 0.08 – 0.4

TABLE J.2 (Cont.)

Impacts from Long-Term Storage as UF_6	Impacts from Long-Term Storage as Oxide	Impacts from Use as Uranium Oxide Cask	Impacts from Use as Uranium Metal Cask	Impacts from Disposal
Human Health – Accidents: Radiological[b]				
Overall accident risk (LCFs): 0.00007 – 0.0005	Overall accident risk (LCFs): 0.001 – 0.007	Overall accident risk (LCFs): 0.001 – 0.007	Overall accident risk (LCFs): 0.00007 – 0.0005	Overall accident risk (LCFs): 0.001 – 0.007
Bounding accident: UF_6 cylinder rail accident in urban area	Bounding accident: UF_6 cylinder rail accident in urban area	Bounding accident: UF_6 cylinder rail accident in urban area	Bounding accident: UF_6 cylinder rail accident in urban area	Bounding accident: UF_6 cylinder rail accident in urban area
Bounding accident frequency: 1×10^{-9} per railcar-km	Bounding accident frequency: 1×10^{-9} per railcar-km	Bounding accident frequency: 1×10^{-9} per railcar-km	Bounding accident frequency: 1×10^{-9} per railcar-km	Bounding accident frequency: 1×10^{-9} per railcar-km
Bounding accident consequences to population within 50 miles (per occurrence): 60 LCFs	Bounding accident consequences to population within 50 miles (per occurrence): 60 LCFs	Bounding accident consequences to population within 50 miles (per occurrence): 60 LCFs	Bounding accident consequences to population within 50 miles (per occurrence): 60 LCFs	Bounding accident consequences to population within 50 miles (per occurrence): 60 LCFs
Bounding accident consequences to MEI (per occurrence): Risk of LCF: 0.002	Bounding accident consequences to MEI (per occurrence): Risk of LCF: 0.002	Bounding accident consequences to MEI (per occurrence): Risk of LCF: 0.002	Bounding accident consequences to MEI (per occurrence): Risk of LCF: 0.002	Bounding accident consequences to MEI (per occurrence): Risk of LCF: 0.002

TABLE J.2 (Cont.)

Impacts from Long-Term Storage as UF_6	Impacts from Long-Term Storage as Oxide	Impacts from Use as Uranium Oxide Cask	Impacts from Use as Uranium Metal Cask	Impacts from Disposal
		Human Health – Accidents: Chemical		
Overall accident risk (irreversible adverse effects): 1×10^{-6} – 0.00003	Overall accident risk (irreversible adverse effects): 0.5 – 20	Overall accident risk (irreversible adverse effects): 0.5 – 20	Overall accident risk (irreversible adverse effects): 7	Overall accident risk (irreversible adverse effects): 0.5 – 20
Bounding accident: UF_6 cylinder rail accident in urban area	Bounding accident: HF rail accident in urban area	Bounding accident: HF rail accident in urban area	Bounding accident: HF rail accident in urban area	Bounding accident: HF rail accident in urban area
Bounding accident frequency: 1×10^{-9} per railcar-km	Bounding accident frequency: 1×10^{-9} per railcar-km	Bounding accident frequency: 1×10^{-9} per railcar-km	Bounding accident frequency: 1×10^{-9} per railcar-km	Bounding accident frequency: 1×10^{-9} per railcar-km
Bounding accident consequences to population within 50 miles (per occurrence): up to 4 irreversible adverse effects	Bounding accident consequences to population within 50 miles (per occurrence): up to 30,000 irreversible adverse effects	Bounding accident consequences to population within 50 miles (per occurrence): up to 30,000 irreversible adverse effects	Bounding accident consequences to population within 50 miles (per occurrence): up to 30,000 irreversible adverse effects	Bounding accident consequences to population within 50 miles (per occurrence): up to 30,000 irreversible adverse effects
Bounding accident consequences to MEI (per occurrence): expected irreversible adverse effects	Bounding accident consequences to MEI (per occurrence): expected irreversible adverse effects	Bounding accident consequences to MEI (per occurrence): expected irreversible adverse effects	Bounding accident consequences to MEI (per occurrence): expected irreversible adverse effects	Bounding accident consequences to MEI (per occurrence): expected irreversible adverse effects
		Human Health — Accidents: Physical Hazards		
Total traffic fatalities: 0.6 – 2	Total traffic fatalities: 1 – 4	Total traffic fatalities: 2 – 4	Total traffic fatalities: 1 – 3	Total traffic fatalities: 1 – 4

[a] Shipping distance of 621 miles (1,000 km) for all materials; vehicle-related impacts were based on round-trip distance. The no action alternative is not included in this table (see Table J.1). Fewer than one off-site shipment per year to a disposal site would be expected for the minor amounts of LLW and LLMW generated during monitoring and maintenance activities under this alternative.

[b] Radiological LCFs were estimated from the calculated dose using dose-to-risk conversion factors of 0.0005 and 0.0004 fatalities per person-rem for members of the general public and occupational workers, respectively, as recommended in Publication 60 of the International Commission on Radiological Protection (ICRP 1991). The approximate corresponding dose for each of the radiological fatality risks listed in this table may be obtained by multiplying the fatality risk by 2,500 (i.e., 1 ÷ 0.0004).

Notation: CaF_2 = calcium fluoride; HF = hydrogen fluoride; LCF = latent cancer fatality; LLW = low-level radioactive waste; LLMW = low-level mixed waste; MEI = maximally exposed individual; MgF_2 = magnesium fluoride; NH_3 = ammonia; UF_6 = uranium hexafluoride; UO_2 = uranium dioxide.

- ***Use as Uranium Oxide Casks.*** Use as uranium oxide casks would involve transportation of the depleted UF_6 cylinders to a UO_2 conversion plant. The conversion facility would also require inbound shipments of ammonia and outbound shipments of HF and waste. Cleaning of the empty cylinders at a cylinder treatment facility colocated with the conversion facility would require outbound shipments of U_3O_8 and waste. The UO_2 would be transported to a cask manufacturing facility, which would also generate some waste for shipment to disposal. Finally, the casks would be shipped to an end user.

- ***Use as Uranium Metal Casks.*** Use as uranium metal casks would involve transportation of the depleted UF_6 cylinders to a metal conversion plant. The conversion facility would also require inbound shipments of ammonia and outbound shipments of HF and waste. Cleaning of the empty cylinders at a cylinder treatment facility colocated with the conversion facility would require outbound shipments of U_3O_8 and waste. The metal would be transported to a cask manufacturing facility, which would also generate some waste for shipment to disposal. Finally, the casks would be shipped to an end user.

- ***Disposal.*** The disposal option would involve the same transportation steps required for long-term storage as oxide, except that the final shipments of oxide would be sent to a disposal facility rather than a storage facility.

The transportation impacts in Table J.2 are presented as ranges of values. The ranges reflect differences in risk between truck and rail modes and differences in the types and quantities of materials required within a given option. The following is a general summary of potential impacts from transportation activities (based on information in Table J.2 and additional detailed information in Section J.3):

- The analysis of transportation risks presented in Table J.2 was based on the assumption that all shipments would travel a distance of 620 miles (1,000 km) and that essentially the entire inventory of DOE-generated depleted uranium would be shipped between long-term storage, conversion, manufacture and use, and disposal facilities. Transportation risks would be reduced or eliminated by colocating facilities or minimizing shipment distances between facilities.

- In general, the greatest risk from transportation would result from vehicle-related physical hazards, that is, potential fatalities caused by the physical trauma received during transportation accidents, independent of the material transported. This risk would increase directly with the number of shipments and shipment distance.

- The overall transportation risk resulting from the radioactive characteristics of the transported material would be small, generally less than one-tenth of the risk from vehicle-related causes for a given shipment.

- The overall transportation risk resulting from the hazardous chemical characteristics of the transported material would also be small, generally less than one-tenth of the risk from vehicle-related causes for most shipments.

- There is potential for low-probability, severe transportation accidents that could have large consequences. The accidents with the largest potential consequences would be rail accidents involving a tank car containing HF. Under unfavorable weather conditions, the HF released from these accidents could result in approximately 10 irreversible adverse effects in a rural environment or approximately 30,000 irreversible adverse effects in an urban environment. These impacts are discussed in Section J.3.4.2.

- Within each material category, the total transportation risk would be dominated by shipments of depleted UF_6 cylinders, U_3O_8, UO_2, uranium metal, and uranium oxide and uranium metal casks because of the large number of shipments required for these materials. Shipments of waste and process chemicals would not contribute significantly to the overall risk, except for potential shipments of the ammonia required for some conversion options and the HF by-product associated with some conversion options.

- In general, rail transportation would result in a slightly lower overall risk than truck transportation for the same amount of material, due primarily to higher rail shipment capacities and therefore fewer shipments.

J.2 TRANSPORTATION MODES

This assessment of transportation impacts was based on data provided in the engineering analysis report (Lawrence Livermore National Laboratory [LLNL 1997]). For each category of option assessed in the PEIS, the engineering analysis report provides estimates of the types, characteristics, and quantities of each material that would require transportation.

J.2.1 Truck Transportation

Truck transportation was considered for all materials shipped, except for some bulk shipments of HF, ammonia, and spent nuclear fuel casks (which are too large for road transport). Truck shipments would generally be in legal-weight semitrailer trucks, consistent with current practices. The maximum gross vehicle weight for truck shipments is limited by the U.S. Department of

Transportation (DOT) to 80,000 lb (36,400 kg). Truck shipments of depleted UF_6 were assumed to consist of a single cylinder per trailer. Shipments of conversion products and waste materials would generally be near the maximum allowed by weight limitations.

J.2.2 Rail Transportation

Rail transportation was considered as an option to truck transportation for the shipment of bulk materials where the amount of material shipped would justify the use of full railcars. These materials would include depleted UF_6 cylinders and conversion products. For rail transportation, the average payload weights for boxcars range from 100,000 to 150,000 lb (45,000 to 68,000 kg). Rail shipments of depleted UF_6 were assumed to consist of four cylinders per railcar, with transport by regular freight train service. In general, rail transportation was not considered for shipments of waste materials and most chemicals generated or used during processing because the annual volumes of these materials would be much less than typical railcar capacities.

J.2.3 Transportation Options Considered But Not Analyzed in Detail

Air and barge transportation options were considered but not analyzed in detail. Air transportation would be prohibitively expensive and is not practical for shipping waste and large amounts of material. The use of barge transportation for the depleted UF_6 cylinders, conversion products, or manufactured products was considered but not examined in detail because sites for the proposed facilities under consideration in the PEIS have not yet been determined. Generic input parameters to estimate the risks associated with barge transport are not as readily applicable as they are for truck or rail transport because of the fixed and limited nature of the inland and coastal waterways.

The use of barge transport for bulk shipments of depleted uranium materials would be a viable alternative if both the shipping and receiving sites were located near the U.S. inland or coastal waterway systems. In general, the risk per shipment would be approximately the same as for a truck or rail (one railcar) shipment, but fewer shipments would be necessary and the costs per ton-mile much lower. The primary risks to workers would occur during loading and unloading operations. Risks to the public could occur in the vicinity of locks when the barges were stopped during their passage through the locks and from accidents that might result in potential releases to the environment. Barge transport of the depleted UF_6 cylinders from the existing storage sites would first require truck or rail transport to the nearest river port, approximately 20 to 25 miles (32 to 40 km) for the Portsmouth and Paducah sites and approximately 1 mile (1.6 km) for the K-25 site.

J.3 IMPACTS OF OPTIONS

The potential environmental impacts associated with transportation activities are summarized in this section. Additional information related to the assessment methodologies for each area of impact is provided in Appendix C.

J.3.1 General Assumptions

The environmental impacts from transportation were evaluated for each category of option (i.e., cylinder preparation, conversion, long-term storage, manufacture and use, and disposal) on the basis of information described in the engineering analysis report (LLNL 1997). The materials transported for each option category are summarized in Table J.3, along with the origin and destination sites for each material and an indication of whether the material poses a radiological, chemical, or vehicle-related risk. The following general assumptions apply to the assessment of impacts:

- Because sites for long-term storage, conversion, disposal, and manufacture and use will not be selected or known until some time in the future, transportation impacts for each material were estimated as the risk per kilometer traveled, using representative national average route statistics. For comparison, total transportation impacts are presented for shipment distances of 155, 620, and 3,100 miles (250, 1,000, and 5,000 km).

- The assessment of total transportation impacts was based on the assumption that the entire inventory of depleted uranium would be shipped between long-term storage, conversion, manufacture and use, and disposal facilities.

- National average accident occurrence rates (accidents per million miles) and fatality rates (accident fatalities per million miles) were used for accident calculations for truck and rail shipments.

- Transportation impacts were estimated for all shipments of depleted UF_6 cylinders, uranium conversion products, chemicals required for or produced during processing (such as HF and ammonia), as well as any LLW and LLMW generated during operations. Some conversion options would produce large quantities of calcium fluoride (CaF_2) or magnesium fluoride (MgF_2). CaF_2 can be used or disposed of as either sanitary waste or LLW, depending on the residual uranium concentration and applicable regulatory release limits at the time of disposal. Similarly, MgF_2 can be disposed of as sanitary waste or LLW.

TABLE J.3 Summary of Materials Transported for Each Transportation Option

Option Category	Material Transported	Risk: Radiological	Risk: Chemical	Risk: Vehicular	Origin Site	Destination Site
Cylinder preparation	LLW	X	X	X	UF_6 current locations	LLW disposal site
	LLMW	X	X	X	UF_6 current locations	LLMW treatment/disposal site
	Hazardous waste	X	X	X	UF_6 current locations	Hazardous waste disposal site
Conversion	Depleted UF_6	X	X	X	Current locations	Conversion site
	LLW	X	X	X	Conversion site	LLW disposal site
	LLMW	X	X	X	Conversion site	LLMW treatment/disposal site
	Hazardous waste	–	X	X	Conversion site	Hazardous waste disposal site
	U_3O_8	X	X	X	Cylinder treatment facility	Storage or disposal site
	LLW	X	X	X	Cylinder treatment facility	LLW disposal site
	LLMW	X	X	X	Cylinder treatment facility	LLMW treatment/disposal
	Hazardous waste	–	X	X	Cylinder treatment facility	Hazardous waste disposal
	HF and NH_3 (various combinations, depending on conversion option)	–	X	X	Chemical manufacturer or conversion site	Conversion or disposal site
	CaF_2	–	–	X	Conversion site	LLW disposal site
	MgF_2	–	–	X	Conversion site	LLW disposal site
Long-term storage	Depleted UF_6	X	X	X	Current locations	Long-term storage site
	UO_2 or U_3O_8	X	X	X	Conversion site	Long-term storage site
Manufacture and use	Uranium metal or UO_2	X	X	X	Conversion site	Manufacturing site
	LLW	X	X	X	Manufacturing site	LLW disposal site
	LLMW	X	X	X	Manufacturing site	LLMW treatment/disposal site
	Uranium oxide or uranium metal casks	X	–	X	Manufacturing site	End user
Disposal	UO_2 or U_3O_8	X	X	X	Conversion or storage site	Disposal site (shallow earthen structure, vault, or mine)

- For the various options, the transportation risk for a number of shipments listed in the engineering analysis report (LLNL 1997) are not included in this PEIS because they would not pose a radiological risk or a chemical fatality risk. Such shipments include chemicals used for processing (hydrochloric acid, sodium hydroxide, and nitric acid) and output hazardous waste for most facilities. The acids would not be in concentrated form, and sodium hydroxide is not an inhalation hazard. Relatively few drums of hazardous waste would be generated with minor amounts per drum, typically less than 1 or 2 kg of hazardous material, some of which would not be an inhalation hazard.

- In general, transportation activities were assumed to take place over a 20-year period, consistent with the operational period of the facilities considered.

J.3.2 Impacts Considered

The transportation of depleted uranium and associated materials would pose potential risks to human health and the environment. These risks would result from both the radioactive and chemical nature of the materials transported, as well as from operation of the transportation vehicles. The potential risks are discussed in this section. Additional details are given in Appendix C. The collective risks are presented in terms of the expected number of fatalities (or potentially life-threatening effects for chemical impacts) among the general public from all shipments for per-shipment distances ranging from 155 to 3,100 miles (250 to 5,000 km). The risks are presented for both truck and rail options, where appropriate.

J.3.2.1 Human Health — Normal Operations

J.3.2.1.1 Radiological Impacts

Radiological risk associated with routine transportation would result from the potential exposure of people to low levels of external radiation near a radioactive shipment. External exposures could occur as shipments moved past members of the public along routes or while the shipment was stopped along the route. No radioactive materials would be released during routine operations. Collective risks were estimated for the transportation crew members and for members of the public living and working along the transportation routes, sharing the routes, and present at stops along the routes.

In addition to assessing the routine collective population risk, risks to the maximally exposed individual (MEI) were estimated for a number of hypothetical exposure scenarios; these risks are listed in Table J.4. The scenarios include exposure of persons living next to a shipment route or being next to a shipment while stopped in traffic. The scenarios were chosen to provide a

TABLE J.4 Definition of Maximally Exposed Individuals for Assessment of Routine Transportation Risk

Maximally Exposed Individual	Assumptions	Distance (m)	Exposure Duration
Inspector (truck and rail)	Federal or state vehicle inspector, not covered by a dosimetry program	3	30 minutes
Resident (truck and rail)	Person living near a site shipment entrance, not protected by shielding	30	Shipments pass at average speed of 24 km/h
Person at traffic obstruction (truck and rail)	Person stopped next to a radioactive material shipment due to traffic or other causes, not protected by shielding	1	30 minutes
Person at truck service station	Worker at a truck stop	20	2 hours
Resident near a rail stop	Resident living near a rail classification yard, not protected by shielding	200	20 hours

range of exposure conditions; they were not intended to be all inclusive. For the transportation-related radiological impacts assessed in this PEIS, all those resulting from external radiation during routine transport would be very small because the highest level of radiation from any one shipment would be less than 1 mrem/h at a distance of 3.3 ft (1 m) from the transport vehicle. This dose rate is more than 10 times less than the regulatory limit of 10 mrem/h at 6.6 ft (2 m) from the transport vehicle, as directed by the DOT (49 *Code of Federal Regulations* [CFR] Part 173) and the U.S. Nuclear Regulatory Commission (10 CFR Part 71).

J.3.2.1.2 Chemical Impacts

The analysis assumed that no leaks would occur in the shipping packages during normal transport. Therefore, no impacts on human health would be related directly to the hazardous nature of chemical shipments during routine operations.

J.3.2.1.3 Vehicle-Related Impacts (Chemical Hazards)

Vehicle-related health risks are independent of the nature of the cargo and would be incurred for similar shipments of any commodity. The routine risks assessed might be caused by potential exposure to increased levels of airborne particulates from vehicular exhaust emissions and from fugitive dust raised from the roadbed by the transport vehicle. The health endpoint assessed was the excess (additional) latent mortality caused by inhalation of these particulates in urban areas where ambient particulate air concentrations already exceed threshold values thought to be necessary before adverse effects are observed. It was assumed that a latent mortality is equivalent to a latent cancer fatality.

J.3.2.2 Human Health — Accident Conditions

J.3.2.2.1 Radiological Impacts

Radiological impacts from transportation-related accidents could result from the potential release and dispersal of radioactive material into the environment during an accident and the subsequent exposure of people through multiple pathways, such as exposure to contaminated soil, inhalation, or ingestion of contaminated food. The radiological impacts are expressed in terms of latent cancer fatalities (LCFs). No acute effects would be expected for the materials relevant to the action under consideration in this PEIS.

The collective accident risks from radiological causes over the life of the project have been estimated for all radioactive material shipments for each option category (see Table J.3 for a list of shipments). The accident risk estimates were based not only on the consequences of potential accidents but also on the probabilities that accidents would occur.

Although the overall radiological accident risk would be small for all shipments, there would be potential for low-probability, severe transportation accidents that could have relatively large consequences. Population and MEI impacts were estimated for such accidents.

J.3.2.2.2 Chemical Impacts

Chemical impacts from transportation-related accidents could result from the potential release and dispersal of hazardous chemicals into the environment during an accident and the subsequent exposure of people through the inhalation pathway. None of the hazardous chemicals involved in the action under consideration are suspected carcinogens, and any acute effects from ingestion or dermal absorption of the contaminants would be expected to be dominated by inhalation effects. The collective accident risks from chemical causes were estimated in the same manner as the radiological risks, taking into account accident probability, the spectrum of accident severities, and accident consequences. The health endpoints presented are potential irreversible adverse effects and expected fatalities, which are discussed in detail in Appendix C and Policastro et al. (1997). Population and MEI consequences from potentially severe accidents are presented.

J.3.2.2.3 Vehicle-Related Impacts (Physical Hazards)

Accident risks from physical hazards are vehicle-related risks that result from the physical trauma created by accidents; such risks are not related to the shipment's cargo. Physical hazard risks represent fatalities from mechanical causes and were determined from fatality rates based on national average statistics maintained by the DOT for truck and rail transportation (Saricks and Kvitek 1994).

J.3.3 Cylinder Preparation Options

Two options were evaluated for preparing nonconforming cylinders for off-site transportation to either a conversion facility or a long-term storage site (see Appendix E). These problem cylinders were classified into three types: (1) overfilled cylinders, (2) overpressurized cylinders, and (3) substandard cylinders. Each of the two cylinder preparation options would prepare all three types of cylinders to meet all DOT requirements for off-site shipment.

J.3.3.1 Cylinder Overcontainers

An overcontainer would be suitable to contain, transport, and store the cylinder contents, regardless of cylinder condition, and could be designed as a pressure vessel enabling liquefaction of the depleted UF_6 for transfer out of the cylinder. Because only minimal cylinder handling operations would be required to load substandard cylinders into an overcontainer, no chemical transportation risks would be associated with this option. Potential risks associated with the transportation of depleted UF_6 cylinders in protective overcontainers are presented in Sections J.3.4.1 and J.3.5.1 for the conversion options and long-term storage options, respectively.

J.3.3.2 Cylinder Transfer Facility

The alternative to placing nonconforming cylinders into overcontainers would be to transfer the depleted UF_6 to new cylinders. A facility necessary to effect such a transfer was assumed to be colocated at each of the three existing sites where the cylinders are currently stored. Therefore, the only transportation risks would be from minor amounts of chemicals used at the facility and small amounts of LLW and LLMW generated at the facility.

The total collective radiological risks (i.e., the total risk to all workers and members of the general public potentially exposed) for shipments associated with the cylinder transfer option are summarized in Tables J.5 and J.6 for routine and accident risks, respectively. Routine risks to MEIs are summarized in Table J.7, whereas potential severe accident consequences to local populations from radiological and chemical hazards are summarized in Tables J.8 and J.9, respectively. Accident consequences to MEIs are summarized in Table J.10.

TABLE J.5 Total Routine Shipment Risks for the Transportation of Materials for the Cylinder Preparation and Conversion Options

			Risks over 250 km			Risks over 1,000 km			Risks over 5,000 km		
Facility/Material	Mode	Total Shipments[a]	Radiological LCF[b]	Chemical Effects[c]	Vehicular LCF	Radiological LCF[b]	Chemical Effects[c]	Vehicular LCF	Radiological LCF[b]	Chemical Effects[c]	Vehicular LCF
Cylinder transfer facility											
LLW	Truck	460 – 580	0.00004 – 0.00005	0	0.0005 – 0.0007	0.0001 – 0.0002	0	0.002 – 0.003	0.0007 – 0.0009	0	0.01
LLMW	Truck	20	2×10^{-8}	0	0.00002	1×10^{-7}	0	0.00009	5×10^{-7}	0	0.0005
Depleted UF_6 cylinders[d]											
Paducah	Truck	28,513	0.02	0	0.03	0.08	0	0.1	0.4	0	0.7
	Rail	7,129	0.01	0	0.005	0.02	0	0.02	0.06	0	0.1
Portsmouth	Truck	13,421	0.009	0	0.02	0.04	0	0.06	0.2	0	0.3
	Rail	3,356	0.005	0	0.003	0.008	0	0.01	0.03	0	0.05
Oak Ridge	Truck	4,732	0.003	0	0.006	0.01	0	0.02	0.06	0	0.1
	Rail	1,183	0.002	0	0.0009	0.003	0	0.004	0.01	0	0.02
UF_6 with overcontainers											
Paducah	Truck	28,351	0.01	0	0.03	0.04	0	0.1	0.2	0	0.7
	Rail	7,088	0.009	0	0.005	0.01	0	0.02	0.03	0	0.1
Portsmouth	Truck	13,388	0.005	0	0.02	0.02	0	0.06	0.09	0	0.3
	Rail	3,347	0.004	0	0.003	0.006	0	0.01	0.01	0	0.05
Oak Ridge	Truck	4,683	0.002	0	0.005	0.006	0	0.02	0.03	0	0.1
	Rail	1,171	0.001	0	0.0009	0.002	0	0.004	0.005	0	0.02

TABLE J.5 (Cont.)

			Risks over 250 km			Risks over 1,000 km			Risks over 5,000 km		
Facility/Material	Mode	Total Shipments[a]	Radiological LCF[b]	Chemical Effects[c]	Vehicular LCF	Radiological LCF[b]	Chemical Effects[c]	Vehicular LCF	Radiological LCF[b]	Chemical Effects[c]	Vehicular LCF
U_3O_8 conversion facility											
Ammonia	Truck	0 – 520	NA	0	0 – 0.0006	NA	0	0 – 0.002	NA	0	0 – 0.01
LLW	Truck	320 – 1,420	0.00002 – 0.0001	0	0.0004 – 0.002	0.00009 – 0.0005	0	0.001 – 0.007	0.0005 – 0.003	0	0.007 – 0.03
LLMW	Truck	20	2×10^{-8}	0	0.00002	1×10^{-7}	0	0.00009	5×10^{-7}	0	0.0005
HF	Rail	0 – 4,860	NA	0	0 – 0.004	NA	0	0 – 0.01	NA	0	0 – 0.07
CaF_2	Truck	460 – 19,760	NA	0	0.0005 – 0.02	NA	0	0.002 – 0.09	NA	0	0.01 – 0.5
	Rail	180 –7,300	NA	0	0.0001 – 0.005	NA	0	0.0005 – 0.02	NA	0	0.003 – 0.01
UO_2 conversion facility											
Ammonia	Rail	960 – 1,120	NA	0	0.0007 – 0.0008	NA	0	0.003	NA	0	0.01 – 0.02
LLW	Truck	360 – 1,680	0.00007 – 0.0003	0	0.0004 – 0.002	0.0003 – 0.001	0	0.002 – 0.008	0.001 – 0.006	0	0.008 – 0.04
LLMW	Truck	20 – 40	2×10^{-8} – 5×10^{-8}	0	0.00002 – 0.00005	1×10^{-7} – 2×10^{-7}	0	0.00009 – 0.0002	5×10^{-7} – 1×10^{-6}	0	0.0005 – 0.0009
HF	Rail	0 – 4,860	NA	0	0 – 0.004	NA	0	0 – 0.01	NA	0	0 – 0.07
CaF_2	Truck	460 – 19,760	NA	0	0.0005 – 0.02	NA	0	0.002 – 0.09	NA	0	0.01 – 0.5
	Rail	180 –7,300	NA	0	0.0001 – 0.005	NA	0	0.0005 – 0.02	NA	0	0.003 – 0.01

TABLE J.5 (Cont.)

Facility/Material	Mode	Total Shipments[a]	Risks over 250 km			Risks over 1,000 km			Risks over 5,000 km		
			Radiological LCF[b]	Chemical Effects[c]	Vehicular LCF	Radiological LCF[b]	Chemical Effects[c]	Vehicular LCF	Radiological LCF[b]	Chemical Effects[c]	Vehicular LCF
Uranium metal conversion facility											
Ammonia	Rail	920	NA	0	0.0007	NA	0	0.003	NA	0	0.01
LLW	Truck	360 – 3,840	0.00003 – 0.004	0	0.0004 – 0.004	0.0001 – 0.02	0	0.002 – 0.02	0.0006 – 0.08	0	0.008 – 0.09
LLMW	Truck	20	2×10^{-8} – 7×10^{-8}	0	0.00002	1×10^{-7} – 3×10^{-7}	0	0.00009	5×10^{-7} – 1×10^{-6}	0	0.0005
HF	Rail	1,640	NA	0	0.001	NA	0	0.005	NA	0	0.02
MgF_2	Truck	10,320 – 10,780	NA	0	0.01	NA	0	0.05	NA	0	0.2 – 0.3
	Rail	3,800 – 3,980	NA	0	0.003	NA	0	0.01	NA	0	0.06
Cylinder treatment facility											
U_3O_8	Truck	22	0.00004	0	0.00003	0.0002	0	0.0001	0.0008	0	0.0005
LLW	Truck	88	3×10^{-7}	0	0.0001	1×10^{-6}	0	0.0004	5×10^{-6}	0	0.002
LLMW	Truck	20	4×10^{-9}	0	0.00002	2×10^{-8}	0	0.00009	8×10^{-8}	0	0.0005

a Risks for rail transport were estimated on a railcar basis; therefore, the number of railcars was used for the total number of rail shipments.

b Radiological LCFs were estimated from the calculated doses using dose-to-risk conversion factors of 0.0005 and 0.0004 fatality per person-rem for members of the general public and occupational workers, respectively, as recommended in ICRP Publication 60 (ICRP 1991). The approximate corresponding dose received for each radiological fatality risk listed in this table may be obtained by multiplying the fatality risk by 2,500 (i.e., 1 ÷ 0.0004).

c Potential for irreversible adverse effects from chemical exposures. Exposure to HF or uranium compounds was estimated to result in fatality for approximately 1% or less of those persons experiencing irreversible adverse effects (Policastro et al. 1997). Exposure to ammonia was estimated to result in fatality for approximately 2% or less of those persons experiencing irreversible adverse effects.

d Includes the estimate for additional cylinders required to handle the depleted uranium in overfilled containers.

TABLE J.6 Total Accident Shipment Risks for the Transportation of Materials for the Cylinder Preparation and Conversion Options

			Risks over 250 km			Risks over 1,000 km			Risks over 5,000 km		
Facility/Material	Mode	Total Shipments[a]	Radiological LCF[b]	Chemical Effects[c]	Vehicular Fatalities	Radiological LCF[b]	Chemical Effects[c]	Vehicular Fatalities	Radiological LCF[b]	Chemical Effects[c]	Vehicular Fatalities
Cylinder transfer facility											
LLW	Truck	460 – 580	1×10^{-9}– 2×10^{-9}	0	0.004 – 0.006	5×10^{-9}– 6×10^{-9}	0	0.02	3×10^{-8}	0	0.1
LLMW	Truck	20	1×10^{-12}	0	0.0002	5×10^{-12}	0	0.0009	2×10^{-11}	0	0.004
Depleted UF_6 cylinders[d]											
Paducah	Truck	28,513	0.00008	5×10^{-6}	0.3	0.0003	0.00002	1	0.002	0.0001	6
	Rail	7,129	0.00001	2×10^{-7}	0.08	0.00004	7×10^{-7}	0.3	0.0002	4×10^{-6}	2
Portsmouth	Truck	13,421	0.00004	2×10^{-6}	0.1	0.0002	0.00001	0.5	0.0008	0.00005	3
	Rail	3,356	5×10^{-6}	8×10^{-8}	0.04	0.00002	3×10^{-7}	0.2	0.0001	2×10^{-6}	0.8
Oak Ridge	Truck	4,732	0.00001	8×10^{-7}	0.05	0.00005	3×10^{-6}	0.2	0.0003	0.00002	0.9
	Rail	1,183	2×10^{-6}	3×10^{-8}	0.01	7×10^{-6}	1×10^{-7}	0.06	0.00003	6×10^{-7}	0.3
UF_6 with overcontainers											
Paducah	Truck	28,351	0.00008	5×10^{-6}	0.3	0.0003	0.00002	1	0.002	0.0001	6
	Rail	7,088	0.00001	2×10^{-7}	0.08	0.00004	7×10^{-7}	0.3	0.0002	4×10^{-6}	2
Portsmouth	Truck	13,388	0.00004	2×10^{-6}	0.1	0.0002	0.00001	0.5	0.0008	0.00005	3
	Rail	3,347	5×10^{-6}	8×10^{-8}	0.04	0.00002	3×10^{-7}	0.2	0.0001	2×10^{-6}	0.8
Oak Ridge	Truck	4,683	0.00001	8×10^{-7}	0.05	0.00005	3×10^{-6}	0.2	0.0003	0.00002	0.9
	Rail	1,171	2×10^{-6}	3×10^{-8}	0.01	7×10^{-6}	1×10^{-7}	0.06	0.00003	6×10^{-7}	0.3

TABLE J.6 (Cont.)

Facility/Material	Mode	Total Shipments[a]	Risks over 250 km: Radiological LCF[b]	Risks over 250 km: Chemical Effects[c]	Risks over 250 km: Vehicular Fatalities	Risks over 1,000 km: Radiological LCF[b]	Risks over 1,000 km: Chemical Effects[c]	Risks over 1,000 km: Vehicular Fatalities	Risks over 5,000 km: Radiological LCF[b]	Risks over 5,000 km: Chemical Effects[c]	Risks over 5,000 km: Vehicular Fatalities
U_3O_8 conversion facility											
Ammonia	Truck	0 – 520	NA	0 – 0.1	0 – 0.005	NA	0 – 0.6	0 – 0.02	NA	0 – 3	0 – 0.1
LLW	Truck	320 – 1,420	2×10^{-7} – 7×10^{-7}	0	0.003 – 0.01	7×10^{-7} – 3×10^{-6}	0	0.01 – 0.06	3×10^{-6} – 0.00001	0	0.06 – 0.3
LLMW	Truck	20	7×10^{-11}	0	0.0002	3×10^{-10}	0	0.0008	1×10^{-9}	0	0.004
HF	Rail	0 – 4,860	NA	0 – 5	0 – 0.06	NA	0 – 20	0 – 0.2	NA	0 – 100	0 – 1
CaF_2	Truck	460 – 19,760	NA	0	0.005 – 0.2	NA	0	0.02 – 0.8	NA	0	0.09 – 4
	Rail	180 – 7,300	NA	0	0.002 – 0.09	NA	0	0.008 – 0.3	NA	0	0.04 – 2.0
UO_2 conversion facility											
Ammonia	Rail	960 – 1,120	NA	0.1	0.01	NA	0.5	0.05	NA	2 – 3	0.2 – 0.3
LLW	Truck	360 – 1,680	5×10^{-7} – 2×10^{-6}	0	0.004 – 0.02	2×10^{-6} – 8×10^{-6}	0	0.01 – 0.07	0.00001 – 0.00004	0	0.07 – 0.3
LLMW	Truck	20 – 40	7×10^{-11} – 3×10^{-10}	0	0.0002 – 0.0004	3×10^{-10} – 1×10^{-9}	0	0.0008 – 0.002	1×10^{-9} – 7×10^{-9}	0	0.004 – 0.008
HF	Rail	0 – 4,860	NA	0 – 5	0 – 0.06	NA	0 – 20	0 – 0.2	NA	0 – 100	0 – 1
CaF_2	Truck	460 – 19,760	NA	0	0.005 – 0.2	NA	0	0.02 – 0.8	NA	0	0.09 – 4
	Rail	180 – 7,300	NA	0	0.002 – 0.09	NA	0	0.008 – 0.3	NA	0	0.04 – 2.0

TABLE J.6 (Cont.)

Facility/Material	Mode	Total Shipments[a]	Risks over 250 km			Risks over 1,000 km			Risks over 5,000 km		
			Radiological LCF[b]	Chemical Effects[c]	Vehicular Fatalities	Radiological LCF[b]	Chemical Effects[c]	Vehicular Fatalities	Radiological LCF[b]	Chemical Effects[c]	Vehicular Fatalities
Uranium metal conversion facility											
Ammonia	Rail	920	NA	0.1	0.01	NA	0.4	0.04	NA	2	0.2
LLW	Truck	360 – 3,840	4×10^{-8} – 3×10^{-6}	0	0.004 – 0.04	1×10^{-7} – 0.00001	0	0.01 – 0.2	7×10^{-7} – 0.00006	0	0.07 – 0.8
LLMW	Truck	20	7×10^{-11}	0	0.0002	3×10^{-10}	0	0.0008	1×10^{-9}	0	0.004
HF	Rail	1,640	NA	2	0.02	NA	7	0.08	NA	30	0.4
MgF_2	Truck	10,320 – 10,780	NA	0	0.1	NA	0	0.4	NA	0	2
	Rail	3,800 – 3,980	NA	0	0.04 – 0.05	NA	0	0.2	NA	0	0.9
Cylinder treatment facility											
U_3O_8	Truck	22	1×10^{-6}	2×10^{-8}	0.0002	6×10^{-6}	7×10^{-8}	0.0009	0.00003	4×10^{-7}	0.004
LLW	Truck	88	7×10^{-10}	0	0.0009	3×10^{-9}	0	0.003	1×10^{-8}	0	0.02
LLMW	Truck	20	3×10^{-11}	0	0.0002	1×10^{-10}	0	0.0008	7×10^{-10}	0	0.004

[a] Risks for rail transport were estimated on a railcar basis; therefore, the number of railcars was used for the total number of rail shipments.

[b] Radiological LCFs were estimated from the calculated doses using dose-to-risk conversion factors of 0.0005 and 0.0004 fatality per person-rem for members of the general public and occupational workers, respectively, as recommended in ICRP Publication 60 (ICRP 1991). The approximate corresponding dose received for each radiological fatality risk listed in this table may be obtained by multiplying the fatality risk by 2,500 (i.e., 1 ÷ 0.0004).

[c] Potential for irreversible adverse effects from chemical exposures. Exposure to HF or uranium compounds was estimated to result in fatality for approximately 1% or less of those persons experiencing irreversible adverse effects (Policastro et al. 1997). Exposure to ammonia was estimated to result in fatality for approximately 2% or less of those persons experiencing irreversible adverse effects.

[d] Includes the estimate for additional cylinders required to handle the depleted uranium in overfilled containers.

TABLE J.7 Consequences to the MEI from Routine Shipment of Depleted Uranium Materials

		Routine Radiological Risk from Single Shipment (Lifetime Risk of LCF[a])				
Facility/Material	Mode	Inspector	Resident	Person in Traffic	Person at Gas Station	Person near Rail Stop
Cylinder transfer facility						
LLW	Truck	2×10^{-9}	2×10^{-13}	6×10^{-9}	3×10^{-10}	NA
LLMW	Truck	9×10^{-11}	9×10^{-15}	3×10^{-10}	1×10^{-11}	NA
Depleted UF_6	Truck	3×10^{-8}	3×10^{-12}	1×10^{-7}	4×10^{-9}	NA
	Rail	6×10^{-8}	8×10^{-12}	1×10^{-7}	NA	5×10^{-10}
UF_6 with overcontainer	Truck	2×10^{-8}	1×10^{-12}	6×10^{-8}	2×10^{-9}	NA
	Rail	3×10^{-8}	3×10^{-12}	6×10^{-8}	NA	2×10^{-10}
U_3O_8 conversion facility						
LLW	Truck	2×10^{-9}	2×10^{-13}	6×10^{-9} – 8×10^{-9}	3×10^{-10}	NA
LLMW	Truck	9×10^{-11}	9×10^{-15}	3×10^{-10}	1×10^{-11}	NA
UO_2 conversion facility						
LLW	Truck	2×10^{-9} – 5×10^{-9}	2×10^{-13} – 5×10^{-13}	6×10^{-9} – 2×10^{-8}	3×10^{-10} – 7×10^{-10}	NA
LLMW	Truck	9×10^{-11}	9×10^{-15}	3×10^{-10}	1×10^{-11}	NA
Uranium metal conversion facility						
LLW	Truck	2×10^{-9} – 3×10^{-8}	2×10^{-13} – 3×10^{-12}	7×10^{-9} – 8×10^{-8}	3×10^{-10} – 4×10^{-9}	NA
LLMW	Truck	9×10^{-11}	9×10^{-15}	3×10^{-10}	1×10^{-11}	NA
Cylinder treatment facility						
U_3O_8	Truck	6×10^{-8}	5×10^{-12}	2×10^{-7}	7×10^{-9}	NA
LLW	Truck	8×10^{-11}	8×10^{-15}	2×10^{-10}	1×10^{-11}	NA
LLMW	Truck	1×10^{-11}	1×10^{-15}	5×10^{-11}	2×10^{-12}	NA
U_3O_8	Truck	6×10^{-8}	5×10^{-12}	2×10^{-7}	7×10^{-9}	NA
	Rail	7×10^{-8}	8×10^{-12}	2×10^{-7}	NA	5×10^{-10}
UO_2	Truck	5×10^{-8}	4×10^{-12}	2×10^{-7}	6×10^{-9}	NA
	Rail	6×10^{-8}	5×10^{-12}	2×10^{-7}	NA	3×10^{-10}
Uranium metal	Truck	1×10^{-8}	8×10^{-13} – 9×10^{-13}	3×10^{-8} – 4×10^{-8}	1×10^{-9}	NA
	Rail	1×10^{-8}	1×10^{-12}	3×10^{-8} – 4×10^{-8}	NA	7×10^{-11} – 8×10^{-11}
Uranium oxide casks						
LLW	Truck	1×10^{-8}	1×10^{-12}	3×10^{-8}	1×10^{-9}	NA
LLMW	Truck	1×10^{-9}	1×10^{-13}	4×10^{-9}	2×10^{-10}	NA
Cask	Rail	2×10^{-8}	2×10^{-12}	8×10^{-8}	NA	1×10^{-10}
Uranium metal casks						
LLW	Truck	2×10^{-9}	2×10^{-13}	5×10^{-9}	2×10^{-10}	NA
LLMW	Truck	5×10^{-9}	5×10^{-13}	1×10^{-8}	7×10^{-10}	NA
Cask	Rail	1×10^{-8}	1×10^{-12}	4×10^{-8}	NA	6×10^{-11}

[a] Lifetime risk of LCF for an individual was estimated from the calculated dose using the dose-to-risk conversion factor of 0.0005 fatalities per person-rem for members of the general public, as recommended in ICRP Publication 60 (ICRP 1991). The corresponding dose received for each radiological fatality risk listed in this table may be obtained by multiplying the risk of LCF by 2,000 (i.e., 1 ÷ 0.0005).

TABLE J.8 Potential Radiological Consequences to the Population from Severe Accidents Involving Shipment of Materials for the Cylinder Preparation and Conversion Options

		Radiological Risk (LCF[a])					
		Neutral Weather Conditions			Stable Weather Conditions		
Facility/Material	Mode	Rural	Suburban	Urban	Rural	Suburban	Urban
Cylinder transfer facility							
LLW	Truck	0.0002	0.0002	0.0004	0.0004	0.0004	0.0009
LLMW	Truck	4×10^{-6}	4×10^{-6}	8×10^{-6}	9×10^{-6}	9×10^{-6}	0.00002
Depleted UF_6	Truck	0.3	0.3	0.6	7	7	20
	Rail	1	1	3	30	30	60
U_3O_8 conversion facility							
LLW	Truck	0.0008 – 0.0009	0.0008 – 0.0009	0.002	0.002	0.002	0.004 – 0.005
LLMW	Truck	6×10^{-6}	5×10^{-6}	0.00001	0.00001	0.00001	0.00003
UO_2 conversion facility							
LLW	Truck	0.001 – 0.002	0.001 – 0.002	0.003 – 0.005	0.003 – 0.006	0.003 – 0.006	0.007 – 0.01
LLMW	Truck	0.00001 – 6×10^{-6}	0.00001 – 6×10^{-6}	0.00001 – 0.00003	0.00001 – 0.00003	0.00001 – 0.00003	0.00003 – 0.00007
Uranium metal conversion facility							
LLW	Truck	0.0005 – 0.002	0.0005 – 0.002	0.001 – 0.004	0.001 – 0.004	0.001 – 0.004	0.003 – 0.009
LLMW	Truck	6×10^{-6}	5×10^{-6}	0.00001	0.00001	0.00001	0.00003
Cylinder treatment facility							
U_3O_8	Truck	0.1	0.1	0.2	0.3	0.2	0.5
LLW	Truck	0.00001	0.00001	0.00003	0.00003	0.00003	0.00007
LLMW	Truck	3×10^{-6}	3×10^{-6}	6×10^{-6}	7×10^{-6}	6×10^{-6}	0.00001

[a] Radiological LCFs were estimated from the calculated doses using dose-to-risk conversion factors of 0.0005 and 0.0004 fatality per person-rem for members of the general public and occupational workers, respectively, as recommended in ICRP Publication 60 (ICRP 1991). The approximate corresponding dose received for each radiological fatality risk listed in this table may be obtained by multiplying the fatality risk by 2,500 (i.e., 1 ÷ 0.0004).

TABLE J.9 Potential Chemical Consequences to the Population from Severe Accidents Involving Shipment of Materials for the Cylinder Preparation and Conversion Options

		Number of Persons with Potential for Irreversible Adverse Effects[a]					
		Neutral Weather Conditions			Stable Weather Conditions		
Facility/Material	Mode	Rural	Suburban	Urban	Rural	Suburban	Urban
Cylinder transfer facility							
LLW	Truck	0	0	0	0	0	0
LLMW	Truck	0	0	0	0	0	0
Depleted UF_6	Truck	0	1	2	0	1	3
	Rail	0	1	3	0	2	4
U_3O_8 conversion facility							
Ammonia	Truck	0 – 1	0 – 100	0 – 200	0 – 10	0 – 1,000	0 – 3,000
LLW	Truck	0	0	0	0	0	0
LLMW	Truck	0	0	0	0	0	0
HF	Rail	0 – 10	0 – 1,000	0 – 3,000	0 – 100	0 – 10,000	0 – 30,000
UO_2 conversion facility							
Ammonia	Rail	1	200	400	20	2,000	5,000
LLW	Truck	0	0	0	0	0	0
LLMW	Truck	0	0	0	0	0	0
HF	Rail	0 – 10	0 – 1,000	0 – 3,000	0 – 100	0 – 10,000	0 – 30,000
Uranium metal conversion facility							
Ammonia	Rail	1	200	400	20	2,000	5,000
LLW	Truck	0	0	0	0	0	0
LLMW	Truck	0	0	0	0	0	0
HF	Rail	10	1,000	3,000	100	10,000	30,000
Cylinder treatment facility							
U_3O_8	Truck	0	0	0	0	4	8
LLW	Truck	0	0	0	0	0	0
LLMW	Truck	0	0	0	0	0	0

[a] Exposure to HF or uranium compounds was estimated to result in fatality for approximately 1% or less of those persons experiencing irreversible adverse effects (Policastro et al. 1997). Exposure to ammonia was estimated to result in fatality for approximately 2% or less of those persons experiencing irreversible adverse effects.

TABLE J.10 Potential Consequences to the MEI from Severe Accidents Involving Shipment of Materials for the Cylinder Preparation and Conversion Options

		Accident Risk			
		Neutral Weather Conditions		Stable Weather Conditions	
Facility/Material	Mode	Radiological Risk of LCF[a]	Chemical Effects[b]	Radiological Risk of LCF[a]	Chemical Effects[b]
Cylinder transfer facility					
LLW	Truck	7×10^{-6}	No	0.0001	No
LLMW	Truck	2×10^{-7}	No	2×10^{-6}	No
Depleted UF_6	Truck	0.0002	Yes	0.0005	Yes
	Rail	0.0009	Yes	0.002	Yes
U_3O_8 conversion facility					
Ammonia	Truck	NA	Yes	NA	Yes
LLW	Truck	0.00003 – 0.00004	No	0.0006	No
LLMW	Truck	2×10^{-7}	No	4×10^{-6}	No
HF	Rail	NA	Yes	NA	Yes
UO_2 conversion facility					
Ammonia	Rail	NA	Yes	NA	Yes
LLW	Truck	0.00006 – 0.0001	No	0.0009 – 0.002	No
LLMW	Truck	$2 \times 10^{-7} - 6 \times 10^{-7}$	No	$4 \times 10^{-6} - 9 \times 10^{-6}$	No
HF	Rail	NA	Yes	NA	Yes
Uranium metal conversion facility					
Ammonia	Rail	NA	Yes	NA	Yes
LLW	Truck	0.00002 – 0.00007	No	0.0004 – 0.001	No
LLMW	Truck	2×10^{-7}	No	4×10^{-6}	No
HF	Rail	NA	Yes	NA	Yes
Cylinder treatment facility					
U_3O_8	Truck	0.004	Yes	0.07	Yes
LLW	Truck	6×10^{-7}	No	9×10^{-6}	No
LLMW	Truck	1×10^{-7}	No	2×10^{-6}	No

[a] Lifetime risk of LCF for an individual was estimated from the calculated doses using a dose-to-risk conversion factor of 5×10^{-4} fatality per person-rem for members of the general public, as recommended in ICRP Publication 60 (ICRP 1991). The approximate corresponding dose received for each radiological fatality risk listed in this table may be obtained by multiplying the fatality risk by 2,000 (i.e., $1 \div 0.0005$).

[b] Yes or No applies to the effect of chemical exposure on the MEI. There is no probability estimate; either there would or would not be an irreversible adverse effect. Exposure to HF or uranium compounds was estimated to result in fatality for approximately 1% or less of those persons experiencing irreversible adverse effects (Policastro et al. 1997). Exposure to ammonia was estimated to result in fatality for approximately 2% or less of those persons experiencing irreversible adverse effects.

Transportation impacts associated with the cylinder transfer facility would be very small. No vehicle-related fatalities would be expected (< 1), and the vehicle-related risks would be about 10 times higher than the radiological risks. No radiological fatalities or irreversible adverse chemical effects would be expected as a result of a potential severe accident. The highest potential routine radiological exposure to an MEI, with a latent cancer fatality risk of 6×10^{-9}, would occur for a person stopped in traffic near a shipment for 30 minutes at a distance of 3.3 ft (1 m). Such an exposure would be about 100 times less than the exposure a person receives from natural sources in the course of 1 day.

J.3.4 Conversion Options

The conversion options would involve transportation of the depleted UF_6 cylinders from their current locations at the three storage sites to a conversion facility, transportation of any chemicals required by the conversion process, and transportation of the waste materials to a disposal site. Transportation of the conversion products is included in the discussion of the long-term storage, manufacture and use, and disposal options in Appendices G, H, and I of this PEIS.

The total collective radiological risks (i.e., the total risks to all workers and members of the public potentially exposed) associated with transportation of the depleted UF_6 cylinders; conversion to U_3O_8, UO_2, and metal; and the cylinder treatment facility are summarized in Tables J.5 and J.6 for routine and accident risks, respectively. Table J.7 summarizes the routine risks to MEIs, and Tables J.8 and J.9 summarize the potential severe accident consequences to local populations from radiological and chemical hazards, respectively. Table J.10 summarizes the accident consequences to MEIs.

J.3.4.1 Transportation of Depleted UF_6

The initial step in the conversion process would be to deliver the depleted UF_6 from the three storage sites to the conversion facility. The cylinders would be prepared for transport at each site, as discussed in Section J.3.3, and shipped to the conversion facility location. Shipment of all cylinders by both truck or rail has been assessed. Rail shipments would consist of four cylinders per railcar, whereas truck shipments would involve only one cylinder per truck. Because the number of cylinders that might require overcontainers is uncertain at this time, impacts were assessed for two bounding cases: under the first case, the depleted UF_6 would be transferred from nonconforming cylinders to new cylinders before transport; under the second case, all cylinders would be shipped in protective overcontainers. Risks for a given combination of cylinder shipments with and without overcontainers can be obtained by a linear interpolation between the two cases.

Protective overcontainers would reduce the external radiation emanating from the shipments by a factor of almost two. Because the radiological risk would be dominated by exposure during routine transport, the radiological risk from shipments with overcontainers would also be about half the value for shipments without overcontainers. On the other hand, shipment of the depleted UF_6 cylinders in overcontainers is not expected to provide additional protection under severe accident conditions. Therefore, the risks from shipment of cylinders with and without over-containers would be expected to be the same for severe accidents.

The chemical risk associated with cylinder transport would be much less than the radiological risk; however, the total risks would be dominated by vehicle-related risks, which would be about 10 times larger than the radiological and chemical risks combined. Thus, risks from transport by rail appear to be slightly less than the truck risks because of higher shipment capacities and therefore fewer shipments.

Impacts from a potential severe accident could lead to fatalities from both radiological and chemical effects. Up to 60 potential latent cancer fatalities from radiological hazards are estimated for a rail accident occurring in an urban population zone under stable weather conditions. On the basis of chemical toxicity effects for the same conditions, up to 4 persons could be affected by irreversible adverse effects.

The highest potential routine radiological exposure to an MEI, with a latent cancer fatality risk of 1×10^{-7}, would be for a person stopped in traffic near a shipment for 30 minutes at a distance of 3.3 ft (1 m). Such an exposure would be approximately 5 times less than the exposure a person receives from natural sources in the course of 1 day.

J.3.4.2 Conversion to U_3O_8, UO_2, or Metal

Conversion of the depleted UF_6 to the U_3O_8 or UO_2 oxide forms was assessed for both long-term storage (Appendix G) and disposal (Appendix I); conversion to UO_2 or metal was also assessed for use in cask manufacture (Appendix H). Transportation of other materials related to the conversion process would include the ammonia used in the conversion processes and the LLW, LLMW, and HF by-products of the conversion processes.

The total transportation risks associated with the conversion process would be low for all three conversion processes. The LLW and LLMW shipments to disposal would pose no irreversible adverse chemical effects, and the radiological risks would be about 100 times less than the vehicle-related risks. The largest risks would be associated with the chemical hazards associated with transportation of the HF by-product. These risks would be about 100 times the vehicle-related risks.

No radiological fatalities would be expected as a result of a potential severe accident. A severe accident involving ammonia or HF could result in fatalities, with a potential for approximately 30,000 persons to experience irreversible adverse effects from an accident involving HF under stable conditions in an urban area. However, the overall probability of an anhydrous HF accident occurring would depend on the total number of shipments and the actual locations of the origin and destination sites. The probability of an accident would increase with the number of shipments and distance between sites. Approximately 5,000 railcars of anhydrous HF would be produced if the entire UF_6 inventory were converted to oxide. Assuming the distance traveled per shipment is 620 miles (1,000 km) and based on national average accident statistics for railcars, the overall probability for such an accident in an urban area would be about 3×10^{-5} (about 1 chance in 30,000) over the duration of the program. The resulting overall risk to the public (defined as the product of the accident consequence and the probability) would be 1 irreversible adverse effect (i.e, about 1 person would be expected to experience irreversible adverse effects) due to HF-related transportation accidents. This calculation assumes that the accident would occur in an urban area under weather conditions that result in maximum consequences. Further discussion on potential severe anhydrous HF accidents is presented in Chapter 5, Section 5.2.2.2.

The risk of latent cancer fatality to an MEI from a single routine radiological exposure to a given shipment would be negligible. The highest potential exposure, with an LCF risk of 6×10^{-9}, would occur for a person stopped in traffic near a shipment for 30 minutes at a distance of 3.3 ft (1 m). Such an exposure would be approximately 100 times less than the exposure a person receives from natural sources in the course of 1 day.

J.3.4.3 Cylinder Treatment Facility

After the depleted UF_6 cylinders were "emptied" at the conversion facility, they would still retain approximately 22 lb (10 kg) of UF_6, which corresponds to the amount remaining in the cylinder in the vapor phase at autoclave pressure and temperature (Charles et al. 1991). A cylinder treatment facility was assumed to be colocated with the conversion facility to clean and decontaminate the cylinders once they had been emptied. Therefore, the only chemical or radioactive material transportation risks would be from small amounts of U_3O_8, LLW, and LLMW generated at the facility. It was assumed that the cleaned cylinders would be placed in the scrap metal pile at the conversion site.

No fatalities would be expected due to transportation of materials from the cylinder treatment facility. The highest potential routine radiological exposure, with a latent cancer fatality risk of 2×10^{-7}, would occur for a person stopped in traffic near a shipment of U_3O_8 for 30 minutes at a distance of 3.3 ft (1 m) if it were shipped to a disposal site. Such an exposure would be less than half the radiological exposure that a person receives from natural sources in the course of 1 day.

Less than one radiological latent cancer fatality might be expected as a result of a potential severe accident involving shipment of U_3O_8 under stable weather conditions. Because of the chemical toxicity of the uranium oxide, approximately 8 persons could experience irreversible adverse effects in an urban area under stable weather conditions.

J.3.5 Long-Term Storage Options

Three options were assessed for long-term storage of depleted uranium compounds at a single location. The depleted uranium could be stored in its current form as depleted UF_6 or converted to an oxide form (UO_2 or U_3O_8) and then stored. Transportation impacts related to conversion of the depleted UF_6 to the oxide forms are discussed in Section J.3.4.2. Potential impacts from transportation of the depleted uranium material in its final form to a long-term storage site are discussed in this section.

Small amounts of waste could be generated due to container failure during the surveillance phase of the long-term storage options. The impacts of transporting this waste to a disposal site was not considered because the number of associated shipments would be less than one per year (LLNL 1997).

The estimated impacts associated with transportation for the long-term storage options are presented in Tables J.11 through J.14. The total collective radiological risks (i.e., the total risk to all workers and members of the public potentially exposed) are summarized in Tables J.11 and J.12 for routine and accident risks, respectively. Table J.7 summarizes the routine risks to MEIs, and Tables J.13 and J.14 summarize the potential severe accident consequences to local populations and MEIs, respectively.

J.3.5.1 Storage as Depleted UF_6

Long-term storage of depleted UF_6 at a single storage site would involve shipping the depleted UF_6 cylinders from their current locations at the three existing storage sites. The potential transportation impacts from shipping these depleted UF_6 cylinders to a storage facility would be the same as for shipping to a conversion facility (Section J.3.4.1).

J.3.5.2 Storage as U_3O_8 or UO_2

Long-term storage of depleted uranium as U_3O_8 or UO_2 would involve shipping the oxide from a single conversion facility to the storage site. The same impacts would also be incurred from shipping the oxide from a conversion facility or storage site to a disposal site (Section J.3.7) or to a cask manufacturing facility (Section J.3.6).

The radiological risk associated with shipping all of the U_3O_8 or UO_2 to a storage site from a conversion facility would be larger than the chemical risk, but the total risks would still be dominated by vehicle-related risks, which would be about 10 times larger than the radiological risks. Therefore, risks from rail transport would be less than risks from truck transport because of higher shipment capacities and therefore fewer shipments.

TABLE J.11 Total Routine Shipment Risks for the Transportation of Materials for Long-Term Storage

			Risks over 250 km			Risks over 1,000 km			Risks over 5,000 km		
Facility/Material	Mode	Total Shipments[a]	Radiological LCF[b]	Chemical Effects[c]	Vehicular LCF	Radiological LCF[b]	Chemical Effects[c]	Vehicular LCF	Radiological LCF[b]	Chemical Effects[c]	Vehicular LCF
Depleted UF_6 cylinders[d]											
Paducah	Truck	28,513	0.02	0	0.03	0.08	0	0.1	0.4	0	0.7
	Rail	7,129	0.01	0	0.005	0.02	0	0.02	0.06	0	0.1
Portsmouth	Truck	13,421	0.009	0	0.02	0.04	0	0.06	0.2	0	0.3
	Rail	3,356	0.005	0	0.003	0.008	0	0.01	0.03	0	0.05
Oak Ridge	Truck	4,732	0.003	0	0.006	0.01	0	0.02	0.06	0	0.1
	Rail	1,183	0.002	0	0.0009	0.003	0	0.004	0.01	0	0.02
UF_6 with overcontainers											
Paducah	Truck	28,351	0.01	0	0.03	0.04	0	0.1	0.2	0	0.7
	Rail	7,088	0.009	0	0.005	0.01	0	0.02	0.03	0	0.1
Portsmouth	Truck	13,388	0.005	0	0.02	0.02	0	0.06	0.09	0	0.3
	Rail	3,347	0.004	0	0.003	0.006	0	0.01	0.01	0	0.05
Oak Ridge	Truck	4,683	0.002	0	0.005	0.006	0	0.02	0.03	0	0.1
	Rail	1,171	0.001	0	0.0009	0.002	0	0.004	0.005	0	0.02
U_3O_8	Truck	25,500	0.05	0	0.03	0.2	0	0.1	0.9	0	0.6
	Rail	8,960	0.02	0	0.007	0.03	0	0.03	0.09	0	0.1
UO_2	Truck	26,260 – 26,800	0.04	0	0.03	0.2	0	0.1	0.8	0	0.6
	Rail	8,480 – 8,800	0.01	0	0.006 – 0.007	0.02	0	0.03	0.06	0	0.1

[a] Risks for rail transport were estimated on a railcar basis; therefore, the number of railcars was used for the total number of rail shipments.

[b] Radiological LCFs were estimated from the calculated doses using dose-to-risk conversion factors of 0.0005 and 0.0004 fatality per person-rem for members of the general public and occupational workers, respectively, as recommended in ICRP Publication 60 (ICRP 1991). The approximate corresponding dose received for each radiological fatality risk listed in this table may be obtained by multiplying the fatality risk by 2,500 (i.e., 1 ÷ 0.0004).

[c] Potential for irreversible adverse effects from chemical exposures. Exposure to HF or uranium compounds was estimated to result in fatality for approximately 1% or less of those persons experiencing irreversible adverse effects (Policastro et al. 1997).

[d] Includes the estimate for additional cylinders required to handle the depleted uranium in overfilled containers.

TABLE J.12 Total Accident Shipment Risks for the Transportation of Materials for Long-Term Storage

Facility/Material	Mode	Total Shipments[a]	Risks over 250 km: Radiological LCF[b]	Risks over 250 km: Chemical Effects[c]	Risks over 250 km: Vehicular Fatalities	Risks over 1,000 km: Radiological LCF[b]	Risks over 1,000 km: Chemical Effects[c]	Risks over 1,000 km: Vehicular Fatalities	Risks over 5,000 km: Radiological LCF[b]	Risks over 5,000 km: Chemical Effects[c]	Risks over 5,000 km: Vehicular Fatalities
Depleted UF_6 cylinders[d]											
Paducah	Truck	28,513	0.00008	5×10^{-6}	0.3	0.0003	0.00002	1	0.002	0.0001	6
	Rail	7,129	0.00001	2×10^{-7}	0.08	0.00004	7×10^{-7}	0.3	0.0002	4×10^{-6}	2
Portsmouth	Truck	13,421	0.00004	2×10^{-6}	0.1	0.0002	0.00001	0.5	0.0008	0.00005	3
	Rail	3,356	5×10^{-6}	8×10^{-8}	0.04	0.00002	3×10^{-7}	0.2	0.0001	2×10^{-6}	0.8
Oak Ridge	Truck	4,732	0.00001	8×10^{-7}	0.05	0.00005	3×10^{-6}	0.2	0.0003	0.00002	0.9
	Rail	1,183	2×10^{-6}	3×10^{-8}	0.01	7×10^{-6}	1×10^{-7}	0.06	0.00003	6×10^{-7}	0.3
UF_6 with overcontainers											
Paducah	Truck	28,351	0.00008	5×10^{-6}	0.3	0.0003	0.00002	1	0.002	0.0001	6
	Rail	7,088	0.00001	2×10^{-7}	0.08	0.00004	7×10^{-7}	0.3	0.0002	4×10^{-6}	2
Portsmouth	Truck	13,388	0.00004	2×10^{-6}	0.1	0.0002	0.00001	0.5	0.0008	0.00005	3
	Rail	3,347	5×10^{-6}	8×10^{-8}	0.04	0.00002	3×10^{-7}	0.2	0.0001	2×10^{-6}	0.8
Oak Ridge	Truck	4,683	0.00001	8×10^{-7}	0.05	0.00005	3×10^{-6}	0.2	0.0003	0.00002	0.9
	Rail	1,171	2×10^{-6}	3×10^{-8}	0.01	7×10^{-6}	1×10^{-7}	0.06	0.00003	6×10^{-7}	0.3
U_3O_8	Truck	25,500	0.002	0.00002	0.3	0.006	0.00009	1	0.03	0.0004	5
	Rail	8,960	0.0004	0.00002	0.1	0.001	0.00007	0.4	0.007	0.0004	2
UO_2	Truck	26,260 – 26,800	0.002	0 – 5×10^{-6}	0.3	0.006	0 – 0.00002	1	0.03	0 – 0.0001	5
	Rail	8,480 – 8,800	0.0004	3×10^{-6} – 6×10^{-6}	0.1	0.001	0.00001 – 0.00003	0.4	0.007	0.00005 – 0.0001	2

[a] Risks for rail transport were estimated on a railcar basis; therefore, the number of railcars was used for the total number of rail shipments.

[b] Radiological LCFs were estimated from the calculated doses using dose-to-risk conversion factors of 0.0005 and 0.0004 fatality per person-rem for members of the general public and occupational workers, respectively, as recommended in ICRP Publication 60 (ICRP 1991). The approximate corresponding dose received for each radiological fatality risk listed in this table may be obtained by multiplying the fatality risk by 2,500 (i.e., 1 ÷ 0.0004).

[c] Potential for irreversible adverse effects from chemical exposures. Exposure to HF or uranium compounds was estimated to result in fatality for approximately 1% or less of those persons experiencing irreversible adverse effects (Policastro et al. 1997).

[d] Includes the estimate for additional cylinders required to handle the depleted uranium in overfilled containers.

TABLE J.13 Potential Consequences to the Population from Severe Accidents Involving Shipment of Materials for Long-Term Storage

		Radiological Risk[a] (LCF)					
		Neutral Weather Conditions			Stable Weather Conditions		
Material	Mode	Rural	Suburban	Urban	Rural	Suburban	Urban
Depleted UF_6	Truck	0.3	0.3	0.6	7	7	20
	Rail	1	1	3	30	30	60
U_3O_8	Truck	0.1	0.1	0.2	0.3	0.2	0.5
	Rail	0.3	0.3	0.6	0.7	0.7	2
UO_2	Truck	0.1	0.1	0.2	0.2	0.2	0.5
	Rail	0.3	0.3	0.6 – 0.7	0.7 – 0.8	0.7	2

		Chemical Risk[b] (no. of persons with potential for irreversible adverse effects)					
		Neutral Weather Conditions			Stable Weather Conditions		
Material	Mode	Rural	Suburban	Urban	Rural	Suburban	Urban
Depleted UF_6	Truck	0	1	2	0	1	3
	Rail	0	1	3	0	2	4
U_3O_8	Truck	0	0	0	0	4	8
	Rail	0	1	1	0	10	20
UO_2	Truck	0	0	0	0	1	2
	Rail	0	0	0	0	3	8

[a] Radiological LCFs were estimated from the calculated doses using dose-to-risk conversion factors of 0.0005 and 0.0004 fatality per person-rem for members of the general public and occupational workers, respectively, as recommended in ICRP Publication 60 (ICRP 1991). The approximate corresponding dose received for each radiological fatality risk listed in this table may be obtained by multiplying the fatality risk by 2,500 (i.e., 1 ÷ 0.0004).

[b] Exposure to HF or uranium compounds was estimated to result in fatality for approximately 1% or less of those persons experiencing irreversible adverse effects (Policastro et al. 1997).

TABLE J.14 Potential Consequences to the MEI from Severe Accidents Involving Shipment of Materials for Long-Term Storage

		Accident Risk			
		Neutral Weather Conditions		Stable Weather Conditions	
Material	Mode	Radiological Risk of LCF[a]	Chemical Effects[b]	Radiological Risk of LCF[a]	Chemical Effects[b]
Depleted UF_6	Truck	0.0002	Yes	0.0005	Yes
	Rail	0.0009	Yes	0.002	Yes
UF_6 with overcontainer	Truck	0.0002	Yes	0.0005	Yes
	Rail	0.0009	Yes	0.002	Yes
U_3O_8	Truck	0.004	No	0.07	Yes
	Rail	0.01	Yes	0.2	Yes
UO_2	Truck	0.004	No	0.06	Yes
	Rail	0.01	No	0.2	Yes

[a] Lifetime risk of LCF for an individual was estimated from the calculated doses using a dose-to-risk conversion factor of 5×10^{-4} fatality per person-rem for members of the general public, as recommended in ICRP Publication 60 (ICRP 1991). The approximate corresponding dose received for each radiological fatality risk listed in this table may be obtained by multiplying the fatality risk by 2,000 (i.e., $1 \div 0.0005$).

[b] Yes or No applies to the effect of chemical exposure on the MEI. There is no probability estimate; either there would or would not be an irreversible adverse effect. Exposure to HF or uranium compounds was estimated to result in fatality for approximately 1% or less of those persons experiencing irreversible adverse effects (Policastro et al. 1997).

The risk of latent cancer fatality to an MEI for a single exposure to a given shipment would be small. The highest potential exposure, with a latent cancer fatality risk of 2×10^{-7}, would occur for a person stopped in traffic near a shipment for 30 minutes at a distance of 3.3 ft (1 m). Such an exposure would be less than half the radiological exposure that a person receives from natural sources in the course of 1 day.

Impacts from a potential severe accident could lead to fatalities from both radiological and chemical effects. Approximately 2 potential latent cancer fatalities from radiological hazards are estimated for a rail accident occurring in an urban population zone under stable weather conditions. Because of the chemical hazard of uranium, an estimated 20 people could experience irreversible adverse effects from chemical toxicity under the same conditions.

J.3.6 Manufacture and Use Options

Two alternative uses of depleted uranium were assessed: manufacture of casks using concrete made with cement and UO_2 and manufacture of casks using uranium metal. Potential impacts would be incurred from transport of the feed material (UO_2 or uranium metal) from a conversion facility to the manufacturing plant, transport of the manufactured cask to an end user, and transport of the small amount of LLW and LLMW expected to be generated at the manufacturing facility to a disposal site. Because of the size of the manufactured casks, cask shipment was assumed to occur by rail only. The shipment risks would be approximately the same for both cask options.

The collective population risks associated with the two manufacture and use options are summarized in Tables J.15 and J.16 for routine and accident risks, respectively. The routine risks to MEIs are summarized in Table J.7, and the accident consequences to MEIs and the population are summarized in Tables J.17 and J.18, respectively.

J.3.6.1 Uranium Oxide Casks

The uranium oxide cask option would involve the use of depleted uranium in the form of high-density UO_2 for the manufacture of depleted uranium concrete for shielding in spent nuclear fuel storage casks. The transportation risks associated with transport of the UO_2 to the cask manufacturing facility would be the same as the risks associated with transport of the UO_2 to a storage site (see Section J.3.5.2). Shipment of the uranium oxide casks to an end user would result in approximately the same overall risks as the UO_2 shipments. No chemical risks would be anticipated for transportation of the fabricated casks, and no radiological fatalities would be expected under severe accident conditions.

J.3.6.2 Uranium Metal Casks

The uranium metal cask option would involve the conversion of depleted UF_6 to uranium metal that would then be fabricated into a cask. Transportation impacts were analyzed for shipment of the uranium metal from a conversion facility to a cask manufacturing facility and shipment of the fabricated cask to an end user. No chemical transportation risks would be expected for this option.

The total radiological risk associated with uranium metal transport would be about a factor of 30 or more less than the vehicle-related risks. Shipment risks for the cask would be about the same as for rail transport of the uranium metal feed material. Risks for the generated waste shipments would be negligible compared with the shipment of uranium metal and casks.

The risk of latent cancer fatality to an MEI for a single exposure to a given shipment would be small. The highest potential routine radiological exposure, with a latent cancer fatality risk of 4×10^{-8}, would occur for a person stopped in traffic near a uranium metal or cask shipment for

TABLE J.15 Total Routine Shipment Risks for the Transportation of Materials for Manufacture and Use

Use/Material	Mode	Total Shipments[a]	Risks over 250 km			Risks over 1,000 km			Risks over 5,000 km		
			Radiological LCF[b]	Chemical Effects[c]	Vehicular LCF	Radiological LCF[b]	Chemical Effects[c]	Vehicular LCF	Radiological LCF[b]	Chemical Effects[c]	Vehicular LCF
Uranium oxide casks											
UO_2	Truck	26,260 – 26,800	0.04	0	0.03	0.2	0	0.1	0.8	0	0.6
	Rail	8,480 – 8,800	0.01	0	0.006 – 0.007	0.02	0	0.03	0.06	0	0.1
LLW	Truck	300	0.0001	0	0.0003	0.0004	0	0.001	0.002	0	0.006
LLMW	Truck	20	1×10^{-6}	0	0.00002	4×10^{-6}	0	0.00009	0.00002	0	0.0005
Cask	Rail	9,600	0.003	0	0.007	0.005	0	0.03	0.02	0	0.1
Uranium metal casks											
Uranium metal	Truck	20,840 – 21,500	0.006 – 0.007	0	0.02 – 0.03	0.03	0	0.1	0.1	0	0.5
	Rail	7,360 – 7,520	0.002	0	0.006	0.004	0	0.02	0.01	0	0.1
LLW	Truck	1,540	0.0001	0	0.002	0.0004	0	0.007	0.02	0	0.04
LLMW	Truck	20	4×10^{-6}	0	0.00002	0.00001	0	0.00009	0.00007	0	0.0005
Cask	Rail	9,060	0.0002	0	0.007	0.0004	0	0.03	0.001	0	0.1

[a] Risks for rail transport were estimated on a railcar basis; therefore, the number of railcars was used for the total number of rail shipments.

[b] Radiological LCFs were estimated from the calculated doses using dose-to-risk conversion factors of 0.0005 and 0.0004 fatality per person-rem for members of the general public and occupational workers, respectively, as recommended in ICRP Publication 60 (ICRP 1991). The approximate corresponding dose received for each radiological fatality risk listed in this table may be obtained by multiplying the fatality risk by 2,500 (i.e., 1 ÷ 0.0004).

[c] Potential for irreversible adverse effects from chemical exposures. Exposure to HF or uranium compounds was estimated to result in fatality for approximately 1% or less of those persons experiencing irreversible adverse effects (Policastro et al. 1997).

TABLE J.16 Total Accident Shipment Risks for the Transportation of Materials for Manufacture and Use

			Risks over 250 km			Risks over 1,000 km			Risks over 5,000 km		
Use/Material	Mode	Total Shipments[a]	Radiological LCF[b]	Chemical Effects[c]	Vehicular Fatalities	Radiological LCF[b]	Chemical Effects[c]	Vehicular Fatalities	Radiological LCF[b]	Chemical Effects[c]	Vehicular Fatalities
Uranium oxide casks											
UO_2	Truck	26,260 – 26,800	0.002	0 – 5×10^{-6}	0.3	0.006	0 – 0.00002	1	0.03	0 – 0.0001	5
	Rail	8,480 – 8,800	0.0004	3×10^{-6} – 6×10^{-6}	0.1	0.001	0.00001 – 0.00003	0.4	0.007	0.00005 – 0.0001	2
LLW	Truck	300	2×10^{-12}	0	0.003	8×10^{-12}	0	0.1	4×10^{-11}	0	0.06
LLMW	Truck	20	8×10^{-11}	0	0.0002	3×10^{-10}	0	0.0008	2×10^{-9}	0	0.004
Cask	Rail	9,600	4×10^{-9}	0	0.1	1×10^{-8}	0	0.5	7×10^{-8}	0	2
Uranium metal casks											
Uranium metal	Truck	20,840 – 21,500	4×10^{-10}	0	0.2	2×10^{-9}	0	0.8	8×10^{-9}	0	4
	Rail	7,360 – 7,520	9×10^{-11}	0	0.09	4×10^{-10}	0	0.3 – 0.4	2×10^{-9}	0	2
LLW	Truck	1,540	2×10^{-6}	0	0.02	8×10^{-6}	0	0.06	0.00004	0	0.3
LLMW	Truck	20	7×10^{-11}	0	0.0002	3×10^{-10}	0	0.0008	1×10^{-9}	0	0.004
Cask	Rail	9,060	1×10^{-10}	0	0.1	4×10^{-10}	0	0.4	2×10^{-9}	0	2

a Risks for rail transport were estimated on a railcar basis; therefore, the number of railcars was used for the total number of rail shipments.

b Radiological LCFs were estimated from the calculated doses using dose-to-risk conversion factors of 0.0005 and 0.0004 fatality per person-rem for members of the general public and occupational workers, respectively, as recommended in ICRP Publication 60 (ICRP 1991). The approximate corresponding dose received for each radiological fatality risk listed in this table may be obtained by multiplying the fatality risk by 2,500 (i.e., 1 ÷ 0.0004).

c Potential for irreversible adverse effects from chemical exposures. Exposure to HF or uranium compounds was estimated to result in fatality for approximately 1% or less of those persons experiencing irreversible adverse effects (Policastro et al. 1997).

TABLE J.17 Potential Consequences to the MEI from Severe Accidents Involving Shipment of Materials for Manufacture and Use

		Accident Risk			
		Neutral Weather Conditions		Stable Weather Conditions	
Use/Material	Mode	Radiological Risk of LCF[a]	Chemical Effects[b]	Radiological Risk of LCF[a]	Chemical Effects[b]
Uranium oxide casks					
UO_2	Truck	0.004	No	0.06	Yes
	Rail	0.01	No	0.2	Yes
LLW	Truck	2×10^{-6}	No	0.00003	No
LLMW	Truck	2×10^{-7}	No	4×10^{-6}	No
Cask	Rail	0.0004	No	0.006	No
Uranium metal casks					
Uranium metal	Truck	0.0001 – 0.0002	No	0.002	No
	Rail	0.0004	No	0.007	No
LLW	Truck	0.00008	No	0.001	No
LLMW	Truck	2×10^{-7}	No	4×10^{-6}	No
Cask	Rail	0.0004	No	0.006	No

[a] Lifetime risk of LCF for an individual was estimated from the calculated doses using a dose-to-risk conversion factor of 0.0005 fatality per person-rem for members of the general public, as recommended in ICRP Publication 60 (ICRP 1991). The approximate corresponding dose received for each radiological fatality risk listed in this table may be obtained by multiplying the fatality risk by 2,000 (i.e., 1 ÷ 0.0005).

[b] Yes or No applies to the effect of chemical exposure on the MEI. There is no probability estimate; either there would or would not be an irreversible adverse effect. Exposure to HF or uranium compounds was estimated to result in fatality for approximately 1% or less of those persons experiencing irreversible adverse effects (Policastro et al. 1997).

30 minutes at a distance of 3.3 ft (1 m). Such an exposure would be approximately 10 times less than the exposure a person receives from natural sources in the course of 1 day.

No fatalities from severe accidents would be expected. The transportation risks associated with the transport of the uranium metal cask would be approximately the same as those for the uranium oxide cask.

J.3.7 Disposal Options

Two options were identified for potential disposal of the depleted uranium: disposal as U_3O_8 or disposal as UO_2. In each case, the uranium oxide form would be transported from a single site, either a conversion facility or a storage site, to a disposal site. The impacts associated with

TABLE J.18 Potential Consequences to the Population from Severe Accidents Involving Shipment of Materials for Manufacture and Use

		Radiological Risk[a] (LCF)					
		Neutral Weather Conditions			Stable Weather Conditions		
Material	Mode	Rural	Suburban	Urban	Rural	Suburban	Urban
Uranium oxide casks							
UO_2	Truck	0.1	0.1	0.2	0.2	0.2	0.5
	Rail	0.3	0.3	0.6 – 0.7	0.7 – 0.8	0.7	2
LLW	Truck	1×10^{-8}	1×10^{-8}	3×10^{-8}	3×10^{-8}	2×10^{-8}	5×10^{-8}
LLMW	Truck	6×10^{-6}	6×10^{-6}	0.00001	0.00001	0.00001	0.00003
Cask	Rail	3×10^{-6}	3×10^{-6}	6×10^{-6}	7×10^{-6}	5×10^{-6}	0.00001
Uranium metal casks							
Uranium metal	Truck	1×10^{-6}	8×10^{-7} – 9×10^{-7}	2×10^{-6}	3×10^{-6}	2×10^{-6}	4×10^{-6} – 5×10^{-6}
	Rail	3×10^{-6} – 4×10^{-6}	2×10^{-6}	5×10^{-6}	8×10^{-6} – 9×10^{-6}	6×10^{-6}	0.00001
LLW	Truck	0.002	0.002	0.004	0.005	0.005	0.01
LLMW	Truck	6×10^{-6}	6×10^{-6}	0.00001	0.00001	0.00001	0.00003
Cask	Rail	3×10^{-6}	2×10^{-6}	5×10^{-6}	8×10^{-6}	5×10^{-6}	0.00001

		Chemical Risk[b] (no. of persons with potential for irreversible adverse effects)					
		Neutral Weather Conditions			Stable Weather Conditions		
Material	Mode	Rural	Suburban	Urban	Rural	Suburban	Urban
Uranium oxide casks							
UO_2	Truck	0	0	0	0	1	2
	Rail	0	0	0	0	3	8
LLW	Truck	0	0	0	0	0	0
LLMW	Truck	0	0	0	0	0	0
Cask	Rail	0	0	0	0	0	0
Uranium metal casks							
Uranium metal	Truck	0	0	0	0	0	0
	Rail	0	0	0	0	0	0
LLW	Truck	0	0	0	0	0	0
LLMW	Truck	0	0	0	0	0	0
Cask	Rail	0	0	0	0	0	0

[a] Radiological LCFs were estimated from the calculated doses using a dose-to-risk conversion factor of 0.0005 fatality per person-rem for members of the general public, as recommended in ICRP Publication 60 (ICRP 1991). The approximate corresponding dose received for each radiological fatality risk listed in this table may be obtained by multiplying the fatality risk by 2,000 (i.e., 1 ÷ 0.0005).

[b] Exposure to HF or uranium compounds was estimated to result in fatality for approximately 1% or less of those persons experiencing irreversible adverse effects (Policastro et al. 1997).

transport to a disposal site would be the same as those for transport to a storage site (see Section J.3.5.2). Comparison of the transportation impacts associated with the two disposal options shows no significant difference between the two.

J.3.8 Other Impacts Considered But Not Analyzed in Detail

Other impacts could potentially occur if the transportation options considered in this PEIS were implemented, including impacts to air quality, water quality, ecology, socioeconomics, cultural resources, visual environment (e.g., aesthetics), recreational resources, wetlands, noise levels, and environmental justice issues. These impacts, although considered, were not analyzed in detail for one or more of the following reasons:

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

- The impacts could not be determined at the programmatic level without consideration of specific routes between specific sites. Potential impacts would be more appropriately addressed in the second-tier *National Environmental Policy Act* (NEPA) documentation when specific sites are considered.

J.4 REFERENCES FOR APPENDIX J

Biwer, B.M., et al., 1996, *Risk Assessment for the On-Site Transportation of Radioactive Wastes for the U.S. Department of Energy Waste Management Programmatic Environmental Impact Statement*, ANL/EAD/TM-18, Argonne National Laboratory, Argonne, Ill., Dec.

Biwer, B.M., et al., 1997, *Transportation Impact Analyses in Support of the Depleted Uranium Hexafluoride Programmatic Environmental Impact Statement*, attachment to memorandum from B. Biwer (Argonne National Laboratory, Argonne, Ill.) to H.I. Avci (Argonne National Laboratory, Argonne, Ill.), May 21.

Charles, L.D., et al., 1991, *Cost Study for the D&D of the GDPs: Depleted Uranium Management and Conversion,* K/D-5940-F, Martin Marietta Energy Systems, Oak Ridge, Tenn.

DOE: see U.S. Department of Energy.

ICRP: see International Commission on Radiological Protection.

International Commission on Radiological Protection, 1991, *1990 Recommendations of the International Commission on Radiological Protection*, ICRP Publication 60, Pergamon Press, Oxford, United Kingdom.

Lawrence Livermore National Laboratory, 1997, *Depleted Uranium Hexafluoride Management Program; the Engineering Analysis Report for the Long-Term Management of Depleted Uranium Hexafluoride*, UCRL-AR-124080, Volumes I and II, prepared by Lawrence Livermore National Laboratory, Science Applications International Corporation, Bechtel, and Lockheed Martin Energy Systems for U.S. Department of Energy.

LLNL: see Lawrence Livermore National Laboratory.

Policastro, A.J., et al., 1997, *Facility Accident Impact Analyses in Support of the Depleted Uranium Hexafluoride Programmatic Environmental Impact Statement*, attachment to memorandum from A.J. Policastro (Argonne National Laboratory, Argonne, Ill.) to H.I. Avci (Argonne National Laboratory, Argonne, Ill.), June 15.

Saricks, C., and T. Kvitek, 1994, *Longitudinal Review of State-Level Accident Statistics for Carriers of Interstate Freight,* ANL/ESD/TM-68, Argonne National Laboratory, Argonne, Ill.

U.S. Department of Energy, 1997, *Final Waste Management Programmatic Environmental Impact Statement for Managing Treatment, Storage, and Disposal of Radioactive and Hazardous Waste*, DOE/EIS-0200-F, Office of Environmental Management, Washington, D.C., May.