APPENDIX C:

ASSESSMENT METHODOLOGIES

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The following is a list of acronyms and abbreviations, including units of measure, used in this appendix.

ACRONYMS AND ABBREVIATIONS

General

AIHA	American Industrial Hygiene Association
ALARA	as low as reasonably achievable
BEA	U.S. Bureau of Economic Analysis
BEMR	*The 1996 Baseline Environmental Management Report*
CFR	*Code of Federal Regulations*
DOE	U.S. Department of Energy
EIS	environmental impact statement
EPA	U.S. Environmental Protection Agency
ERPG	Emergency Response Planning Guideline
HEPA	high-efficiency particulate air (filter)
HVAC	heating, ventilating, and air conditioning
ICRP	International Commission on Radiological Protection
INEL EIS	*Department of Energy Programmatic Spent Nuclear Fuel Management and Idaho National Engineering Laboratory Environmental Restoration and Waste Management Programs Final Environmental Impact Statement*
IRIS	Integrated Risk Information System
ISCST	Industrial Source Complex Short Term model
LCF	latent cancer fatality
LLNL	Lawrence Livermore National Laboratory
LLMW	low-level mixed waste
LLW	low-level radioactive waste
LMES	Lockheed Martin Energy Systems, Inc.
MEI	maximally exposed individual
NEPA	*National Environmental Policy Act*
NRC	U.S. Nuclear Regulatory Commission
ORR	Oak Ridge Reservation
OSHA	U.S. Occupational Safety and Health Administration
PEIS	programmatic environmental impact statement
PEL	permissible exposure limit
$PM_{2.5}$	particulate matter having a particle diameter equal to or less than 2.5 µm
PM_{10}	particulate matter having a particle diameter equal to or less than 10 µm
ROI	region of influence
SIC	Standard Industrial Classification

TEDE	total effective dose equivalent
WM PEIS	*Waste Management Programmatic Environmental Impact Statement for Managing Treatment, Storage, and Disposal of Radioactive and Hazardous Waste*

Chemicals

CaF_2	calcium fluoride
HF	hydrogen fluoride
MgF_2	magnesium fluoride
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

cm	centimeter(s)
cm^3	cubic centimeter(s)
d	day(s)
ft	foot (feet)
g	gram(s)
h	hour(s)
kg	kilogram(s)
km	kilometer(s)
km^2	square kilometer(s)
L	liter(s)
lb	pound(s)
µg	microgram(s)
m	meter(s)
m^3	cubic meter(s)
mg	milligram(s)
min	minute(s)
mrem	millirem(s)
ppm	part(s) per million
rem	roentgen-equivalent man (men)
s	second(s)
Sv	sievert(s)
yr	year(s)

APPENDIX C:

ASSESSMENT METHODOLOGIES

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 near Paducah, Kentucky; Portsmouth, Ohio; and on the Oak Ridge Reservation in 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 methodology used to assess the potential environmental impacts for continued cylinder storage, cylinder preparation, conversion options, long-term storage, manufacture and use, and disposal. The general methodology is explained, and special applications for specific options or alternatives are summarized. For several technical areas — such as air resources, human health, water resources, socioeconomics, and transportation — separate technical reports provide additional details regarding these methods.

C.1 AIR RESOURCES

The assessment of air quality impacts in the depleted UF_6 PEIS considered pollutant emissions under normal operating conditions. Atmospheric dispersion of pollutant emissions from construction, operation, and maintenance activities were estimated with conventional modeling techniques, i.e., U.S. Environmental Protection Agency (EPA) Industrial Source Complex Short Term (ISCST) model (EPA 1995b) and SCREEN3 model (EPA 1995a).

For the evaluation of continued storage, internal combustion emissions and fugitive dust emissions from the planned construction of new storage areas were assessed. Additionally, material loss from hypothetical cylinder breaches was assessed. Loss of any depleted UF_6 through corrosion of cylinders in the storage yards would occur slowly enough that the depleted UF_6 would react with atmospheric moisture while still in the cylinder. The pollutant of concern from atmospheric releases due to cylinder breaches is hydrogen fluoride (HF). Emissions from postulated breaches were modeled using the ISCST model.

Estimated emissions were taken from the engineering analysis report (Lawrence Livermore National Laboratory [LLNL] 1997). Emissions data were provided for construction of facilities and for normal operations of the conversion, cylinder preparation, long-term storage, manufacture and use, and disposal options.

Air concentrations of radionuclides due to the emission of radioactive materials were estimated with the GENII code (Napier et al. 1988). Emissions of hazardous chemicals and other pollutants were estimated with the ISCST code (EPA 1995b). Results from the ISCST and GENII codes for given conditions are in good agreement with each other. The hour-by-hour meteorological data from the three current storage sites show the range of air quality impacts that could be anticipated at the facility boundaries from the estimated emissions. For the Paducah and Portsmouth site-specific and representative analyses, the plant boundaries rather than the site perimeters were used (see Chapter 3). The SCREEN3 model (EPA 1995a) was used to determine the maximum impacts possible under worst-case meteorological conditions.

For impact analyses of representative environmental settings (i.e., analyses for the conversion and long-term storage options), the representative facility was assumed to be centered within a larger site (i.e., the plant boundaries of the three representative sites), and pollutant concentrations were estimated for the boundaries of that site. Screening modeling of construction emissions was used to estimate hourly pollutant concentrations under very conservative meteorological conditions at the boundary point that would be the shortest distance from the center of the facility. For impact analyses of generic environmental settings (i.e., analyses for the manufacture and use and disposal options), the pollutant concentrations at several distances from the center of the facility were estimated because of uncertainty regarding the size and location of the generic sites. Estimates at 2,460 ft (750 m) from the center of the generic facilities are comparable to the estimates for options based on representative environmental settings (i.e., conversion and long-term storage options using the three current storage sites as representative). The shortest distances from the centers of the representative sites to their boundaries range from 2,300 to 2,600 ft (700 to 800 m).

The radiological impacts under normal operational conditions would be long-term, cumulative impacts. Site-specific data (for facilities located at the existing cylinder storage sites) or representative long-term meteorological data (joint frequency data) were used to estimate air concentrations of the released radionuclides. For hazardous chemicals and other pollutants, short-term meteorological data were used because of the required regulatory compliance with short-term standards and different human health impact endpoints.

Additional meteorological data sets were used in the analyses of the disposal and manufacture and use options. The data sets were grouped into dry and wet environmental settings. The historical meteorological conditions for five actual “dry” locations in the southwestern United States and five actual “wet” locations in the central and southeastern United states were averaged to develop estimates for these generic environmental settings.

The type of data used for the air quality analysis included the following:

- On-site meteorological data — such as temperature, wind speed, and wind direction — and a description of the recording tower;

- Air quality data from the plant environs (state data); and

- State and federal ambient air quality standards.

Impacts relative to the ambient air quality standards for particulate matter with a particle diameter equal to or less than 2.5 µm ($PM_{2.5}$), announced by the EPA on July 17, 1997, were not estimated because the worst-case particulate emissions are likely to be coarse particulates (dust) emitted during construction, for which the PM_{10} (particulate matter with a particle diameter equal to or less than 10 µm) standards are more appropriate.

Complex terrain analysis was not required for SCREEN3 modeling. Also, to estimate air quality impacts at the facility perimeter and off the site, downwash calculations to determine the influence of on-site buildings were not needed.

Additional details on the analysis of air quality impacts are presented in Tschanz (1997).

C.2 WATER RESOURCES

For the depleted UF_6 PEIS, hydrological assessments were performed for all options for both surface water and groundwater. The assessment of water resources included evaluation of (1) existing hydrological environment for continued storage at the three current storage sites; (2) potential impacts of construction, operation, and accident scenarios for the cylinder preparation and conversion facility/storage options; and (3) potential impacts to the hydrological environment for hypothetical generic sites with respect to disposal and manufacture and use. For these generic options, two environmental settings were evaluated, a dry environment and a wet environment.

C.2.1 Continued Cylinder Storage

For the continued cylinder storage option, storage of depleted UF_6 cylinders would continue at each of the existing sites. A large number of cylinders containing depleted UF_6 are currently stored at the Paducah, Portsmouth, and K-25 sites. Because of their age, potential direct contact with the ground, and skirted ends (an extension of the cylinder walls to protect the cylinder valve from potential impact damage, which was used in a limited number of cylinder designs), many of these cylinders show signs of corrosion. Some instances of cylinder wall breach through corrosion have occurred, with subsequent exposure of depleted UF_6 to the environment (see Appendix B).

Unknown quantities (estimated to be small) of solid depleted UF_6, uranium tetrafluoride (UF_4), uranyl fluoride (UO_2F_2), and HF dissolved in water might come in contact with the material beneath a breached cylinder. For cylinders stored on concrete pads, the released material could be transported laterally by precipitation and surface runoff. If not collected or if the collection system failed, the transported material could gather in surface depressions or be swept into nearby surface drainages, potentially contaminating streams or other surface water bodies. Soluble forms could infiltrate the ground surface in areas of groundwater recharge and potentially contaminate underlying aquifers. The released material could also dissolve and infiltrate the surface and contaminate shallow groundwater adjacent to the storage area. The released material would act as a source of potential contamination until it was fully dissolved or remediated.

For impact analysis, each active breached cylinder was assumed to release 4 lb (1.8 kg) of uranium over a 4-year period. For each of the three sites, the yard with the most predicted breaches was used in the calculations (C-745-G yard [G-yard] at Paducah, K-1066-K yard [K-yard] at Oak Ridge, and a combination of the X-745-E yard [E-yard] and X-745-C [C-yard] at Portsmouth). Because more than one breach could be active at any one time, the maximum number of active breaches was estimated by using a moving 4-year sum of breaches (see Appendix B).

For continued storage of cylinders, existing conditions were evaluated for surface water and groundwater. Surface water conditions were derived from field measurements of water quality in appropriate drainages where data were available. If data were not available, the existing conditions were estimated using the solubility of the potential contaminants and dilution estimates for the surface water features.

The concentrations of uranium leaving the yards at the three current storage sites were estimated with a simple mass balance based on the area of the yard, the average annual precipitation, and the maximum number of active breached cylinders (Tomasko 1997b). This contaminated water was then assumed to flow over land to the nearest stream, where it would mix with initially clean water and become more dilute. Maximum concentrations in the receiving water were evaluated at the point of discharge from the yards; additional downstream mixing and dispersion were not considered.

To estimate groundwater quality downgradient of the storage yards, the maximum concentration at the water table was estimated by using a one-dimensional analytical solution to a governing partial differential equation that incorporates advection, dispersion, adsorption, and decay for a time-dependent, step-function source (Tomasko 1997a-b). For groundwater quality calculations, the contaminant source was assumed to have a maximum concentration equal to the maximum value in water leaving the storage yard with the most breached cylinders. All water leaving the yard was then assumed to infiltrate the surface and move vertically downward to the underlying groundwater aquifer. To provide conservative yet realistic estimates of groundwater concentrations, the source was modeled as a step-function having a duration equal to the full width of the half-maximum concentration value (approximately 20 years for each of the three sites). Additional details on the groundwater modeling are discussed in Tomasko (1997a-b).

C.2.2 Other Options

For the cylinder preparation, conversion, and storage options, physical impacts to surface water (i.e., changes in runoff and floodplain encroachment) and groundwater (i.e., changes in recharge, depth to groundwater, and direction of flow) were evaluated for construction, operations, and accident scenarios identified in the engineering analysis report (LLNL 1997).

Impacts to runoff were evaluated with a two-step procedure. First, the amount of land area was estimated that would be changed by installing paved lots and other low-permeability features, which would modify surface permeability (ease with which water infiltrates the ground surface). Decreases in surface permeability would lead to increases in runoff, and increases in permeability would produce less runoff but more infiltration. Second, impacts to runoff were then evaluated by comparing the altered area to the total land area available at the actual or representative site that was contributing runoff to surface water. This method was used because of the direct relationship between impermeable area and runoff (Tomasko 1997b). On the basis of this procedure, large sites would be preferable to small ones because more land would be available at the larger site to mitigate the presence of the proposed construction and operation.

Potential impacts to floodplains during construction and normal operations were evaluated for two aspects: addition or subtraction (withdrawal) of water from a nearby river. In either case, the impacts were assessed by comparing the volume of water either added or withdrawn to average flow conditions in the actual or representative river. This method was implemented because of the direct relationship between volumetric flow and channel depth (Tomasko 1997b) and floodplain prediction. As with runoff, a site located near a large river would have smaller impacts than a site located near a small river or stream because the larger river would have a larger flow volume that could mitigate withdrawals or discharges easier than would a small stream.

Groundwater physical parameters could be impacted during construction by direct extraction from a well or a series of wells. Groundwater levels would decrease during pumping, and the direction of groundwater flow in the vicinity of the well would be changed. Similarly, groundwater extraction for normal operations could also impact the physical parameters. Potential impacts were evaluated by comparing the pumping rate with the current groundwater usage at the actual or representative sites and by using a simple drawdown model (Tomasko 1997b). This method was used because of the direct correlation between pumping rates and water table elevations.

Surface water quality was estimated by using simple mixing models to estimate contaminant concentrations based on the quantity and solubility of the constituents in the effluent stream and the average flow conditions in the actual or representative receiving water bodies (Tomasko 1997b). For groundwater quality, the maximum concentration at the water table (point of compliance) was estimated by using the one-dimensional analytical solution discussed in Section C.2.1.

Two generic environmental settings were evaluated for the disposal and manufacture and use options, a dry environment and a wet environment. For the dry environmental setting, the depth to groundwater was assumed to be large (100 to 500 ft [30 to 150 m]), consistent with the depth to groundwater at such locations as the mixed waste landfill at Sandia National Laboratories [Johnson et al. 1994]). For the wet setting, the depth to groundwater was assumed to be small (30 ft [9 m]). Because site-specific parameters are needed to quantify impacts, the PEIS provided only a qualitative discussion of impacts for activities assumed to occur in generic environmental settings (i.e., discussion of non-site-specific parameters such as water use, effluent volumes, paved areas, and excavation volumes).

C.2.3 Data Requirements

Input data for the analyses performed for the PEIS were obtained from various site and contractor reports, when possible. Engineering judgment and professional experience were used to define input parameters if site-specific data were not available or calculations were for a representative or generic setting.

C.3 BIOTIC RESOURCES

Impacts to ecological resources were evaluated for continued cylinder storage, and for the cylinder preparation, conversion, storage, manufacture and use, and disposal options. Potential impacts were evaluated for terrestrial and aquatic biota, including vegetation and wildlife, wetlands, and federal- and state-listed threatened and endangered species. The impact analysis focused on the radiological and chemical toxicity effects to biota resulting from exposure to depleted UF_6 and related compounds and from physical disturbance to biota and habitats.

C.3.1 Continued Cylinder Storage and Cylinder Preparation

The impact analysis for continued cylinder storage and cylinder preparation included site-specific evaluation of impacts to biota in the vicinity of the Portsmouth, Paducah, and K-25 sites. Exposure to the contaminants of concern (depleted UF_6, UO_2F_2, and HF) under current management practices was analyzed in the context of storage cylinder integrity and potential release of contents, including effects of groundwater contamination, surface water contamination, contamination of soils, and airborne transport of contaminants. Also assessed were other effects of the operation of the three facilities associated with continued storage of depleted UF_6 that might impact biota (e.g., air quality) and potential impacts from cylinder preparation with respect to habitat loss and changes in biotic communities.

C.3.2 Other Options

The other options for management of depleted UF_6 were evaluated in generic terms, based on the following potential components: technologies for converting depleted UF_6 to other forms or products (including potential exposure to those forms or products and residual products and waste); technologies for using depleted UF_6, long-term storage of depleted UF_6 or uranium oxides; and disposal of depleted UF_6 or uranium oxides (including potential exposure to those compounds). The analysis considered potential impacts of these options to biota in the vicinity of the three representative sites (i.e., Paducah, Portsmouth, and K-25 sites) for all options but disposal and manufacture and use, for which generic environmental settings were assumed.

C.3.3 Impact Analysis

The analysis of impacts to wildlife addressed the effects of facility construction and operations — such as air quality, radiological, and chemical toxicity effects — through the exposure pathways of inhalation, dermal contact, and ingestion. Exposures were based on predicted air, surface water, groundwater, and soil concentrations of contaminants. Predictive modeling is discussed in Sections C.1 and C.2 of this appendix. Radiological dose rate estimates (in rad/day) were calculated for aquatic biota (fish and shellfish) on the basis of undiluted effluent concentrations (in pCi/L), energy released per decay (MeV) for depleted uranium, and a bioconcentration factor (factors of 2 and 60 were applied for fish and shellfish, respectively). These dose rate estimates were compared with the dose limit of 1 rad/d specified in DOE Order 5400.5. Additionally, concentrations of uranium, uranium compounds, and HF in air, water, and/or soil were compared with published benchmark values (levels with no, or lowest observed, effects) for determination of potential toxicity effects. Benchmark values for air concentration lowest observable effects due to inhalation were 7 mg/m^3 for HF, 17 mg/m^3 for triuranium octaoxide (uranyl uranate, U_3O_8), 1 mg/m^3 for uranium dioxide (UO_2), and 0.5 mg/m^3 for UF_4 (Voegtlin and Hodge 1949). The benchmark value for aquatic toxicity was a lowest observable effect level of 150 µg/L for total uranium (Hyne et al. 1992). Potential impacts analyzed included impacts to individuals (such as mortality, physical disturbance, injury, or reduction of reproductive capacity) and potential changes in biotic community structure or function (such as changes in species dominance, trophic relationships, or ecological processes).

The analysis of ecological impacts to plant species addressed facility construction and operations effects (such as removal of vegetation during construction) and chemical toxicity effects. Estimated uranium soil concentrations were compared with a benchmark value of 5 µg/g, which is the lowest observed effects concentration (Will and Suter 1994). Potential impacts analyzed included impacts to individuals (such as mortality, reduction of productivity) and potential changes in biotic community structure or function (such as changes in species dominance, species diversity, or ecological processes).

Physical disturbances to biota and habitats were also evaluated. The general guidelines used to assess impacts of habitat loss and wildlife disturbance were as follows: (1) negligible impacts, corresponding to less than 10 acres of required land; (2) moderate impacts, corresponding to between 10 and 100 acres of required land; and (3) potential large impacts, corresponding to greater than 100 acres of required land. The potential for impacts to wetlands and federal- and state-listed threatened or endangered species is a site-specific consideration, and it would be determined in Phase II analyses and *National Environmental Policy Act* (NEPA) reviews.

C.3.4 Data Requirements

Data input for the impact analysis included plant and animal species known to occur or potentially occurring at each storage site and in ecosystems (such as wetland, forest, grassland) in the vicinity of each site. Also required was information regarding potential releases due to cylinder failure, transportation, processing of depleted UF_6 and related compounds, handling (such as during repackaging), and disposal. Chemical and physical properties of depleted UF_6 and related compounds were required, including fate in soil, air, and water (such as adsorption or transformation).

C.4 ENVIRONMENTAL RADIATION SOURCES AND EXPOSURES

C.4.1 Normal Operations

Radiological impacts to human health from normal operations at different facilities were assessed for the continued storage option and for different categories of options. The option categories corresponded to the different technologies developed in the engineering analysis report (LLNL 1997). Additional details on the analysis of radiological impacts under normal operations are presented in Cheng et al. (1997).

C.4.1.1 Receptors

For the PEIS, radiation effects during normal (or routine) operations were estimated by first calculating the radiation dose to workers and members of the general public from the anticipated activities required under each alternative. The analysis considered three groups of people: (1) involved workers, (2) noninvolved workers, and (3) members of the general public, defined as follows:

- ***Involved Workers*** **—** Persons working at a site who are directly involved with the handling of radioactive or hazardous materials:
    - Might be exposed to direct gamma radiation emitted from radioactive materials, such as depleted UF_6 or other uranium compounds.
    - Would receive very small radiation doses from inhaling uranium compared with the direct radiation doses resulting from enclosed processes; ventilation controls would be used to inhibit airborne emissions in facilities.

  - Would be protected by a dosimetry program to control doses below the maximum regulatory limit of 5 rem/yr for workers (10 *Code of Federal Regulations* [CFR] Part 835).

- ***Noninvolved Workers*** — Persons working at a site but not directly involved with the handling of radioactive or hazardous materials:

  - Might be exposed to direct radiation from radioactive materials (although at a great distance) and to trace amounts of uranium released to the environment through site exhaust stacks.

  - Would receive radiation exposure primarily through inhalation of radioactive material in the air, external radiation from radioactive material deposited on the ground, and incidental ingestion of soil.

- ***Members of the General Public*** — Persons living within 50 miles (80 km) of the site:

  - Might be exposed to trace amounts of uranium released to the environment through exhaust stacks or wastewater discharges.

  - Would receive radiation exposures primarily through inhalation of radioactive material in the air, external radiation from deposited radioactive material, and ingestion of contaminated water, food, or soil.

For each of these groups, doses were estimated for the group as a whole (population or collective dose), as well as for a maximally exposed individual (MEI). The MEI was defined as a hypothetical person who — because of proximity, activities, or living habits — could receive the highest possible dose. The MEI for noninvolved workers and members of the general public usually was assumed to be at the location of the highest on-site or off-site air concentrations of contaminants, respectively — even if no individual actually worked or lived there. The average individual dose for involved workers was estimated, rather than the MEI dose, because of uncertainties about involved worker activities and locations. Under actual conditions, all radiation exposures and releases of radioactive material to the environment are required to be as low as reasonably achievable (ALARA), a practice that has as its objective the attainment of dose levels as far below applicable limits as possible.

C.4.1.2 Radiation Doses and Health Effects

All radiological impacts were assessed in terms of committed dose and associated health effects. The calculated dose was the total effective dose equivalent (10 CFR Part 20), which is the sum of the effective dose equivalent from exposure to external radiation and the 50-year committed effective dose equivalent from exposures to internal radiation. Radiation doses were calculated in units of milliroentgen-equivalent man (mrem) for individuals and in units of person-rem for collective populations.

The potential radiation doses resulting from normal operations would be so low that the primary adverse health effects would be the potential induction of latent cancer fatalities (LCFs). Health risk conversion factors (expected LCFs per absorbed dose) from Publication 60 of the International Commission on Radiological Protection (ICRP 1991) were used to convert radiation doses to LCFs, i.e., 0.0005 per person-rem for members of the general public and 0.0004 per person-rem for workers. Adverse health effects for individuals were assessed in terms of the probability of developing an excess LCF, whereas adverse health effects for collective populations were assessed as the number of excess LCFs expected in the population.

C.4.1.3 Exposure Pathways

External radiation would be the primary exposure pathway for involved workers due to the direct handling of radioactive materials and/or the close working distances to radiation sources. Radiation exposures through inhalation and incidental ingestion of contaminated particulates would be possible but would be expected to be very small compared with exposures from external radiation. Operations that could result in potential airborne emissions would be conducted under a fume hood or in glove boxes. Even if airborne emissions did occur, the use of high-efficiency particulate air (HEPA) filters and various air circulation systems would reduce the airborne pollutants in the working place to a minimal level. Exposures from inhalation could also be prevented by implementation, as required, of as low as reasonably achievable (ALARA) practices, such as workers wearing respirators while performing activities with potential airborne emissions. Potential exposure from incidental ingestion of particulates could be reduced by workers wearing gloves and exercising good working practices. On the basis of the small stack emission rates of radioactive materials estimated in the engineering analysis report (LLNL 1997) and the implementation of various mitigative measures, radiological impacts to involved workers were analyzed only for external radiation exposures.

Inhalation of contaminated particulates and incidental ingestion of deposited particulates were considered for noninvolved workers who, because of being located farther away from the radiation sources handled in the facilities, would not be exposed to direct external radiation from those sources. However, secondary external radiation would be possible from the deposited radionuclides on ground surfaces and from airborne radionuclides when the emission plume from the stacks of the processing buildings passed the locations of the noninvolved workers. To obtain conservative estimates with the calculation, the noninvolved workers were assumed to be exposed to radiation caused by airborne emissions without any shielding from buildings or other structures.

Radiation exposures of members of the off-site general public were assessed for both airborne and waterborne pathways. The airborne pathways included inhalation of contaminated particulates, external radiation from deposited radionuclides and from airborne radionuclides, incidental ingestion of deposited radionuclides, and ingestion of contaminated food products (plants, meat, and dairy products). Plants grown in the area where the emission plume passed could become contaminated by deposition of radionuclides on the leaves or ground surfaces. Radionuclides deposited on leaves could subsequently translocate to the edible portions of the plants, and those deposited on ground surfaces could subsequently be absorbed by plant roots. Livestock and their products could become contaminated if the livestock ate the contaminated surface soil and plants.

The waterborne pathways included ingestion of surface water and groundwater; ingestion of contaminated plant foods, meat, and dairy products; and potential radon exposure from using contaminated water. Plant foods and fodder could be contaminated from irrigation with contaminated water, and the livestock and their products could become contaminated if the livestock were fed with contaminated water and ate contaminated fodder. Potential indoor radon exposures would be possible if contaminated water was used indoors and radon gas emanated from the water. Because of the large dilution capability of surface water at the representative sites, the estimated radionuclide concentrations in surface water were always very low, and potential radiation exposures from the food chain pathways associated with these low water concentrations would be negligible. Therefore, radiation exposures resulting from contaminated surface water were assessed only for the drinking water pathway. The dilution capability would be smaller for groundwater, resulting in higher groundwater concentrations. Therefore, if the groundwater would be contaminated, radiation exposures from the food chain pathways, radon pathway, and drinking water pathway were all estimated.

C.4.1.4 Sources of Data and Application of Software

The external exposures incurred by the involved workers were estimated on the basis of information on worker activities, radiation sources, and exposure distances provided in the radiation exposure and manpower distribution estimating data in the engineering analysis report (LLNL 1997), with the use of the MicroShield (Negin and Worku 1992) computer code. MicroShield is a commercial software program designed to estimate external radiation doses from a variety of sources; it is widely used for such applications. It was used to calculate the external radiation dose rate associated with each worker activity, which was then used to calculate collective worker exposures. After collective worker exposures were determined, the average worker dose was calculated by dividing the collective dose by the number of involved workers. At this preliminary stage of engineering design, the information on radiation sources, worker activities, and number of required workers is subject to a large degree of uncertainty, as are the calculated collective and average worker doses. Therefore, the calculation results presented should be used only for comparative purposes among different technologies and options. In reality, the radiation dose to the individual worker would be monitored and maintained below the DOE administrative control limit of 2,000 mrem/yr (DOE 1992b), which is below the regulatory dose limit of 5,000 mrem/yr (10 CFR Part 835).

Radiological impacts from airborne pathways were estimated with the emission data provided in the engineering analysis report (LLNL 1997), with the use of the GENII (Napier et al. 1988) computer code, which was also used in several previous environmental impact statement projects, such as the *Final Waste Management Programmatic Environmental Impact Statement for Managing Treatment, Storage, and Disposal of Radioactive and Hazardous Waste* (WM PEIS; DOE 1997), for the same application. The GENII computer code uses the site-specific or representative meteorological data (joint frequency data) selected for each option to estimate the air concentrations at downwind locations. It then calculates the biota concentrations by using biotransfer models and estimates the radiation doses with a built-in dosimetry model.

The MEI for the noninvolved workers was assumed to be within the site boundary at a location that would have the maximum air concentration and would yield the largest radiation dose. For the general public, the location of the MEI was assumed to be either at the site boundary or at an off-site location that would have the largest air concentration. The site boundary was determined with actual site information (for the three current storage sites) or with the information on facility dimensions provided in the engineering analysis report (LLNL 1997). If the facility was assumed to be at one of the three representative sites, the collective dose for the noninvolved workers was estimated with information on sitewide worker distribution. If no exact location was determined for the facility, the noninvolved workers in the facility were assumed to be evenly distributed between 100 to 200 m from the emission point. Population distributions within 50 miles (80 km) around the three representative sites were obtained from census data and were used to estimate the collective dose to the off-site public. For facilities without specific locations, a representative population density of 6 persons/km^2 was used for a rural environment and 275 persons/km^2 was used for an urban environment. These would result in a total population of approximately 120,000 and 5,600,000 within a radius of 50 miles (80 km) for a rural and urban environment, respectively.

Surface water and groundwater concentrations were obtained through water quality analyses. Biota concentrations (plant foods, meat, and milk) and indoor radon concentrations from using contaminated groundwater were estimated with the RESRAD code (Yu et al. 1993). The RESRAD code contains biotransfer models comparable with those in GENII to estimate biota concentrations but also has the capability to predict indoor radon concentrations and the associated radiation doses.

C.4.1.5 Exposure Parameters and Dose Conversion Factors

Inhalation rates for workers were assumed to be 1.2 m^3/h (ICRP 1994), with an exposure duration of 8 hours per day for 250 days per year. Incidental ingestion of particulates was assumed to be 50 mg/d for the workers. The inhalation rate for the general public was assumed to be 20 m^3/d, with an exposure duration of 24 hours per day for 365 days per year. The ingestion rates for drinking water and soil for the general public were assumed to be 2 L/d for water, 100 mg/d of soil for adults, and 200 mg/d of soil for children. No building shielding effect was considered for inhalation and external radiation exposures. Therefore, radiation doses estimated in this way would be greater than the actual doses, which would always be associated with some shielding from buildings.

Site-specific agriculture data (yield per unit area) for food crops and fodder were used for the three cylinder storage sites (Oak Ridge National Laboratory 1995). When the location of the facility was not specified, the default agriculture data in the GENII and RESRAD computer codes were used. Default food consumption data from the two codes were also used, which were close to each other and would both result in conservative estimates of the ingestion doses. Nevertheless, in all the options examined, radiation doses from the food ingestion pathways constituted just a small fraction of the total dose, which is dominated (>95%) by doses from inhalation (for airborne pathways) or ingestion of drinking water (for waterborne pathways).

The GENII computer code incorporates an internal dosimetry model to estimate the committed effective doses from internal radiation, whereas the RESRAD code uses the EPA internal dose conversion factors (EPA 1988) to estimate internal doses. Previous benchmarking studies (Faillace et al. 1994) showed that the two methods resulted in approximately the same radiation doses under the same exposure conditions. The inhalation doses depend strongly on the solubilities of the inhaled chemicals. With high solubility, a chemical would be excreted from the human body within a shorter period of time and would result in less internal exposure. Except for UO_2F_2 and UF_4, which were assumed to be excreted from the human body within a few days and a few weeks, respectively (due to the high and moderate solubilities in water), all other uranium chemicals considered in this PEIS were assumed to remain in the human body for years, thus resulting in greater radiation exposures. The ingestion doses were estimated by assuming that the uranium compounds would be absorbed by the gastrointestinal tract to the largest extent possible for uranium compounds; this would result in the maximum internal exposure.

C.4.2 Accident Conditions

For the assessment of radiological impacts under accident conditions, an accident was defined as a series of unexpected or undesirable events leading to a release of radioactive or hazardous material within a facility or the general environment. Accident source terms were defined as the amounts of radioactive or hazardous materials released to the atmosphere from the primary container or confinement in dispersible forms. Accident scenarios, source terms, and frequencies for most component activities of the alternative management strategies are provided in the engineering analysis report (LLNL 1997). For continued cylinder storage at the current sites and long-term storage as UF_6 in yards, the accident information was obtained from the safety analysis reports for the three storage yards (Lockheed Martin Energy Systems, Inc. [LMES] 1997 a-c). The health impacts from depleted uranium compounds would be expected to be dominated by their chemical toxicity and not by their radiological effects. A lethal exposure from the chemical toxicity of uranium would occur with an internal radiation dose of about 1 rem, which is a dose not considered to have any significant radiation health effects.

C.4.2.1 Receptors

Radiation doses and health risk effects were calculated for noninvolved workers and the general public. Population doses were calculated up to a distance of 50 miles (80 km) from the release point. Except under the continued cylinder storage and cylinder preparation options, where actual locations of storage yards were used, all accidental releases were assumed to be at the centers of the representative or generic sites. Ten downwind distances and 16 wind directions were applied. Radiation doses were calculated for the following receptors for accident conditions:

- ***Noninvolved MEI Worker:*** A worker located on-site at the point of maximum air concentration for uranium compounds (but more than 330 ft [100 m] from the accident location).

- ***Noninvolved Worker Population:*** All workers on the site located more than 330 ft (100 m) from the accident location (including those workers in the facility where the accident occurred).

- ***Off-Site MEI:*** A hypothetical member of the general public living off-site and receiving the maximum exposure from accidental releases.

- ***General Population:*** General population within a 50-mile (80-km) radius of the site where the accident might occur.

During an accident, involved workers might be subject to severe physical and thermal (fire) forces and could be exposed to releases of chemicals and radiation. The risk to the involved workers is very sensitive to the specific circumstances of each accident and would depend on how rapidly the accident developed, the exact location and response of the workers, the direction and amount of the release, the physical and thermal forces causing or caused by the accident, meteorological conditions, and characteristics of the room or building if the accident occurred indoors. However, it is recognized that worker injuries and fatalities are possible from chemical, radiological, and physical forces if an accident did occur.

C.4.2.2 Radiological Doses and Health Risks

Radiological consequences were calculated in terms of total effective dose equivalent (TEDE) and LCF. The TEDE is the sum of the effective dose equivalent from external radiation and the 50-year committed effective dose equivalent from internal radiation. Radiation doses were expressed in units of rem for individuals and in units of person-rem for populations. The health risk conversion factors provided in ICRP Publication 60 (ICRP 1991) were used to calculate LCFs. These factors are 0.0004/rem for workers and 0.0005/rem for members of the general public. The conversion factor for the public is slightly higher than that for workers because some individuals in the public, such as infants, are more sensitive to radiation than the average worker. If these conversion factors are applied to the individual dose, the result is the individual increased lifetime probability of developing an LCF. If these factors are applied to collective (population) dose, the result is the number of excess LCFs.

C.4.2.3 Methodology

Radiation doses from atmospheric releases were evaluated by using the GENII computer code (Napier et al. 1988) developed at Pacific Northwest Laboratory. The code implements the internal dosimetry models recommended by the ICRP in Publication 26 (ICRP 1977) and Publication 30 (ICRP 1979). The GENII code considers the transport of radioactive material in air, soil, water, and food sources to the human body. To achieve consistency in the impact analysis among chemical and radiological releases, air concentrations per unit release were derived by using the HGSYSTEM (Post 1994a-b; Hanna et al. 1994) and FIREPLUME (Brown et al. 1997) models and used as input to GENII. The GENII code was used to develop baseline radiation doses from unit releases (release-to-dose conversion factors) to the various receptors. Accident consequences were then calculated by multiplying the dose conversion factors with the actual source terms for each accident.

Accident frequencies are categorized into four groups:

- I — Likely (L): Accidents estimated to occur one or more times in 100 years of facility operations (frequency $\geq 1 \times 10^{-2}$/yr).

- II — Unlikely (U): Accidents estimated to occur between once in 100 years and once in 10,000 years of facility operations (frequency = from 1×10^{-2}/yr to 1×10^{-4}/yr).

- III — Extremely Unlikely (EU): Accidents estimated to occur between once in 10,000 years and once in 1 million years of facility operations (frequency = from 1×10^{-4}/yr to 1×10^{-6}/yr).

- IV — Incredible (I): Accidents estimated to occur less than one time in 1 million years of facility operations (frequency $< 1 \times 10^{-6}$/yr).

The results of the accident impacts were summarized on the basis of these frequency categories. One accident was selected in each category. The chosen accident was the one that would result in the highest dose to the general public MEI; that accident was then the bounding accident (most conservative) in that frequency category. The probability of occurrence for an accident is indicated by its frequency category. For example, an accident that belongs to the extremely unlikely category has a probability of occurrence between 1 in 10,000 and 1 in 1 million in any 1 year. Therefore, the overall risk of an LCF to the receptors can be estimated by multiplying the LCF result by the probability of occurrence of the accident and by the number of years of operations.

C.4.2.4 Exposure Pathways

Atmospheric releases from accidents would result in radiation exposure to various receptors through the following pathways: (1) external exposure from immersion in the plume containing the airborne radioactive material (air submersion), a pathway considered in the dose calculations for all receptors; (2) external exposure from radioactive material deposited on the ground (ground irradiation or groundshine), a pathway included in the dose calculations for the off-site MEI and general population; (3) internal exposure from inhalation of radioactive airborne material in the plume (inhalation), a pathway considered in the dose calculations for all receptors; (4) internal exposure from inhalation of radioactive airborne material suspended in air due to wind action (inhalation), a pathway included in the dose calculations for the off-site MEI and general population; and (5) internal exposure from the ingestion of food crops and animal products (ingestion), a pathway included in the dose calculations for the off-site MEI and general population. The plume inhalation pathway was found to dominate other pathways, accounting for more than 99% of the dose.

C.4.2.5 Data Requirements

A variety of data were used in GENII for dose calculations. Unless different values were provided, the values used in the PEIS are listed in Table C.1.

C.5 CHEMICAL SOURCES AND EXPOSURES

The approach taken for addressing nonradiological human health and safety impacts is outlined below. The assessment included risk during normal facility operations, risk from accidental chemical releases, and risk of physical injury (industrial risk).

C.5.1 Normal Operations

This section describes the methodologies used for assessing chemical impacts on human health from normal operations of different facilities. Chemical impacts were assessed for different categories of options, which correspond to the different technologies developed in the engineering analysis report (LLNL 1997), as well as to continued cylinder storage.

C.5.1.1 Receptors

The assessment of health risks associated with chemical sources and exposures was consistent with the assessment of radiological risks, insofar as possible. The receptors evaluated included MEIs for noninvolved workers (i.e., those not involved in handling hazardous chemicals) and the general public. Because the standard methodologies for chemical health risk assessment do

TABLE C.1 Parameters and Values Used for Dose Calculations with the GENII Code

Parameter	Values Used in GENII Code
Inhalation	Chronic breathing rate = 1.2 m^3/h Acute breathing rate = 1.5 m^3/h Plume exposure time = 100% of plume duration Internal exposure period for dose calculation = 50 years
Air submersion	Immersion duration = 100% of plume duration
Ground irradiation	Exposure to contaminated soil = 1 year Building shielding factor = 0.3, which represents exposure of an individual to contaminated soil 8 hours per day or 2,920 hours per year
Ingestion	Ingestion takes place over a period of 1 year Internal exposure period for dose calculation = 50 years Ingestion of contaminated food = 100% of total consumption rates for the MEI and 10% of total consumption rates (30% for milk) for the general population Annual dietary consumption rates (kg/yr): Leafy vegetables = 18.3; Beef = 84.7 Root vegetables = 73.4; Poultry = 9.5 Fruits = 68.3; Milk = 111.7 Grain = 35.4; Egg = 15.0
Meteorology	For 95% meteorological conditions, Pasquill Class F, with a wind speed of 1 m/s in all directions For 50% meteorological conditions, Pasquill Class D, with a wind speed of 4 m/s in all directions
Other default data	Plume mixing layer height = 1,000 m Infinite plume and far-field release conditions Wet deposition = 0 Deposition velocity = 0.001 m/s for particulates, 0.01 m/s for iodines, and 0 for noble gases Soil density = 1.5 g/cm^3 Depth of surface soil available for resuspension = 10 cm Soil resuspension calculated in the code using the Anspaugh model Leaf resuspension factor = 1.0×10^{-9}/m
Site-specific data	Population distribution at each site Location of MEI at each site Meteorological data at each site Description of accident scenarios Release elevation (m) (ground release vs. stack release) for each accident Frequency of each accident

not usually involve assessment of collective (population) dose or risk, population risk was not generally evaluated for chemical exposures. However, if a health risk was shown to exist for the MEI in any of the receptor groups assessed, additional assessment of the likely number of individuals affected was evaluated.

Because of the conceptual nature of the facility designs, individual worker activities were highly uncertain, and process-specific chemical concentrations could not be accurately estimated. As a result, potential impacts to the involved worker MEI were not quantified for normal operations at the different facilities. However, potential exposures of involved workers to chemicals generated during the various processes would be addressed by proposed U.S. Occupational Safety and Health Administration (OSHA) permissible exposure limits (PELs) for soluble uranium compounds and for HF (29 CFR Part 1910, Subpart Z, as of March 1998). To maintain compliance with OSHA standards, it is likely that chemical exposures would be minimized by various engineering mitigative controls (e.g., fume hoods and glove boxes and heating, ventilating, and air conditioning [HVAC] designs for high hazard areas) and extensive indoor air monitoring.

C.5.1.2 Chemical Doses and Associated Health Effects

For normal operations, risks were expressed by using the hazard quotient concept for exposures to noncarcinogens (i.e., comparison of estimated receptor doses with reference levels or doses below which adverse effects would be very unlikely to occur). In general, the chemicals of concern for this PEIS were uranium and fluoride compounds, especially HF gas. These substances would not be chemical carcinogens, so cancer risk calculations were not applicable. The toxicity of the exposures for relevant receptors was estimated through comparison with oral and inhalation reference levels (levels below which adverse effects would be very unlikely to occur). The oral reference dose of 0.003 mg/kg-d was used for evaluating risks from ingestion of soluble uranium compounds; EPA derived this value based on a lowest-observed-adverse-effect level in rabbits of 3 mg/kg-d of uranyl nitrate hexahydrate combined with an uncertainty factor of 1,000 (Maynard and Hodge 1949; EPA 1998a). Because of conflicting results concerning absorption of insoluble uranium compounds such as U_3O_8 and UO_2 from the gastrointestinal tract, the oral reference dose of 0.003 mg/kg-d was also used in this analysis for calculating hazard quotients for these compounds. This assumption is conservative because the gastrointestinal tract would absorb a smaller amount of insoluble than soluble uranium compounds.

Inhalation reference concentrations for uranium compounds and hydrogen fluoride are not currently available from standard EPA sources. To assess potential risks from inhalation of these compounds, interim reference levels were developed from proposed OSHA PELs (29 CFR Part 1910, Subpart Z, as of March 1998). The 8-hour time-weighted-average PEL for soluble and insoluble uranium compounds is 0.05 mg/m^3; for HF it is 2.5 mg/m^3. These values were converted to assumed inhalation reference level values for noninvolved workers in mg/kg-d by assuming an inhalation rate of 20 m^3/day and a body weight of 70 kg, resulting in interim worker inhalation reference level values of 0.014 and 0.71 mg/kg-d for uranium compounds and hydrogen fluoride, respectively. To generate interim inhalation reference levels values for the general public, these worker values were adjusted to account for increased exposure duration of the general public (assumed 168 hours per week instead of 40 hours per week); an additional uncertainty factor of 10 was used to account for sensitive subpopulations in the general public. This results in interim inhalation reference levels for the general public of 0.0003 and 0.02 mg/kg-d for uranium compounds and hydrogen fluoride, respectively.

The reference levels used for preliminary evaluation of general public hazard quotients and carcinogenic risks from the existing environment at the three current storage sites (see Sections 3.1.7.2, 3.2.7.2 and 3.3.7.2) were obtained from the EPA's Integrated Risk Information System (IRIS) when available (EPA 1998a). The slope factor value used for trichloroethylene was obtained from the EPA's National Center for Environmental Assessment (Choudhury 1996). The derived reference concentration levels for uranium compounds and HF discussed above were used as reference levels for evaluating inhalation of these substances.

C.5.1.3 Exposure Pathways and Parameters

For the noninvolved worker MEI, chemical intakes and health risks from inhalation of uranium compounds and HF were assessed, provided that there were airborne emissions from the facility being evaluated. Incidental ingestion of uranium compounds deposited on soil was also assessed. For the general population MEI, intake of uranium compounds and HF was summed over all appropriate potential air-associated pathways (i.e., inhalation and incidental ingestion of contaminants deposited on soil). Soil-related pathways other than incidental ingestion would have been evaluated only if the predicted soil concentrations were high enough to indicate that intakes via the food chain would be significant. Data for uranium compounds generated for the radiological impact analyses by the GENII computer code were used to derive appropriate uranium concentration levels for the various environmental media. Air dispersion modeling for HF, as discussed in Section C.1, was used to obtain the air concentration of HF at the MEI location. Additional exposures for the MEI would include ingestion of contaminated water, for which uranium concentrations were provided through modeling of contaminant transport from effluent sources into surface waters and/or groundwater. Pathways involving the ingestion of plant foods, meat, and dairy products contaminated through the use of groundwater for irrigation were included when failure of engineering barriers and containers could result in the eventual leaching of uranium to groundwater.

Appropriate exposure factors for the various pathways evaluated can generally be obtained from EPA guidance documents. Generally, the worker MEI was assumed to be exposed for 8 hours per day, 250 days per year, for a period of 25 years. The MEI for the general public was assumed to be exposed for 24 hours per day, 365 days per year, for a period of 30 years. These exposure factors were modified as appropriate for various options and predicted exposure circumstances.

C.5.1.4 Exposure Modeling and Risk Evaluation

Media-specific concentrations of contaminants associated with the normal operation of facilities for the various options were modeled on the basis of effluent data provided in the engineering analysis report (LLNL 1997). For airborne pathways, these effluent amounts were modeled by using either the GENII computer code (see Section C.4.1.4) or the ISCST computer code (see Section C.1). Surface water and groundwater concentrations were obtained through water quality analyses (see Section C.2).

Modeled concentrations of contaminants in the various environmental media were used to estimate average daily intakes for the various receptors examined. The ratios of the daily intakes to appropriate reference dose levels were calculated to generate hazard quotients. Hazard quotients were summed for individual contaminants and across all appropriate exposure routes (e.g., inhalation, soil ingestion) to generate hazard indices for the noninvolved worker and general public MEIs for the various options. These hazard indices were compared with the reference hazard index of 1. A hazard index of less than 1 is interpreted to indicate that adverse noncancer effects are very unlikely; a hazard index of greater than 1 would indicate that adverse effects are possible for the MEI, and that further investigation of potential exposures and additivity of individual contaminant toxicity would be warranted.

When no adverse effects would be expected for the MEI of a given population (i.e., the hazard index is less than 1), then by definition no adverse effects would be expected in that population. Therefore, calculation of population risks is not applicable when MEI hazard indexes are less than 1.

C.5.2 Accident Conditions

C.5.2.1 Health Criteria

For the assessment of the impact of source terms from accidental releases in this PEIS, two primary potential health effects endpoints were evaluated: adverse effects and irreversible adverse effects. Evaluation of these two health endpoints was consistent with the accident evaluations typically conducted to assess industrial risks (American Industrial Hygiene Association [AIHA] 1996) and with the approach taken in the safety analysis reports (LMES 1997a-c) for the three sites. The selection of appropriate health criteria (e.g., intake levels or air concentrations) to represent these health effect endpoints for uranium compounds and for other chemicals of potential concern is discussed in the following subsections. It should be noted that human responses do not occur at precise exposure levels but can extend over a wide range of concentrations. The values used as guidelines for potential adverse effects and potential irreversible adverse effects in this PEIS should not be expected to protect everyone but should be applicable to most individuals in the general population. In all populations, there are hypersensitive individuals who will show adverse responses at exposure concentrations far below levels at which most individuals would normally respond (AIHA 1996). Alternatively, some individuals will show no adverse response even at exposure concentrations somewhat higher than the guideline levels.

On the basis of health criteria levels discussed below, the models described in Section C.5.2.2 were used to generate contours for the appropriate air concentration levels. The number of workers or the number of people from the general population projected to be inside each contour were the number of individuals tabulated as at risk for the health effect endpoint (e.g., potential irreversible adverse effects).

In addition to potential adverse effects and irreversible adverse effects, the number of fatalities from accidental chemical exposures was estimated to facilitate comparisons with radiological impacts. For exposures to uranium and HF, it was estimated that the number of fatalities occurring would be about 1% of the number of irreversible adverse effects (EPA 1993a; Policastro et al. 1997). Similarly, for exposure to ammonia, the number of fatalities was estimated to be about 2% of the number of irreversible adverse effects (Policastro et al. 1997).

C.5.2.1.1 Potential Irreversible Adverse Effects

Uranium. An intake of 30 mg of uranium was used as the health criterion for potential irreversible adverse effects for exposure to all forms of uranium evaluated in the PEIS. The background document for the U.S. Nuclear Regulatory Commission (NRC) regulations for the Certification of Gaseous Diffusion Plants (10 CFR 76) states that “in assessing the adequacy of protection of the public health and safety from potential accidents, the NRC will consider whether the potential consequences of a reasonable spectrum of postulated accident scenarios exceed 0.25 Sv (25 rem), or uranium intakes of 30 mg, taking into account the uncertainties associated with modeling and estimating such consequences” (NRC 1994). According to these regulations, the selection of the 30 mg uranium intake level as an evaluation guideline level for irreversible injury was based on information provided in Fisher et al. (1994). This intake level was also used as the evaluation guideline for the off-site public and for noninvolved workers in accident analysis for evaluation basis events (annual frequency between 0.01 and 10^{-6}) conducted for the safety analysis reports for the three sites (LMES 1997a-c).

In applying the 30 mg uranium intake to accident analysis for the many uranium compounds considered in this PEIS (i.e., UO_2F_2, UF_4, uranium metal, U_3O_8, and UO_2), the following parameters were accounted for: molecular weight, solubility, inhalation rate, and duration of predicted exposure. On the basis of an inhalation rate of 1.5 m^3/h as the ventilation rate during light exercise (ICRP 1994), and on appropriate adjustments to account for the percent uranium in each compound, air concentrations corresponding to an intake level of 30 mg were calculated for modeled exposure durations. For example, the air concentration of 26 mg/m^3 UO_2F_2 corresponding to a 30 mg uranium intake for a 60-minute exposure to UO_2F_2 would be calculated as follows:

$$\frac{30 \text{ mg uranium} \times 308/238 \text{ (molecular weight } UO_2F_2\text{/molecular weight uranium)}}{1.5 \text{ m}^3\text{/h} \times \text{modeled exposure duration (h)}}$$

Additionally, for the insoluble uranium compounds, an uptake factor was incorporated into the calculated air concentrations, based on ICRP guidance that 0.2% absorption be assumed for inhalation of less soluble uranium compounds that have biological half-lives of years (i.e., U_3O_8 and UO_2), as compared with 5% absorption for soluble and slightly soluble compounds such as UO_2F_2 and UF_4 (ICRP 1979).

Other Chemicals. Potential irreversible adverse effects were also assessed for exposure to other chemicals of concern with respect to accidental releases; these chemicals were HF, hydrochloric acid, ammonia, sulfuric acid, and nitric acid. Several of these substances would be used and/or transported only in dilute forms that would not result in potential for irreversible adverse effects if accidentally released (i.e., hydrochloric acid, sulfuric acid, and nitric acid). For HF and ammonia, levels corresponding to irreversible adverse effects for exposures of 1-hour duration were set at corresponding Emergency Response Planning Guideline 2 (ERPG-2) levels. The ERPG levels are developed for a variety of chemicals by the AIHA; ERPG-2 levels are defined as “the maximum airborne concentration below which it is believed nearly all individuals could be exposed for up to 1 hour without experiencing or developing irreversible or other serious health effects or symptoms that could impair their abilities to take protective action” (AIHA 1996). The ERPG-2 values are 20 parts per million (ppm) for HF and 200 ppm for ammonia; these values were used in the PEIS as evaluation guideline levels for potential for irreversible adverse effects for modeled exposure durations of 60 minutes.

The guideline exposure level of 20 ppm used to estimate irreversible adverse effects from HF exposure is likely to result in overestimates. This is because no deaths have been known to occur as a result of acute exposures (i.e., 1 hour or less) of animals or humans at concentrations of less than 50 ppm (AIHA 1988), and generally, if death does not occur quickly after HF exposure, recovery is complete (McGuire 1991).

The chemicals evaluated exhibit irritant characteristics; the toxicity of these substances is generally not linearly proportional to the intake amount. For example, the toxic effect of exposure to 32 mg/m^3 HF for 30 minutes would actually be greater than the toxic effect of exposure to 16 mg/m^3 HF for 60 minutes, because the irritant action of the HF is greater at higher air concentrations. Data on the appropriate adjustments of HF concentrations for evaluation of shorter exposure times are presented and discussed in various documents dealing with the toxicity of uranium hexafluoride (Fisher et al. 1994; McGuire 1991). On the basis of these data, for modeled exposure durations of between 5 and 60 minutes, the air concentrations of HF and ammonia corresponding to the ERPG-2 value were calculated from:

$$C = C_{ERPG\text{-}2}(60/t)^{0.5}$$

where:

C = adjusted exposure guideline value and

t = modeled exposure duration (min).

It was conservatively assumed that the 5-minute adjusted exposure guideline value would be applied even for modeled exposure durations of less than 5 minutes.

C.5.2.1.2 Potential Adverse Effects

Uranium. An intake of 10 mg of uranium was used as the health criterion for potential adverse effects for exposure to all forms of uranium evaluated in the PEIS. This value was based on conclusions stated in NUREG-1391 (McGuire 1991) that "an intake level of soluble uranium with no significant detectable health effects, transient or permanent, appears to be about 10 mg in round numbers." This level was also used as the evaluation guideline for the off-site public and noninvolved workers for accident analysis of anticipated events (annual frequency between 0.1 and 0.01) conducted for the safety analysis reports for the three sites (LMES 1997a-c).

Adjustment of the 10-mg intake level for the various uranium compounds and modeled exposure durations was conducted in the same manner as for evaluation of irreversible adverse effects (see Section C.5.2.1.1).

Other Chemicals. Potential adverse effects were assessed for exposure to HF and ammonia by using ERPG-1 levels. ERPG-1 levels are defined as "the maximum airborne concentration below which it is believed nearly all individuals could be exposed for up to 1 hour without experiencing or developing any but mild transient adverse health effects or perceiving a clearly defined objectionable odor" (AIHA 1996). The ERPG-1 value is 1.6 mg/m^3 for HF and 25 ppm for ammonia; these values were used in the PEIS as evaluation guideline levels for potential adverse effects for modeled exposure durations of 60 minutes. Scaling of these values for modeled exposure durations of less than 60 minutes was conducted in the same manner as for evaluation of irreversible adverse effects (see Section C.5.2.1.1). As for irreversible adverse effects, it was conservatively assumed that the 5-minute adjusted exposure guideline value would be applied even for modeled exposure durations of less than 5 minutes.

C.5.2.2 Methods and Models

Accident scenarios, source terms, and frequencies for most component activities of the alternative management strategies were provided in the engineering analysis report (LLNL 1997). For continued cylinder storage at the current sites and long-term storage as UF_6 in yards, this accident information was obtained from the safety analysis reports for the three storage yards (LMES 1997a-c). For options considered under each activity, the reference document(s) provided the hypothetical accident, as well as the release amount as a function of time and duration of release and any special characteristics of the accidents. Accidents may be due to natural phenomena (earthquakes, tornadoes, etc.) or due to process accidents or temporary storage facility accidents at the various facilities. The chemical accidents often include fires and involve such chemicals as depleted UF_6 (liquid or solid form), and its degradation products UO_2F_2 and HF, uranium oxides, or the metallic form of uranium. The chemicals identified for accident scenarios depend upon the specific options chosen (e.g., conversion, disposal).

Although all accident scenarios presented in the engineering analysis report for the various options were evaluated and consequences and impacts predicted, only those scenarios necessary to fully represent the range of potential consequences were quantitatively assessed in the PEIS. The following models were used to estimate downwind dispersion through air of releases of chemicals:

- HGSYSTEM (Post 1994a-b) for HF releases and releases of uranium compounds,
- HGSYSTEM/UF_6 model (Hanna et al. 1994) for UF_6 vapor releases, and
- FIREPLUME model (Brown et al. 1997) for releases from toxic fires of UF_6 and other chemicals.

Detailed descriptions of these models are provided in Policastro et al. (1997). Except for the tornado accident scenario, two meteorological conditions were assumed: D stability with 4 m/s wind speed and F stability with 1 m/s wind speed. Both sets of assumptions were evaluated, and the results are presented in this PEIS.

C.5.2.3 Receptors

For each accident, the impacts on noninvolved workers and the general population were estimated. No quantitative predictions of impacts were made for involved workers (see Section C.4.2.1).

Noninvolved workers were considered to be at risk for a given health endpoint if they were located within the plume contour (based on ERPG level or uranium intake level) for the wind direction that would lead to the largest worker count. Workers were assumed to be in the locations where they work and for conservatism, the protection provided by the building structure was not included. This computation involved the overlay of the plume contour from the source point and the rotation of the plume 30 to 100 times to identify the direction with the highest worker count. That count was reported in the impact evaluation.

Individuals in the general population were also considered to be at risk if they were located within the plume contour. For the wind direction that would lead to the largest general population count, a separate overlay was done for the predicted plume to determine maximum population affected for the human health endpoint for that accident. As usually was the case, the direction leading to the maximum worker count did not necessarily match the direction for the maximum general population count. The adverse effects and irreversible adverse effects contours were predicted for each accident, with the adverse effects contour the larger of the two. For UF_6 releases, both the UO_2F_2 contour and the HF contour were predicted for both adverse effects and irreversible adverse effects levels; in general, the HF contours were larger than the uranium contours and led to larger population risks.

The MEI worker was assumed to be located 100 m from the accident location. The MEI for the general population was assumed to be located at the nearest fence line position, although there are currently no residences at these locations at the three current storage sites. Impacts for MEIs are presented as “yes” or “no,” depending upon whether the air concentrations of chemicals greater than or equal to corresponding adverse effects and irreversible adverse effects were modeled at the MEI locations.

C.5.2.4 Data Requirements

General data used in the accident predictions included the following:

- Estimate of the frequency of the accident per year,
- Release amounts (time history) and quantities for each chemical released,
- Number of workers on site and population off-site by direction, and
- Relative locations of source and receptors for both workers and members of the general public.

In the fire accident scenarios, the release quantities were presented as a function of time for the three phases of the release: puff, fire release, and cooldown. Fire and vapor temperatures were available as well for predictions.

C.5.3 Physical Hazards

The expected number of worker fatalities and injuries associated with each option was calculated based on statistics available from the Bureau of Labor Statistics, as reported by the National Safety Council (1995), and on estimates of total worker hours required for construction and operational activities for each option, as given in the engineering analysis report (LLNL 1997).

Construction and manufacturing annual fatality and injury rates were used for the construction and operational phases of each option. For injuries, rates for 1993 were used because 1994 rates were not yet available; for fatalities, estimated rates for 1994 were used. The use of data from two years should not result in incompatible data, since fatality rates in the applicable industry divisions were identical for 1993 and 1994. Injury incidence rates used were for injuries involving lost workdays (not including the day of injury).

The specific rates used in calculations for each option were as follows: fatalities during construction, 15 per 100,000 workers; fatalities during operations, 4 per 100,000 workers; injuries during construction, 5.5 per 100 full-time workers; injuries during operations, 5.3 per 100 full-time workers.

Fatality and injury risks were calculated as the product of the appropriate incidence rate (given above), the number of years for construction and operations, and the number of full-time equivalent employees for construction and operations for each option. The employment data reported in the engineering analysis report (LLNL 1997) were used to calculate option-specific risks. For construction, the data were generally reported in the engineering analysis report as peak and average employment for each year of construction (construction periods ranged from 4 to 20 years); the average number of employees for the peak construction year was used in risk calculations. For the operations phase, the fatality and injury rates were computed for all facility employees for each option (no distinction was made between involved and noninvolved workers). The available fatality and injury statistics by industry are not refined enough to warrant analysis of involved and noninvolved workers as separate classes.

The calculation of risks of fatality and injury from industrial accidents was based solely on historical industrywide statistics and therefore did not consider a threshold (i.e., any activity would result in some estimated risk of fatality and injury). Whatever alternative was implemented would be accompanied by best management practices, thereby reducing fatality and injury incidence rates.

C.6 SOCIOECONOMICS

C.6.1 Scope of the Analysis

Analysis of the socioeconomic impacts of the depleted UF_6 management options included assessment of the construction and operations impacts of continued storage, cylinder preparation, conversion, manufacture and use, long-term storage, and disposal. For continued storage and cylinder preparation, site-specific impacts were estimated by using the regions of influence (ROIs) surrounding the Paducah, Portsmouth, and K-25 sites. For conversion and long-term storage options (except long-term storage in mines), the ROIs surrounding the three current storage sites were also used as representative of locations where these types of facilities might be located in the future. For site-specific and representative site impacts, the analysis estimated the impacts of each option on (1) regional economic activity, including direct (on-site) and indirect (off-site) employment and income, (2) population in-migration, (3) local housing markets, and (4) local jurisdictional revenues and expenditures. The analyses for the manufacture and use, long-term storage in mines, and disposal options assumed generic, nonspecific sites for the required activities, although it was assumed that disposal would occur in a rural environment, whereas manufacture and use could occur in a range of population densities, from rural to urban. For the generic sites, the analysis was limited to estimating the impacts of each option on direct (on-site) employment and income. Additional details on the analysis of socioeconomic impacts is provided in Allison and Folga (1997).

Assessment of the socioeconomic impacts for transportation of depleted UF_6 was not included in the PEIS analysis. The transportation of depleted UF_6 would not be likely to lead to significant en route socioeconomic impacts because total expenditures for transportation related to depleted UF_6 would probably be small compared with expenditures related to total shipments of all other goods for any of the routes that might be used. The analysis might also have considered the socioeconomic impacts of potential accidents, particularly for depleted UF_6-related transportation activities. However, because it is unlikely that any potential accident would release large quantities of hazardous or radioactive material into the environment, accidents would be expected to create only minor local economic disruption, and substantial commitment of fiscal resources for accident remediation is unlikely to be necessary at any of the current storage sites or along transportation routes.

C.6.2 Technical Approach for the Analysis of Site-Specific and Representative Site Impacts

C.6.2.1 Regional Economic Impacts

The analysis of regional economic impacts used engineering cost data for facilities that would be constructed and operated for each option and input-output economic data for the ROI surrounding each storage site. The ROI at each site was defined as the counties in which 90% of site employees currently reside (see Chapter 3, Sections 3.1.8, 3.2.8, and 3.3.8). Additional data taken from data files of the U.S. Bureau of the Census (1994) and from regional economic information system data files of the U.S. Bureau of Economic Analysis (BEA) (1996a-c) were also used to forecast economic data at each site to provide the basis for the presentation of relative impacts.

To perform the analysis, engineering cost data for the construction and operation of each facility were taken from the cost data obtained from LLNL (1996). This report specifies cost and schedule data for the appropriate work breakdown structure elements, including the cost of materials, direct labor (installation) costs, and indirect labor (contractor field costs, contractor overhead and profit, architecture and engineering, construction management, and program management) costs.

Direct (on-site) employment and income impacts were then calculated on the basis of average total labor costs (i.e., fully loaded labor costs, including site overhead, contractor profit, and employee benefits) in each category. Estimates of direct income impacts were calculated by adjusting average fully loaded labor costs to exclude the various components of site overhead, state and federal income taxes, and other payroll deductions. This process produces a measure of disposable wage and salary income that would likely be spent in the regional economy at each of the sites.

Indirect (off-site) impacts were based on detailed item-specific procurement data for material and adjusted direct and indirect labor costs. Cost information was associated with the relevant Standard Industrial Classification (SIC) codes and construction and operation schedule information to provide estimates of procurement and wage and salary expenditures for each sector in the local economy for the year in which expenditures would be made. Information on the expected pattern of local and nonlocal procurement for the various materials and labor expenditures by SIC code were then calculated on the basis of local shares of national employment in each material and labor procurement category and information provided for each site. Expenditures by SIC code by year occurring in the ROI at each site were then mapped into the BEA sectors used in an IMPLAN input-output model (Minnesota IMPLAN Group, Inc. 1994) specified for the ROI at each site (see Section C.6.2.2). Each model was used to produce employment and income multipliers for each sector where procurement and labor expenditures occur. Indirect impacts were then calculated by multiplying expenditures in each sector by the input-output multipliers produced by the model for the ROI at each site.

Site-specific and representative site impacts are presented in terms of (1) the direct, indirect, and total employment impacts of each option; (2) the direct and total income impacts of each option; and (3) the relative employment impact of each option, or the magnitude of the absolute impact compared to the growth in the local economic employment baseline. Construction impacts for each option are presented for the peak construction year. Operations impacts are generally presented as annual averages, except for continued cylinder storage, for which peak operation year values are presented.

C.6.2.2 Description of the Regional Economic Impact Assessment Model

The analysis used county-level IMPLAN input-output economic data (Minnesota IMPLAN Group, Inc. 1994) to measure the regional economic impacts for the three representative sites for applicable options. The IMPLAN input-output model is a microcomputer-based program that allows construction of input-output models for counties or combinations of counties for any location in the United States. Input-output data are the economic accounts of any given region and show the flow of commodities to industries from producers and institutional consumers. The accounts also show consumption activities by workers, owners of capital, and imports from outside the region. The model contains 528 sectors, representing industries in agriculture, mining, construction, manufacturing, wholesale and retail trade, utilities, finance, insurance and real estate, and consumer and business services. The model also includes information for each sector on employee compensation; proprietary and property income; personal consumption expenditure; federal, state, and local expenditure; inventory and capital formation; and imports and exports. The model can be used to produce accurate estimates of the impact of changes in expenditures in specific local activities on employment and income in any given year. The analysis of regional economic impacts uses the model to calculate multipliers for each sector in the ROI at each site for which procurement and wage and salary expenditures would be likely to occur. These multipliers were calculated for the year 1993, the latest year available at the time the analysis was undertaken.

C.6.2.3 Impacts on Population

Construction and operation of continued storage, cylinder preparation, and long-term storage options would likely lead to population in-migration into the ROI surrounding each of the representative sites. In-migration would be both direct, related to new employment created on site, and indirect, related to changes in employment opportunities in the ROI as a whole. The number of direct employees in-migrating to each site was based on information on employment in existing DOE programs and on the level of contractor support at each site. Indirect in-migration that would occur for each ROI was calculated by using assumed in-migration rates at each site associated with changes in employment in the local industries most significantly affected indirectly by construction and operation expenditures for each option, with residual in-migration rates assumed for the remaining industries in the economy indirectly affected. Population impacts are presented in terms of (1) the absolute total (direct and indirect) in-migration impact of each option and (2) the relative population impact of each option, or the magnitude of the absolute impact compared to the growth in the local economic population baseline.

C.6.2.4 Impacts on Local Housing Markets

In-migration occurring with construction and operation at each facility has the potential to affect the local housing market in the ROI at the representative sites for each option. The analysis considered these impacts by estimating the increase in demand for housing units in each year of construction and operation based on the number of in-migrating workers to the area surrounding each of the representative sites and average household size. The results were compared to forecasts for housing supply and demand and owner-occupied and rental vacancy rates, for each year during construction and operation, based on information provided by the U.S. Bureau of the Census (1994) and in regional economic forecasts (BEA 1996a-c).

C.6.2.5 Impacts on Local Jurisdictions

Construction and operation of each facility would likely lead to some in-migration into the area surrounding each site, which would translate into changes in demand for educational services provided by school districts and for public services (police, fire protection, health services, etc.) provided by cities and counties. To assess the impacts on local jurisdictions, in-migration estimates (see Section C.6.2.3) were used as the basis for estimating impacts of revenues and expenditures for the various counties, cities, and school districts in each ROI. Revenue and expenditure data were based on the annual comprehensive financial reports produced by individual jurisdictions surrounding each site and on information provided by the U.S. Bureau of the Census (1994). Impacts are presented in terms of percentage change in forecasted revenues and expenditures for counties, cities, and school districts in the peak year of construction and in the first year of operations for each facility.

C.6.3 Technical Approach for the Analysis of Generic Site Impacts

The analysis of the socioeconomic impacts of the long-term storage in mines, manufacture and use, and disposal options was limited to the calculation of direct (on-site) employment and income impacts. No indirect impacts were calculated because the sites for these facilities have not been determined. The calculation of direct impacts was based on similar engineering cost information provided by LLNL (1996, 1997) for each facility and used the same methods as described in Section 6.2.2. The impacts of long-term storage in mines, manufacture and use, and disposal are presented in terms of the absolute direct impacts of each option at the generic site. No relative impacts were calculated because the site for these options has not been determined. For the same reason, estimates of population in-migration, local housing market impacts, and impacts on local jurisdiction revenues and expenditures are not provided.

C.7 LAND USE

The assessment of potential land-use impacts for the continued storage, cylinder preparation, conversion, manufacturing and use, long-term storage, and disposal options was based on a determination of areal requirements and incompatibility. Where appropriate, the amount of land that would be required under each option was calculated as a percentage of existing or available land at the three representative sites. The potential for program options to result in land conversion, land-use conflicts, or incompatibility with existing site planning documents or controls was explored.

Conversion refers to the potential of an action to convert land from one type of use to another (e.g., from agricultural to commercial). The potential for program options to result in impacts to surrounding land use is discussed qualitatively and includes an examination of potential level-of-service traffic impacts. Levels of service are defined by the Transportation Research Board (1994) and describe service characteristics and thresholds of congestion for highways.

For purposes of analysis in this PEIS, general criteria for estimation of impacts were as follows: land-use requirement of less than 50 acres corresponds to negligible impacts, land-use requirement of between 50 and 200 acres corresponds to potential moderate impacts, and land-use requirement of greater than 200 acres corresponds to potential large impacts. The actual potential for land conversion in conflict with existing land-use plans and controls and/or traffic flow problems will be determined during the Phase II analyses and NEPA reviews. Potential impacts to prime farmland will also be assessed in the site-specific tier of NEPA documentation that will accompany facility site selection.

No land-use impacts beyond respective site boundaries would be expected from the off-site transport aspect of the various management options under consideration. Any commitment of land at existing facilities that would be necessary for the off-site transport of UF_6, oxide, or uranium by-products is expected to be so small that no impacts would result.

C.8 ENVIRONMENTAL JUSTICE

C.8.1 Background

Executive Order 12898, "Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations," was issued by President Clinton in February of 1994 and directs federal agencies to incorporate environmental justice into all agency missions (U.S. President 1994). Under Executive Order 12898, federal agencies are directed to identify and address, as appropriate, high and adverse human health or environmental effects caused by agency programs, policies, or actions that disproportionately impact minority or low-income populations. Environmental justice refers to the equal and fair application of all environmental laws, regulations, and policies to all races, cultures, and income levels. The goal of the Executive Order is to ensure that no federal agency program, policy, or action results in impacts that affect minority or low-income populations to a greater degree than would be expected for the general population.

Executive Order 12898 directed the Administrator of the U.S. Environmental Protection Agency to establish an interagency working group (called the Federal Working Group on Environmental Justice) to develop criteria for identifying disproportionately high and adverse human health or environmental effects and to assist every federal agency in developing an environmental justice strategy. The Working Group, in coordination with the Council on Environmental Quality, has issued definitions to describe disproportionately high and adverse human health effects and disproportionately high and adverse environmental impacts as they apply to NEPA (Council on Environmental Quality 1997). DOE has also issued interim guidance for implementation of the Executive Order (DOE 1995e), and EPA has issued guidance for incorporating environmental justice concerns in EPA's NEPA activities (EPA 1998b).

C.8.2 Methodology

A determination of the potential for a given project or action to result in environmental justice impacts requires (1) an examination of the composition of the population residing within a defined zone of impact and (2) the existence of high and adverse human health effects or impacts resulting from the project or action under analysis. The potential for a given project or action to unfairly or "disproportionately" affect a particular segment of the affected population can only be determined after the minority and low-income populations that make up all or a portion of the affected population have been defined and identified. Once these populations have been defined and identified, high and adverse human health effects, if any, can be examined in the context of their likelihood to disproportionately affect minority or low-income populations.

The analysis of potential environmental justice impacts was limited to site-specific options because such an analysis requires an examination of the composition of a specific local population. Surrogate populations cannot be substituted for facilities that have not been specifically sited or located.

C.8.2.1 Definitions

The following definitions were used in the analysis of potential environmental justice impacts and were derived from the U.S. Census Bureau and the Working Group's definitions:

- ***Census Tract*** **—** An area usually containing between 2,500 and 8,000 persons that is used for organizing and monitoring census data. The spatial dimensions of census tracts vary widely, depending on population settlement density. Census tracts do not cross county borders.

- ***Disproportionately High and Adverse Environmental Impact*** — A deleterious environmental impact determined to be unacceptable or above generally accepted norms. A disproportionately high impact refers to an environmental hazard with a risk or rate of exposure for a low-income or minority population that exceeds the risk or rate of exposure for the general population.

- ***Disproportionately High and Adverse Human Health Effects* —** Any human health effect from exposure to environmental hazards that exceeds generally accepted levels of risk and affects low-income and minority populations at a rate that appreciably exceeds the rate for the general population. Adverse health effects were measured in risks and rates that could result in LCFs as well as nonfatal adverse impacts to human health.

- ***Low-Income Population* —** Persons of low-income status. Low-income status was based on U.S. Census Bureau data definitions of individuals living below the poverty line. The poverty line is defined by a statistical threshold that considers family size and income. For 1990, the poverty line threshold for a family unit consisting of four individuals was $12,674 (based on 1989 income). For purposes of this analysis, low-income population consists of any census tract located within a 50-mile (80-km) radius of a storage site that has a low-income population proportion greater than the respective state average.

- ***Minority Population* —** Persons classified by the U.S. Bureau of the Census as Negro/Black/African-American, Hispanic, Asian and Pacific Islander, American Indian, Eskimo, Aleut, or other nonwhite, based on self-classification by individuals according to the race with which they most closely identify. To avoid double-counting minority Hispanic persons (Hispanics can be of any race), only white Hispanics were included in the tabulation of minorities. Nonwhite Hispanics had already been counted under their respective minority classification (Black, American Indian, etc.). For purposes of this analysis, a minority population consists of any census tract located within a 50-mile (80-km) radius of a storage site that has a minority population proportion greater than the respective state average.

C.8.2.2 Identification and Illustration of Minority and Low-Income Populations

Demographic information obtained from the U.S. Bureau of the Census was used to profile the population residing within a 50-mile (80-km) radius of each current storage site. A 50-mile (80-km) radius was selected because it would capture virtually all of the human health risks and environmental impacts that could potentially occur. For each current storage site, a geographic information system based on 1990 Census Bureau *Tiger Line Files* and Summary Tape Files 1 and 3A was utilized to generate maps illustrating minority and low-income populations residing within the 50-mile (80-km) zone of impact surrounding each site (U.S. Bureau of the Census 1992a-c).

The unit of analysis was the census tract. For those census tracts only partially located inside a 50-mile (80-km) radius of a given site, an even population distribution was assumed, and the population was calculated as a proportion of the tract area physically located within the 50-mile (80-km) radius (i.e., if 50% of the census area was inside of the 50-mile (80-km) radius, then 50%

of its population was counted). The maps are presented as Figures C.1 through C.3 and depict the distribution of minority and low-income census tracts within a 50-mile (80-km) radius of each site. Information regarding the proportion of the total population residing within 50 miles (80 km) of each site that is minority or low-income accompanies each figure.

For each current storage site, the proportion thresholds for determining the low-income and/or minority status of a census tract were based on the proportion of low-income and minority populations residing within the state where the storage site was located. If the 50-mile (80-km) radius around a particular current storage site included a portion of another state or states, a weighted average based on all the affected state low-income and minority population proportions was assigned. Other reference threshold proportions were considered (i.e., national, multistate regional), but state population proportions were chosen because they tend to present a more accurate portrayal of the affected population.

C.8.2.3 Impact Approach

The analysis of potential environmental justice impacts resulting from continued storage and cylinder preparation was based on the conclusions drawn in the risk assessment of human health effects (radiological and chemical) and a review of environmental impacts presented in discussions of other technical areas such as air quality, water quality and soils, socioeconomics, and ecological resources. The analysis of health effects included an examination of risks to the off-site population associated with normal facility operations and accidents. On-site worker populations were not included in the analysis because minority population proportion information for each site was not available and low-income status for workers, regardless of site, could not be determined. If conclusions drawn in the health risk assessment indicated negligible or low risks to the general population residing within a 50-mile (80-km) radius of any of the three storage sites, then no particular subset of the general population, including minorities and low-income persons, was assumed to experience high and adverse health effects. Consequently, no disproportionate impacts (i.e., environmental justice impacts) would occur. Likewise, if the review of environmental impacts across the other technical areas indicated that impacts were negligible or low within a 50-mile (80-km) radius of a particular site, then no environmental justice impacts would result because the potential for high and adverse impacts to disproportionately affect minority or low-income populations would be essentially removed.

An assessment of human health risks for persons or population groups residing within 50 miles (80 km) of a storage site who rely on local plants or animals for a portion of their food supply was not included in this analysis. A comprehensive analysis that includes an evaluation of an affected population’s dietary and consumption habits would be considered in the site-specific tier of NEPA documentation that would follow a Depleted Uranium Hexafluoride Management Program decision.

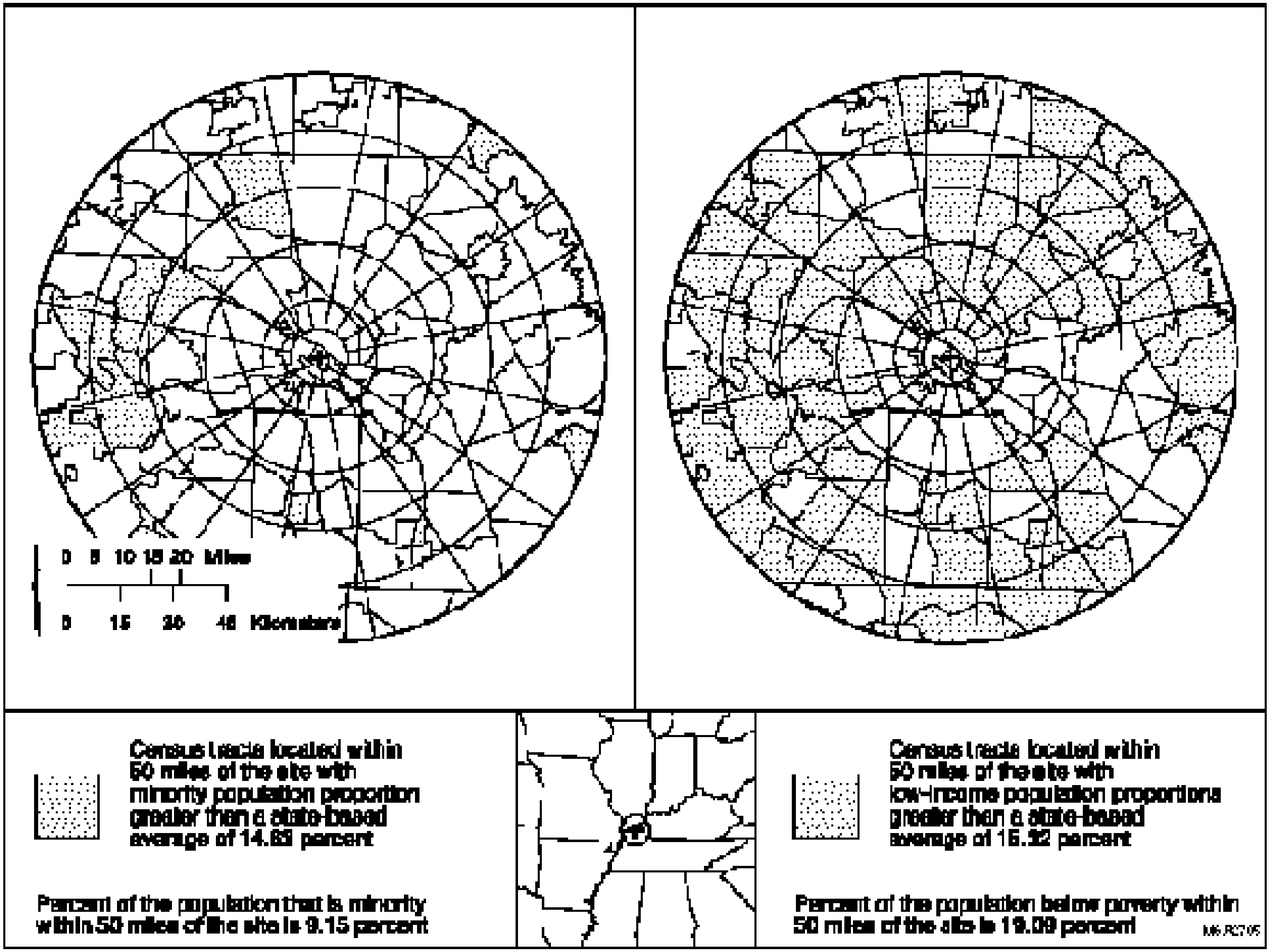

FIGURE C.1 Distribution of Minority and Low-Income Census Tracts within a 50-Mile Radius of the Paducah Site

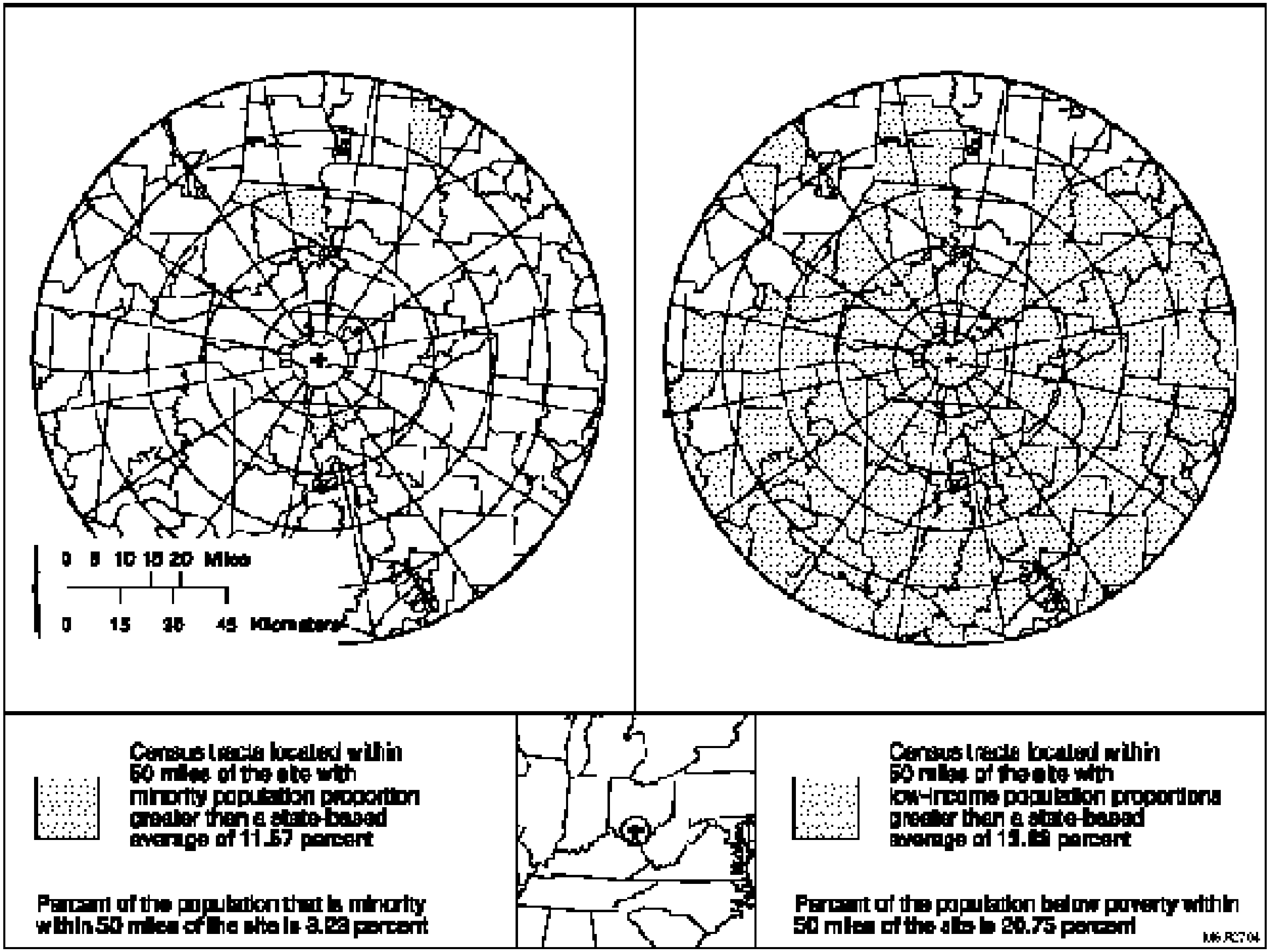

FIGURE C.2 Distribution of Minority and Low-Income Census Tracts within a 50-Mile Radius of the Portsmouth Site

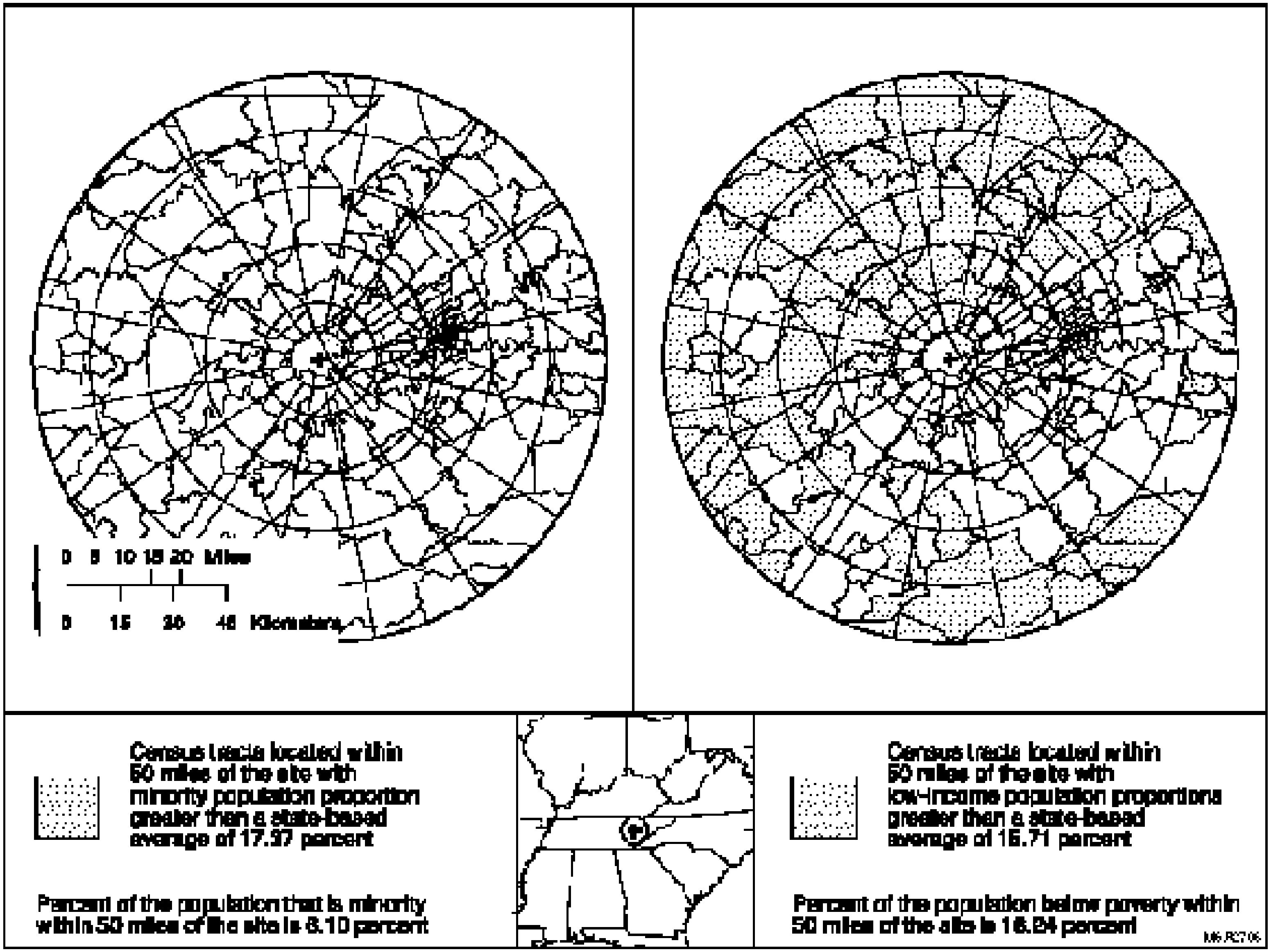

FIGURE C.3 Distribution of Minority and Low-Income Census Tracts within a 50-Mile Radius of the K-25 Site

An assessment of potential environmental justice impacts resulting from transportation accidents was not conducted for this analysis. Although environmental justice impacts could occur within a given transportation corridor following an accident, a site-specific (i.e., corridor-specific) demographic analysis cannot be conducted because the transportation analysis did not predict the location of accidents, and because it is impossible to predict reliably who will be involved in transportation accidents. There is no reason to believe that impacts of transportation accidents will affect minority or low-income populations disproportionately.

C.8.2.3.1 Screening Criteria

To evaluate the potential for continued storage to result in disproportionate impacts to minority and low-income populations, screening criteria based on the assessment of radiological and chemical risks were used to determine what sites, if any, would require further analysis. These criteria included:

- A dose to the general public MEI exceeding 100 mrem/yr under normal operations.
- An expected LCF equal to or greater than 1 from radioactive sources under accident conditions.
- A hazard index for the MEI equal to or greater than 1 from chemical sources under normal operations.
- An expected incidence of irreversible adverse effects equal to or greater than 1 from accidental chemical releases, when accident frequency categories and duration of operations were considered.

In assessing accident risks, the consequence of an accident must be considered as a function of the expected frequency of the accident. For example, if a particular accidental chemical release was projected to result in 100 fatalities but was expected to occur only once in 10,000 years (also expressed as 1×10^{-4} per year), then expected annual fatalities could be calculated by multiplying the consequence (100 fatalities) of the accident by the expected accident frequency (1×10^{-4} per year), which yields 0.01 expected fatalities per year from the particular accident analyzed. The PEIS assessment of human health risk categorizes accident frequencies according to the likelihood of occurrence. A discussion of risk conversion factors, accident consequences, and frequency categories is presented in Chapter 4.

The hazard index for the MEI (see Appendix D, Table D.5) was used to determine health effects from chemical sources under normal operations. This methodology is discussed in greater detail in Section C.5.

To determine expected LCFs from radiological source accidents, the LCF risk for the general public (see Appendix D, Table D.8) was multiplied by the frequency category value of the worst accident scenarios to determine maximum effects. For purposes of this analysis, the midrange value of the frequency category under consideration was used (i.e., 10^{-5} for the frequency category that is defined by a range of 10^{-4} to 10^{-6}).

The expected incidence of irreversible adverse effects from accidental chemical releases was determined by multiplying the number of persons projected to be affected under the worst accidental release scenario by the midrange value of the appropriate frequency category value, and then multiplying that total by the number of years under consideration. Although the depleted UF_6 PEIS risk assessment projected possible radiological and chemical human health effects from disposal beyond the year 2039, such effects could not be included in the analysis of potential environmental justice impacts because the composition of the population residing within 50 miles (80 km) of a site cannot be projected with accuracy beyond the year 2040. Current minority and low-income population proportions for each site were assumed to the year 2039.

C.8.2.3.2 Demographic Analysis

If projected human health effects exceeded screening criteria limits at any of the three sites, a demographic analysis would be conducted. For radiological impacts from normal operations, the 50-mile (80-km) radius surrounding each site would be divided into sectors and blocks for a higher resolution examination. A grid consisting of pie-shaped sectors (see Figures C.1 through C.3) positioned 360E around the centroid of the storage yards and six concentric circles (with interval sizes of 5 and 10 miles [8 and 16 km]) radiating outward would be used to break the 50-mile (80-km) zone of impact surrounding each site into sectors and blocks. A block consists of the portion of a preshaped sector bounded by (or located between) two concentric circles.

If the dose to the general public MEI from radiological sources under normal operations equaled or exceeded 100 mrem/yr, a block dose value would be assigned to each census tract in the affected sector block or blocks. A comparative analysis of the tracts receiving the highest doses (upper 10%) would be conducted to determine the proportion of tracts that were minority or low-income. If the proportion of minority or low-income tracts in the upper 10% was higher than the proportion of minority or low-income tracts inside the 50-mile (80-km) zone of impact surrounding an affected site, then an environmental justice impact would be declared.

For chemical releases associated with routine operations that resulted in a hazard index equal to or greater than 1 for the MEI, the block containing the MEI would be examined for population composition. If the MEI block was composed of minority or low-income census tracts, then a declaration of potential disproportionate health impacts would be included in the impact discussion for the appropriate site. In cases where the MEI block would contain more than one census tract, the tract closest to the site would be used to determine potential disproportionality.

If screening criteria were exceeded for radiological and chemical accident releases, a population composition analysis would be conducted for census tracts in all sectors and blocks within a 5-mile (8-km) radius of the release source. A 5-mile (8-km) limit was chosen because release plume analysis indicated that at least 95% of the effects from accidental releases would occur within 5 miles (8 km) of the release point. Although an accidental release would have the greatest potential to affect persons residing in sectors and blocks located downwind from the release, a 5-mile (8-km) radius provides a conservative means to estimate potential disproportionate effects, regardless of wind direction at the time of release. If the proportion of minority or low-income census tracts located within a 5-mile (8-km) radius of release points was higher than the proportion for the entire 50-mile (80-km) zone of impact surrounding the site, then a declaration of potential disproportionate health impacts would be included in the impact discussion for the affected site.

C.9 TRANSPORTATION

The technical approach for conducting the transportation risk assessment was developed following an extensive review of the literature and existing NEPA documentation for federal actions involving transportation of radioactive materials. The transportation risk assessment approach for the PEIS is consistent with the approach developed to support the WM PEIS (DOE 1997). Recently, the same approach was also applied in the *Department of Energy Programmatic Spent Nuclear Fuel Management and Idaho National Engineering Laboratory Environmental Restoration and Waste Management Programs Final Environmental Impact Statement* (INEL EIS; DOE 1995a) and in the *Final Environmental Impact Statement on a Proposed Nuclear Weapons Nonproliferation Policy Concerning Foreign Research Reactor Spent Nuclear Fuel* (DOE 1996a). The basic assessment approach has been previously reviewed by DOE and by representatives of DOE, including a transportation technical review group whose mission was to evaluate available analytical methods for the INEL EIS. The review group included technical representatives of Argonne National Laboratory; Bettis Atomic Power Laboratory (Naval Reactors); and Savannah River Site, Hanford Site, and Science Applications International Corporation-Idaho (preparers of the INEL EIS). In addition, comments on the approach were also solicited from the NRC for the WM PEIS. The approach is described below.

The approach for the hazardous chemical component of the transportation risk assessment was similar to the radiological approach. However, no cargo-related impacts were assessed under routine conditions.

C.9.1 Scope of the Analysis

The transportation risk assessment for management of depleted UF_6 involved estimating the potential human health risks during transportation of depleted uranium in different forms. Risks were estimated from both “vehicle-related” and “cargo-related” causes. Vehicle-related risks result from the nature of transportation itself, independent of the radioactive characteristics of the cargo. For example, increased levels of pollution from vehicular exhaust emissions may affect human health. Similarly, accidents during transportation may cause injuries and fatalities from physical trauma. On the other hand, cargo-related risk generally refers to risks that would be attributable to the characteristics of the shipment cargo. The cargo-related risks from the transportation of depleted uranium would be caused by exposure to ionizing radiation. Exposures to radiation occur under both routine (i.e., incident-free) transportation and during accident conditions.

For each of the alternatives considered for managing depleted UF_6 that would involve transportation, cargo-related and vehicle-related risks were calculated for shipments between each of the origin and destination sites (see Table C.2). Options evaluated included the shipment of depleted UF_6 from its current location(s) to storage or conversion facilities; the shipment of UO_2 from conversion facilities to storage, cask manufacture, or disposal facilities; the shipment of U_3O_8 from conversion facilities to storage or disposal facilities; the shipment of depleted uranium metal from conversion facilities to cask manufacture facilities; and the shipment of low-level radioactive waste (LLW) from conversion and manufacturing facilities to LLW disposal sites. The number of shipments between each pair of origin and destination sites was calculated for truck and rail modes by using projected site-specific inventories.

Unit risks per kilometer were developed because the locations of the conversion, storage, manufacturing, end user, and disposal facilities have not been determined. These unit risks were based on national average data derived from the data discussed below for route-specific data. The application of these data is discussed in the PEIS.

The technical approach for estimating transportation risks uses several computer models and databases. Transportation risks were assessed for both routine and accident conditions. For the routine assessment, risks were calculated for the collective populations of all potentially exposed individuals, as well as for a small set of MEI receptors. The accident assessment consisted of two components: (1) an accident risk assessment, which considered the probabilities and consequences of a range of possible transportation-related accidents, including low-probability accidents that have high consequences, and high-probability accidents that have low consequences; and (2) an accident consequence assessment, which considered only the radiological consequences of low-probability accidents that were postulated to result in the largest releases of radioactive material. The release fractions used in the accident risk assessment were based on the data in NUREG-0170 (NRC 1977a) and independent engineering analyses.

C.9.2 Routine Risk Assessment Method

The RADTRAN 4 computer code (Neuhauser and Kanipe 1993) was used for the routine and accident cargo-related risk assessments to estimate the radiological impacts to collective populations. RADTRAN 4 was developed by Sandia National Laboratories to calculate population risks associated with the transportation of radioactive materials by a variety of modes, including

TABLE C.2 Potential Shipments of Radioactive Material Analyzed in the PEIS for Depleted UF_6

Material	Origin	Destination
Depleted UF_6	Gaseous diffusion plants site storage yards	Storage or conversion facilities
UO_2	Conversion facilities	Storage, manufacturing, or disposal facilities
Uranium oxide cask	Manufacturing facilities	End user
U_3O_8	Conversion facilities	Storage or disposal facilities
Depleted uranium metal	Conversion facilities	Manufacturing facilities
Depleted uranium metal cask	Manufacturing facilities	End user
Low-level waste (depleted uranium-contaminated material)	Conversion, manufacturing, and cylinder transfer and treatment facilities	Low-level waste disposal sites
Mixed waste	Conversion, manufacturing, and cylinder transfer and treatment facilities	Mixed waste treatment

truck, rail, air, ship, and barge. The code has been used extensively for transportation risk assessments since it was issued in the late 1970s and has been reviewed and updated periodically.

As a complement to the RADTRAN calculations, the RISKIND computer code (Yuan et al. 1995) was used to estimate scenario-specific doses to MEIs for both routine operation and accident conditions and to estimate population impacts for the accident consequence assessment. The RISKIND computer code was originally developed for the DOE Office of Civilian Radioactive Waste Management specifically to analyze radiological consequences to individuals and population subgroups from the transportation of spent nuclear fuel and is now capable of analyzing the transport of other radioactive materials.

Routine risks from hazardous chemical shipments would not be expected. The shipping packages were assumed not to leak during routine transportation operations.

C.9.2.1 Collective Population Risk

The radiological risk associated with routine transportation results from the potential exposure of people to low-level external radiation in the vicinity of loaded shipments. Because the radiological consequences (dose) occur as a direct result of normal operations, the probability of routine consequences is taken to be unity in the RADTRAN 4 code. Therefore, the dose risk is equivalent to the estimated dose.

For routine transportation, the RADTRAN 4 computer code considers all major groups of potentially exposed persons. The RADTRAN 4 calculations of risk for routine highway and rail transportation include exposures of the following population groups:

- ***Persons along the Route (Off-Link Population).*** Collective doses were calculated for all persons living or working within 0.5 mile (0.8 km) of each side of a transportation route. The total number of persons within the 1-mile (1.6-km) corridor was calculated separately for each route considered in the assessment.

- ***Persons Sharing the Route (On-Link Population).*** Collective doses were calculated for persons in all vehicles sharing the transportation route. This group includes persons traveling in the same or opposite directions as the shipment, as well as persons in vehicles passing the shipment.

- ***Persons at Stops.*** Collective doses were calculated for people who might be exposed while a shipment was stopped en route. For truck transportation, these stops include stops for refueling, food, and rest. For rail transportation, stops were assumed to occur for purposes of classification.

- ***Crew Members.*** Collective doses were calculated for truck and rail transportation crew members involved in the actual shipment of material. Workers involved in loading or unloading were not considered.

The doses calculated for the first three population groups were added together to yield the collective dose to the general public; the dose calculated for the fourth group represents the collective dose to workers. The RADTRAN 4 models for routine dose are not intended for use in estimating specific risks to individuals.

The RADTRAN 4 calculations for routine dose are based on generically expressing the dose rate as a function of distance from a point source (Neuhauser and Kanipe 1993). Associated with the calculation of routine doses for each exposed population group are parameters such as the radiation field strength, the source-receptor distance, the duration of exposure, vehicular speed, stopping time, traffic density, and route characteristics such as population density. The RADTRAN manual contains derivations of the equations and descriptions of these parameters (Neuhauser and Kanipe 1993).

For the depleted UF_6 PEIS, the collective routine risks were calculated for each set of shipments as follows. Impacts were estimated on a unit risk per kilometer traveled basis because the origin and destination sites for the alternatives have not yet been determined. As such, RADTRAN 4 was used to calculate the collective risks to workers and the public on the basis of accident rates and population densities, which are summarized in Biwer et al. (1997), and representative radiological and physical properties of the transported material. The collective risks presented incorporated the total number of shipments over the life of the project (20 years in most cases). For a given option, the number of shipments for each type of material was determined by the annual input or output capacities for the facility under consideration (conversion, treatment, storage, manufacture, or disposal). To give the reader a perspective on the routine risks involved, results were presented for shipment distances of 250, 1,000, and 5,000 km.

C.9.2.2 Maximally Exposed Individual Risk

In addition to the assessment of the routine collective population risk, the risk to MEIs was estimated for a number of hypothetical exposure scenarios by using RISKIND. The receptors included transportation crew members, departure inspectors, and members of the public exposed during traffic delays, while working at a service station, or while living near a facility.

The dose to each MEI considered was calculated with RISKIND for an exposure scenario defined by a given distance, duration, and frequency of exposure specific to that receptor. The distances and durations of exposure were similar to those given in previous transportation risk assessments (DOE 1990, 1995a, 1996a) The scenarios were not meant to be exhaustive but were selected to provide a range of potential exposure situations.

The RISKIND external dose model considers direct external exposure and exposure from radiation scattered from the ground and air. RISKIND was used to calculate the dose as a function of distance from a shipment on the basis of the dimensions of the shipment (millirem per hour for stationary exposures and millirem per event for moving shipments). The code approximates the shipment as a cylindrical volume source, and the calculated dose includes contributions from secondary radiation scattering from buildup (scattering by the material contents), cloudshine (scattering by the air), and groundshine (scattering by the ground). The dose rate curve (relative dose rate as a function of distance) specific to depleted uranium was determined by using the MicroShield code (Negin and Worku 1992; see Section C.4.1.4) for input into RISKIND. As a conservative measure, credit for potential shielding between the shipment and the receptor was not considered.

C.9.2.3 Vehicle-Related Risk

Vehicle-related health risks resulting from routine transportation might be associated with the generation of air pollutants by transport vehicles during shipment and would be independent of the radioactive or chemical nature of the shipment. The health endpoint assessed under routine transportation conditions was the excess latent mortality due to inhalation of vehicular emissions. These emissions consist of particulate matter in the form of diesel engine exhaust and fugitive dust raised from the road/railway by the transport vehicle.

Risk factors for pollutant inhalation in terms of latent mortality have been generated by Rao et al. (1982). These risk factors are 1.6×10^{-7}/mile (1×10^{-7} mortality/km) and 2.1×10^{-7}/mile (1.3×10^{-7} mortality/km) for truck and rail travel, respectively, in urban areas. The risk factors are based on regression analyses of the effects of sulfur dioxide and particulate releases from diesel exhaust on mortality rates. Excess latent mortalities were assumed to be equivalent to LCFs. Vehicle-related risks from routine transportation were calculated for each shipment by multiplying the total distance traveled in urban areas by the appropriate risk factor. This method has been used in several reports to calculate risks from routine transportation of radioactive wastes (DOE 1990, 1995a, 1996a).

The routine vehicle-related health risks were considered to be incremental risks. The risk of mortality from air pollutants is thought to occur after some threshold air concentration is exceeded (EPA 1993b). In addition, the air concentration thresholds were derived when considering chronic exposure over extended periods of time. Such higher air pollutant concentrations exist primarily in populated urban areas, where the increase in pollutant levels by a single shipment would incrementally add to the mortality risk. Rural and suburban population areas generally do not have such high air pollutant levels, and the relatively small amount added as the result of a single shipment would not be enough to raise air concentrations above threshold levels for injury for even a brief period of time.

C.9.3 Accident Assessment Methodology

As discussed in the previous section, the radiological transportation accident risk assessment uses the RADTRAN 4 code for estimating collective population risks and the RISKIND code for MEI and population consequences.

The hazardous chemical transportation accident risk assessment relies on the HGSYSTEM model (Post 1994a-b) for both the collective population and individuals. The model is a widely applied code recognized by the EPA for chemical accident consequence predictions.

The collective accident risk for each type of shipment was determined in a manner similar to that described for routine collective risks. Unit accident risks on a per kilometer traveled basis were first calculated for each type of shipment. As discussed in Chapter 4, the accident risk assessment uses national route average characteristics such as accident rates and population density information. In addition, the radiological, chemical, and physical properties of the material transported and its packaging characteristics were incorporated into the calculations. The collective accident risks presented incorporated the total number of shipments over the life of the project (20 years in most cases). For a given option, the number of shipments for each type of material was determined by the annual input or output capacities for the facility under consideration (conversion, treatment, storage, manufacture, or disposal). To give the reader a perspective on the accident risks involved, results were presented for shipment distances of 250, 1,000, and 5,000 km.

C.9.3.1 Radiological Accident Risk Assessment

The risk analysis for potential accidents differs fundamentally from the risk analysis for routine transportation because occurrences of accidents are statistical in nature. The accident risk assessment is treated probabilistically in RADTRAN 4 and in the HGSYSTEM approach used to estimate the hazardous chemical component of risk. Accident risk is defined as the product of the accident consequence (dose or exposure) and the probability of the accident occurring. In this respect, RADTRAN 4 and the HGSYSTEM approach both estimate the collective accident risk to populations by considering a spectrum of transportation-related accidents. The spectrum of accidents was designed to encompass a range of possible accidents, including low-probability accidents that have high consequences, and high-probability accidents that have low consequences (such as “fender benders”). The total collective radiological accident dose risk was calculated as:

$$R_{Total} = D \times A \times \sum_{i=1,n} (P_i \times C_i) \quad ,$$

where:

R_{Total} = total collective dose risk for a single shipment distance *D* (person-rem),

D = distance traveled (km),

A = accident rate for transport mode under consideration (accidents/km),

P_i = conditional probability that the accident is in severity category *I*, and

C_i = collective dose received (consequence) should an accident of severity category *I* occur (person-rem).

The results for collective accident risk can be directly compared with the results for routine collective risk because the latter results implicitly incorporate a probability of occurrence of one if the shipment takes place.

The RADTRAN 4 calculation of collective accident risk employs models that quantify the range of potential accident severities and the responses of transported packages to accidents. The spectrum of accident severity is divided into a number of categories. Each category of severity is assigned a conditional probability of occurrence — that is, the probability that an accident will be of a particular severity if an accident occurs. The more severe the accident, the more remote the chance of such an accident. Release fractions, defined as the fraction of the material in a package that could be released in an accident, are assigned to each accident severity category on the basis of the physical and chemical form of the material. The model takes into account the mode of transportation and the type of packaging being considered. The accident rates, the definition of accident severity categories, and the release fractions used in this analysis are discussed further in Biwer et al. (1997). The approach for hazardous chemicals incorporates the same accident severity categories and release fractions used by RADTRAN 4.

For accidents involving the release of radioactive material, RADTRAN 4 assumes that the material is dispersed in the environment according to standard Gaussian diffusion models. For the risk assessment, default data for atmospheric dispersion were used, representing an instantaneous ground-level release and a small-diameter source cloud (Neuhauser and Kanipe 1993). The calculation of the collective population dose following the release and dispersal of radioactive material includes the following exposure pathways:

- External exposure to the passing radioactive cloud,
- External exposure to contaminated ground,
- Internal exposure from inhalation of airborne contaminants, and
- Internal exposure from the ingestion of contaminated food.

For the pathway of ingestion, national-average food transfer factors, which relate the amount of radioactive material ingested to the amount deposited on the ground, were calculated in accordance with the methods described by NRC Regulatory Guide 1.109 (NRC 1977b) and were used as input to the RADTRAN code. Doses of radiation from the ingestion or inhalation of radionuclides were calculated by using standard dose conversion factors (DOE 1988a-b).

C.9.3.2 Chemical Accident Risk Assessment

The risks from exposure to hazardous chemicals during transportation-related accidents can be either acute (result in immediate injury or fatality) or latent (result in cancer that would present itself after a latency period of several years). Both population risks and risks to the MEI were evaluated for transportation accidents. The acute health endpoint, potential irreversible adverse effects, was evaluated for the assessment of cargo-related population impacts from transportation accidents. Accidental releases during transport of various uranium compounds (e.g., UF_6, UO_2, U_3O_8, uranium metal), HF, and ammonia were evaluated quantitatively.

The acute effects evaluated were assumed to exhibit a threshold nonlinear relationship with exposure; that is, some low level of exposure can be tolerated without inducing a health effect. To estimate risks, chemical-specific concentrations were developed for potential irreversible adverse effects. All individuals exposed at these levels or higher following an accident were included in the transportation risk estimates. In addition to acute health effects, the cargo-related risk of excess cases of latent cancer from accidental chemical exposures could be evaluated. However, none of the chemicals that might be released in any of the accidents would be carcinogenic. As a result, no predictions for excess latent cancers are presented in this report for accidental chemical releases.

Additionally, to address MEIs, the locations of maximum hazardous chemical concentration were identified for shipments with the largest potential releases. Estimates of exposure duration at those locations were obtained from modeling output and used to assess whether MEI exposure to uranium and other compounds exceeded the criteria for potential irreversible adverse effects.

The primary exposure route of concern with respect to accidental release of hazardous chemicals would be inhalation. Although direct exposure to hazardous chemicals via other pathways, such as ingestion or dermal absorption, would also be possible, these routes would be expected to result in much lower exposure than the inhalation pathway doses for the chemicals of concern in the depleted UF_6 PEIS. The likelihood of acute effects would be much less for the ingestion and dermal pathways than for inhalation.

The HGSYSTEM Version 3.0 model (Hanna et al. 1994) has a built-in source-term algorithm that is used to compute the rate, quantity, and type of atmospheric release of a hazardous air pollutant, including pool evaporation from a volatile organic liquid spill. The model is able to handle frequently encountered accidental releases from ruptured tanks, drums, and pipes. The model incorporates a chemical data library of physical and chemical properties (such as vapor pressure, boiling point, and molecular weight) for 30 chemical compounds. Physical properties of the chemical released, along with container content input, such as the container geometry and rupture characteristics (e.g., hole size), are used by HGSYSTEM to compute chemical release rate and duration. The risk assessment for hazardous chemicals assumed that organic liquid spills and particulate releases would be of short duration as liquid and solid (as respirable fraction) aerosols. The release fractions were estimated with the approach used for radionuclide releases. The risks associated with the consequences estimated with the HGSYSTEM code were computed separately with a risk quantification spreadsheet program.

C.9.3.3 Accident Consequence Assessment

Because predicting the exact location of a severe transportation-related accident is impossible when estimating population impacts, separate accident consequences were calculated for accidents occurring in rural, suburban, and urban zones of population density. Moreover, to address the effects of the atmospheric conditions existing at the time of an accident, two different atmospheric conditions were considered. The first case assumed neutral (i.e., unstable) atmospheric conditions, and the second assumed stable conditions.

The MEI for severe transportation accidents was considered to be located at the point of highest hazardous material concentration that would be accessible to the general public. This location was assumed to be 100 ft (30 m) or farther from the release point at the location of highest air concentration as determined by the HGSYTSTEM and FIREPLUME models. Only the shipment accident resulting in the highest contaminant concentration was evaluated for the MEI.

C.9.3.3.1 Radiological Accident Consequence Assessment

The RISKIND code was used to provide a scenario-specific assessment of radiological consequences of severe transportation-related accidents. Whereas the RADTRAN 4 accident risk assessment considers the entire range of accident severities and their related probabilities, the RISKIND accident consequence assessment focuses on accidents that result in the largest releases of radioactive material to the environment. Accident consequences were presented for each type of shipment that might occur under any given option for each alternative. The accident consequence assessment was intended to provide an estimate of the potential impacts posed by a severe transportation-related accident.

The severe accidents considered in the consequence assessment are characterized by extreme mechanical and thermal forces. In all cases, these accidents result in a release of radioactive material to the environment. The accidents correspond to those within the highest accident severity category, as described previously. These accidents represent low-probability, high-consequence events. The probability of accidents of this magnitude would be dependent on the number of shipments and the total shipping distance for the options considered; however, accidents of this severity would be expected to be extremely rare.

Severe accidents involving solid radioactive material that result in the highest impacts generally are related to fire. The fire acts to break down and distribute the material of concern. Air concentrations of radioactive contaminants at receptor locations following a hypothetical accident were determined by using the FIREPLUME model. On the basis of these air concentrations, RISKIND was used to calculate the radiological impacts for the accident consequence assessment.

The accident consequences were calculated for both local populations and MEIs. The population dose includes the population within 50 miles (80 km) of the site of the accident. The exposure pathways considered would be similar to those discussed previously for the accident risk assessment. Although remedial activities after the accident (e.g., evacuation or ground cleanup) would reduce the consequences of an accident, these activities were not given credit in the consequence assessment.

C.9.3.3.2 Chemical Accident Consequence Assessment

The HGSYSTEM model version 3.0 was used to estimate the potential consequences from severe hazardous chemical accidents. The FIREPLUME model was used to predict the consequences of transportation accidents involving fires. The HGSYSTEM model is described in Section C.9.3.2.

C.9.3.4 Vehicle-Related Accident Risk Assessment

The vehicle-related accident risk refers to the potential for transportation-related accidents that could directly result in fatalities not related to the cargo in the shipment. This risk represents fatalities from mechanical causes. National-average rates for transportation-related fatalities were used in the assessment. Vehicle-related accident risks were calculated by multiplying the total distance traveled by the rate for transportation-related fatalities. In all cases, the vehicle-related accident risks were calculated by using distances for round-trip shipment.

C.10 WASTE MANAGEMENT

C.10.1 General Methods

Impacts to the waste management resources at each of the sites were evaluated for the continued storage, cylinder preparation, conversion, manufacture and use, long-term storage, and disposal options. For the continued storage and cylinder preparation options, site-specific impacts were estimated on the basis of actual cylinder populations in the storage yards of the Paducah, Portsmouth, and K-25 sites. For the conversion and long-term storage options (except long-term storage in mines), the three current storage sites were used as representative locations. The analysis of site-specific and representative site impacts compared the volume throughputs resulting from normal activities at the waste management facilities at each site with the waste throughputs expected from the different options. Wastes were considered according to the standard categories of LLW, low-level mixed waste (LLMW), hazardous waste, and nonhazardous waste. In addition, waste streams were identified as to media type (e.g., solid or liquid) and the likely treatment (e.g., incineration, compaction, or sanitary discharge). Where new waste management facilities would be needed at a particular site, the impacts for waste management from construction of these facilities were also evaluated. The analysis for manufacturing and use, long-term storage in mines, and disposal options assumed generic, nonspecific environmental settings for the required activities.

For purposes of analysis for the generic options, the wastes generated at each site were compared with the total amount of waste generated nationwide in all DOE waste management activities. The comparison of waste generation rates with available capacity for depleted UF_6 waste (especially LLW) was limited primarily to the DOE waste management system. Currently three commercial facilities (Barnwell, South Carolina; Richland, Washington; and Envirocare in Utah) are accepting about 37,000 m^3/yr of commercial LLW, and DOE is disposing of about 65,000 m^3/yr of LLW at DOE facilities. DOE LLW generation is expected to increase to about 100,000 to 200,000 m^3/yr once environmental restoration operations begin. Commercial facilities that manage LLW have the capability to expand rapidly and may accept DOE LLW in the future if it can be managed profitably. Also, some of the depleted UF_6 wastes might not be considered DOE wastes (e.g., calcium fluoride [CaF_2] or magnesium fluoride [MgF_2] possibly generated during conversion processes, if the conversion were conducted by a private commercial enterprise).

The analysis also included the secondary waste streams associated with storage of treated or untreated waste and any secondary waste streams associated with the packaging or handling of treated wastes in preparation for disposal.

C.10.2 Data Requirements

For each option considered, projected annual generation volumes for the various waste types were compared with waste treatment volumes/disposal capacities projected from existing programs at the representative sites or projected to be available at the national level (especially for the disposal, manufacturing and use, and long-term storage in mines). The projected waste generation volumes and contaminant levels for each option were obtained from the engineering analysis report (LLNL 1997) and other programmatic sources for continued storage and long-term yard storage (Parks 1997; Folga 1996). The waste generation volumes projected for each site (or nationwide) are shown in Table C.3. To estimate waste, these projected site-dependent LLW and LLMW data were obtained from analysis of site-generated data listed in the *Integrated Data Base Report — 1994* (DOE 1995b) for LLW and from the *Mixed Waste Inventory Summary Report* (DOE 1995c) for LLMW. The estimated wastes generated from each depleted UF_6 management option are compared with the estimated waste treatment volumes listed in Table C.3. The treatment volumes in Table C.3 are associated with operations and do not include waste from environmental restoration activities.

Estimates of projected wastes for the next 20 years were used in this comparison rather than current waste volumes because the comparison should represent waste management conditions some 10 to 30 years from now. Waste management programs at particular sites could change over time.

Estimates of the LLW to be disposed of at DOE waste management disposal facilities depend critically upon the time frame under consideration and the types of waste to be included. The WM PEIS estimates that approximately 1,060,000 m^3 of LLW will be disposed of during the time frame 1995-2014 (DOE 1997). This estimate does not include any LLW from environmental restoration activities or facility stabilization activities. A more appropriate estimate that includes environmental restoration waste (perhaps more uncertain) comes from *The 1996 Baseline Environmental Management Report* (BEMR) (DOE 1996b), which estimates the total amount of LLW for treatment at waste management facilities to be 3,400,000 m^3. This estimate is for the next 75 years and includes contributions from environmental restoration and facility stabilization programs. The majority of environmental restoration wastes are expected to be generated between 2003 and 2033, approximately the correct time frame to compare with the depleted UF_6 program. For this reason, the BEMR estimate was used for comparison with the estimated depleted UF_6 waste. Adjustments must be made to the BEMR estimate to convert treatment volumes into disposal volumes. Both volume reductions and expansions would occur during waste treatment and grouting, depending on the relative amounts of the different types of waste. On the basis of the WM PEIS analysis (DOE 1997), the BEMR estimate was adjusted to 4,250,000 m^3 for the estimated disposal volume. The total disposal volumes for LLW generated from various depleted UF_6 alternatives were

TABLE C.3 Projected Site and National DOE Waste Treatment Volumes

	Waste Treatment Volume[a] (m^3/yr)			
Waste Category	Paducah	Portsmouth	K-25 (ORR)[b]	Nationwide
Low-level waste[c]	2,200	4,800	8,100	68,000[d]
Low-level mixed waste[e]	100	1,600	(5,000)	19,000[d]
Hazardous waste[f]	76	120	1,000	–
Nonhazardous waste[f]				
Solids	2,100	–	(27,500)	–
Wastewater	–	–	–	–
Sanitary waste	560,000	500,000	880,000	–

[a] A hyphen (–) indicates no data reported.

[b] Waste treatment volumes for the K-25 site are listed where available. Much of the waste generated at K-25 is included in the combined treatment volumes listed under the Oak Ridge Reservation (ORR) treatment, storage, and disposal facilities. These combined volumes (enclosed in parentheses) include waste generated at ORNL, K-25, and Y-12.

[c] Source: DOE (1995b).

[d] Estimated operational waste for 1995 for all DOE sources combined (DOE 1997).

[e] Source: DOE (1995c).

[f] Source: DOE (1995d).

compared to the total estimated disposal volume for LLW for all DOE waste management activities (including environmental restoration waste).

A distinction is made between treatment volumes and disposal volume. Treatment volumes were compared as cubic meters per year (m^3/yr) because the limitations to the treatment facility are likely related to the throughput volume (m^3/yr) of the treatment facility. Disposal volumes were compared as total cubic meters (m^3) because disposal facilities generally have no throughput limitations but rather are limited by the total volume of waste (m^3) they can accept.

Although the current LLW disposal capacity is inadequate to dispose of the projected 4 million m^3 of LLW, such land is available at DOE and commercial LLW disposal facilities to accommodate disposal of this waste (DOE 1992a). These lands will be developed for LLW disposal, as needed.

C.11 CULTURAL RESOURCES

Cultural resources were generally evaluated with respect to the potential for impact to archaeological sites and historic structures listed on or eligible for the *National Register of Historic Places*, the environmental setting of a listed or eligible property, and traditional use areas (e.g., cemetery, Native American resource). Because specific sites have not been chosen for the options (with the exception of continued storage and cylinder preparation activities), only limited impact evaluation was possible. A site-specific evaluation as a part of the second tier of NEPA documentation will assess the location of proposed ground disturbance with respect to locations of significant cultural resources to determine impacts.

For the continued storage and cylinder preparation options, information regarding cultural resources was collected from each of the three current storage sites (Paducah, Portsmouth, and K-25). The potential for impacts resulting from these options was determined on the basis of ground disturbance caused by the construction of the new storage yards (if any), or a new transfer facility. Although each of the sites will prepare its own NEPA documentation for these projects, this PEIS provides a general discussion of what potential impacts might occur.

C.12 RESOURCE REQUIREMENTS

The evaluation of resource requirements identified the major irreversible and irretrievable commitments of resources that could be determined at this programmatic level of analysis. The commitment of material and energy resources during the entire life cycle of the various options in this PEIS includes construction materials that could not be recovered or recycled, materials rendered radioactive that could not be decontaminated, and materials consumed or reduced to unrecoverable forms or waste. Where construction would be necessary, materials required could include wood, concrete, sand, gravel, steel, and other metals. Materials consumed during operations could include operating supplies, miscellaneous chemicals, and gases. Strategic and critical materials, or resources with small reserves, were also identified and considered.

Energy resources irretrievably committed during construction and operations would include the consumption of fossil fuels used to generate heat and electricity. Energy would also be expended in the form of diesel fuel, gasoline, and oil for construction equipment and transportation vehicles.

The assessment of potential resource requirements for the continued storage, cylinder preparation, conversion, and long-term storage options was based on comparing the resource requirements of building and operating proposed facilities to existing capacities of on-site infrastructure systems and to current off-site demands at the three current storage sites. A variation of the methodology applied in the WM PEIS (DOE 1997) was utilized in this study. The effects of the various options on on-site infrastructure systems such as electrical demand were assessed qualitatively by comparing the new demand to the existing maximum capacity. The demand on off-site infrastructure resulting from new resource requirements for each option was compared to estimated current demand.

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