ANL/EAD/TM-112

Transportation Impact Assessment for Shipment of Uranium Hexafluoride (UF_6) Cylinders from the East Tennessee Technology Park to the Portsmouth and Paducah Gaseous Diffusion Plants

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

ACRONYMS AND ABBREVIATIONS

General

ANPR	advanced notice of proposed rulemaking
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
CEDE	committed effective dose equivalent
CFR	*Code of Federal Regulations*
DNFSB	Defense Nuclear Facilities Safety Board
DOE	U.S. Department of Energy
DOE O	DOE Order
DOT	U.S. Department of Transportation
DUF_6	depleted uranium hexafluoride
DUF_6 PEIS	*Programmatic Environmental Impact Statement for Alternative Strategies for the Long-Term Management and Use of Depleted Uranium Hexafluoride*
EIS	environmental impact statement
EPA	U.S. Environmental Protection Agency
ERPG	Emergency Response Planning Guideline
ETTP	East Tennessee Technology Park
FR	*Federal Register*
HMR	Hazardous Materials Regulations
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
LCF	latent cancer fatality
LLMW	low-level mixed waste
LLNL	Lawrence Livermore National Laboratory
LLW	low-level (radioactive) waste
LSA	low specific activity
LSA-I	low-specific-activity materials, group I
MEI	maximally exposed individual
non-DU	non-depleted-uranium
NEPA	National Environmental Policy Act
NPRM	notice of proposed rulemaking

NRC	U.S. Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
PEIS	programmatic environmental impact statement
Pub. L.	Public Law
RFP	request for proposal
ROD	record of decision
TI	transport index
USEC	United States Enrichment Corporation
WM PEIS	*Final Waste Management Programmatic Environmental Impact Statement for Managing Treatment, Storage, and Disposal of Radioactive and Hazardous Waste*

Chemicals

HF	hydrogen fluoride
U	uranium
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

Ci	curie(s)
cm	centimeter(s)
d	day(s)
°C	degree(s) Celsius
°F	degree(s) Fahrenheit
ft	foot (feet)
ft^3	cubic foot (feet)
g	gram(s)
h	hour(s)
in.	inch(es)
kg	kilogram(s)
km	kilometer(s)
km^2	square kilometer(s)
kPa	kilopascal(s)
L	liter(s)
lb	pound(s)
µCi	microcuries

µg	microgram(s)
µm	micrometer(s)
m	meter(s)
m^3	cubic meter(s)
mg	milligram(s)
mi	mile(s)
mi^2	square mile(s)
min	minute(s)
mrem	millirem
MT	metric ton(s) (1 MT = 1,000 kilograms)
psia	pound(s) per square inch (absolute)
rem	roentgen equivalent man
s	second(s)
ton(s)	short ton(s) (2,000 pounds)
wt%	percent by weight
yr	year(s)

TRANSPORTATION IMPACT ASSESSMENT FOR SHIPMENT OF URANIUM HEXAFLUORIDE (UF_6) CYLINDERS FROM THE EAST TENNESSEE TECHNOLOGY PARK TO THE PORTSMOUTH AND PADUCAH GASEOUS DIFFUSION PLANTS

by

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ABSTRACT

The U.S. Department of Energy (DOE) is moving forward in its effort to design, build, and operate new facilities to convert its inventory of depleted uranium hexafluoride (UF_6) to a more stable chemical form. The DOE maintains approximately 700,000 metric tons of depleted UF_6 in about 57,000 cylinders stored at its Paducah, Kentucky; Portsmouth, Ohio; and Oak Ridge, Tennessee, sites. Current DOE plans call for building and operating conversion facilities at the Portsmouth and Paducah sites, where the vast majority of depleted UF_6 cylinders are stored. The plans also call for the depleted UF_6 cylinders currently stored at the East Tennessee Technology Park (ETTP) in Oak Ridge to be transported to the Portsmouth site for conversion. This report presents a transportation impact assessment for the shipment of the 4,683 full depleted UF_6 cylinders (containing approximately 56,000 metric tons) stored at the ETTP to the Portsmouth site for conversion. The transportation of 2,400 cylinders stored at ETTP that contain a total of 25 metric tons of enriched and normal uranium or that are empty is also considered. For completeness in addressing all reasonable alternatives in future National Environmental Policy Act (NEPA) reviews and to allow maximum flexibility in future decision making, the possibility of moving the ETTP cylinders to the Paducah site is also considered, to the same degree of detail as shipments to Portsmouth. Transportation by truck, regular train, and dedicated train is considered. The assessment includes estimates of both the radioactive and chemical hazards associated with the cylinder shipments. In addition, the report contains an analysis of the current and pending regulatory requirements applicable to packaging UF_6 for transport by truck or rail and evaluates regulatory options for meeting the packaging requirements.

1 INTRODUCTION

The U.S. Department of Energy (DOE) is moving forward in its effort to design, build, and operate new facilities to convert its inventory of depleted uranium hexafluoride (depleted UF_6) to a more stable chemical form. This effort supports the decision presented in the *Record of Decision for Long-Term Management and Use of Depleted Uranium Hexafluoride* (DOE 1999a), namely to begin conversion of the depleted UF_6 inventory as soon as possible, either to uranium oxide, uranium metal, or a combination of both, while allowing for future uses of as much of this inventory as possible. The DOE maintains approximately 700,000 metric tons[1] of depleted UF_6 in about 57,000 cylinders stored at its Paducah, Kentucky; Portsmouth, Ohio; and Oak Ridge, Tennessee, sites.

Current DOE plans call for building and operating conversion facilities at the Portsmouth and Paducah sites, where the vast majority of depleted UF_6 cylinders are stored. The plans also call for the depleted UF_6 cylinders currently stored at the East Tennessee Technology Park (ETTP) in Oak Ridge, formerly known as the K-25 gaseous diffusion plant, to be transported to the Portsmouth site for conversion.

This report presents an assessment of the impacts of transporting 4,683 cylinders full of depleted UF_6 (containing approximately 56,000 metric tons) stored at the ETTP to the Portsmouth site for conversion. The transportation of 2,400 cylinders stored at ETTP that contain a total of 25 metric tons of enriched and normal uranium or that are empty (collectively called “non-depleted-uranium [non-DU] cylinders” in this report) is also considered. In addition, the report contains an analysis of the current and pending regulatory requirements applicable to packaging UF_6 for transport by truck or rail, and it evaluates regulatory options for meeting the packaging requirements (Section 7).

For completeness in addressing all reasonable alternatives in future National Environmental Policy Act (NEPA) reviews and to allow maximum flexibility in future decision making, the possibility of moving the ETTP cylinders to the Paducah site is also considered, to the same degree of detail as shipments to Portsmouth. Transportation by truck, regular train, and dedicated train is considered. The assessment covers both the radioactive and chemical hazards associated with the cylinder shipments.

DOE has determined that the construction and operation of depleted UF_6 conversion facilities constitute a major federal action requiring preparation of a site-specific environmental impact statement (EIS), as required by NEPA, as amended. Consequently, this transportation impact assessment has been conducted at a level appropriate for site-specific NEPA reviews in order to

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[1] A metric ton is 1,000 kilograms, or approximately 2,200 pounds.

facilitate its incorporation into the site-specific conversion facility EIS that is to be prepared in the future. Commonly accepted transportation assessment methodologies and approaches are used. As is the case for similar NEPA assessments, the evaluation focuses on potential impacts to human health and safety during routine transportation and from potential transportation accidents; other potential impact areas, such as air quality, noise, and ecology, are considered but not analyzed in detail.

1.1 PROGRAM BACKGROUND

In 1994, DOE began work on the *Programmatic Environmental Impact Statement for Alternative Strategies for the Long-Term Management and Use of Depleted Uranium Hexafluoride* (DUF_6 PEIS). The DUF_6 PEIS was completed in 1999 (DOE 1999b) and identified conversion of depleted UF_6 to another chemical form for use or long-term storage as part of a preferred management alternative. In addition to producing a depleted uranium product, conversion also produces a fluorine product, usually aqueous or anhydrous hydrogen fluoride (HF), that has potential beneficial uses. In the corresponding *Record of Decision for the Long-Term Management and Use of Depleted Uranium Hexafluoride* (ROD) (*Federal Register*, Volume 64, page 43358 [64 FR 43358], August 10, 1999 [DOE 1999a]), DOE decided to promptly convert the depleted UF_6 inventory to depleted uranium oxide, depleted uranium metal, or a combination of both. The ROD further explained that depleted uranium oxide will be used as much as possible and the remaining depleted uranium oxide will be stored for potential future uses or disposal, as necessary. In addition, according to the ROD, conversion to depleted uranium metal will occur only if uses are available.

During the time that DOE was analyzing its long-term strategy for managing the depleted UF_6 inventory, several other events related to depleted UF_6 management occurred. In 1995, the Department began an aggressive program to better manage the depleted UF_6 cylinders, known as the DUF_6 Cylinder Project Management Plan. In part, this program responded to Defense Nuclear Facilities Safety Board (DNFSB) Recommendation 95-1, Safety of Cylinders Containing Depleted Uranium. This program involved more rigorous and frequent inspections, a multiyear program for painting and refurbishing cylinders, and construction of concrete-pad cylinder yards. Implementation of the DUF_6 Cylinder Project Management Plan has been successful, and, as a result, on December 16, 1999, the DNFSB closed out Recommendation 95-1.

In February 1999, DOE and the Tennessee Department of Environment and Conservation entered into a consent order that included a requirement to perform two environmentally beneficial projects: implement a negotiated management plan governing the storage of the small inventory (relative to other sites) of all UF_6 (depleted, low-enriched, and natural) cylinders stored at the ETTP site, and remove the depleted UF_6 from the ETTP site or convert the material by December 31, 2009.

In July 1998, the President signed Public Law (Pub. L.) 105-204. It directed the Secretary of Energy to prepare a plan to ensure that all amounts of depleted UF_6 to be disposed of that had accrued on the books of the United States Enrichment Corporation (USEC) be used. It also stipulated that on-site facilities to treat and recycle depleted UF_6 consistent with NEPA would begin to be built no later than January 31, 2004 (and subsequently operated) at the gaseous diffusion plants at Paducah and Portsmouth. DOE responded to Pub. L. 105-204 by issuing the Final Plan for the Conversion of Depleted Uranium Hexafluoride (referred to herein as the Conversion Plan) in July 1999. The Conversion Plan describes DOE's intent to chemically process the depleted UF_6 to create products that would both present a lower long-term storage hazard and provide a material that would be suitable for use or disposal.

On July 30, 1999, DOE initiated the Conversion Plan with the announced availability of a draft request for proposal (RFP) to procure a contractor to design, construct, and operate depleted UF_6 conversion facilities at the Paducah and Portsmouth uranium enrichment plant sites. On the basis of comments received on the draft RFP, DOE revisited some of the assumptions about management of the depleted UF_6 inventory made previously in the PEIS and ROD. For example, as documented in the Oak Ridge National Laboratory (ORNL) study, *Assessment of Preferred Depleted Uranium Disposal Forms* (Croff et al. 2000), four potential conversion forms (triuranium octoxide [U_3O_8], uranium dioxide [UO_2], uranium tetrafluoride [UF_4], and uranium metal) were evaluated and found to be acceptable for near-surface disposal at low-level radioactive waste (LLW) disposal sites such as those at DOE's Nevada Test Site and Envirocare of Utah, Inc. Therefore, the RFP was modified to allow for a wide range of potential conversion product forms and process technologies. However, any of the proposed conversion forms must have an assured, environmentally acceptable path for final disposition.

On October 31, 2000, DOE issued a final RFP to procure a contractor to design, construct, and operate depleted UF_6 conversion facilities at the Paducah and Portsmouth plant sites. The facilities will convert the depleted UF_6 to a more stable chemical form that is suitable for either beneficial use or disposal. The selected contractor will design the conversion facilities using the technology it proposes and construct them. This contractor also will operate the facilities for a five-year period, which will include maintaining depleted uranium and product inventories, transporting all UF_6 storage cylinders in Tennessee to a conversion facility at Portsmouth, as appropriate, and transporting converted product for which there is no use to a disposal site. The selected contractor will be expected to prepare excess material for disposal at an appropriate site.

1.2 CHARACTERISTICS OF UF_6

Depleted UF_6 is a by-product of the process of producing enriched uranium for use as fuel for nuclear reactors or for military applications. The use of uranium in these applications requires increasing the proportion of the uranium-235 isotope through an isotopic separation process called *enrichment*. The most commonly used enrichment process is *gaseous diffusion*.

Natural uranium contains only about 0.7% uranium-235 with the remaining 99.3% being primarily uranium-238. The gaseous diffusion process takes a stream of UF_6 gas and divides it into two parts: one enriched in uranium-235 and the other depleted in uranium-235. The enriched UF_6 is then used for manufacturing commercial reactor fuel, which typically contains 2 to 5% uranium-235, or for military applications (e.g., naval reactor fuel), which requires further enrichment of up to 95% or more uranium-235. Uranium enriched between 0.7% and 20% uranium-235 is defined as low-enriched uranium. The depleted UF_6 typically contains 0.2 to 0.4% uranium-235 and is stored in large metal cylinders near the point of enrichment.

The characteristics of UF_6 pose potential health risks, and the material is handled accordingly. Uranium is radioactive and decays into a series of other radioactive elements. Therefore, UF_6 in storage emits low levels of radiation. The radiation levels measured on the outside surface of filled depleted UF_6 storage cylinders are typically about 2 to 3 millirem per hour (mrem/h), decreasing to about 1 mrem/h at a distance of 1 ft (0.3 m).

In addition to its radioactive properties, if UF_6 is released to the atmosphere, the uranium compounds and hydrogen fluoride (HF) that are formed by reaction with moisture in the air can be chemically toxic. Uranium is a heavy metal that, in addition to being radioactive, can have toxic chemical effects (primarily on the kidneys) if it enters the bloodstream by means of ingestion or inhalation. HF is an extremely corrosive gas that can damage the lungs and cause death if inhaled at sufficiently high concentrations.

1.3 UF_6 CYLINDER INVENTORIES

FIGURE 1.1 Typical 12-metric-ton Depleted UF_6 Storage Cylinder

Approximately 700,000 metric tons of depleted UF_6 is now stored in large metal cylinders at the ETTP, Paducah, and Portsmouth sites. Most of the cylinders contain 12 metric tons of depleted UF_6 (Figure 1.1), although cylinders containing 9 metric tons are also in use. During storage, the cylinders usually are stacked two layers high in outdoor areas called yards (Figure 1.2). Table 1.1 lists the number of full cylinders containing depleted UF_6 in storage at each of the three sites. The number of full depleted UF_6 cylinders stored at the ETTP is 4,683 (containing approximately 56,000 metric

FIGURE 1.2 Depleted UF_6 Cylinder Storage Yard at the ETTP Site

TABLE 1.1 Inventory of Depleted UF_6 Cylinders in Storage[a]

Location	Original DOE Cylinders	Cylinders from USEC	Total Cylinders	Total DUF_6 (metric tons)
Paducah, Kentucky	28,351	8,559	36,910	450,000
Portsmouth, Ohio	13,388	2,653	16,041	198,000
ETTP, Oak Ridge, Tennessee	4,683	0	4,683	56,000
Total	46,422	11,212	57,634	704,000

[a] Only the 4,683 depleted UF_6 cylinders stored at the ETTP are the subject of this report.

Source: DOE (1999b).

tons of UF_6). Approximately 1,500 of the cylinders contain 9 metric tons, with the remainder containing 12 metric tons.

In addition to the 4,683 full depleted UF_6 cylinders, a number of non-DU cylinders also are at ETTP. These non-DU cylinders are of various sizes and contain enriched UF_6, contain normal UF_6, or are empty, as summarized in Table 1.2. The total number of non-DU cylinders is 2,394, containing a total of about 25 metric tons of UF_6 (6 metric tons of enriched UF_6 and 19 metric tons of normal UF_6). The majority of these non-DU cylinders are empty. Of the 673 non-DU cylinders that contain enriched uranium, fewer than 30 contain uranium enriched to greater than 5% uranium-235. All of them are small 1S sample cylinders containing less than 3 lb (1.4 kg) of UF_6 each. In general, the enriched uranium in cylinders at ETTP contains less than 5% uranium-235.

TABLE 1.2 Summary of Non-DU Cylinders Stored at ETTP

	Number of Cylinders			
Cylinder Type[a]	Enriched U[b]	Normal U[c]	Empty	Total
Small cylinders (1S, 2S, 5A, 5B, 8A, 10A, 12A, 12B)	85	183	562	830
30-in.-diameter cylinders (30A, 30B)	255	0	810	1,065
48-in.-diameter cylinders (48A, 48G, 48H, 48HX, 48O, 48OH, 48OHI, 48OM, 48T, 48X, 48Y)	332	20	99	451
Other	1	21	26	48
Total	673	224	1,497	2,394

[a] Cylinder type designations (e.g., 1S, 5A, 8A, 30B, etc.) generally correspond to the approximate diameter of the cylinder. For instance, 1S cylinders have a diameter of about 1.5 in.; 5A and 5B cylinders, a diameter of 5 in.; 8A cylinders, a diameter of 8 in.; 12A and 12B cylinders, a diameter of 12 in., and so on. For this report, small cylinders are defined as cylinders with a diameter of 12 in. or less. Small cylinders contain less than 500 lb (230 kg) of UF_6.

[b] Enriched uranium is uranium with weight percent of uranium-235 greater than 0.711. In general, the enriched uranium in cylinders at ETTP contains less than 5% uranium-235.

[c] Normal uranium is uranium with weight percent of uranium-235 equal to 0.711.

Source: Taylor (2000).

The nuclear properties of depleted UF_6 are such that the occurrence of a nuclear criticality is not a concern, regardless of the amount of depleted UF_6 present. However, criticality is a concern for the handling, packaging, and shipping of enriched UF_6. For enriched UF_6, criticality control is accomplished by employing, individually or collectively, specific limits on uranium-235 enrichment, mass, volume, geometry, moderation, and spacing for each type of cylinder. The amount of UF_6 that may be contained in an individual cylinder and the total number of cylinders that may be transported together are determined by the nuclear properties of enriched UF_6. Spacing of cylinders of enriched UF_6 in transit during routine and accident conditions is ensured by use of regulatory approval packages that provide protection against impact and fire. Consequently, because of these controls and the relatively small number of shipments containing enriched UF_6, the occurrence of an inadvertent criticality is not considered to be credible and therefore is not analyzed in the accident consequence assessment conducted in this report.

1.4 CONDITION OF ETTP CYLINDERS

Many of the cylinders currently stored at ETTP cannot be demonstrated to meet U.S. Department of Transportation (DOT) transportation requirements without extensive effort, such as a comprehensive inspection and ultrasonic measurement of the cylinder wall thickness. A detailed discussion of pertinent transportation regulations and the various options for addressing the shipment of nonconforming cylinders is presented in Section 7 of this report.

It is unknown exactly how many of the depleted UF_6 cylinders currently do not meet the DOT transportation requirements. The *Depleted Uranium Management Program; the Engineering Analysis Report for the Long-Term Management of Depleted Uranium Hexafluoride* (LLNL et al. 1997), which was prepared to support the PEIS, presents estimates of the number of depleted UF_6 cylinders at the ETTP not meeting DOT requirements, ranging from half to all of the ETTP depleted UF_6 cylinders (2,342 to 4,683). Assumptions and options concerning shipment of nonconforming cylinders are discussed in Section 3.

2 ASSESSMENT SCOPE

This report considers the potential environmental impacts associated with the transportation of full depleted UF_6 cylinders and a variety of non-DU cylinders currently stored at the ETTP, Oak Ridge, Tennessee, to both the Portsmouth and Paducah sites for eventual conversion to another chemical form. The scope of this assessment is summarized in Table 2.1 and discussed below.

This assessment considers the shipment of 4,683 full depleted UF_6 cylinders to both Portsmouth and Paducah. The total amount of depleted UF_6 contained in these cylinders is approximately 56,000 metric tons. For assessment purposes, it is assumed that all of the cylinders contain 12 metric tons of depleted UF_6, although approximately 1,500 of the cylinders stored at ETTP actually contain 9 metric tons. This assumption results in a conservative (i.e., overestimate) of potential accident impacts. In addition, the assessment considers the shipment of 2,394 cylinders of various sizes stored at ETTP that contain slightly enriched UF_6, normal UF_6, or are empty. The total amount of UF_6 contained in these non-DU cylinders is approximately 25 metric tons (6 metric tons of enriched UF_6 and 19 metric tons of normal UF_6).

Three potential shipment modes are considered, legal weight truck, regular train, and dedicated train. All three sites have extensive experience shipping UF_6 cylinders by both truck and train. Shipments by both air and barge were also considered, but not analyzed in detail. Shipment by air is not practical considering the weight of UF_6 cylinders; barge shipments may be viable, but were not evaluated for the reasons given in Section 3. For each shipment mode, representative shipment routes were identified by using standard routing models, and route-specific data were used in the impact assessment. The routes were selected to be reasonable and consistent with routing regulations and general practice, but they are considered representative because the actual routes to be used would be chosen in the future and are often determined at that time by the carrier.

Two cylinder preparation options are considered for the shipment of nonconforming depleted uranium cylinders: cylinder overpacks and cylinder transfer. An overpack would be a container into which a cylinder would be placed and that was designed to meet all applicable DOT shipment requirements. The cylinder transfer option would involve transferring the contents from nonconforming cylinders to new cylinders prior to shipment. The impacts associated with cylinder preparation are not evaluated in this report; however, such impacts would be the same as those presented in the DUF_6 PEIS (DOE 1999b). For assessment purposes, it was assumed that all the ETTP depleted UF_6 cylinders would require cylinder preparation prior to shipment. Additional details concerning the cylinder preparation options are provided in Section 3, with a discussion of the regulatory aspects provided in Section 7.

The impacts evaluated include potential human health impacts from radiological and chemical hazards during both routine and accident conditions, as well as the potential for

TABLE 2.1 Summary of the Scope of the ETTP UF_6 Cylinder Transportation Assessment

Parameter	Assumption
General approach	Same assumptions and methodologies as used for the Depleted UF_6 PEIS (as appropriate), as well as other NEPA transportation assessments.
Depleted UF_6 cylinders considered	4,683 full depleted UF_6 cylinders, containing 56,000 MT of depleted UF_6, shipped from ETTP, Oak Ridge, Tenn.
Non-DU cylinders considered	2,394 UF_6 cylinders, containing 25 MT of UF_6, shipped from ETTP, Oak Ridge, Tenn.
Destinations	(1) Portsmouth Site, Portsmouth, Ohio (2) Paducah Site, Paducah, Ky.
Shipment modes	(1) Legal-weight truck (2) Regular train (3) Dedicated train
Cylinder preparation options for nonconforming cylinders	(1) Cylinder overpacks (2) Transfer to new cylinders
Route information	Representative routes generated using standard route prediction models and using route-specific population data
Impacts evaluated	(1) Human health (radiological, chemical hazards) during normal and accident conditions (2) Environmental justice (3) Regulatory considerations

environmental justice impacts. Potential impacts in other areas, such as impacts to air quality, water quality, ecology, socioeconomics, cultural resources, visual environment (e.g., aesthetics), recreational resources, wetlands, and noise levels were considered, but they were not analyzed in detail. Impacts in these areas were not evaluated because all shipments would take place over well-established truck and rail corridors, and the relatively small number of shipments would not appreciably increase traffic levels in the vicinity of the three sites. This approach is consistent with current NEPA transportation risk assessments. A discussion of the assessment methodologies is provided in Section 4.

Potential human health risks are presented separately for workers and for members of the general public. The workers considered are truck and rail crew members involved in transportation activities. The general public includes all persons who could be exposed to a shipment while it is moving or stopped en route. Potential risks are estimated for the collective populations of exposed people and for maximally exposed individuals (MEIs). The collective population risk is a measure of the radiological and chemical risk posed to society as a whole by the option being considered. As such, the collective population risk is used as the primary means of comparing the truck and rail options.

The report also contains an analysis of the current and pending regulatory requirements applicable to packaging UF_6 for transport by truck or rail, and evaluates regulatory options for meeting the packaging requirements (Section 7).

3 DESCRIPTION OF OPTIONS

This section provides a brief summary of the cylinder preparation and shipment mode options considered in the assessment of impacts.

3.1 CYLINDER PREPARATION OPTIONS

Prior to shipment, each cylinder would be inspected to determine if it meets DOT requirements (see Section 7 for a complete description of regulatory requirements). This inspection would include a record review to determine if the cylinder was overfilled; a visual inspection for damage or defects; a pressure check to determine if the cylinder was overpressurized; and an ultrasonic wall thickness measurement (if deemed necessary on the basis of the visual inspection). If a cylinder passed the inspection, the appropriate documentation would be prepared, and the cylinder would be prepared for shipment.

Following the inspection, the preparation of standard cylinders for shipment (cylinders that meet DOT requirements) would include unstacking, on-site transfer, and loading onto a truck trailer or railcar. The cylinders would be secured with the appropriate tiedowns, and the shipment would be labeled in accordance with DOT requirements. Handling and support equipment and procedures for on-site movement and loading of the cylinders would be of the same type currently used for cylinder management activities at the storage sites.

Two cylinder preparation options are considered for the shipment of nonconforming cylinders: use of cylinder overpacks and cylinder transfer. The information for these options is based on preconceptual design data provided in an engineering analysis report on depleted UF_6 management (LLNL et al. 1997). The engineering analysis report includes much more detailed information.

Note that the impacts associated with cylinder preparation are not evaluated in this report; however, such impacts would be the same as those presented in Appendix E of the DUF_6 PEIS (DOE 1999b). For assessment purposes, it was assumed that all the ETTP cylinders would require cylinder preparation before shipment.

3.1.1 Cylinder Overpacks

Use of cylinder overpacks are one option for transporting cylinders that do not meet DOT requirements. An overpack is simply a container into which a cylinder would be placed for shipment. The metal overpack would be designed, tested, and certified to meet all DOT shipping requirements. The overpack would be suitable to contain, transport, and store the cylinder contents regardless of cylinder condition. In addition, the overpacks could be designed as pressure vessels, enabling the withdrawal of the depleted UF_6 from the cylinder in an autoclave (a device using hot air to heat cylinders).

The type of overpack evaluated in the DUF_6 PEIS is a horizontal “clamshell” nonpressure vessel (LLNL et al. 1997). For transportation, a cylinder not meeting DOT requirements would be placed into an overpack already on a truck trailer or railcar. The overpack would be closed and secured, and the shipment would be labeled in accordance with DOT requirements. The handling and support equipment for on-site movement and loading the cylinder into the overpack would be of the same type currently used for cylinder management activities at the three DOE sites. The overpacks could be reused following completion of the shipment and removal of the cylinder.

Shipment of the UF_6 cylinders in overpacks is not expected to provide additional protection under severe accident conditions. However, protective overpacks would reduce the external radiation emanating from a cylinder by about a factor of two.

3.1.2 Cylinder Transfer

A second option for transporting cylinders that do not meet DOT requirements would be to transfer the UF_6 from substandard cylinders to new or used cylinders that meet all DOT requirements. This option could require the construction of a cylinder transfer facility. The new cylinders could be shipped by placing them directly on appropriate trucks or railcars.

If the transfer option were selected, the number of filled cylinders would increase slightly because of the current inventory of over-filled cylinders that would need to be processed before shipment. However, because this assessment assumed that the 4,683 cylinders in the ETTP inventory were 12-metric-ton cylinders, and roughly one-third of the cylinders currently stored at the ETTP are in fact 9-metric-ton cylinders, no adjustment was made to the estimated number of shipments required.

3.2 SHIPMENT MODE OPTIONS

Three potential shipment modes are considered — legal-weight truck, regular train, and dedicated train. All three sites have extensive experience shipping UF_6 cylinders by truck and train.

3.2.1 Legal-Weight Truck Transportation

Truck shipments of UF_6 cylinders would be by legal-weight semitrailer trucks, consistent with current practices. The maximum gross vehicle weight for truck shipments is limited by DOT to 80,000 lb (36,400 kg). Truck shipments of depleted UF_6 were assumed to consist of a single cylinder per trailer. For shipment of non-DU cylinders, the number of cylinders per shipment would vary, depending on cylinder type, contents, and size (see Section 5.1).

3.2.2 Rail Transportation

Shipments by rail were assumed to occur by either general freight service or by dedicated rail. General freight service would consist of a railcar containing UF_6 cylinders that would be shipped as part of a larger train containing railcars shipping other commodities. Conversely, a dedicated train would involve a train consisting only of railcars of UF_6 (plus buffer cars). Shipments by general freight spend more time in railroad classification yards than do dedicated shipments, thereby potentially increasing the routine external dose to railroad workers and the general population surrounding the railroad yards when the shipment contains radioactive materials. Rail shipments of depleted UF_6 were assumed to consist of four cylinders per railcar. For shipment of non-DU cylinders, the number of cylinders per shipment would vary, depending on cylinder type, contents, and size (see Section 5.1).

3.2.3 Transportation Options Considered but Not Analyzed in Detail

Air and barge transportation options were considered but not analyzed in detail. Air transportation would be prohibitively expensive and is not practical for shipping UF_6 cylinders. The use of barge transport for shipments of UF_6 cylinders could be a viable alternative. Barge transport of the UF_6 cylinders to or from the existing storage sites would require truck or rail transport to the nearest river port, approximately 20 to 25 mi (32 to 40 km) for the Portsmouth and Paducah sites and approximately 1 mi (1.6 km) for the ETTP site. Generic input parameters to estimate the risks associated with barge transport are not as readily applicable as they are for truck or rail transport because of the fixed and limited nature of the inland and coastal waterways.

Shipment by barge was not considered in this report because it has not been used historically and it is not currently being considered for UF_6 shipments. However, in general, the risk per shipment would be approximately the same as for a truck or rail (one railcar) shipment, but fewer shipments would be necessary and the costs per ton-mile much lower. The primary risks to workers would occur during loading and unloading. Risks to the public could occur in the vicinity of locks when the barges were stopped during their passage through the locks and from accidents that might result in potential releases to the environment.

4 METHODS FOR CALCULATING TRANSPORTATION-RELATED IMPACTS

4.1 OVERVIEW OF HUMAN HEALTH RISK ASSESSMENT

For this analysis, the transportation-related risks to human health were assessed for both cargo- and vehicle-related causes. Cargo-related risks are related directly to the characteristics of the material being shipped. Vehicle-related risks, on the other hand, are independent of the nature of the cargo.

Cargo-related risks arising from the radiological and chemical hazards of the UF_6 shipments were assessed where appropriate. Generally, the approaches are similar for the radioactive and chemical risk assessment components, except that the measures for assessing the cargo-related effects on health are fundamentally different. Differences also exist in the assumptions and data used to develop the risk estimators for these two components.

For the radioactive nature of UF_6, the cargo-related impacts on human health during transportation would be caused by exposure to ionizing radiation. Exposures to radiation would occur during both routine (i.e., incident-free) transportation and during accidents. During routine operations, the external radiation field in the vicinity of a shipment must be below limits specified in federal regulations. During transportation-related accidents, human exposures may occur following the release and dispersal of radioactive materials via multiple environmental pathways, such as exposure to contaminated ground or contaminated air, or ingestion of contaminated food.

In contrast, the chemical nature of UF_6 would not pose cargo-related risks to humans during routine transportation-related operations. Transportation operations are generally well regulated with respect to packaging, such that small spills or seepages during routine transport are kept to a minimum and do not result in exposures. Potential cargo-related health risks to humans could occur only if the integrity of a container was compromised during an accident (that is, a container is breached). Under such conditions, some chemicals might cause an immediate health threat to exposed individuals.

Vehicle-related health impacts and health impacts from the radioactive and chemical nature of the UF_6 are presented separately in the tables of this report. No attempt has been made (even in cases where both radioactive and chemical characteristics must be considered) to add the estimated radioactive, chemical, and vehicle-related risks. To understand and interpret the estimated health impacts presented in this report, readers must keep in mind the fundamental differences between the radioactive, chemical, and vehicle-related hazards discussed below.

Transportation risks were assessed for both routine and accident conditions. For the routine assessment, radiological risks were calculated for the collective populations of all potentially exposed individuals, as well as for a small set of maximally exposed individual (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 consequences of low-probability accidents that were postulated to result in the largest releases of material.

4.1.1 Radiological Impacts

All radiological impacts are expressed in terms of dose and associated health effects in the exposed populations. The radiation dose calculated is the total effective dose equivalent (TEDE) as specified in the *Code of Federal Regulations*, Title 10, Part 20 (10 CFR Part 20), which is the sum of the deep dose equivalent (DDE) from exposure to external radiation and the 50-year committed effective dose equivalent (CEDE) (International Commission on Radiological Protection [ICRP] 1977) from exposure to internal radiation. Doses of radiation are calculated in units of rem (roentgen-equivalent man) for individuals and in units of person-rem for collective populations.

The potential radiation doses to the general population from transportation of radioactive materials, whether during normal operations or from postulated accidents, are usually low, such that the primary adverse health effect is the potential induction of latent cancers (i.e., cancers that occur after a latency period of several years from the time of exposure). The correlation of radiation dose and human health effects for low doses has been traditionally based on what is termed the "linear/no-threshold hypothesis," which has been described by various international authorities on protection against radiation. This hypothesis implies, in part, that even small doses of radiation cause some risk of inducing cancer and that doubling the radiation dose would mean doubling the expected numbers of cancers. The data on the health risk from radiation have been derived primarily from human epidemiological studies of past exposures, such as Japanese survivors of the atomic bomb in World War II and persons exposed during medical applications. The types of cancer induced by radiation are similar to "naturally occurring" cancers and can occur later in the lifetimes of the exposed individuals.

On the basis of the analyses conducted for this report, transportation-related operations are not expected to cause acute (short-term) radiation-induced fatalities or to produce immediately observable effects in exposed individuals. Acute radiation-induced fatalities occur at doses well in excess of 100 rem (ICRP 1991), which generally would not occur for a wide range of transportation activities, including routine operations and accidents.[2] For all severe accident scenarios analyzed, other short-term effects, such as temporary sterility and changes in blood chemistry, are not expected.

In this report, the radiological impacts are expressed as health risks in terms of the number of estimated latent-cancer fatalities (LCFs) for each option. The health risk conversion factors (expected LCFs per unit dose absorbed) were taken from ICRP publication 60 (ICRP 1991). The health risk conversion factors used were 5×10^{-4} and 4×10^{-4} LCFs per person-rem for members of the general public and occupational workers, respectively.

The approach for conducting the radiological component of the transportation risk assessment is summarized in Figure 4.1. This transportation risk assessment approach is consistent with the approach used in numerous recent DOE NEPA transportation assessments. For each option, radiological risks are assessed for both routine transportation and accidents.

The RADTRAN 4 computer code (Neuhauser and Kanipe 1992) was used in 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 truck, rail, air, ship, and barge. The code, which is used extensively for transportation risk assessments, was issued in the late 1970s and has been updated periodically.

The RADTRAN 4 calculations of population risk take into account both the consequences and the probabilities of potential exposures. The collective population risk is a measure of the total radiological risk posed to society as a whole by the option being considered. As such, the collective population risks are used as the primary means of comparing the various options.

As a complement to the RADTRAN calculations, the RISKIND computer code (Yuan et al. 1995) is used to estimate scenario-specific radiological doses to MEIs for both routine transportation operations and accidents and to estimate population impacts for the accident consequence assessment. The RISKIND computer code was 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. The latest revision of the code permits analyses for shipments of any type of radioactive material.

The RISKIND calculations are conducted to supplement the results for collective risk calculated with RADTRAN 4. Whereas the results for collective risk provide a measure of the overall risks of each case, the RISKIND calculations are meant to address areas of specific concern to individuals and subgroups of the population. Essentially, the RISKIND analyses are meant to

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[2] In general, individual acute whole-body doses in the range of 300-500 rem are expected to cause fatality of 50% of the exposed individuals within 30-60 days (ICRP 1991).

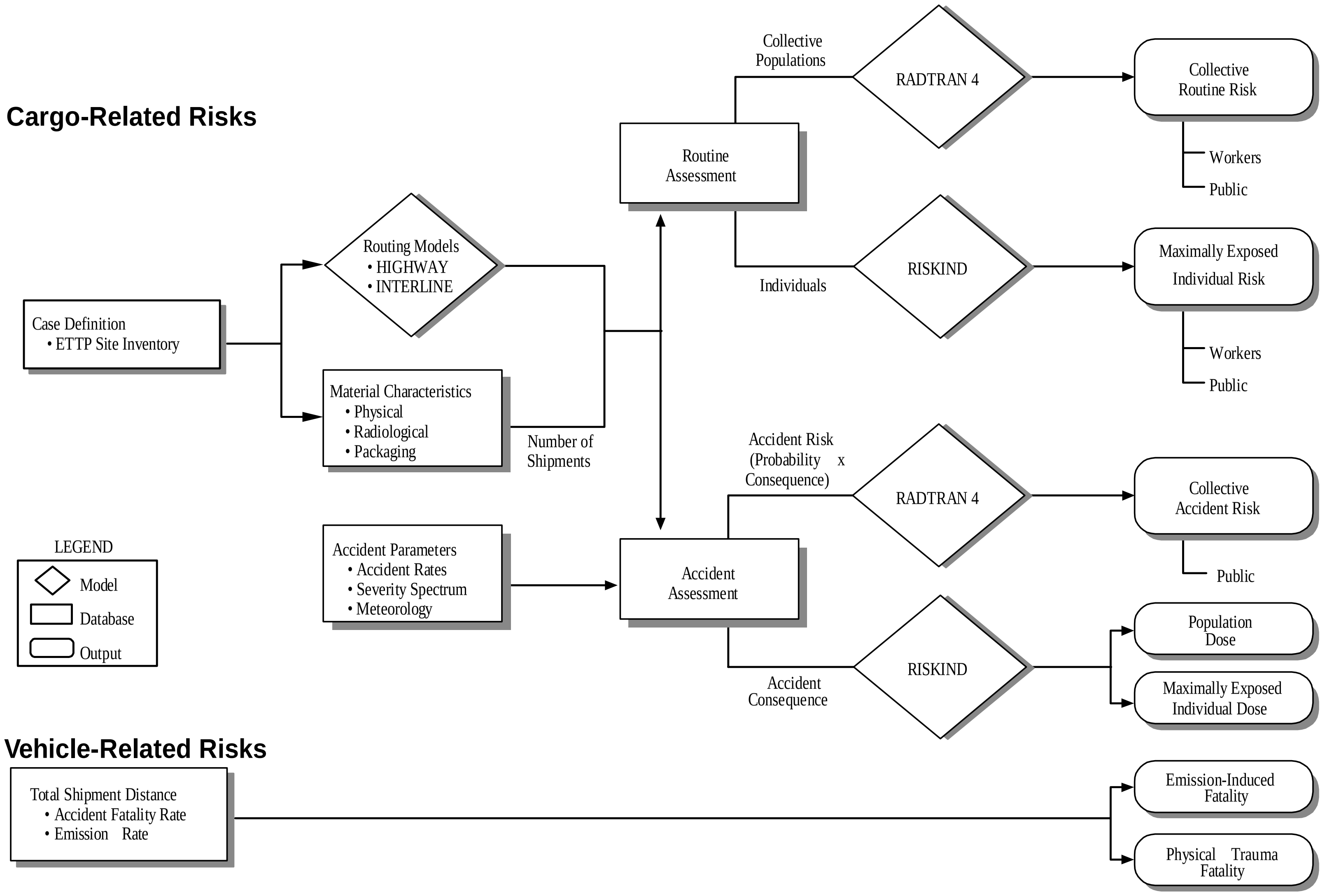

FIGURE 4.1 Technical Approach for the Radiological Component of the UF_6 Cylinder Transportation Risk Assessment

address “what if” questions, such as, “What if I live next to a site access road?” or “What if an accident happens near my town?”

4.1.2 Chemical Impacts

In contrast to the radioactive hazards of materials, the chemical hazards do not pose cargo-related risks to humans during routine transportation-related operations. Transportation operations are generally well regulated with respect to packaging, such that small spills or seepages during routine transport are kept to a minimum and do not result in exposures. With respect to chemical hazards, the cargo-related impacts to human health during transportation would be caused by exposure occurring as a result of container failure and chemical release during an accident (i.e., a collision with another vehicle or road obstacle). Therefore, chemical risks (i.e., risks that result from the toxicology of the chemical composition of the material transported) are assessed only for cargo-related transportation accidents. The chemical risk from transportation-related accidents lies in the potential release, transport, and dispersion of chemicals into the environment and the subsequent exposure of people through primarily inhalation exposure.

Accidental release of UF_6 to the atmosphere would result in the formation of uranyl fluoride (UO_2F_2) and hydrogen fluoride (HF) from the reaction of UF_6 with moisture in the atmosphere. Both compounds are highly water soluble and toxic to humans.

The risks from exposure to hazardous chemicals during transportation-related accidents can be either acute (immediate impact) or latent (result in cancer that would present itself after a latency period of several years). The severity of the immediate health effects depends strongly on the toxicity and exposure concentration of the specific chemical(s) released. The severity of the immediate (i.e., acute) health effects can range from slight irritation to fatality for the exposed individuals. Neither the uranium compounds or HF are carcinogens or suspected carcinogens. Therefore, latent cancer incidences and fatalities from chemical exposure are not expected and are not assessed in this report for potential accidents.

In this assessment, two endpoints for acute health effects are assessed: potential for irreversible adverse health effects (from permanent organ damage or the impairment of everyday functions up to and including lethality) and potential for adverse effects (effects that occur at lower concentrations and tend to be mild and transient in nature) have been evaluated for the assessment of cargo-related population impacts from transportation accidents. A nonlinear, or threshold, correlation is assumed between the exposure concentration and the toxicity for the evaluation of these acute effects; that is, some low level of exposure can be tolerated without affecting health. In many cases, data on human toxicity relating acute health effects to chemical exposures do not exist. When data on toxicity in humans are not available, chemical risk estimators are derived from levels that are toxic to laboratory animals. The use of animal data to predict toxic concentrations in humans adds uncertainty to the risk estimates.

In addition to the results presented in terms of the two health endpoints described above, it is of interest to understand how they relate to potential fatalities. Exposure to HF or uranium compounds is estimated to result in fatality for approximately 1% or less of those persons experiencing irreversible adverse effects (Policastro et al. 1997).

The approach for the chemical component of the transportation risk assessment is summarized in Figure 4.2. This approach is similar to the radiological approach; however, no cargo-related impacts are assessed under routine conditions for the chemical component.

The chemical transportation accident consequence assessment relies on the FIREPLUME model (Brown et al. 1997) for both the collective population and individuals. This model predicts the downwind dispersion of chemical emissions released into the environment from a transportation accident. The model is used to predict downwind impacts at ground level for both conservative daytime conditions (class D atmospheric stability, 4-m/s wind speed) and conservative nighttime conditions (F stability, 1-m/s wind speed). The results of the predictions are used to determine areas of impacts above two threshold levels of chemical concentrations — one for adverse health effects and the other for irreversible adverse health effects. Considering the population density around the transportation route, the risk to the public can be computed. The FIREPLUME model is similar in its purpose to the RISKIND model for potential radiological releases.

4.1.3 Vehicle-Related Impacts

In addition to the cargo-related risks posed by transportation-related activities, risks are also assessed for vehicle-related causes for the same routes. These risks are independent of the nature of the cargo and would be incurred for similar shipments of any commodity. The vehicle-related risks are assessed for both routine conditions and accidents.

Vehicle-related risks during routine transportation are incremental risks caused by potential exposure to airborne particulate matter from fugitive dust and vehicular exhaust emissions. These risks are based on epidemiological data that associate mortality rates with ambient air particulate concentrations.

The vehicle-related accident risk refers to the potential for transportation-related accidents that result in injuries and fatalities due to physical trauma regardless of the nature of the cargo in the

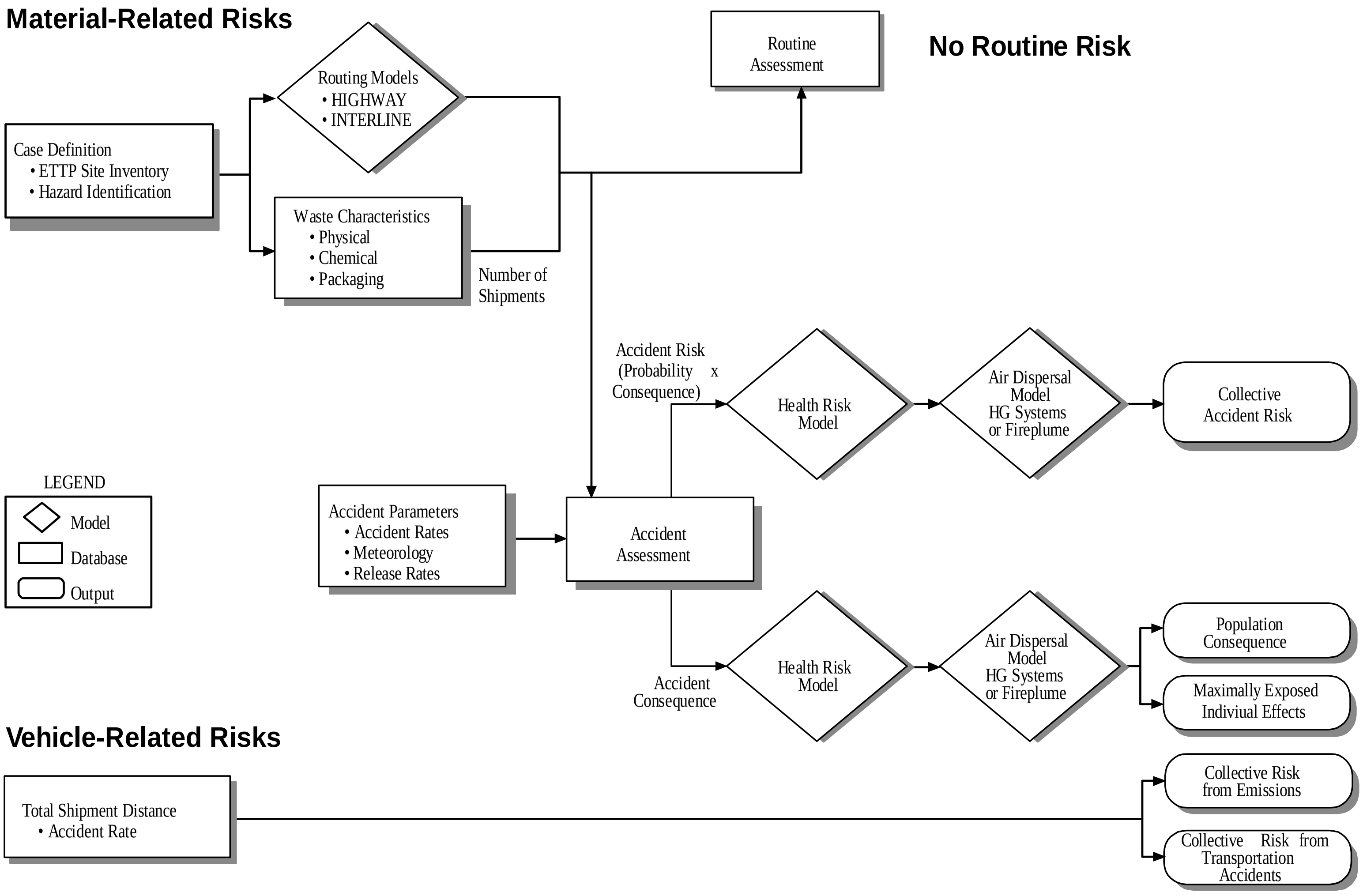

FIGURE 4.2 Technical Approach for the Chemical Component of the UF_6 Cylinder Transportation Risk Assessment

shipment. State average rates for transportation-related injuries and fatalities are used in the assessment. Vehicle-related risks are presented in terms of estimated injuries and fatalities for the truck and rail options considered.

4.2 ROUTINE RISK ASSESSMENT METHOD

4.2.1 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. No similar cargo-related risks occur from the hazardous chemical component of any shipment. 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:

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

2. *Persons Sharing the Route (On-Link Population).* Collective doses are 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.

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

4. *Crew Members*. Collective doses are calculated for truck and rail transportation crew members involved in the actual shipment of material. Workers involved in loading or unloading are 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 estimating specific risks to individuals.

The RADTRAN 4 calculations of dose for routine transport are based on generically expressing the dose rate as a function of distance from a point source (Neuhauser and Kanipe 1995). 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 1995). The values for many of the most important parameters are presented in Section 5.

4.2.2 Maximally Exposed Individual Risk

In addition to the assessment of the routine collective population risk with RADTRAN 4, RISKIND was used to estimate the risk to MEIs for a number of hypothetical exposure scenarios. The receptors included transportation crew members, departure inspectors, and members of the public exposed during traffic delays, working at a service station, or living near an origin or destination 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 1987, 1990, 1995, 1996) and are presented in Section 5. 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 using the Microshield shielding code (Negin and Worku 1992) for input into RISKIND. As a conservative measure, credit for potential shielding between the shipment and the receptor was not considered.

4.2.3 Routine Vehicle-Related Risk

Vehicle-related health risks resulting from routine transportation would be those associated with exposures to air pollutants generated by transport vehicles during shipment and are independent of the radioactive or chemical nature of the cargo being shipped. The health endpoint assessed for routine transportation conditions was the excess latent mortality caused by inhalation of vehicular emissions. Those emissions consist of particulate matter in the form of diesel engine exhaust and fugitive dust raised from the road or railway by the transport vehicle.

Risk factors, expressed in terms of latent morality, for pollutant inhalation have been generated by Biwer and Butler (1999) for transportation risk assessments. These risks are based on epidemiological data that associate mortality rates with ambient air particulate concentrations. The potential for increased latent mortality rates resulting from cardiovascular and pulmonary diseases has been linked to incremental increases in particulate air concentrations. Thus, the increased ambient air particulate concentrations caused by the transport vehicle, in the forms of fugitive dust and diesel exhaust emissions were related to such premature latent fatalities in the form of risk factors. In this report, a value of 8.36×10^{-10} latent fatalities/km for truck transport and 1.20×10^{-10} latent fatalities/railcar-km for rail transport were used. The truck value is for heavy combination trucks (truck class VIIIB). The risk factors are for areas with an assumed population density of 1 person/km^2. One-way shipment risks are obtained by multiplying the appropriate risk factor by the average population density along the route and by the route distance. The routine vehicle risks reported in this document are for round-trip travel of the transport vehicle.

The vehicle risks reported here are estimates based on the best available data. However, as is true for the radiological risks, there is a large degree of uncertainty in the vehicle emission risk factors that is not readily quantifiable. For example, large uncertainties exist as to the extent of increased mortality with an incremental rise in particulate air concentrations, and as to whether there are threshold air concentrations that are applicable. Also, estimates of the particulate air concentrations caused by transport vehicles depend on location, road conditions, vehicle conditions, and weather.

4.3 ACCIDENT ASSESSMENT METHOD

As discussed in Section 4.1.1, the radiological transportation accident risk assessment uses the RADTRAN 4 code for estimating collective population risks and the RISKIND code for estimating MEI and population consequences. The chemical transportation accident risk assessment relies on the FIREPLUME model (Brown et al. 1997) as discussed in Section 4.1.2 for both the collective population and individuals.

4.3.1 Accident Risk Assessment

The collective accident risk for each type of shipment was determined in a manner similar to that described for routine collective risks. The accident risk assessment uses state average accident rates and route-specific characteristics, such as 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 incorporate the total number of shipments over the life of the shipping campaign.

The risk analysis for potential accidents differs fundamentally from the risk analysis for routine transportation because predicting accident occurrences is statistical in nature. The accident risk assessment is treated probabilistically in RADTRAN 4 for evaluating radiological risks and in the approach used to estimate the chemical component of risk. Accident risk is defined as the product of the accident consequence (dose or exposure) and the probability of the accident's occurring. In this respect, the radiological and chemical 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").

4.3.1.1 Radiological Accident Risk Assessment

The total collective radiological accident dose risk was calculated as:

$$R_{Total} = D \times A \times \sum_{i=1,n} (P_i \times C_i) \tag{4.1}$$

where

R_{Total} = total collective dose risk for a single shipment (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 1 if the shipment occurs.

The RADTRAN 4 calculation of collective accident risk uses 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, if an accident occurs, it will be of a particular severity. 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 Section 5. The approach for chemical hazards incorporates the same accident severity categories and release fractions used with 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 1995). 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 ingestion of contaminated food.

For the pathway of ingestion, state-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 in U.S. Nuclear Regulatory Commission (NRC) Regulatory Guide 1.109 (NRC 1977a) 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).

4.3.1.2 Chemical Accident Risk Assessment

The approach used for the chemical accident risk assessment follows that used for the radiological accident risk assessment (Section 4.3.1.1). Models are used that quantify the range of potential accident severities and the responses of transported packages to accidents. The chemical accident risks incorporate the same accident rates, accident severity categories, and release fractions used in the radiological accident risk assessment. The primary difference between the radiological and chemical accident risk approaches is the modeling of the health effects consequences following exposure.

Both population risks and risks to the MEI were evaluated for transportation accidents. The acute health endpoints, potentially adverse effects and potentially irreversible adverse effects, were evaluated for the assessment of cargo-related population impacts from transportation accidents.

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 threshold concentrations were developed for potential adverse effects and potential irreversible adverse effects. All individuals exposed at these levels or higher following an accident were included in the transportation risk estimates.

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

The primary exposure route of concern with respect to accidental release of chemicals would be inhalation. Although direct exposure to chemicals by 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 (UF_6, UO_2F_2, and HF). The likelihood of acute effects would be much less for the ingestion and dermal pathways than for inhalation.

The FIREPLUME model was used to simulate the dispersion of toxic gases and particulates from transportation accidents involving UF_6 fires. The model is described in detail in Brown et al, 1997. The model can simulate three phases that UF_6 fires may undergo: the instantaneous puff that is released in a hydraulic rupture, the emissions from the continuous fire that occurs afterwards, and the emissions from the cooldown phase in which releases decline to zero as the temperature of the fire declines. FIREPLUME can predict the consequences at any downwind distance as a function of time and can determine the associated health impacts.

4.3.2 Accident Consequence Assessment

The radiological and chemical consequences of accidents — that is, the potential impacts assuming an accident has occurred — were estimated for accidents of the highest postulated severity for each shipment mode. 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. These impacts are meant to provide a general estimate of the magnitude of extremely severe, but highly unlikely accidents, not to represent consequences along specific routes.

National average population densities were used for the consequence assessment, corresponding to densities of 16 persons/mi^2 (6/km^2), 1,860 persons/mi^2 (719/km^2) and 4,150 persons/mi^2 (1,600/km^2) for rural, suburban, and urban zones, respectively. Potential impacts were estimated for the population within a 50-mi (80-km) radius, assuming a uniform population density for each zone. It is important to note that the urban population density generally applies to relatively small urbanized area — very few, if any, urban areas have a population density as high as the 4,150 persons/mi^2 (1,600/km^2) extending as far as 50 mi (80 km). The urban population density corresponds to approximately 32 million people within the 50-mi (80-km) radius, well in excess of the total populations along the routes considered in this assessment.

Moreover, to address the effects of the atmospheric conditions existing at the time of an accident, two different cases were considered. The first case assumed neutral atmospheric conditions (conservative conditions for daytime), and the second assumed stable conditions (conservative conditions for nighttime).

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 release model used for the material being transported. Only the shipment accident resulting in the highest contaminant concentration was evaluated for the MEI.

4.3.2.1 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. The accident consequence assessment was intended to provide an estimate of the potential impacts posed by a severe transportation 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. The FIREPLUME model was used to determine air concentrations of radioactive contaminants at receptor locations following a hypothetical accident. RISKIND was used to calculate the radiological impacts for the accident consequence assessment on the basis of these calculated air concentrations.

The accident consequences were calculated for both local populations and MEIs. The population dose includes the population within 50 mi (80 km) of the site of the accident. The exposure pathways considered were 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.

The nuclear properties of depleted UF_6 are such that the occurrence of a nuclear criticality is not a concern, regardless of the amount of depleted UF_6 present. However, criticality is a concern for the handling, packaging, and shipping of enriched UF_6. For enriched UF_6, criticality control is accomplished by employing, individually or collectively, specific limits on uranium-235 enrichment, mass, volume, geometry, moderation, and spacing for each type of cylinder. The amount of UF_6 that may be contained in an individual cylinder and the total number of cylinders that may be transported together are determined by the nuclear properties of enriched UF_6. Spacing of cylinders of enriched UF_6 in transit during routine and accident conditions is ensured by use of regulatory approval packages, which provide protection against impact and fire. Consequently, because of these controls and the relatively small number of shipments containing enriched UF_6, the occurrence of an inadvertent criticality is not considered to be credible and therefore is not analyzed in the accident consequence assessment conducted for this report.

4.3.2.2 Chemical Accident Consequence Assessment

The FIREPLUME model was used to predict the consequences of transportation accidents involving fires. The FIREPLUME model is described in Section 4.3.1.2.

Assessment of transportation accidents involving solid materials uses a respirable aerosols emission approach to calculate the direct release of particulates to the atmosphere. This method is the same approach used for the radiological transportation risk assessment and uses the same mass, aerosol, and respirable release fractions.

Because predicting the exact location of a severe transportation-related accident is impossible, separate accident consequences are 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 cases are considered. The first case assumes neutral atmospheric conditions, and the second assumes stable conditions. Atmospheric conditions are further discussed in Section 5.

4.3.3 Maximally Exposed Individual Risk Assessment

4.3.3.1 Radiological Maximally Exposed Individual Risk

RISKIND is used to estimate the radiological dose to MEIs in the vicinity of the hypothetical severe transportation accidents. The location of the MEI is determined by the FIREPLUME model on the basis of the atmospheric conditions assumed at the time of the accident and the thermal characteristics of the release. The MEI is assumed to be present during the entire passage of the radioactive plume. The dose calculation considers inhalation, cloudshine, and groundshine for a period of two hours following the accident. No ingestion dose is considered.

4.3.3.2 Chemical Maximally Exposed Individual Risk

The MEI for chemical risks is considered to be located at the point of highest chemical concentration accessible to the general public. This location is assumed to be 100 ft (30 m) or farther from the release point (the closest distance to a residence from the middle of the roadway or farther if contaminant ground-level air concentrations are higher farther away). Only the shipment accident resulting in the highest chemical concentration is evaluated for the MEI. To evaluate the MEI for each health endpoint, the primary factors considered are a combination of chemical potency, quantity released, and vapor plume dispersion, as reflected by the chemical concentrations in air predicted by the FIREPLUME model.

4.3.4 Vehicle-Related Accident Risk Assessment

The vehicle-related accident risk refers to the potential for transportation-related accidents that cause injuries and fatalities (from trauma) that are not related to the cargo in the shipment. This risk represents impacts from mechanical causes. State-average rates for transportation-related injuries and fatalities are used in the assessment and are discussed in Section 5. Vehicle-related accident risks are calculated by multiplying the total distance traveled by the occurrence rate for transportation-related injuries and fatalities. In all cases, the vehicle-related accident risks are calculated on the basis of the distances for round-trip shipment.

4.4 ENVIRONMENTAL JUSTICE ASSESSMENT

An analysis was conducted to examine the possibility that minorities or low-income populations would be disproportionately affected if any impacts were to occur within the transportation corridors. Minorities are defined as the total population less the number of non-Hispanic whites. The federal poverty level is the basis for identifying the low-income population.

For the evaluation of potential environmental justice impacts, 1990 Census data are used to develop information for minorities and low-income populations (U.S. Bureau of the Census 1992, 1993). To identify potentially affected populations, the Census block groups lying within a zone extending 0.5 mi (0.8 km) on either side of the road or railway are first identified. Where block group areas are only partially within this zone, the proportion of their total land area lying within the zone is assumed to also represent the proportion of the block group population residing within the zone. The percentages of minorities and low-income populations along each route are compared to state averages to determine if possible environmental justice issues exist.

5 RISK ASSESSMENT INPUT PARAMETERS AND ASSUMPTIONS

The transportation risk assessment is designed to ensure — through uniform and judicious selection of models, data, and assumptions — that relative comparisons of risk between the truck and rail options are meaningful and that potential shipment impacts are not underestimated. This goal is accomplished by uniformly applying to each option the input parameters and assumptions common to the material transported and selecting conservative parameter values where uncertainty exists. The principal input parameters and assumptions used in the transportation risk assessment are discussed in this section.

5.1 SHIPMENT CONFIGURATIONS AND SOURCE TERMS

5.1.1 Depleted UF_6 Cylinder Shipments

For the purpose of this assessment, all depleted UF_6 cylinders were assumed to contain 12 metric tons of depleted UF_6. A total of 4,683 depleted UF_6 cylinders (DOE 1999b) were assumed to require shipment. Because approximately one-third of the cylinders stored at ETTP are 9-metric ton cylinders, these assumptions result in an overestimate of potential accident risks.

The depleted UF_6 cylinders were assumed to be shipped on dedicated truck-trailers or railcars according to current practice. One cylinder per truck shipment or four cylinders per railcar were assumed. This assumption results in a total of 4,683 truck shipments or 1,171 railcar shipments. The average radiological source terms (curies per shipment) used in the accident calculations for truck and rail shipments were taken from the DUF_6 PEIS (DOE 1999b) and are summarized in Table 5.1.

Rail shipments both by general freight service and by dedicated rail were evaluated. The differences between the two rail modes affects only the routine radiological risk portion of the risk assessment. General freight shipments spend more time in railroad classification yards than do dedicated shipments, thereby increasing the routine external dose to railroad workers and the general population surrounding the railroad yards when the shipment contains radioactive materials. Even if general freight trains were to be used, the radiological transportation risk from shipping depleted uranium materials by rail would remain very low (Section 6).

If more than one railcar were to be used in an actual train shipment, such as in a dedicated train, the number of shipments would be correspondingly reduced, but the overall accident-related transportation risk estimated for this assessment remains the same. As discussed in Section 5.3.3.2, the rail accident rates used in this assessment are based on units of railcar-kilometers, irrespective of whether the actual shipment consists of more than one railcar containing depleted UF_6 cylinders. However, the cumulative collective radiological routine risks would decrease if dedicated, rather than regular, train service were used because less time would be spent in rail classification yards. Additional discussion of rail accident rates and the relationship to regular and dedicated train service is given in Section 5.3.

TABLE 5.1 Average Source Terms Assumed for Depleted UF_6 Cylinder Shipments

	Average Shipment Inventory (Ci/shipment)	
Radionuclide	Truck	Rail
Uranium-234	0.509	2.04
Uranium-235	0.0479	0.192
Uranium-238	2.77	11.08
Thorium-234	2.77	11.08
Protactinium-234m	2.77	11.08

Source: DOE (1999b).

5.1.2 Non-DU Cylinder Shipments

The determination of the number of shipments required to transport the non-DU cylinders from ETTP is not as straightforward as that for depleted UF_6 cylinders because of the wide variety of cylinder types present and the presence of uranium enriched to different assays. For this assessment, the number of non-DU shipments required was estimated by evaluating the contents of each of the 2,394 cylinders and applying the following criteria:

- Cylinders that contain an enrichment assay greater than 1% must be overpacked according to current DOT regulations.

- Weight limit for transportation of cylinders is 80,000 lb (36,000 kg) gross weight of the vehicle plus cargo for domestic transportation.

- Only four or five fissile-30 series cylinders greater than 1% enrichment can be carried on either a truck trailer or train car on the basis of weight, enrichment, and weight of the overpack.

The calculation of the estimated number of non-DU shipments for both truck and train is provided in Webber (2001); a summary of that number is provided in Table 5.2. The average radiological source terms for the non-DU shipments were calculated on the basis of the enrichment assay and amount of UF_6 in each cylinder and the estimated number of shipments. For each cylinder type, the activities (curies) of uranium-234, uranium-235, and uranium-238 were calculated for each cylinder and then averaged over the estimated total number of shipments for that cylinder type. Separate overall averages were calculated for non-overpacked and overpacked cylinders for both truck and train shipments. Details of these calculations are provided in Monette (2001). The average source terms used in accident calculations are summarized in Table 5.3.

TABLE 5.2 Estimated Number of Non-DU Cylinder Shipments

	Number of Shipments	
Shipment Type	If Truck	If Rail
Non-overpacked cylinders (< 1% U-235 enrichment)	105	69
Overpacked cylinders (> 1% U-235 enrichment)	377	100
Empty cylinders	18	12
Total	500	181

Source: Webber (2001).

TABLE 5.3 Average Source Terms (Ci/shipment) Assumed for Non-DU Cylinder Shipments

	Average Shipment Inventory (Ci/shipment)			
	Non-Overpacked Cylinders		Overpacked Cylinders	
Radionuclide	Truck	Rail	Truck	Rail
Uranium-234	0.156	0.176	0.0724	0.0969
Uranium-235	0.00747	0.00841	0.00355	0.00475
Uranium-238	0.156	0.176	0.0195	0.0256
Thorium-234	0.156	0.176	0.0195	0.0256
Protactinium-234m	0.156	0.176	0.0195	0.0256

Source: Monette (2001).

5.2 EXTERNAL DOSE RATES

The dose (and, correspondingly, the risk) to populations during routine transportation of radioactive materials is directly proportional to the assumed external dose rate from the shipment. The actual dose rate from the shipment is a complex function of the composition and configuration of shielding and containment materials used in the packaging, the geometry of the loaded shipment, and the characteristics of the radioactive material itself.

In the DUF_6 PEIS, representative shipment dose rates were developed using the MicroShield™ shielding code (Negin and Worku 1992). The input to MicroShield™ consisted of the activity of a material, the geometry and composition of the shipping package, and the amount of material in the package, as provided in the engineering analysis report (LLNL et al. 1997). When multiple packages per shipment were assumed, a dose rate for the shipment was derived by the addition of the individual package dose rates, taking into consideration the configuration of the packages on the transport vehicle and the relative distances to a receptor.

Table 5.4 lists the external dose rates developed for the DUF_6 PEIS and used in this transportation analysis. The dose rates are presented in terms of the transport index (TI), which is the dose rate at 3.3 ft (1 m) from the lateral sides of the transport vehicle. The regulatory limit established in 49 CFR Part 173 and 10 CFR Part 71 to protect the public is 10 mrem/h at 6.6 ft (2 m) from the side of the transport vehicle. For depleted UF_6 shipments, the estimated dose rates at 3.3 ft (1 m) from a truck shipment or the side of a loaded railcar were approximately 0.46 mrem/h and 0.50 mrem/hr, respectively (DOE 1999b). These dose rates are 3% percent or less of the allowed maximum value. For shipments in overpacks, it was estimated that the dose rate would be decreased by a factor of about one-half, resulting in dose rates of 0.23 and 0.24 mrem/h for truck and railcar shipments, respectively.

For shipments of non-DU cylinders, the external dose rates were calculated from historical information provided in Webber (2001). It was conservatively assumed that the dose rate at 1 m from non-DU cylinders would be 1 mrem/h for cylinders without overpacks, and 0.5 mrem/h for cylinders in overpacks (see Table 5.4). On the basis of the historical information, it is believed that these values will overestimate the incident-free dose from non-DU cylinder shipments.

TABLE 5.4 General RADTRAN Input Parameters[a]

		Train	
Parameter	Truck[b]	Regular[b]	Dedicated
No. of crew	2	5	5
Distance from source to crew (m)	3.1	152	21[c]
No. of cylinders per shipment			
DU shipments	1	4	16
Non-DU shipments	Variable	Variable	Variable
Package size (m)	3.8	15	15
Transport index (mrem/h at 1 m)			
DU cylinders; transfer option	0.46	0.50	0.50
DU cylinders; overpack option	0.23	0.24	0.24
Non-DU cylinders; no overpacks	1.0	1.0	1.0
Non-DU cylinders; in overpacks	0.50	0.50	0.50
Average vehicular speed (km/h)			
Rural	88.49	64.37	64.37
Suburban	40.25	40.25	40.25
Urban	24.16	24.16	24.16
Minimum time in classification yards (h)[d]	----	60	2[e]
Stop time (h/km)	0.011	0.033	0.004[e]
No. of people exposed while stopped	50	100	100
Distance for exposure while stopped (m)	20	20	20
No. of people per vehicle sharing route	2	3	3
Population densities (persons/km^2)[f]			
Risk assessment	Route specific	Route specific	Route specific
Accident consequence assessment	6	719	1,600
One-way traffic count (vehicles/h)			
Rural	470	1	1
Suburban	780	5	5
Urban	2,800	5	5

[a] Accident conditional probabilities are listed by severity category in Table 5.6; accident release fractions are given in Table 5.7.

[b] Source: DOE (1999b).

[c] Accounts for idler car.

[d] Accounts for time spent in classification yards at the start and end of shipments.

[e] Source: Ostmeyer (1986).

[f] Route-specific population densities are listed in Table 5.5 in Section 5.3.

5.3 SHIPMENT ROUTES

The total potentially exposed population along a route and the expected frequency of transportation-related accidents depend on the specific transportation route selected for a shipment. For truck and rail transportation, the route characteristics most important to the transportation risk assessment include the total shipping distance between each origin-and-destination pair of sites (ETTP to either Portsmouth or Paducah) and the fractions of travel in rural, suburban, and urban zones of population density. Federal regulations do not place route restrictions on the movement of UF_6 cylinders on U.S. highways or railroads.

For each shipment mode, representative shipment routes were identified by using the routing models HIGHWAY 3.3 (Johnson et al. 1993a) for truck shipments and INTERLINE 5.10 (Johnson et al. 1993b) for rail shipments. The routes were selected to be reasonable and consistent with routing regulations and general practice, but are considered representative because the actual routes used would be chosen in the future, often by the carrier near the time of the shipment. The predicted routes used in this assessment were benchmarked for reasonableness by comparison with historical routes used by carriers of radioactive material.

5.3.1 Truck Route (HIGHWAY 3.3)

The HIGHWAY 3.3 computer program (Johnson et al. 1993a) is used for predicting highway routes for transporting radioactive materials by truck within the United States. The HIGHWAY database is a computerized road atlas that describes at least 240,000 mi (386,243 km) of roads. This database includes a complete description of the interstate highway system and of all U.S. highways. In addition, most principal state highways and many local and community highways are identified. The code is updated periodically to reflect current road conditions and has been compared with reported mileages and observations of commercial trucking firms.

Routes are calculated within the model by minimizing the total impedance between origin and destination. The impedance is basically defined as a function of distance and driving time along a particular segment of highway. The population densities along a route are derived from 1990 census data from the U.S. Bureau of the Census.

The HIGHWAY database version used in this assessment was HW-94.1. Listings of the truck routes between the ETTP and the Portsmouth and Paducah sites are given in Appendix A. Highway route data are summarized in Table 5.5.

TABLE 5.5 Summary Route Data

Parameter	ETTP to Portsmouth	ETTP to Paducah
Total distance (miles)		
Truck	373	309
Rail	427	512

	Population Zone			Population Zone		
	Rural	Suburban	Urban	Rural	Suburban	Urban
Fraction of travel in zone						
Truck	74.2	25.1	0.7	79.6	19.0	1.4
Rail	76.1	21.6	2.3	87.7	10.6	1.8
Average population density in zone (persons/km^2)						
Truck	21.3	263.8	1,864	12.9	287.4	2,343
Rail	16.2	363.6	2,101	17.9	302.5	2,101

5.3.2 Rail Route (INTERLINE 5.10)

The INTERLINE computer program (Johnson et al. 1993b) is designed to simulate routing of the U.S. rail system. The INTERLINE database consists of 94 separate subnetworks and represents various competing rail companies in the United States. The database used by INTERLINE was originally based on data from the Federal Railroad Administration and reflected the U.S. railroad system in 1974. The database has been expanded and modified over the past two decades. The code is updated periodically to reflect current track conditions and has been compared with reported mileages and observations of commercial rail firms.

The INTERLINE 5.10 model uses a shortest route algorithm that finds the path of minimum impedance within an individual subnetwork. A separate method is used to find paths along the subnetworks. The route chosen for this study used the standard assumptions in the INTERLINE model that simulate the process of selection that railroads would use to direct shipments. The population densities along a route are derived from 1990 census data.

INTERLINE rail network 13.00 (3/13/98 version) was used in this assessment. Listings of the railroad routes between the ETTP and the Portsmouth and Paducah sites are given in Appendix A. Rail route summary data are provided in Table 5.5.

5.3.3 Route Characteristics

5.3.3.1 Population Density

As previously indicated, three population density zones — rural, suburban, and urban — were used for the population risk assessment. The fractions of travel and average population density in each zone were determined with the HIGHWAY and INTERLINE routing models. Rural, suburban, and urban areas are characterized according to the following breakdown: rural population densities range from 0 to 139 persons/mi^2 (0 to 54 persons/km^2); the suburban range is 140 to 3,326/mi^2 (55 to 1,284/km^2); and urban covers all population densities greater than 3,326/mi^2 (1,284/km^2). Occurrence of the three population density zones is based on an aggregation of the 12 population density zones provided in the HIGHWAY and INTERLINE model outputs. For calculation purposes, information about population density was generated at the state level and used as RADTRAN input for all routes. Route average population densities are given in Table 5.5.

National average population densities were used for the accident consequence assessment, corresponding to densities of 16 persons/mi^2 (6/km^2), 1,860 persons/mi^2 (719/km^2), and 4,150 persons/mi^2 (1,600/km^2) for rural, suburban, and urban zones, respectively. Potential impacts were estimated for the population within a 50-mi (80-km) radius, assuming a uniform population density for each zone. It is important to note that the urban population density generally applies to relatively small urbanized area, very few (if any) urban areas have a population density as high as the 4,150 persons/mi^2 extending as far as 50 mi. That urban population density corresponds to approximately 32 million people within the 50-mi radius, well in excess of the total populations along the routes considered in this assessment.

5.3.3.2 Accident Rates

To calculate accident risks, vehicle accident involvement, injury rates, and fatality rates were taken from data provided in Saricks and Tompkins (1999). For each transport mode, accident rates are generically defined as the number of accident involvements (injuries, fatalities) in a given year per unit of travel of that mode in the same year. Therefore, the rate is a fractional value — the accident-involvement count is the numerator, and vehicular activity (total traveled distance) is the denominator. Accident rates are derived from multiple-year averages that automatically account for such factors as heavy traffic and adverse weather conditions. For assessment purposes, the total number of expected accidents, injuries, or fatalities was calculated by multiplying the total shipping distance for a specific case by the appropriate accident, injury, or fatality rate.

For truck transportation, the rates presented in Saricks and Tompkins (1999) are specifically for heavy combination trucks involved in interstate commerce. Heavy combination trucks are rigs composed of a separable tractor unit containing the engine and one to three freight trailers connected to each other and the tractor. Heavy combination trucks are typically used for shipping radioactive wastes. Truck accident rates are computed for each state on the basis of statistics compiled by the DOT Office of Motor Carriers for 1994 to 1996. Saricks and Tompkins (1999) present accident involvement and injury and fatality counts, estimated kilometers of travel by state, and the corresponding average accident involvement, fatality, and injury rates for the 3 years investigated. Fatalities (including of crew members) are deaths attributable to the accident that occurred any time within 30 days of the accident.

Rail accident rates are computed and presented similarly to truck accident rates in Saricks and Tompkins (1999); however, for rail transport, the unit of haulage is the railcar. State-specific rail accident involvement and injury and fatality rates per railcar-kilometer are based on statistics compiled by the Federal Railroad Administration for 1994 to 1996. Rail accident rates include both mainline accidents and those occurring in rail yards.

The truck accident assessment presented in this report uses accident (injury, fatality) rates for travel on interstate highways. The total accident risk for a case depends on the total distance traveled in various states and does not rely on national average accident statistics. However, for comparative purposes, the national average truck accident rate on interstate highways presented in Saricks and Tompkins (1999) is 3.15×10^{-7} accidents/truck-km (5.07×10^{-7} accidents/mi).

For the rail accident assessment, accident (injury, fatality) rates by state also are used from Saricks and Tompkins (1999). For comparison, the national average railcar accident rate is 2.74×10^{-7} accidents/km (4.41×10^{-7} accidents/mi). National average injury and fatality rates are 1.17×10^{-7} injuries/railcar-km (1.88×10^{-7} injuries/railcar-mi) and 7.82×10^{-8} fatalities/railcar-km (1.26×10^{-7} fatalities/railcar-km).

The accident rates used in this assessment were computed on the basis of all interstate shipments, regardless of the cargo. Saricks and Kvitek (1994) point out that shippers and carriers of radioactive material generally have a higher-than-average awareness of transportation risk and prepare cargoes and drivers for such shipments accordingly. This preparation should have the twofold effect of reducing component and equipment failure and mitigating the contribution of human error to accident causation. However, these effects were not considered in the accident assessment.

5.4 ACCIDENT CHARACTERISTICS

Results of the transportation accident risk assessment depend on the fraction of material in a package that would be released or spilled to the environment during an accident, commonly referred to as the release fraction. The release fraction is a function of the severity of the accident and the material packaging; for instance, a low-impact accident, such as a "fender-bender," would not be expected to cause any release of material. Conversely, a very severe accident would be expected to release nearly all of the material in a shipment into the environment. The method used to characterize accident severities and the corresponding release fractions for estimating both radioactive and chemical risks are described here.

5.4.1 Accident Severity Categories

A method to characterize the potential severity of transportation-related accidents is described in an NRC report commonly referred to as NUREG-0170 (NRC 1977b). The NRC method divides the spectrum of transportation accident severities into 8 categories. Other studies have divided the same accident spectrum into 6 categories (Wilmot 1981) and into 20 categories (Fischer et al. 1987); however, these other studies focused primarily on accidents involving shipments of spent nuclear fuel and, thus, are not directly applicable to this assessment.

The NUREG-0170 scheme for accident classification is shown in Figures 5.1 and 5.2 for truck and rail transportation, respectively. Severity is described as a function of the magnitudes of the mechanical forces (impact) and thermal forces (fire) to which a package may be subjected during an accident. Because all accidents can be described in these terms, severity is independent of the specific accident sequence. In other words, any sequence of events that results in an accident in which a package is subjected to forces within a certain range of values is assigned to the accident severity category associated with that range. The scheme for accident severity is designed to take into account all credible transportation-related accidents, including accidents with low probability but high consequences and those with high probability but low consequences.

Each severity category represents a set of accident scenarios defined by a combination of mechanical and thermal forces. A conditional probability of occurrence — that is, the probability that if an accident occurs, it is of a particular severity — is assigned to each category. The fractional occurrences for accidents by the accident severity category and the population density zone are shown in Table 5.6 and were used for estimating both radioactive and chemical risks.

Category I accidents are the least severe but the most frequent, whereas Category VIII accidents are very severe but very infrequent. To determine the expected frequency of an accident of a given severity, the conditional probability in the category is multiplied by the baseline accident rate. Each population density zone has a distinct distribution of accident severities related to differences in average vehicular velocity, traffic density, and other factors, including location (rural, suburban, or urban).

For the accident consequence assessment, the impacts were assessed for populations and individuals by assuming occurrence of an accident of severity Category VIII. This accident severity

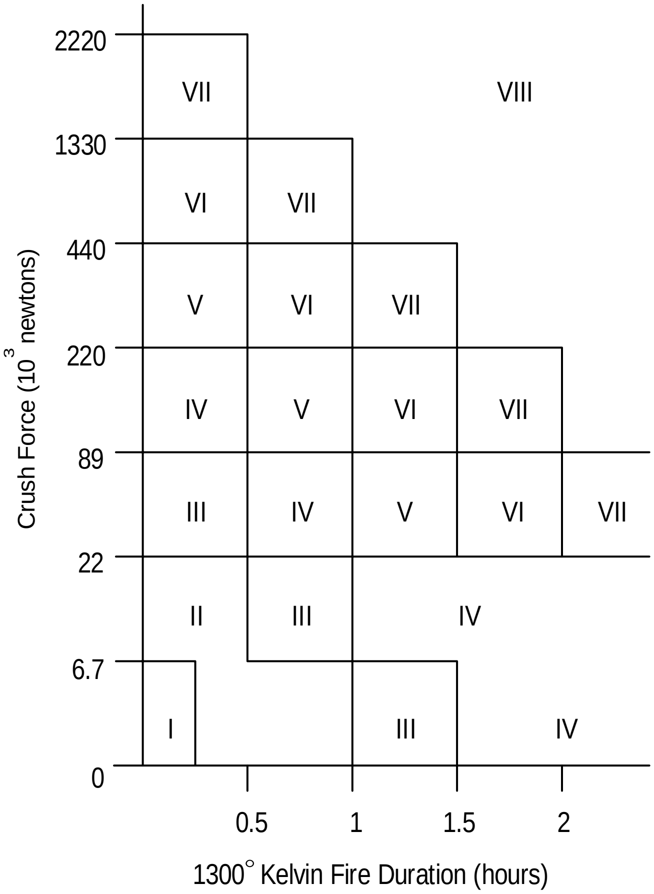

FIGURE 5.1 Scheme for NUREG-0170 Classification by Accident Severity Category for Truck Accidents (Source: NRC 1977b)

category represents the most severe accident scenarios that can be postulated that would result in the largest release of hazardous material. Accidents of this severity are extremely rare, occurring approximately once in every 70,000 truck or 100,000 rail accidents involving a shipment of radioactive material. On the basis of national accident statistics (Saricks and Tompkins 1999), for every 1 mi (1.6 km) of loaded shipment, the probability of an accident of this severity is 3×10^{-12} for shipment by truck and 3×10^{-12} for shipment by rail.

5.4.2 Package Release Fractions

Radiological and chemical consequences are calculated by assigning package release fractions to each accident severity category. The release fraction is defined as the fraction of the material in a package that could be released from the package as the result of an accident of a given severity. Release fractions take into account all mechanisms necessary to cause release of material

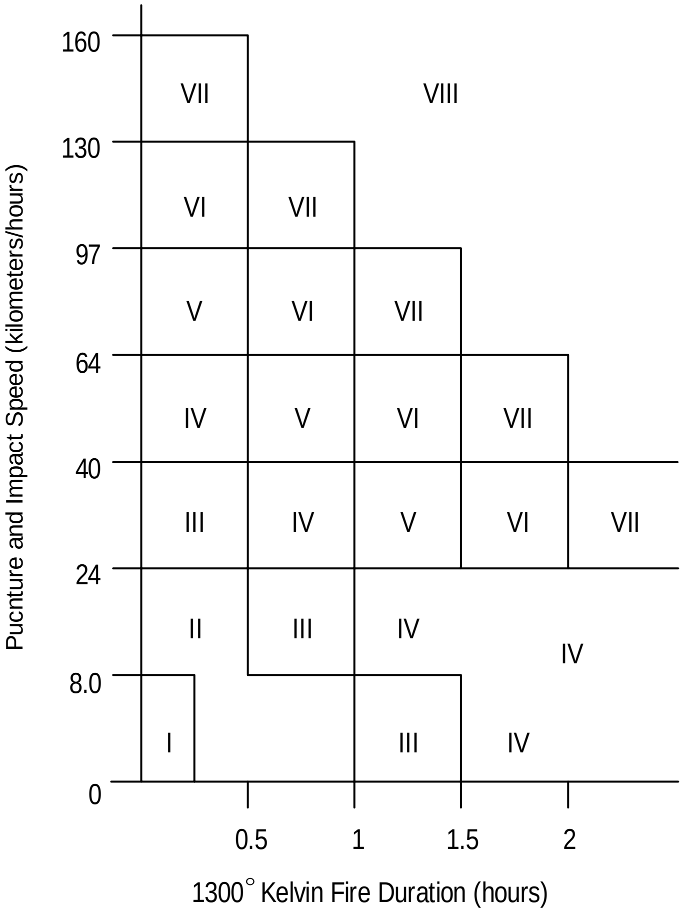

FIGURE 5.2 Scheme for NUREG-0170 Classification by Accident Severity Category for Rail Accidents (Source: NRC 1977b)

from a damaged package to the environment. Release fractions vary according to the type of package and the physical form of the material.

Representative release fractions for accidents involving UF_6 shipments were taken from NUREG-0170 (NRC 1977b). The recommendations in NUREG-0170 are based on best engineering judgments and have been shown to provide conservative estimates of material releases following accidents. The release fractions used are those reported in NUREG-0170 for both LSA drums and NRC Type A packages. Release fractions for accidents of each severity category are given in Table 5.7. As shown in the table, the amount of material released from the packaging ranges from zero for minor accidents to 100% for the most severe accidents.

Also important for the purposes of risk assessment are the fraction of the released material that can be entrained in an aerosol (part of an airborne contaminant plume) and the fraction of the aerosolized material that is also respirable (of a size that can be inhaled into the lungs). These

TABLE 5.6 Fractional Occurrences for Accidents by Severity Category and Population Density Zone

Severity Category	Fractional Occurrence	Fractional Occurrence by Population Density Zone: Rural	Suburban	Urban
Truck				
I	0.55	0.1	0.1	0.8
II	0.36	0.1	0.1	0.8
III	0.07	0.3	0.4	0.3
IV	0.016	0.3	0.4	0.3
V	0.0028	0.5	0.3	0.2
VI	0.0011	0.7	0.2	0.1
VII	8.5×10^{-5}	0.8	0.1	0.1
VIII	1.5×10^{-5}	0.9	0.05	0.05
Rail				
I	0.50	0.1	0.1	0.8
II	0.30	0.1	0.1	0.8
III	0.18	0.3	0.4	0.3
IV	0.018	0.3	0.4	0.3
V	0.0018	0.5	0.3	0.2
VI	1.3×10^{-4}	0.7	0.2	0.1
VII	6.0×10^{-5}	0.8	0.1	0.1
VIII	1.0×10^{-5}	0.9	0.05	0.05

Source: NRC (1977b).

fractions depend on the physical form of the material. Most solid materials are difficult to release in particulate form and are, therefore, relatively nondispersible. Conversely, liquid or gaseous materials are relatively easy to release if the container is compromised in an accident. The aerosolized fraction for the UF_6 was taken to be 0.01 except in the case of higher severity accidents (Categories VI through VIII) involving fire, where it was taken to be 0.33 (Policastro et al. 1997). The respirable fraction was taken to be 1 for all accidents.

5.4.3 Atmospheric Conditions during Accidents

Hazardous material released to the atmosphere is transported by the wind. The amount of dispersion, or dilution, of the contaminant material in the air depends on the meteorologic conditions at the time of the accident. Because predicting the specific location of an off-site transportation-related accident is impossible, generic atmospheric conditions were selected for the accident risk and consequence assessments.

For the accident risk assessment, neutral weather conditions were assumed; these conditions were represented by Pasquill stability Class D with a wind speed of 9 mph (4 m/s). Because neutral meteorological conditions constitute the most frequently occurring atmospheric stability condition in the United States, these conditions are most likely to be present if an accident occurs involving a hazardous material shipment. Observations at National Weather Service surface meteorological stations from more than 300 U.S. locations indicate that on a yearly average, neutral conditions (represented by Pasquill Classes C and D) occur about half (50%) the time, while stable conditions (Pasquill Classes E and F) occur about one-third (33%) of the time, and unstable conditions (Pasquill Classes A and B) occur about one-sixth (17%) of the time (Doty et al. 1976). The neutral category predominates in all seasons, but is most prevalent (nearly 60% of the observations) during winter.

TABLE 5.7 Estimated Release Fractions for LSA Drums and Type A Packages under Various Accident Severity Categories

Severity Category	Release Fraction[a]
I	0
II	0.01
III	0.1
IV	1
V	1
VI	1
VII	1
VIII	1

[a] Values are for total material release fraction (the fraction of material in a package released to the environment during an accident).

Source: NRC (1977b).

For the accident consequence assessment, doses were assessed under neutral atmospheric conditions (Pasquill Stability Class D with a wind speed of 9 mph [4 m/s]) and stable conditions (Pasquill Stability Class F with a wind speed of 2.2 mph [1 m/s]). The results calculated for neutral conditions represent the most likely consequences, and the results for stable conditions represent a "worst case" weather situation in which the least amount of dilution is evident with the highest air concentrations of radioactive material.

5.5 RADIOLOGICAL MAXIMALLY EXPOSED INDIVIDUAL RECEPTOR ASSUMPTIONS

The radiological risk to MEIs has been estimated for a number of hypothetical exposure scenarios for UF_6 cylinder shipments. The receptors include crew members, departure inspectors, and members of the public exposed during traffic obstructions (traffic jams), while working at a service station, or by living near a conversion site. The dose and risk to MEIs were calculated for given distances and durations of exposure. The distances and durations of exposure for each receptor are similar to those given in previous transportation assessments (DOE 1987, 1990, 1995, 1996, 1997). The scenarios for exposure are not meant to be exhaustive but were selected to provide a range of potential situations for exposure. The assumptions for exposure scenarios are as follows:

- *Crew Members*. Truck and rail crew members are assumed to be occupational radiation workers and would be monitored by a dosimetry program. Therefore, the maximum allowable dose would be 5 rem/yr. As an administrative procedure, the DOE limits doses to DOE workers to 2 rem/yr (DOE 1999).

- *Inspectors (Truck and Rail).* Inspectors are assumed to be either federal or state vehicle inspectors. Inspectors are not assumed to be monitored by a dosimetry program. An average exposure distance of 10 ft (3 m) and an exposure duration of 30 minutes are assumed.

- *Resident (Truck and Rail).* A resident is assumed to live 98 ft (30 m) from a site entrance route (truck or rail). Shipments pass at an average speed of 15 mph (24 km/h), and the resident is exposed unshielded. Cumulative doses are assessed for each site on the basis of the number of shipments entering or exiting the site, with the assumption that the resident is present for 100% of the shipments.

- *Person in Traffic Obstruction (Truck and Rail).* A person is assumed to be stopped next to a UF_6 cylinder shipment (e.g., because of traffic slowdown). The person is assumed to be exposed unshielded at a distance of 3.3 ft (1 m) for 30 minutes.

- *Person at Truck Service Station*. A person is assumed to be exposed at an average distance of 66 ft (20 m) for a duration of two hours. This receptor could be a worker at a truck stop.

- *Resident near a Rail Stop.* A resident is assumed to live near a rail classification yard. The resident is assumed to be exposed unshielded at a distance of 656 ft (200 m) for 20 hours.

The largest uncertainty in predicting the dose to MEIs during transportation involves determining the frequency of exposures. This difficulty results from the uncertainties in future shipment schedules and route selection and from the uncertainty inherent in predicting the frequency of random or chance events. For instance, that an individual may be stopped in traffic next to a shipment of UF_6 is conceivable; however, predicting how often the same individual would experience this event is difficult. Therefore, for the majority of receptors considered, doses are assessed on a per-event basis. To account for possible multiple exposures, ranges of realistic total doses are discussed qualitatively. One exception is the calculation of the dose to a hypothetical resident living near an entrance route to a conversion site. For such residents, total doses are calculated on the basis of the number of shipments entering or exiting each site for each case.

5.6 CHEMICAL HEALTH EFFECTS ENDPOINTS

To estimate the consequences of chemical accidents, two potential health effects endpoints were evaluated: (1) adverse effects and (2) irreversible adverse effects. Potential adverse effects range from mild and transient effects — such as respiratory irritation, redness of the eyes, and skin rash — to more serious and potentially irreversible effects. Potential irreversible adverse effects are defined as effects that generally occur at higher concentrations and are permanent in nature — including death, impaired organ function (such as damaged central nervous system or lungs), and other effects that may impair everyday functions.

For uranium compounds, an intake of 10 mg or more was assumed to cause potential adverse effects (McGuire 1991), and an intake of 30 mg or more was assumed to cause potential irreversible adverse effects. These intake levels are based on NRC guidance (NRC 1994). For hydrogen fluoride (HF), potential adverse effects levels were assumed to occur at levels that correspond to Emergency Response Planning Guideline No. 1 (ERPG-1) or equivalent levels, and potential irreversible adverse effects levels were assumed to occur at levels that correspond to ERPG-2 or equivalent levels. The ERPG values have been generated by teams of toxicologists who review all published (as well as some unpublished) data for a given chemical (AIHA 1996). Additional information concerning the hazardous chemical response levels is provided in Appendix C of the DUF_6 PEIS (DOE 1999b).

5.7 GENERAL RISK ASSESSMENT CRITERIA

5.7.1 Radiological

In addition to the specific parameters discussed previously, values for a number of general parameters must be specified within the RADTRAN code to calculate radiological risks. These general parameters define basic characteristics of the shipment and traffic and are specific to the mode of transportation. The user's manual for the RADTRAN code (Neuhauser and Kanipe 1992) contains derivations and descriptions of these parameters. The general RADTRAN input parameters used in the radiological transportation risk assessment are summarized in Table 5.4.

5.7.2 Chemical

Application of the FIREPLUME code involves the choice of a number of parameters that affect the results. Examples are surface roughness, which was chosen as 4 in. (10 cm), which is thought to be representative of a generic site. The U.S. Environmental Protection Agency (EPA) uses that roughness length as a representative value. Values below 10 cm lead to less mixing and numbers greater than 10 cm lead to additional mixing and dilution. The FIREPLUME model runs also require a simulation of the meteorology represented by D stability 9 mph (4 m/s) and F stability 2.2 mph (1 m/s). Choices of Monin-Obukhov length and friction velocity were made to represent reasonable simulation of these conditions without being too conservative. More details about those models and input parameters are presented in Post et al. (1994a,b) and Brown et al. (1997).

6 RISK ASSESSMENT RESULTS

The estimated potential environmental impacts from transportation of UF_6 cylinders are presented in this section for shipments from ETTP to the Portsmouth and Paducah sites. Potential impacts for the shipment of depleted UF_6 cylinders are presented in Section 6.1; potential impacts for the shipment of non-DU cylinders are presented in Section 6.2. As discussed in Section 4, the impacts of transportation were calculated in three areas: (1) collective population risks during routine conditions and accidents, (2) radiological risks to MEIs during routine conditions, and (3) consequences to individuals and populations after the most severe accidents involving a release of UF_6. Shipments of cylinders by both truck and rail were assessed.

6.1 DEPLETED UF_6 CYLINDER SHIPMENTS

6.1.1 Collective Population Risk

The collective population risk is a measure of the total risk posed to society as a whole by the actions being considered. For a collective population risk assessment, the persons exposed are considered as a group, without specifying individual receptors. The collective population risk is used as the primary means to compare various options. Collective population risks are calculated from both vehicle- and cargo-related causes for routine transportation and accidents. Vehicle-related risks are independent of the cargo in the shipment and include risks from vehicular exhaust emissions and traffic accidents (injuries and fatalities caused by physical trauma).

Estimates of the collective population risks for single depleted UF_6 shipments are presented in Tables 6.1 and 6.2[3] for the cylinder transfer and cylinder overpack options, respectively. Note that the two cylinder preparation options differ only in the radiological risks during routine transportation conditions; this is because the overpack was estimated to reduce the external dose rate by approximately a factor of 2, but not affect the performance of the cylinder during accident conditions.

The total collective population risks for shipment of the entire ETTP inventory (4,683 cylinders) are presented in Table 6.3 for the cylinder transfer option and in Table 6.4 for the cylinder overpack option. Annual impacts would depend on the duration of the shipping campaign and can be computed by dividing the total risk by the campaign duration. No fatalities are expected as a result of the shipping campaign because all estimated collective fatality risks are much less than 0.5. The estimated radiation doses from the shipments are much less than levels expected to cause

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[3] For reader convenience, all the tables referred to in Section 6 are at the end of the section.

an appreciable increase in the risk of cancer in crew members and the public. The highest fatality risks are from vehicle-related causes, with the risks for truck shipments being higher than for rail. The vehicle-related risks are not related to the nature of the cargo. In general, risks are slightly lower for shipments to Paducah compared to Portsmouth, although the risks are small in both cases and the difference is minimal.

For rail transport, accident rates (as used to estimated the radiological and chemical accident risks below) can be derived for an entire train or a single railcar. In either case, the number of accidents estimated for a shipping campaign would be approximately the same whether using dedicated trains or general freight trains because most accidents are the result of railcar derailment (DOT 1997). However, the apportionment of injuries and fatalities on a railcar or train basis is not straightforward. Most fatalities are the result of the lead locomotive involved in a collision, while the remainder occur in rail switching yards. While the railcar injury and fatality rates in Saricks and Tompkins (1999) are based on an average train length of approximately 68 railcars, it is not statistically defensible to multiply the rail injury or fatality results in Tables 6.1 to 6.4 by the average number of railcars in a train (68) and then divide by the number of railcars in the unit train to obtain a train-based rate. Thus, the number of injuries and fatalities expected for a shipping campaign involving dedicated train shipments is expected to be larger than the estimates in Tables 6.1 through 6.4. The results may vary depending on the number of railcars per shipment and could be higher than the truck estimates.

The highest radiological risks are for routine transport by general train (0.031 crew LCFs) followed by truck (0.010 crew LCFs) and dedicated train (6.5×10^{-5} LCFs). In RADTRAN, rail crew risks are calculated for railcar inspectors in rail yards. During transport, members of the rail crew are assumed to be shielded completely by the locomotive(s) and any intervening railcars. Thus, the dedicated train radiological risks are much lower than those for general train shipments because the dedicated train shipments spend less time in rail yards for classification purposes. The radiological risks from accidents are approximately 10 times lower than those for routine transport.

No chemical impacts would occur under normal transport conditions because the package contents are assumed to remain confined. Chemical accident risks for the entire shipping campaign would be negligible for any transport option. No adverse effects (4×10^{-6} or less) or irreversible adverse effects (3×10^{-6} or less) are expected.

6.1.2 Maximally Exposed Individuals during Routine Conditions

During the routine transportation of radioactive material, specific individuals may be exposed to radiation in the vicinity of a shipment. RISKIND has been used to estimate the risk to these individuals for a number of hypothetical exposure-causing events. The receptors include transportation crew members, inspectors, and members of the public exposed during traffic delays, while working at a service station, or while living near a origin or destination site. The assumptions about exposure are given in Section 5.5. The scenarios for exposure are not meant to be exhaustive but instead were selected to provide a range of representative potential exposures. Doses were assessed and are presented in Table 6.5 on a per-event basis for the cylinder transfer option — no attempt is made to estimate the frequency of exposure-causing events.

The highest potential routine radiological exposure to an MEI, with a latent cancer fatality risk of 1×10^{-7}, would be for a person stopped in traffic near a shipment for 30 minutes at a distance of 3.3 ft (1 m). There is also the possibility for multiple exposures. For example, if an individual lived near either the ETTP, Portsmouth, or Paducah sites and all shipments were made by truck, the resident could receive a combined dose of approximately 2.5×10^{-5} rem if present for all shipments (calculated as the product of 4,683 shipments and an estimated exposure per shipment of 5.4×10^{-9} rem). However, this dose is still very low, approximately 10,000 times lower than the individual average annual exposure of 0.3 rem from natural background radiation. Truck inspectors would receive a higher dose per shipment (6.3×10^{-5} rem/event) than the hypothetical resident and might also be exposed to multiple shipments. If the same inspector were present for all shipments, that person would receive a combined dose of approximately 0.3 rem distributed over the duration of the shipping campaign, about the same as would be received from an average annual exposure to natural background radiation. Note that for the overpack option, incident-free risks to the MEIs would be approximately one-half those values listed in Table 6.5.

6.1.3 Accident Consequence Assessment

Whereas the collective accident risk assessment considers the entire range of accident severities and their related probabilities, the accident consequence assessment assumes that an accident of the highest severity category (Category VIII) has occurred. The consequences, in terms of committed dose (rem) and latent-cancer fatalities for radiological impacts and in terms of adverse affects and irreversible adverse effects for chemical impacts, were calculated for both exposed populations and individuals in the vicinity of an accident. Tables 6.6 and 6.7 present the radiological and chemical consequences, respectively, to the population from severe accidents involving shipment of depleted UF_6. Tables 6.8 and 6.9 present the radiological and chemical consequences, respectively, to the MEI from severe accidents involving shipment of depleted UF_6.

Severe rail accidents could have higher consequences than truck accidents because each railcar would carry four cylinders, compared with only one for each truck. The accident estimated to have the greatest potential consequences would be a severe rail accident involving four cylinders. The consequences of such an accident were estimated on the basis of the assumption that the accident occurred in an urban area under stable weather conditions (such as at nighttime). In such a case, it was estimated that approximately four persons might experience irreversible adverse effects (such as lung or kidney damage) from exposure to HF and uranium. The number of fatalities expected following an HF or uranium chemical exposure is expected to be somewhat less than 1% of the potential irreversible adverse effects. Thus, no fatalities would be expected (1% of 4). Over the long term, radiation effects are possible from exposure to the uranium released. In a highly populated urban area, it was estimated that about 3 million people could be exposed to small amounts of uranium as it was dispersed by the wind. Among those exposed, it was estimated that approximately 60 LCFs could occur in the urban population in addition to those occurring from all other causes. For comparison, in a population of 3 million people, approximately 700,000 would be expected to die of cancer from all causes.

The occurrence of a severe rail accident breaching four cylinders in an urban area under stable weather conditions would be expected to be rare. The consequences of cylinder accidents occurring in rural environments, during unstable weather conditions (typical of daytime) or involving a truck shipment, were also assessed. The consequences of all other accident conditions were estimated to be considerably less than those described above for the severe urban rail accident. Impacts from a potential severe accident could lead to fatalities from both radiological and chemical effects.

Since the consequence results are based on the premise of an all-engulfing fire, the results for rail may be conservative because all four cylinders on a railcar were assumed to be involved. Also, the results for dedicated and general trains are estimated to be similar for the same reason; the involvement of all the cylinders on more than one railcar is expected to be highly unlikely.

6.2 NON-DU CYLINDER SHIPMENTS

6.2.1 Collective Population Risk

Estimates of the collective population risks for single non-DU cylinder shipments are presented in Tables 6.10 and 6.11 for shipments to Portsmouth and Paducah, respectively. The total collective population risks for shipment of the entire ETTP inventory (2,394 non-DU cylinders) are presented in Table 6.12. Annual impacts would depend on the duration of the shipping campaign and can be computed by dividing the total risk by the campaign duration.

On a per-shipment basis, the radiological risks during routine transportation would be slightly higher for non-DU shipments than for DUF_6 cylinder shipments because a higher external dose rate (TI) was assumed for the non-DU shipments. Conversely, radiological accident risks per shipment would be much less for the non-DU shipments than for the depleted UF_6 cylinder shipments. This is because the average uranium content per non-DU cylinder shipment is much less than that for a depleted UF_6 cylinder shipment: the *total* amount of UF_6 in the 2,394 non-DU cylinders is 25 metric tons, compared with approximately 12 metric tons in *each* depleted UF_6 cylinder.

In general, the total potential impacts from radiological and vehicular causes would be small for the shipment of non-DU cylinders; no fatalities are expected as a result of the shipping campaign because all estimated collective fatality risks are much less than 0.5. Overall, the estimated total impacts from non-DU shipments are about a factor of 10 less than the total impacts from depleted UF_6 cylinder shipments (primarily because of the difference in the numbers of shipments).

As for depleted UF_6 cylinder shipments, the highest fatality risks for non-DU shipments would be from vehicle-related causes, with risks being higher for truck shipments than for rail. The vehicle-related risks are not related to the nature of the cargo. In general, risks are slightly lower for shipments to Paducah than to Portsmouth because of the shorter distance to Paducah, although the risks are small in both cases, and the difference is minimal.

Because of the much lower quantity of uranium in the non-DU shipments compared with depleted UF_6 shipments, the chemical impacts associated with the shipment of the non-DU cylinders would be expected to be insignificant and were not evaluated.

6.2.2 Maximally Exposed Individuals during Routine Conditions

For MEIs, radiological doses and risks were assessed and are presented in Table 6.13 on a per-event basis for the shipment of non-DU cylinders — no attempt is made to estimate the frequency of exposure-causing events.

On a per-shipment basis, the radiological risks to an MEI during routine transportation would be slightly higher for non-DU shipments than for depleted UF_6 cylinder shipments because a higher external dose rate (TI) was assumed. The highest potential routine radiological exposure to an MEI, with a latent cancer fatality risk of 3×10^{-7}, would be for a person stopped in traffic near a shipment for 30 minutes at a distance of 3.3 ft (1 m). There is also the possibility for multiple exposures. For example, if an individual lived near either the ETTP, Portsmouth, or Paducah sites and all non-DU shipments were made by truck, that person could receive a combined dose of approximately 1.0×10^{-5} rem if present for all shipments (calculated as the product of 500 shipments and an estimated exposure per shipment of 2.0×10^{-8} rem). However, this dose is still very low, approximately 10,000 times lower than the individual average annual exposure of 0.3 rem from natural background radiation. Truck inspectors would receive a higher dose per shipment (1.4×10^{-4} rem/event) than the hypothetical resident and might also be exposed to multiple shipments. If the same inspector were present for all shipments, that person would receive a combined dose of approximately 0.07 rem distributed over the duration of the shipping campaign, much less than the average annual exposure to natural background radiation.

6.2.3 Accident Consequence Assessment

Because the average uranium content of each non-DU cylinder shipment is much less than that for a depleted UF_6 cylinder shipment (the *total* amount of UF_6 in the 2,394 non-DU cylinders is 25 metric tons, compared to approximately 12 metric tons in *each* DUF_6 cylinder), a separate accident consequence assessment was not conducted for non-DU cylinder shipments. The potential impacts of the highest consequence accidents for non-DU cylinder shipments would be much less than those presented in Table 6.7 for depleted UF_6 shipments.

6.3 ENVIRONMENTAL JUSTICE ISSUES

An analysis was conducted to examine the possibility that minorities or low-income populations would be disproportionately affected if any adverse impacts were to occur within the transportation corridors. Minorities are defined as the total of all non-White populations. These include four racial categories (Black, American Indian and Eskimo, Asian and Pacific Islanders, and other) and one ethnic category (Hispanic). Hispanics may be of any race. This definition was used because of data limitations at the block level and can overstate the minority population in situations where Hispanics who identify in one of the non-White racial categories comprise a substantial portion of the population. This does not appear to be the case in the areas evaluated. Persons with income less than the federal poverty level for 1990 are identified as the low-income population.

1990 Census data for block groups within a transportation corridor extending one-half mile (0.8 km) on either side of the road or railway were used to develop the information in Tables 6.14 through 6.17. To identify potentially affected populations, the Census block groups lying within the zone were first identified. Where block group areas were only partially within this zone, the proportion of their total land area lying within the zone was assumed to also represent the proportion of the block group population residing within the zone.

The transportation routes from ETTP to Portsmouth, Ohio, cross three states: Tennessee, Kentucky, and Ohio. Comparisons of population characteristics were conducted for each state segment of the transportation route. In all three states, the minority percentage of the population in the transportation corridor is lower than or close to the statewide percentage (Table 6.14). In Ohio, where the corridor percentage minority is higher for truck transport than the state level, it is less than 2% higher. In contrast, the low-income population percentages in the corridors are generally slightly higher than the statewide percentages with one exception (Table 6.15). On average, approximately 27% of the population near the truck route in Ohio is low income, compared with the statewide average of approximately 13%. Differences from the state levels are greater for truck transport than for rail.

The transportation routes from ETTP to Paducah, Kentucky, cross Tennessee and Kentucky. As shown in Tables 6.16 and 6.17, population characteristics are compared for each state segment of the transportation route. In both states, the minority percentage of the population in the transportation corridor ranges from lower than to substantially larger than the statewide percentage (Table 6.16). The low-income population percentages in the corridors are also slightly to substantially larger than the statewide percentages (Table 6.17). The pattern of percentage elevation in the population categories relative to the state as a whole differs between Kentucky and Tennessee and occurs for both rail and truck transport.

Because the overall risk is small for any of the transport options considered (i.e., no fatalities are expected), no disproportionate impacts to minorities or low-income populations are expected. However, if the scope of the proposed action were to increase (e.g., if more material was to be shipped or more individual shipments were to be made than have been assumed for this assessment), a closer examination of the environmental justice impacts would be required.

6.4 SUMMARY OF TRANSPORTATION OPTION IMPACTS

The greatest risk from transportation of UF_6 cylinders would result from vehicle-related hazards, that is, potential fatalities caused by the physical trauma received during transportation accidents and by exposure to vehicle emissions, independent of the material transported. This risk would increase directly with the number of shipments and shipment distance. However, this risk is small; no vehicle-related fatalities were estimated for the entire shipping campaign for truck or rail transport.

The overall transportation risk resulting from the radioactive characteristics of the transported material would also be small, generally less than one-tenth of the risk from vehicle-related causes for a given shipment. The overall transportation risk resulting from the chemical characteristics of the transported material would be very small, generally five orders of magnitude (a factor of 100,000) less than the risk from vehicle-related causes for most shipments.

In general, rail transportation would result in a slightly lower overall risk than truck transportation for the same amount of material, due primarily to higher rail shipment capacities and therefore fewer shipments. Dedicated rail shipments would result in lower radiological impacts because of less time spent in rail classification yards, but their use could lead to slightly higher injuries and fatalities because of the increase of the number of trains on the route. However, the risks for all modes are low and their differences are within the limits of uncertainty of the calculations.

The potential exists for low-probability, severe transportation accidents that could lead to potential fatalities. The accidents with the largest potential consequences would be rail accidents involving depleted UF_6 cylinder shipments occurring during unfavorable weather conditions in an urban environment. Up to 60 LCFs and 4 irreversible adverse effects were estimated to be possible. These impacts are discussed in Section 6.1.3. Such accidents would be considered highly unlikely.

TABLE 6.1 Depleted UF_6 Cylinder Single-Shipment Collective Population Impacts: Cylinder Transfer Option

	ETTP to Portsmouth			ETTP to Paducah		
Impact	Truck	General Train[a]	Dedicated Train[a]	Truck	General Train[a]	Dedicated Train[a]
Cargo-related[b]						
Radiological impacts						
Dose risk (person-rem)						
Routine crew	5.39×10^{-3}	0.0668	1.39×10^{-4}	4.29×10^{-3}	0.0718	1.50×10^{-4}
Routine public						
Off-link	5.81×10^{-5}	9.78×10^{-4}	9.78×10^{-4}	5.23×10^{-5}	7.26×10^{-4}	7.26×10^{-4}
On-link	1.67×10^{-4}	3.73×10^{-5}	3.73×10^{-5}	1.47×10^{-4}	2.93×10^{-5}	2.93×10^{-5}
Stops	1.60×10^{-3}	1.14×10^{-3}	6.56×10^{-5}	1.32×10^{-3}	1.00×10^{-3}	6.08×10^{-5}
Total	1.82×10^{-3}	2.16×10^{-3}	1.08×10^{-3}	1.52×10^{-3}	1.76×10^{-3}	8.16×10^{-4}
Accident[c]	4.86×10^{-5}	1.76×10^{-5}	1.76×10^{-5}	2.34×10^{-5}	1.25×10^{-5}	1.25×10^{-5}
Latent cancer fatalities[d]						
Crew	2×10^{-6}	3×10^{-5}	6×10^{-8}	2×10^{-6}	3×10^{-5}	6×10^{-8}
Public	9×10^{-7}	1×10^{-6}	6×10^{-7}	8×10^{-7}	9×10^{-7}	4×10^{-7}
Chemical impacts						
Adverse effects	7.4×10^{-10}	8.1×10^{-11}	8.1×10^{-11}	3.5×10^{-10}	5.0×10^{-11}	5.0×10^{-11}
Irreversible adverse effects[e]	5.3×10^{-10}	6.2×10^{-11}	6.2×10^{-11}	2.5×10^{-10}	3.9×10^{-11}	3.9×10^{-11}

TABLE 6.1 (Cont.)

	ETTP to Portsmouth			ETTP to Paducah		
Impact	Truck	General Train[a]	Dedicated Train[a]	Truck	General Train[a]	Dedicated Train[a]
Vehicle-related[f]						
Emission fatalities	5×10^{-5}	1×10^{-5}	1×10^{-5}	4×10^{-5}	8×10^{-6}	8×10^{-6}
Accident injuries	2.2×10^{-4}	5.5×10^{-5}	5.5×10^{-5}	1.3×10^{-4}	6.8×10^{-5}	6.8×10^{-5}
Accident fatalities	1.4×10^{-5}	2.4×10^{-5}	2.4×10^{-5}	1.1×10^{-5}	2.5×10^{-5}	2.5×10^{-5}

[a] Risks are presented on a railcar basis. One shipment is equivalent to one railcar. See discussion in text concerning potential differences in vehicle-related impacts for general freight and dedicated train shipments.

[b] Cargo-related impacts are impacts attributable to the radioactive or chemical nature of the material being transported.

[c] Dose risk is a societal risk and is the product of accident probability and accident consequence.

[d] Latent cancer fatalities are calculated by multiplying dose by the ICRP Publication 60 health risk conversion factors of 4×10^{-4} fatal cancers per person-rem for workers and 5×10^{-4} for the public (ICRP 1991).

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

[f] Vehicle-related impacts are impacts independent of the cargo in the shipment.

TABLE 6.2 Depleted UF_6 Cylinder Single-Shipment Collective Population Impacts: Cylinder Overpack Option

Impact	ETTP to Portsmouth			ETTP to Paducah		
	Truck	General Train[a]	Dedicated Train[a]	Truck	General Train[a]	Dedicated Train[a]
Cargo-related[b]						
Radiological impacts						
Dose risk (person-rem)						
Routine crew	2.70×10^{-3}	0.0320	6.68×10^{-5}	2.14×10^{-3}	0.0345	7.18×10^{-5}
Routine public						
Off-link	2.90×10^{-5}	4.69×10^{-4}	4.69×10^{-4}	2.62×10^{-5}	3.48×10^{-4}	3.48×10^{-4}
On-link	8.37×10^{-5}	1.79×10^{-5}	1.79×10^{-5}	7.33×10^{-5}	1.41×10^{-5}	1.41×10^{-5}
Stops	7.99×10^{-4}	5.48×10^{-4}	3.15×10^{-5}	6.62×10^{-4}	4.81×10^{-4}	2.92×10^{-5}
Total	9.11×10^{-4}	0.00104	5.19×10^{-4}	7.62×10^{-4}	8.43×10^{-4}	3.92×10^{-4}
Accident[c]	4.86×10^{-5}	1.76×10^{-5}	1.76×10^{-5}	2.34×10^{-5}	1.25×10^{-5}	1.25×10^{-5}
Latent cancer fatalities[d]						
Crew	1×10^{-6}	3×10^{-5}	3×10^{-8}	9×10^{-7}	1×10^{-5}	3×10^{-8}
Public	5×10^{-7}	5×10^{-7}	3×10^{-7}	4×10^{-8}	4×10^{-8}	2×10^{-7}
Chemical impacts						
Adverse effects	7.4×10^{-10}	8.1×10^{-11}	8.1×10^{-11}	3.5×10^{-10}	5.0×10^{-11}	5.0×10^{-11}
Irreversible adverse effects[e]	5.3×10^{-10}	6.2×10^{-11}	6.2×10^{-11}	2.5×10^{-10}	3.9×10^{-11}	3.9×10^{-11}

TABLE 6.2 (Cont.)

Impact	ETTP to Portsmouth			ETTP to Paducah		
	Truck	General Train[a]	Dedicated Train[a]	Truck	General Train[a]	Dedicated Train[a]
Vehicle-related[f]						
Emission fatalities	5×10^{-5}	1×10^{-5}	1×10^{-5}	4×10^{-5}	8×10^{-6}	8×10^{-6}
Accident injuries	2.2×10^{-4}	5.5×10^{-5}	5.5×10^{-5}	1.3×10^{-4}	6.8×10^{-5}	6.8×10^{-5}
Accident fatalities	1.4×10^{-5}	2.4×10^{-5}	2.4×10^{-5}	1.1×10^{-5}	2.5×10^{-5}	2.5×10^{-5}

[a] Risks are presented on a railcar basis. One shipment is equivalent to one railcar. See discussion in text concerning potential differences in vehicle-related impacts for general freight and dedicated train shipments.

[b] Cargo-related impacts are impacts attributable to the radioactive or chemical nature of the material being transported.

[c] Dose risk is a societal risk and is the product of accident probability and accident consequence.

[d] Latent cancer fatalities are calculated by multiplying dose by the ICRP Publication 60 health risk conversion factors of 4×10^{-4} fatal cancers per person-rem for workers and 5×10^{-4} for the public (ICRP 1991).

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

[f] Vehicle-related impacts are impacts independent of the cargo in the shipment.

TABLE 6.3 Depleted UF_6 Cylinders, Collective Population Impacts for All Shipments: Cylinder Transfer Option

	ETTP to Portsmouth			ETTP to Paducah		
Impact	Truck	General Train[a]	Dedicated Train[a]	Truck	General Train[a]	Dedicated Train[a]
Shipment summary						
Shipments	4,683	1,171	1,171	4,683	1,171	1,171
Mileage (10^6 mi)	1.75	0.500	0.500	1.4	0.599	0.599
Population impacts						
Cargo-related[b]						
Radiological impacts						
Dose risk (person-rem)						
Routine crew	25.2	78.2	0.163	20.1	84.1	0.176
Routine public						
Off-link	0.272	1.15	1.15	0.245	0.850	0.850
On-link	0.782	0.0437	0.0437	0.688	0.0343	0.0343
Stops	7.49	1.33	0.0768	6.18	1.17	0.0712
Total	8.52	2.53	1.26	7.12	2.06	0.956
Accident[c]	0.228	0.0206	0.0206	0.110	0.0146	0.0146
Latent cancer fatalities[d]						
Crew	0.01	0.03	7×10^{-5}	0.008	0.03	7×10^{-5}
Public	4×10^{-3}	1×10^{-3}	6×10^{-4}	4×10^{-3}	1×10^{-3}	5×10^{-4}
Chemical impacts						
Adverse effects	3.5×10^{-6}	9.5×10^{-8}	9.5×10^{-8}	1.6×10^{-6}	5.9×10^{-8}	5.9×10^{-8}
Irreversible adverse effects[e]	2.5×10^{-6}	7.3×10^{-8}	7.3×10^{-8}	1.2×10^{-6}	4.6×10^{-8}	4.6×10^{-8}

TABLE 6.3 (Cont.)

Impact	ETTP to Portsmouth			ETTP to Paducah		
	Truck	General Train[a]	Dedicated Train[a]	Truck	General Train[a]	Dedicated Train[a]
Vehicle-related[f]						
Emission fatalities	0.2	0.01	0.01	0.2	0.01	0.01
Accident injuries	1.0	0.064	0.064	0.61	0.080	0.080
Accident fatalities	0.066	0.028	0.028	0.052	0.029	0.029

[a] Risks are presented on a railcar basis. One shipment is equivalent to one railcar. See discussion in text concerning potential differences in vehicle-related impacts for general freight and dedicated train shipments.

[b] Cargo-related impacts are impacts attributable to the radioactive or chemical nature of the material being transported.

[c] Dose risk is a societal risk and is the product of accident probability and accident consequence.

[d] Latent cancer fatalities are calculated by multiplying dose by the ICRP Publication 60 health risk conversion factors of 4×10^{-4} fatal cancers per person-rem for workers and 5×10^{-4} for the public (ICRP 1991).

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

[f] Vehicle-related impacts are impacts independent of the cargo in the shipment.

TABLE 6.4 Depleted UF_6 Cylinders, Collective Population Impacts for All Shipments: Cylinder Overpack Option

	ETTP to Portsmouth			ETTP to Paducah		
Impact	Truck	General Train[a]	Dedicated Train[a]	Truck	General Train[a]	Dedicated Train[a]
Shipment summary						
Shipments	4,683	1,171	1,171	4,683	1,171	1,171
Mileage (10^6 mi)	1.75	0.500	0.500	1.4	0.599	0.599
Population impacts						
Cargo-related[b]						
Radiological impacts						
Dose risk (person-rem)						
Routine crew	12.6	37.5	0.0782	10.0	40.4	0.0841
Routine public						
Off-link	0.136	0.549	0.549	0.123	0.408	0.408
On-link	0.392	0.0210	0.0210	0.343	0.0165	0.0165
Stops	3.74	0.642	0.0369	3.10	0.563	0.0342
Total	4.27	1.22	0.608	3.57	0.987	0.459
Accident[c]	0.228	0.0206	0.0206	0.110	0.0146	0.0146
Latent cancer fatalities[d]						
Crew	0.005	0.01	3×10^{-5}	0.004	0.02	3×10^{-5}
Public	0.002	6×10^{-4}	3×10^{-4}	0.002	5×10^{-4}	2×10^{-4}
Chemical impacts						
Adverse effects	3.5×10^{-6}	9.5×10^{-8}	9.5×10^{-7}	1.6×10^{-6}	5.9×10^{-8}	5.9×10^{-8}
Irreversible adverse effects[e]	2.5×10^{-6}	7.3×10^{-8}	7.3×10^{-8}	1.2×10^{-6}	4.6×10^{-8}	4.6×10^{-8}

TABLE 6.4 (Cont.)

	ETTP to Portsmouth			ETTP to Paducah		
Impact	Truck	General Train[a]	Dedicated Train[a]	Truck	General Train[a]	Dedicated Train[a]
Vehicle-related[f]						
Emission fatalities	0.2	0.01	0.01	0.2	0.01	0.01
Accident injuries	1.0	0.064	0.064	0.61	0.080	0.080
Accident fatalities	0.066	0.028	0.028	0.052	0.029	0.029

[a] Risks are presented on a railcar basis. One shipment is equivalent to one railcar. See discussion in text concerning potential differences in vehicle-related impacts for general freight and dedicated train shipments.

[b] Cargo-related impacts are impacts attributable to the radioactive or chemical nature of the material being transported.

[c] Dose risk is a societal risk and is the product of accident probability and accident consequence.

[d] Latent cancer fatalities are calculated by multiplying dose by the ICRP Publication 60 health risk conversion factors of 4×10^{-4} fatal cancers per person-rem for workers and 5×10^{-4} for the public (ICRP 1991).

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

[f] Vehicle-related impacts are impacts independent of the cargo in the shipment.

TABLE 6.5 Estimated Radiological Impacts to the MEI from Routine Shipment of Depleted UF_6 Cylinders

Mode	Inspector	Resident	Person in Traffic	Person at Gas Station	Person near Rail Stop
Routine Radiological Dose from a Single Shipment (rem)					
Truck	6.3×10^{-5}	5.4×10^{-9}	2.3×10^{-4}	7.5×10^{-6}	NA[a]
Rail	1.1×10^{-4}	1.5×10^{-8}	2.6×10^{-4}	NA	9.3×10^{-7}
Routine Radiological Risk from a Single Shipment (Lifetime Risk of an LCF)[b]					
Truck	3×10^{-8}	3×10^{-12}	1×10^{-7}	4×10^{-9}	NA
Rail	6×10^{-8}	8×10^{-12}	1×10^{-7}	NA	5×10^{-10}

[a] NA = not applicable.

[b] Latent cancer fatalities are calculated by multiplying dose by the ICRP Publication 60 health risk conversion factors of 4×10^{-4} fatal cancers per person-rem for workers and 5×10^{-4} for the public (ICRP 1991).

TABLE 6.6 Potential Radiological Consequences to the Population from Severe Accidents Involving Shipment of Depleted UF_6 Cylinders[a]

	Neutral Weather Conditions			Stable Weather Conditions		
Mode	Rural	Suburban	Urban[b]	Rural	Suburban	Urban[b]
Radiological Dose (person-rem)						
Truck	590	580	1,300	15,000	15,000	32,000
Rail	2,400	2,300	5,200	60,000	58,000	130,000
Radiological Risk (LCF)[c]						
Truck	0.3	0.3	0.6	7	7	20
Rail	1	1	3	30	30	60

[a] National average population densities were used for the accident consequence assessment, corresponding to densities of 6 persons/km^2, 719 persons/km^2, and 1,600 persons/km^2 for rural, suburban, and urban zones, respectively. Potential impacts were estimated for the population within a 50-mi (80-km) radius, assuming a uniform population density for each zone.

[b] It is important to note that the urban population density generally applies to relatively small urbanized area — very few, if any, urban areas have a population density as high as 1,600 persons/km^2 extending as far as 50 mi. That urban population density corresponds to approximately 32 million people within the 50-mi radius, well in excess of the total populations along the routes considered in this assessment.

[c] Latent cancer fatalities are calculated by multiplying dose by the ICRP Publication 60 health risk conversion factors of 4×10^{-4} fatal cancers per person-rem for workers and 5×10^{-4} for the public (ICRP 1991).

Source: DOE (1999b).

TABLE 6.7 Potential Chemical Consequences to the Population from Severe Accidents Involving Shipment of Depleted UF_6 Cylinders[a]

	Neutral Weather Conditions			Stable Weather Conditions		
Mode	Rural	Suburban	Urban[b]	Rural	Suburban	Urban[b]
Number of Persons with Potential for Adverse Health Effects						
Truck	0	2	4	6	760	1,700
Rail	4	420	940	110	13,000	28,000
Number of Persons with Potential for Irreversible Adverse Health Effects[c]						
Truck	0	1	2	0	1	3
Rail	0	1	3	0	2	4

[a] National average population densities were used for the accident consequence assessment, corresponding to densities of 6 persons/km^2, 719 persons/km^2, and 1,600 persons/km^2 for rural, suburban, and urban zones, respectively. Potential impacts were estimated for the population within a 50-mi (80-km) radius, assuming a uniform population density for each zone.

[b] It is important to note that the urban population density generally applies to relatively small urbanized area — very few, if any, urban areas have a population density as high as 1,600 persons/km^2 extending as far as 50 mi. That urban population density corresponds to approximately 32 million people within the 50-mi radius, well in excess of the total populations along the routes considered in this assessment.

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

Source: DOE (1999b).

TABLE 6.8 Potential Radiological Consequences to the MEI from Severe Accidents Involving Shipment of Depleted UF_6 Cylinders

	Neutral Weather Conditions		Stable Weather Conditions	
Mode	Dose (mrem)	Radiological Risk of LCF[a]	Dose (mrem)	Radiological Risk of LCF[a]
Truck	0.43	2×10^{-4}	0.91	5×10^{-4}
Rail	1.7	9×10^{-4}	3.7	2×10^{-3}

[a] Latent cancer fatalities are calculated by multiplying dose by the ICRP Publication 60 health risk conversion factors of 4×10^{-4} fatal cancers per person-rem for workers and 5×10^{-4} for the public (ICRP 1991).

Source: DOE (1999b).

TABLE 6.9 Potential Chemical Consequences to the MEI from Severe Accidents Involving Shipment of Depleted UF_6

	Neutral Weather Conditions		Stable Weather Conditions	
Mode	Adverse Effects	Irreversible Adverse Effects[a]	Adverse Effects	Irreversible Adverse Effects[a]
Truck	Yes	Yes	Yes	Yes
Rail	Yes	Yes	Yes	Yes

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

Source: DOE (1999b).

TABLE 6.10 Non-DU Cylinder Single-Shipment Collective Population Impacts: ETTP to Portsmouth

	Cylinders without Overpacks			Cylinders with Overpacks		
Impact	Truck	General Train[a]	Dedicated Train[a]	Truck	General Train[a]	Dedicated Train[a]
Cargo-related[b]						
Radiological impacts						
Dose risk (person-rem)						
Routine crew	0.0117	0.140	2.91×10^{-4}	5.86×10^{-3}	0.0699	1.46×10^{-4}
Routine public						
Off-link	3.80×10^{-4}	2.08×10^{-3}	2.08×10^{-3}	1.90×10^{-4}	1.04×10^{-3}	1.04×10^{-3}
On-link	1.09×10^{-3}	7.91×10^{-5}	7.91×10^{-5}	5.47×10^{-4}	3.96×10^{-5}	3.96×10^{-5}
Stops	0.0104	2.42×10^{-3}	1.39×10^{-4}	5.22×10^{-3}	1.21×10^{-3}	6.96×10^{-5}
Total	0.0119	4.58×10^{-3}	2.29×10^{-3}	5.96×10^{-3}	2.29×10^{-3}	1.15×10^{-3}
Accident[c]	4.85×10^{-6}	4.95×10^{-7}	4.95×10^{-7}	4.85×10^{-6}	4.95×10^{-7}	4.95×10^{-7}
Latent cancer fatalities[d]						
Crew	5×10^{-6}	6×10^{-5}	1×10^{-7}	2×10^{-6}	3×10^{-5}	6×10^{-8}
Public	6×10^{-6}	2×10^{-6}	1×10^{-6}	3×10^{-6}	1×10^{-6}	6×10^{-7}
Vehicle-related[e]						
Emission fatalities	5×10^{-5}	1×10^{-5}	1×10^{-5}	5×10^{-5}	1×10^{-5}	1×10^{-5}
Accident injuries	2.2×10^{-4}	5.5×10^{-5}	5.5×10^{-5}	2.2×10^{-4}	5.5×10^{-5}	5.5×10^{-5}
Accident fatalities	1.4×10^{-5}	2.4×10^{-5}	2.4×10^{-5}	1.4×10^{-5}	2.4×10^{-5}	2.4×10^{-5}

[a] Risks are presented on a railcar basis. One shipment is equivalent to one railcar. See discussion in text concerning potential differences in vehicle-related impacts for general freight and dedicated train shipments.

[b] Cargo-related impacts are impacts attributable to the radioactive or chemical nature of the material being transported.

[c] Dose risk is a societal risk and is the product of accident probability and accident consequence.

[d] Latent cancer fatalities are calculated by multiplying dose by the ICRP Publication 60 health risk conversion factors of 4×10^{-4} fatal cancers per person-rem for workers and 5×10^{-4} for the public (ICRP 1991).

[e] Vehicle-related impacts are impacts independent of the cargo in the shipment.

TABLE 6.11 Non-DU Cylinder Single-Shipment Collective Population Impacts: ETTP to Paducah

	Cylinders without Overpacks			Cylinders with Overpacks		
Impact	Truck	General Train[a]	Dedicated Train[a]	Truck	General Train[a]	Dedicated Train[a]
Cargo-related[b]						
Radiological impacts						
Dose risk (person-rem)						
Routine crew	9.32×10^{-3}	0.15	3.13×10^{-4}	4.66×10^{-3}	0.0752	1.57×10^{-4}
Routine public						
Off-link	3.42×10^{-4}	1.54×10^{-3}	1.54×10^{-3}	1.71×10^{-4}	7.71×10^{-4}	7.71×10^{-4}
On-link	9.59×10^{-4}	6.23×10^{-5}	6.23×10^{-5}	4.79×10^{-4}	3.11×10^{-5}	3.11×10^{-5}
Stops	8.65×10^{-3}	2.13×10^{-3}	1.29×10^{-4}	4.33×10^{-3}	1.06×10^{-3}	6.45×10^{-5}
Total	9.95×10^{-3}	3.73×10^{-3}	1.73×10^{-3}	4.98×10^{-3}	1.86×10^{-3}	8.66×10^{-4}
Accident[c]	2.34×10^{-6}	3.52×10^{-7}	3.52×10^{-7}	2.34×10^{-6}	3.52×10^{-7}	3.52×10^{-7}
Latent cancer fatalities[d]						
Crew	4×10^{-6}	6×10^{-5}	1×10^{-7}	2×10^{-6}	3×10^{-5}	6×10^{-8}
Public	5×10^{-6}	2×10^{-6}	9×10^{-7}	2×10^{-6}	9×10^{-7}	4×10^{-7}
Vehicle-related[e]						
Emission fatalities	4×10^{-5}	8×10^{-6}	8×10^{-6}	4×10^{-5}	8×10^{-6}	8×10^{-6}
Accident injuries	1.3×10^{-4}	6.8×10^{-5}	6.8×10^{-5}	1.3×10^{-4}	6.8×10^{-5}	6.8×10^{-5}
Accident fatalities	1.1×10^{-5}	2.5×10^{-5}	2.5×10^{-5}	1.1×10^{-5}	2.5×10^{-5}	2.5×10^{-5}

[a] Risks are presented on a railcar basis. One shipment is equivalent to one railcar. See discussion in text concerning potential differences in vehicle-related impacts for general freight and dedicated train shipments.

[b] Cargo-related impacts are impacts attributable to the radioactive or chemical nature of the material being transported.

[c] Dose risk is a societal risk and is the product of accident probability and accident consequence.

[d] Latent cancer fatalities are calculated by multiplying dose by the ICRP Publication 60 health risk conversion factors of 4×10^{-4} fatal cancers per person-rem for workers and 5×10^{-4} for the public (ICRP 1991).

[e] Vehicle-related impacts are impacts independent of the cargo in the shipment.

TABLE 6.12 Total Non-DU Cylinder Collective Population Impacts for All Shipments

	ETTP to Portsmouth			ETTP to Paducah		
Impact	Truck	General Train[a]	Dedicated Train[a]	Truck	General Train[a]	Dedicated Train[a]
Shipment summary						
Shipments	500	181	181	500	181	181
Mileage (10^6 mi)	0.187	0.077	0.077	0.155	0.093	0.093
Cargo-related[b]						
Radiological impacts						
Dose risk (person-rem)						
Routine crew	3.44	16.7	0.0347	2.74	17.9	0.0373
Routine public						
Off-link	0.112	0.248	0.248	0.100	0.183	0.183
On-link	0.321	9.42×10^{-3}	9.42×10^{-3}	0.281	7.41×10^{-3}	7.41×10^{-3}
Stops	3.06	0.288	0.0166	2.54	0.253	0.0154
Total	3.50	0.545	0.273	2.92	0.443	0.206
Accident[c]	2.34×10^{-3}	8.37×10^{-5}	8.37×10^{-5}	1.13×10^{-3}	5.95×10^{-5}	5.95×10^{-5}
Latent cancer fatalities[d]						
Crew	1×10^{-3}	7×10^{-3}	1×10^{-5}	1×10^{-3}	7×10^{-3}	1×10^{-5}
Public	2×10^{-3}	3×10^{-4}	1×10^{-4}	1×10^{-3}	2×10^{-4}	1×10^{-4}
Vehicle-related[e]						
Emission fatalities	0.02	2×10^{-3}	2×10^{-3}	0.02	2×10^{-3}	2×10^{-3}
Accident injuries	0.11	0.010	0.010	0.065	0.013	0.013
Accident fatalities	7.0×10^{-3}	4.3×10^{-3}	4.3×10^{-3}	5.5×10^{-3}	4.7×10^{-3}	4.7×10^{-3}

[a] Risks are presented on a railcar basis. One shipment is equivalent to one railcar. See discussion in text concerning potential differences in vehicle-related impacts for general freight and dedicated train shipments.

[b] Cargo-related impacts are impacts attributable to the radioactive or chemical nature of the material being transported.

[c] Dose risk is a societal risk and is the product of accident probability and accident consequence.

[d] Latent cancer fatalities are calculated by multiplying dose by the ICRP Publication 60 health risk conversion factors of 4×10^{-4} fatal cancers per person-rem for workers and 5×10^{-4} for the public (ICRP 1991).

[e] Vehicle-related impacts are impacts independent of the cargo in the shipment.

TABLE 6.13 Estimated Radiological Impacts to the MEI from Routine Shipment of Non-DU Cylinders

Mode	Inspector	Resident	Person in Traffic	Person at Gas Station	Person near Rail Stop
Routine Radiological Dose from a Single Shipment (rem)					
Truck	1.4×10^{-4}	2.0×10^{-8}	5.0×10^{-4}	2.7×10^{-5}	NA[a]
Rail	1.8×10^{-4}	2.5×10^{-8}	5.0×10^{-4}	NA	1.6×10^{-6}
Routine Radiological Risk from a Single Shipment (Lifetime Risk of an LCF)[b]					
Truck	9×10^{-8}	1×10^{-11}	3×10^{-7}	1×10^{-8}	NA
Rail	9×10^{-8}	1×10^{-11}	3×10^{-7}	NA	8×10^{-10}

[a] NA = not applicable.

[b] Latent cancer fatalities are calculated by multiplying dose by the ICRP Publication 60 health risk conversion factors of 4×10^{-4} fatal cancers per person-rem for workers, and 5×10^{-4} for the public (ICRP 1991).

TABLE 6.14 Percentage of Minority Groups within the Potential Transportation Corridors from ETTP to Portsmouth

State	Percentage of Minorities in State	Percentage of Minorities within Half Mile of Route	
		Truck	Rail
Tennessee	17.4	11.5	6.4
Kentucky	8.3	4.4	8.5
Ohio	12.8	14.0	12.2

TABLE 6.15 Percentage of Low-Income Population within the Potential Transportation Corridors from ETTP to Portsmouth

State	Percentage of Low-Income Population in State	Percentage of Minorities within Half Mile of Route	
		Truck	Rail
Tennessee	15.7	21.0	16.8
Kentucky	19.0	19.4	19.2
Ohio	12.5	27.1	15.8

TABLE 6.16 Percentage of Minority Groups within the Potential Transportation Corridors from ETTP to Paducah

State	Percentage of Minorities in State	Percentage of Minorities within Half Mile of Route	
		Truck	Rail
Tennessee	17.4	32.6	5.6
Kentucky	8.3	6.6	14.7

TABLE 6.17 Percentage of the Low-Income Population within the Potential Transportation Corridors from ETTP to Paducah

State	Percentage of Low-Income Population in State	Percentage of Low-Income Population within Half Mile of Route	
		Truck	Rail
Tennessee	15.7	40.4	23.6
Kentucky	19.0	20.0	38.0

7 REGULATORY CONSIDERATIONS

7.1 PURPOSE

As is explained in Section 1.3 of this report, approximately 4,700 cylinders full of depleted UF_6 are being stored at the ETTP. In addition, some stored depleted UF_6 cylinders are partially filled and a few contain only “heels.” The ETTP also stores approximately 220 cylinders that are full, partially filled, or contain only “heels” of natural UF_6, and approximately 670 cylinders that are full, partially filled, or contain only “heels” of slightly enriched UF_6.[4] All of the cylinders will eventually have to be transported off-site in a manner that complies with applicable regulatory requirements. The purpose of this section is to identify current and pending regulatory requirements applicable to packaging UF_6 for transport by truck or rail and to evaluate regulatory options for meeting the packaging requirements. This evaluation also characterizes regulatory constraints, if any.

7.2 DEPARTMENT OF ENERGY

Transportation of UF_6 (depleted, natural, or slightly enriched) from one DOE facility to another on behalf of DOE is subject to DOE Order (O) 460.1A, “Packaging and Transportation Safety,” and to the requirements of the U.S. Department of Transportation (DOT). DOE O 460.1A establishes DOE-specific requirements for the proper packaging and transportation of DOE off-site shipments and on-site transfers of hazardous materials (including radioactive materials) and for modal transport. These requirements apply to all DOE materials transportation, except classified shipments and shipments of nuclear explosives, components, and special assemblies. Regarding packaging and handling of radioactive materials, DOE O 460.1A requires that each package and shipment be prepared in compliance with DOT Hazardous Materials Regulations (HMR) (i.e., 49 CFR Parts 171 through 180).[5] Therefore, this section focuses primarily on the applicable DOT regulations, including certain standards incorporated therein by reference.

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[4] For the purpose of the regulatory discussion in this section, it is assumed that enriched uranium in the ETTP cylinders contains no more than 5 percent by weight (wt%) of the isotope U-235.

[5] In this section, citations to the *Code of Federal Regulations* (CFR) refer to the October 1, 2000, edition, unless otherwise indicated.

7.3 DEPARTMENT OF TRANSPORTATION

7.3.1 Regulations Applicable to UF_6 Packaging

UF_6 is a unique material with respect to transportation requirements because it presents hazards due to both radioactivity and corrosivity. As a result, the DOT HMR impose specific packaging requirements on UF_6, in addition to the otherwise applicable radioactive material transportation requirements.

In the HMR, the radioactive material transportation requirements are specified in 49 CFR Part 173, Subpart I, "Class 7 (Radioactive) Materials." According to this subpart, solid unirradiated natural uranium and depleted uranium (and their solid or liquid compounds or mixtures) are low–specific-activity group I (LSA-I) radioactive materials, while UF_6 enriched in U-235 to 5 percent by weight (wt%) or less falls within the definition of "fissile material" (49 CFR 173.403).[6] Importantly, packages containing UF_6 enriched in U-235 to 1.0 wt% or less are exempt from requirements imposed for criticality control (referred to as "fissile excepted" packages) [49 CFR 173.453(c)]. As such, these packages are typically shipped as LSA packages. Therefore, from the perspective of its radioactivity, the solid UF_6 addressed in this report must be packaged and shipped as either LSA material or fissile material, depending on its enrichment in U-235.

Specific UF_6 transportation packaging requirements are in 49 CFR 173.420 and apply to all UF_6 packages. As a practical matter, cylinders that meet the specific requirements for UF_6 comply with the LSA packaging requirements. Hence, 49 CFR 173.420 is of primary concern for identifying transportation regulatory options for depleted UF_6, natural UF_6, and UF_6 enriched 1.0 wt% or less at the ETTP. In the case of UF_6 enriched greater than 1.0 wt%, other sections of the regulations specifying fissile material packaging requirements are also pertinent. Hence, the following sections summarize 49 CFR 173.420 and discuss several other regulatory sections in 49 CFR Part 173 that apply to packaging of UF_6 enriched to greater than 1.0 wt%.

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[6] According to 49 CFR 173.403, "fissile material" means plutonium-238, plutonium-239, plutonium-241, uranium-233, uranium-235, or any combination of these radionuclides. However, the definition does not include unirradiated natural uranium, unirradiated depleted uranium, or either natural or depleted uranium that has been irradiated in a thermal reactor.

7.3.1.1 Code of Federal Regulations, Title 49, Section 173.420

According to 49 CFR 173.420(a)(2), any packaging used to ship UF_6 must be designed, fabricated, inspected, tested, and marked in accordance with one of the following standards:

- The version of American National Standard N14.1, *Uranium Hexafluoride — Packaging for Transport* (1971, 1982, 1987, and 1990), that was in effect at the time the packaging was manufactured;
- The specifications for Class DOT-106A multiunit tank car tanks (referred to in the industry as the Model 30A cylinder; see 40 CFR 179.300 and 179.301); or
- Section VIII, Division I, of the ASME code, provided the packaging: (1) was manufactured before June 30, 1987; (2) conforms to the edition of the ASME Code in effect at the time it was manufactured; (3) is used within the original design limitations; and (4) has shell and head thicknesses that have not decreased below minimum values, which are specified in Table 7.1.

Other requirements imposed by 49 CFR 173.420 on UF_6 for transportation include the following:

- The UF_6 must be in solid form [49 CFR 173.420(a)(3)];
- The volume of solid UF_6, *except solid depleted* UF_6, must not exceed 61% of the certified volumetric capacity of the package at 68°F (20°C) [49 CFR 173.420(a)(4)];
- The volume of solid depleted UF_6 in a package must not exceed 62 percent of the certified volumetric capacity of the package at 68°F (20°C) [49 CFR 173.420(a)(4)]; and
- The pressure in a package at 68°F (20°C) must be less than 14.8 psia (101.3 kPa) [49 CFR 173.420(a)(5)].

Regarding maintenance of UF_6 packaging for transportation, 49 CFR 173.420 requires that:

- Before initial filling and during periodic inspection and tests, UF_6 packaging must be cleaned in accordance with ANSI N14.1 [49 CFR 173.420(a)(1)];

TABLE 7.1 Minimum Allowable Wall Thicknesses for UF_6 Cylinders

Packaging Model Number	Minimum Thickness (in.)
1S, 2S	0.062
5A, 5B, 8A	0.125
12A, 12B	0.187
30B	0.312
48A, 48F, 48X, 48Y	0.500
48T, 48O, 48OM, 48OM Allied, 48HX, 48H, 48G	0.250

Source: 49 CFR 173.420(a)(2)(iii)(D).

- UF_6 packaging must be periodically inspected, tested, marked, and otherwise conform with ANSI N14.1-1990 [49 CFR 173.420(b)]; and

- Each repair to UF_6 packaging must be performed in accordance with ANSI N14.1-1990 [49 CFR 173.420(c)].

For ease of reference, Appendix B provides a summary of pertinent sections in ANSI N14.1 that relate to design, fabrication, inspection, testing, marking, and repair of UF_6 packaging. In general, ANSI N14.1 provides that when UF_6 is packaged for transport in cylinders meeting the specified inspection, testing, and in-service requirements, it may be shipped in one of the packagings listed below:

- In a bare cylinder that:
  - meets the specific requirements in 49 CFR 173.420 for UF_6;
  - incorporates a feature, such as a seal that, while intact, will be evidence that the package has not been illicitly opened; and
  - qualifies as a "strong, tight package" for LSA material transport in accordance with 49 CFR 173.427.

  This type of packaging is required for exclusive-use shipments of natural UF_6, depleted UF_6, and UF_6 enriched to 1.0 wt% or less.
- In a bare cylinder that:
  - meets the specific requirements in 49 CFR 173.420 for UF_6;
  - incorporates a feature, such as a seal that, while intact will be evidence that the package has not been illicitly opened; and

  - qualifies as a DOT Specification 7A package (domestic shipments only) (see 49 CFR 178.350) or as Industrial Packaging Type 2 (IP-2) (domestic and international shipments) (see 49 CFR 173.411).

  This type of packaging is required for non-exclusive-use shipments of natural UF_6, depleted UF_6, and UF_6 enriched to 1.0 wt% or less and for shipments of fissile UF_6 “heels.”

- In a cylinder having an outer protective packaging that meets DOT Specification 20PF or 21PF or is authorized by an NRC or a DOE certificate of compliance or an IAEA certificate of competent authority. The outside of such a package must incorporate a feature, such as a seal that, while intact, will be evidence that the package has not been illicitly opened. This type of packaging is required for UF_6 enriched greater than 1.0 wt% U-235, except for “heels,” which may be shipped in bare cylinders that qualify as DOT Specification 7A packages.

7.3.1.2 Other DOT Requirements Pertinent to UF_6 Enriched to Greater Than 1.0 wt%

The HMR require fissile materials to be packaged in one of the authorized packages listed in 49 CFR 173.417. Among those authorized packages, the following two are designated for transportation of certain quantities of fissile UF_6:

- Any metal cylinder that meets the requirements for Specification 7A Type A packaging (see 49 CFR 178.350) may be used for the transport of residual “heels” of enriched solid UF_6 without a protective overpack, if the limitations shown below [in Table 7.2] are met [49 CFR 173.417(a)(7)].

- A cylinder that meets DOT Specification 20 PF-1, 20 PF-2, or 20 PF-3, or Specification 21PF-1A, 21PF-1B, or 21PF-2, phenolic-foam insulated overpack with snug-fitting inner metal cylinders meeting all general packaging requirements (49 CFR 173.24), general requirements for Type A packaging (49 CFR 173.410 and 173.412), and specific requirements for UF_6 packaging (49 CFR 173.420). In addition, the following conditions apply:
  - Handling procedures and packaging criteria must be in accordance with USEC-651 [“Uranium Hexafluoride — A Manual of Good Handling Practices,” formerly DOE ORO-651 (USEC 1995)] or ANSI N14.1.
  - The quantity of UF_6 in each package is limited as shown below [in Table 7.3], and the minimum transport index indicated applies [49 CFR 173.417(a)(8)].

TABLE 7.2 Allowable Content of UF_6 "Heels" in a Specification 7A Cylinder

Maximum Cylinder Diameter (in.)	Cylinder Volume (ft^3)	Maximum Enrichment (wt%)	Maximum "Heel" Weight per Cylinder (lb)	
			UF_6	U-235
5	0.311	100.0	0.1	0.07
8	1.359	12.5	0.5	0.04
12	2.410	5.0	1.0	0.03
30	25.64	5.0	25.0	0.84
48	108.9[a]	4.5	50.0	1.52
48	142.7[b]	4.5	50.0	1.52

[a] 9 metric tons.

[b] 12 metric tons.

Source: 49 CFR 173.417(a)(7).

7.3.1.3 Pending Regulatory Modifications

A revision of ANSI N14.1 was completed in the year 2000 and will be published in 2001 (it is referred to as ANSI N14.1-2000). The summary of ANSI N14.1 requirements presented in Appendix B covers sections of ANSI N14.1-2000, -1995, and -1990 that are pertinent to design, fabrication, inspection, testing, and marking of new UF_6 packages. Appendix B also presents ANSI N14.1 requirements for inspection, testing, cleaning, marking, and repair of used UF_6 packaging.

It is important to note that DOT periodically harmonizes its HMR with international regulations in order to facilitate the international transportation of hazardous materials. Presently, the HMR are harmonized with the International Atomic Energy Agency (IAEA) publication entitled *Regulations for the Safe Transport of Radioactive Materials,* Safety Series No. 6 (IAEA 1990) However, in 1996, the IAEA issued an update of Safety Series No. 6. This update is entitled *IAEA Safety Standards Series: Regulations for the Safe Transport of Radioactive Material,* 1996 Edition, Requirement No. ST-1 (hereafter referred to as IAEA ST-1) (IAEA 2000).[7]

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[7] In 2000, the IAEA published an updated version of the ST-1, 1996 Edition. The revised ST-1, which is officially designated as IAEA Safety Standards Series Requirements No. TS-R-1, includes minor editorial changes and changes in two specific paragraphs to remove rounding of pressure values that had resulted in an inconsistency between the ST-1 and worldwide accepted standards.

TABLE 7.3 Authorized Quantities of Fissile UF_6 in Specification 20PF and 21PF Overpack Packagings

Protective Overpack Specification Number	Maximum Inner Cylinder Diameter (in.)	Maximum Weight of UF_6 Contents (lb)	Maximum U-235 Enrichment (wt%)	Minimum Transport Index
20PF-1	5	55	100.0	0.1
20PF-2	8	255	12/5	0.4
20PF-3	12	460	5.0	1.1
21PF-1A[a] or 21PF-1B[a]	30[b]	4,950	5.0	5.0
21PF-1A[a] or 21PF-1B[a]	30[c]	5,020	5.0	5.0
21PF-2[a]	30[b]	4,950	5.0	5.0
21PF-2[a]	30[c]	5,020	5.0	5.0

[a] For 30-in. (76-cm) cylinders, the maximum H/U atomic ratio is 0.088.

[b] Model 30A inner cylinder [reference USEC-651 (formerly DOE ORO-651)].

[c] Model 30B inner cylinder [reference USEC-651 (formerly DOE ORO-651)].

Source: 49 CFR 173.417(b)(5).

In 1999, DOT published an advance notice of proposed rulemaking (ANPR) announcing that, on the basis of IAEA ST-1, it was considering amendments to the radioactive materials transport regulations (64 FR 72633, December 28, 1999). Regarding UF_6, the ANPR identified certain IAEA ST-1 requirements being considered for incorporation into the HMR and invited comment. This rulemaking remains pending. Accordingly, Appendix C, describing the new IAEA ST-1 requirements for UF_6 packaging, is included in this report.

It is not yet known whether a final DOT rule incorporating the IAEA ST-1 requirements into the HMR would affect DOE's shipments of UF_6 from the ETTP to Portsmouth or Paducah. According to the DOT regulatory agenda (65 FR 74308; November 30, 2000), a notice of proposed rulemaking (NPRM) was scheduled for April 2001. However, DOT has not projected a date for issuance of the final rule.

Separately, in October 2000, the DOT announced a proposal to amend its regulations to require import and export shipments, and shipments passing through the United States in the course of being shipped between places outside the United States, to comply with either IAEA Safety Series No. 6 or IAEA ST-1, depending on which requirements apply in the country of origin (65 FR 63294, 63306; October 23, 2000). According to the NPRM, such an approach allows flexibility for the interim period during which international shipments are required to comply with the IAEA ST-1 (which became effective January 1, 2001) and domestic shipments remain subject to the HMR (which are based on Safety Series No. 6) (65 FR 63294, 63295; October 23, 2000).

On the basis of Appendix C, Table C.1, it appears that the designs for most currently approved fissile UF_6 packagings (including the cylinder and a protective overpack) (especially those that are NRC-certified) probably comply with the new IAEA ST-1 requirements.[8] However, LSA UF_6 cylinders (i.e., cylinders containing depleted UF_6, natural UF_6, or UF_6 enriched 1.0 wt% or less) probably do not. Hence, if the DOT finalizes regulations incorporating the IAEA ST-1 (revised) standards into the hazardous material regulations, it is likely that prior DOT approval will be needed to transport noncompliant LSA UF_6 cylinders. IAEA ST-1, Section 632, allows DOT to grant such approval.

7.3.2 Options for Transporting Cylinders Containing Natural UF_6, Depleted UF_6, and UF_6 Enriched to 1.0 wt% or Less

7.3.2.1 Full Cylinders

For the purpose of this report, it is assumed that a case-by-case assessment will be made of each full cylinder containing natural UF_6, depleted UF_6, or UF_6 enriched to 1.0 wt% or less (referred to hereafter as LSA UF_6) at the ETTP to determine if it can be demonstrated that the cylinder complies with pertinent requirements and, accordingly, can be shipped “as is” (i.e., as a compliant, bare cylinder) or can be repaired to achieve compliance. It is further assumed that any cylinder for which compliance cannot be verified will be managed by using one of the following options:

- An exception will be obtained from the DOT, allowing the LSA UF_6 cylinder to be transported either as is or following repairs.
- The LSA UF_6 will be transferred from its noncompliant cylinder into a compliant cylinder.
- The noncompliant cylinder will be shipped in a compliant overpack.

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[8] The NRC stated its belief that NRC-certified UF_6 packages already comply with the IAEA ST-1 requirements in the proposed rule, “Major Revision to 10 CFR Part 71: Compatibility with ST-1 — The IAEA Transportation Safety Standards — and Other Transportation Safety Issues, Issues Paper, and Notice of Public Meetings,” 65 FR 44360, 44363 (July 17, 2000).

The regulatory process applicable to implementation of these options are discussed in Sections 7.3.2.1.1 through 7.3.2.1.4.

7.3.2.1.1 Verify Compliance with DOT Regulations

Between the 1950s and 1985, DOE filled cylinders with LSA UF_6 at the ETTP (formerly the K-25 site). No attempt has been made for the purpose of this report to determine the number of stored cylinders that might comply with applicable regulatory provisions. Demonstrating that a particular cylinder complies with such provisions would require the following steps:

1. The cylinder would have to be inspected and/or tested to verify that:
   - A standard referenced in the regulations applies to the cylinder (e.g., a version of ANSI N14.1 existing at the time the cylinder was manufactured designates requirements for the cylinder model number);
   - The cylinder's wall thicknesses are not below the minimums specified in the appropriate version of ANSI N14.1 or in 49 CFR 173.420(a)(2);
   - The cylinder is not overfilled;
   - The cylinder is not overpressurized; and
   - The cylinder is not leaking and does not have cracks, excessive distortion, bent or broken valves or plugs, broken or torn stiffening rings or skirts, or other conditions that may render the cylinder unsafe during transport.
2. If a cylinder passes the inspection/testing conducted to complete step 1, then documentation (e.g., "as built" drawing, radiographs, Manufacturer's Data Report, certifications) would have to be assembled to demonstrate that:
   - The cylinder was designed, fabricated, inspected, and tested prior to service in a manner consistent with a standard specified in 49 CFR 173.420(a)(2); and
   - While in service, the cylinder was cleaned, inspected, tested, marked, and repaired in accordance with ANSI N14.1.

If no standard specified in 49 CFR 173.420(a)(2) applies to a cylinder, then compliance would have to be demonstrated on the basis of the provision in ANSI N14.1 indicating that:

"Packagings currently in service and not specifically defined in this standard are acceptable for use, provided they are used within their original design limitations and are inspected, tested, and maintained so as to comply with the intent of this standard."

Considering the time frame over which the cylinders in the ETTP inventory were produced, completing the above steps for all full cylinders containing LSA UF_6 would likely require considerable time and effort. Furthermore, preliminary reports suggest that many cylinders would be nonconforming for one or more of the following reasons:

- Documentation is not available to demonstrate that, prior to service, the cylinder was designed, fabricated, inspected, and tested in a manner consistent with standards specified in 49 CFR 173.420(a)(2), or documentation is not available to demonstrate that, during its life, the cylinder has been cleaned, inspected, tested, marked, and repaired in accordance with ANSI N14.1-1990, as required by 49 CFR 173.420(b) and (c) (i.e., it is "undocumented").

- Corrosion has reduced cylinder wall thicknesses to below the acceptable minimum specified in the applicable design standard [see 49 CFR 173.420(a)(2)], or the cylinder is leaking, has cracks, has excessive distortion, has bent or broken valves or plugs, has broken or torn stiffening rings or skirts, or has other conditions that may affect the integrity of the cylinder during transport (i.e., it is "substandard").

- The cylinder contains more UF_6 than allowed by 49 CFR 173.420(a)(4) (i.e., it is "overfilled").

- The pressure inside the cylinder exceeds the pressure allowed by 49 CFR 173.420(a)(5) (i.e., it is "overpressured").

Hence, for a potentially large percentage of LSA UF_6 cylinders, the option of transportation "as is" following verification of compliance may not be reasonable.

7.3.2.1.2 Obtain an Exception

As stated above, the UF_6 packaging requirements in 49 CFR 173.420 apply unless an exception has been authorized by the DOT [49 CFR 173.3(b)]. Exceptions may be obtained for groups of cylinders located at the ETTP (e.g., cylinders with the same model number and similar reasons for noncompliance), or for single cylinders. Applying for an exception would require the following steps:

1. Prepare a written application, which must include all of the following information that is relevant to the exception being proposed [49 CFR 107.101(a), (c) and (d)]:

    - Name, street and mailing addresses, email address (optional), and telephone number of an individual designated as an agent of DOE for all purposes related to the application.

    - Citation(s) of the specific regulation(s) from which relief is sought.

    - Specification of the proposed mode or modes of transportation.

    - Detailed description of the proposed exception (e.g., alternative packaging, test, procedure, or activity) including, as appropriate, written descriptions, drawings, flow charts, plans, and other supporting documents.

    - Specification of the proposed duration or schedule of events for which the exception is sought.

    - Statement outlining the basis for seeking relief from compliance with the specified regulations and, if the exception is requested for a fixed period, a description of how compliance will be achieved at the end of that period.

    - Identification and description of the hazardous materials planned for transportation under the exception.

    - Description of each package, including a specification or exception number, as applicable, to be used in conjunction with the requested exception.

    - For alternative packagings, documentation of quality assurance controls, package design, manufacture, performance test criteria, in-service performance, and service-life limitation.

    - Demonstration that the proposed exception will achieve a level of safety at least equal to that required by the applicable regulations. If the applicable regulations do not specify a required safety level, then a demonstration must be provided that the proposed exception will be consistent with the public interest. At a minimum, this demonstration must provide the following:

- Information describing all relevant shipping and incident experience of which DOE is aware that relates to the application.

- A statement identifying any increased risk to safety or property that may result if the exception is granted, and a description of the measures to be taken to address that risk.

- Either:
    - Substantiation (with applicable analyses, data, or test results) that the proposed alternative will achieve a level of safety that is at least equal to that required by the regulation from which the exception is sought; or if the regulations do not establish a level of safety,
    - An analysis that identifies each hazard, potential failure mode and the probability of its occurrence, and how the risks associated with each hazard and failure mode are controlled for the duration of an activity or life-cycle of a packaging.

2. At least 120 days before the requested effective date of the exception, submit two originals of the application to:

   Associate Administrator of Hazardous Materials Safety
   Research and Special Program Administration
   U.S. Department of Transportation
   400 Seventh Street, S.W.
   Washington, DC 20590-0001
   Attention: Exemptions, DHM-31

3. Respond to any written request from DOT for additional information within 30 days of the date such a request is received. The response may contain the requested information, or a petition for an additional 30 days within which to gather the requested information. If a response is not filed, the application may be deemed incomplete and denied.

Once DOT has determined the application for an exception to be complete, it will be docketed, evaluated, and processed in the manner required by 49 CFR 107.11. As part of this processing, DOT will publish a notice in the *Federal Register* and request comments on the application. However, no public hearing is required. The primary finding that DOT must make to justify granting an application for an exception is that the proposed alternative will achieve a level of safety that either: (1) is at least equal to the level of safety required by the otherwise applicable regulation; or, (2) if the otherwise applicable regulations do not establish a required level of safety, is consistent with the public interest and will adequately protect against the risks to life and property inherent in the transportation of hazardous materials in commerce.

For some full cylinders containing LSA UF_6, it is likely that exceptions could be obtained that would allow the bare cylinders to be shipped either "as is," or after making certain repairs. Therefore, from a regulatory perspective, this approach may be a reasonable option for some, but probably not all, cylinders.

7.3.2.1.3 Transfer UF_6 to Compliant Cylinders

If DOE cannot either show that a full LSA UF_6 cylinder complies with the pertinent requirements of 49 CFR Part 173, Subpart I, or obtain an exception for the cylinder, another option would be to transfer the UF_6 contained in the cylinder to a new or used compliant cylinder. If new cylinders are used, they will have to be designed, fabricated, inspected, tested, and marked in accordance with the version of ANSI N14.1 in effect at the time they are manufactured (49 CFR 173.420(a)(2)). In addition, if the HMR have been harmonized with the IAEA ST-1 by the time new cylinders are manufactured, IAEA ST-1 requirements may also apply.

Alternatively, if previously used UF_6 cylinders are utilized, the version of ANSI N14.1 that was effective at the time any particular used cylinder was manufactured would apply (unless the used cylinder was manufactured before 1987, in which case the version of Section VIII, Division I, of the ASME Code in effect at the time the package was manufactured could be applied as an alternative). Documentation showing compliance with the appropriate version of the applicable standard would be needed in order to implement this option.

The DOT requirements contained in the HMR should not prevent this option from being considered a reasonable alternative. Other nonregulatory considerations affecting the reasonableness of the option are described elsewhere in this report.

7.3.2.1.4 Place Cylinders in Compliant Overpacks

Another option (if DOE cannot either show that a UF_6 cylinder complies with the requirements of 49 CFR Part 173, Subpart I, or obtain an exception for the cylinder itself) would be to obtain an exception allowing the existing cylinder, regardless of its condition, to be transported if it is placed into a metal overpack. The metal overpack would have to be specially designed. Furthermore, DOT would have to determine that if the overpack is fabricated, inspected, and marked according to its design, the resulting packaging (including the cylinder and the overpack) would have a level of safety at least equal to the level of safety required for a new bare UF_6 cylinder. This level of safety is reflected in the standards described in Section 7.3.1. The contents of an exception application and the procedure for filing the application and obtaining the exception would be the same as described in Section 7.3.2.1.2.

7.3.2.2 Partially Filled Cylinders

The same requirements apply to transporting partially filled LSA UF_6 cylinders as apply to transporting full cylinders. Accordingly, the same options are available for partially filled cylinders as are available for full cylinders. These requirements and options are presented in Section 7.3.2.1.

7.3.2.3 Empty Cylinders Containing "Heels"

In general, the same requirements apply to transporting empty LSA UF_6 cylinders containing "heels" as apply to full and partially filled cylinders. In the case of an empty cylinder containing a "heel," however, transferring the contents of the noncompliant cylinder to a compliant cylinder is not really an option. Instead, the empty cylinder could be cleaned to remove the "heel," such that the clean cylinder would no longer qualify as "radioactive material" for the purpose of shipment under the HMR. Hence, the options for transporting cylinders containing LSA "heels" would include the following:

- Verify that the empty cylinder complies "as is" with pertinent provisions in 49 CFR Part 173, Subpart I.

- Obtain an exception from the DOT regulations, which allows the emptied cylinder to be transported either "as is" or following repairs, in spite of any noncompliance.

- Place the emptied cylinder into a compliant overpack.

- Clean the empty cylinder such that the cylinder would no longer qualify as "radioactive material" for the purpose of shipment under the HMR.

The first three options listed above are the same as the options described in Sections 7.3.2.1.1, 7.3.2.1.2, and 7.3.2.1.4, respectively. The fourth option would involve cleaning each empty cylinder such that any residual contamination would have specific activity of 0.002 µCi/g or less. If this level of decontamination could be assured, then the clean cylinder could be shipped with no special precautions other than those used in normal (i.e., nonradioactive) operations. If assurance could not be given that the specific activity of a cylinder after cleaning would be less than 0.002 µCi/g, then the cylinder could not be shipped using this option. While regulatory requirements would not prevent this option from being a reasonable alternative, facilities would have to be installed at the ETTP to conduct the cleaning process. In addition, it may not be practical or feasible to conduct the sampling necessary to assure that the specific activity is 0.002 µCi/g or less.

7.3.3 Options for Transporting Cylinders of UF_6 Enriched to Greater Than 1.0 wt%

7.3.3.1 Full Cylinders

For the purpose of this report, it is assumed that a case-by-case assessment will be made of each full cylinder at the ETTP containing UF_6 enriched greater than 1.0 wt% to determine if it can be demonstrated that the cylinder complies with pertinent requirements in 49 CFR 173.420. If compliance can be confirmed for any cylinder, or the cylinder can be repaired to achieve compliance, the compliant cylinder can be shipped in a specification overpack, as described in 49 CFR 173.417(a)(8). It is further assumed that any cylinder for which compliance cannot be demonstrated will be managed by using one of the following options:

- Obtain an exception from the DOT, allowing the cylinder to be transported “as is” in a specially designed overpack.

- Obtain an exception from the DOT, allowing the cylinder to be repaired to the extent practicable and placed into a specially designed overpack for transport.

- Transfer the enriched UF_6 from the noncompliant cylinder into a compliant cylinder and place the compliant cylinder into a specification overpack, to create an authorized package, as described in 49 CFR 149.417(a)(8).

7.3.3.1.1 Verify Compliance with DOT Regulations

The process for verifying that a UF_6 cylinder complies with DOT regulations is described in Section 7.3.2.1.1. That process would apply to cylinders containing UF_6 enriched greater than 1.0 wt% in the same manner as to cylinders containing LSA UF_6. However, as was the case for LSA UF_6 cylinders, completing the compliance verification process for full cylinders of enriched UF_6 would likely require considerable time and effort, and the percentage of such cylinders likely to be found compliant is unknown. Also, even if a cylinder is itself verified to be compliant, an exception may still be needed if the cylinder size is one for which a specification overpack has not been authorized. Hence, the option of verifying cylinder compliance and shipping the cylinder “as is,” once placed into a specification overpack, as described in 49 CFR 173.417(a)(8), may not be reasonable for some full cylinders containing UF_6 enriched greater than 1.0 wt%.

7.3.3.1.2 Obtain an Exception

Two options for transporting full cylinders containing UF_6 enriched greater than 1.0 wt% involve applying to DOT for an exception from the HMR. These options are (1) obtain an exception from the DOT allowing the cylinder to be transported “as is” in a specially designed overpack; and (2) obtain an exception from the DOT allowing the cylinder to be repaired to the extent practicable and placed into a specially designed overpack for transport. The process for obtaining an exception for each of the options involving cylinders containing UF_6 enriched greater than 1.0 wt% would be the same process as was described in Section 7.3.2.1.2 for LSA UF_6.

It is likely that for some full cylinders containing UF_6 enriched greater than 1.0 wt%, one of the options for obtaining an exception could be used. However, obtaining an exception in either case would require that DOT approve a specially designed overpack to contain the noncompliant cylinder filled with enriched UF_6. Obtaining such approval could be a lengthy process. Notwithstanding, from a regulatory perspective, this approach may be a reasonable option for some, if not all, noncompliant cylinders containing UF_6 enriched greater than 1.0 wt%.

7.3.3.1.3 Transfer UF_6 to Compliant Cylinders

If DOE cannot either show that a full cylinder containing UF_6 enriched greater than 1.0 wt% complies with the pertinent requirements of 49 CFR Part 173, Subpart I, or obtain an exception for the cylinder, then another option would be to transfer the UF_6 from the noncompliant cylinder into a new or used compliant cylinder. If new cylinders are used, they will have to be designed, fabricated, inspected, tested and marked in accordance with the version of ANSI N14.1 in effect at the time they are manufactured [49 CFR 173.420(a)(2)]. The summary of ANSI N14.1 requirements presented in Appendix B covers the 1990, 1995, and 2000 versions of ANSI N14.1. In addition, if the HMR have been harmonized with the IAEA ST-1 by the time new cylinders are manufactured, IAEA ST-1 requirements may also apply. The new IAEA ST-1 requirements are discussed in Appendix C.

The DOT requirements contained in the HMR should not prevent this option from being a reasonable alternative. Other nonregulatory considerations affecting the reasonableness of the option are described elsewhere in this report.

7.3.3.2 Partially Filled Cylinders

The same requirements apply to transporting partially filled cylinders containing UF_6 enriched greater than 1.0 wt% as apply to transporting full cylinders. Accordingly, the same options are available for partially filled cylinders as are available for full cylinders. These requirements and options are discussed in Section 7.3.3.1.

7.3.3.3 Empty Cylinders Containing "Heels"

The options for transporting cylinders containing heels of UF_6 enriched greater than 1.0 wt% would include the following:

- Demonstrate that the empty cylinder complies as is with the requirements in 49 CFR 173.417(a)(7) for transport of heels without an overpack.

- Obtain an exception from the DOT regulations allowing the emptied cylinder to be transported without an overpack either as is or following repairs, in spite of any noncompliance.

- Clean the empty cylinder such that the cylinder would no longer qualify as "radioactive material" for the purpose of shipment under the HMR.

7.3.3.3.1 Verify Compliance with DOT Regulations

As mentioned in Section 7.3.1.2, the HMR authorize transport of residual heels composed of enriched solid UF_6 without a protective overpack in metal cylinders that meet the requirements for Specification 7A Type A packaging, provided that restrictions are met on the size of the heel in relation to cylinder size [49 CFR 173.417(a)(7)] (see Table 7.2). No attempt has been made for this study to definitively determine the number of cylinders containing heels enriched greater than 1.0 wt% that might satisfy this regulatory provision. Demonstrating that a particular cylinder complies with such provisions would require the following steps:

1. The cylinder would have to be inspected and/or tested to verify that:

    - The cylinder size is among those addressed by the authorization in 49 CFR 173.417(a)(7);

    - The enrichment is below the maximum allowed for the pertinent cylinder size; and

  - The weight of the heel is less than the maximum allowed for the corresponding cylinder size and enrichment.

2. If a cylinder passes the inspection/testing conducted to complete step 1, then documentation (e.g., as built drawing, radiographs, Manufacturer's Data Report, certifications) would have to be assembled to demonstrate that the cylinder was designed, fabricated, inspected, and tested prior to service in a manner consistent with the requirements in:

   - 49 CFR 173.410 [general design requirements for Class 7 (radioactive) materials packages];
   - 49 CFR 173.412 (additional design requirements for Type A packages);
   - 49 CFR 173.415 (authorized Type A packages); and
   - 49 CFR 173.465 (Type A packaging tests).

Considering the age of many of the UF_6 cylinders at the ETTP, completing the second step listed above for all empty cylinders containing heels enriched greater than 1.0 wt% may either require considerable time and effort or not be possible. Therefore, for some, if not all, of the empty enriched uranium cylinders, this option may not be reasonable.

7.3.3.3.2 Obtain an Exception

The process for obtaining an exception is described in Section 7.3.2.1.2 for cylinders containing depleted or natural UF_6. The process would be the same for empty nonconforming cylinders containing "heels" enriched greater than 1.0 wt%. It is likely that exceptions could be obtained allowing some such cylinders, to be shipped without overpacks. Therefore, from a regulatory perspective, this approach may be a reasonable option for some nonconforming empty cylinders containing "heels" enriched greater than 1.0 wt%.

7.3.3.3.3 Clean the Empty Cylinders

The last option would involve cleaning each empty nonconforming cylinder such that any residual contamination would have a specific activity of 0.002 μCi/g or less. If this level of decontamination could be assured, then the clean cylinder could be shipped with no special precautions other than those used in normal (i.e., nonradioactive) operations. If assurance could not be given that the specific activity of a cylinder after cleaning would be less than 0.002 μCi/g, then the cylinder could not be shipped using this option. While regulatory requirements would not prevent this option from being a reasonable alternative, facilities would have to be installed at the ETTP to clean the cylinders.

7.3.4 Summary of Options

Table 7.4 summarizes the options for transporting UF_6 cylinders from the ETTP to Portsmouth, Ohio, or Paducah, Kentucky, for which regulatory requirements were analyzed.

TABLE 7.4 Summary of Options for Which Regulatory Requirements Are Analyzed

Description of Cylinder Contents	Option	Conclusion
LSA UF_6 – full and partially filled	1. Verify and document compliance with DOT regulations and transport compliant cylinders "as is."	May not be reasonable for a potentially large percentage of full and partially filled LSA UF_6 cylinders.
	2. Obtain an exception for individual cylinders or groups of cylinders allowing the bare cylinders to be shipped either "as is" or after repairs, in spite of noncompliance.	May be a reasonable option for some, but probably not all, full and partially filled LSA UF_6 cylinders.
	3. Transfer UF_6 from noncompliant cylinders into new or used compliant cylinders.	Nonregulatory considerations may affect the reasonableness of this option for full and partially filled LSA UF_6 cylinders.
	4. Obtain an exception allowing noncompliant cylinders to be transported in specially designed overpacks.	May be a reasonable option for all full and partially filled LSA UF_6 cylinders.

TABLE 7.4 (Cont.)

Description of Cylinder Contents		Option	Conclusion
LSA UF_6 – empty containing “heels”	1.	Verify and document compliance with DOT regulations and transport compliant cylinders “as is.”	May not be reasonable for a potentially large percentage of empty LSA UF_6 cylinders containing “heels.”
	2.	Obtain an exception for individual cylinders or groups of cylinders allowing the bare cylinders to be shipped either “as is” or after repairs, in spite of noncompliance.	May be a reasonable option for some, but probably not all, empty LSA UF_6 cylinders containing “heels.”
	3.	Clean the empty cylinders such that the cleaned cylinders do not qualify as “radioactive material” for the purpose of shipment under DOT regulations.	Nonregulatory considerations may affect the reasonableness of this option for empty LSA UF_6 cylinders containing “heels.”
	4.	Obtain an exception allowing noncompliant cylinders to be transported in specially designed overpacks.	May be a reasonable option for all empty LSA UF_6 cylinders containing “heels.”
UF_6 enriched greater than 1.0 wt% – full and partially filled	1.	Verify and document compliance with DOT regulations and transport compliant cylinders “as is” in a specification overpack.	May not be reasonable for some full and partially filled cylinders containing UF_6 enriched greater than 1.0 wt%.
	2.	Obtain an exception from the DOT allowing cylinders to be transported “as is” in a specially designed overpack, in spite of any cylinder noncompliance.	May be a reasonable option for some full and partially filled cylinders containing UF_6 enriched greater than 1.0 wt%.
	3.	Obtain an exception from the DOT allowing cylinders that have been repaired to the extent practicable to be transported in a specially designed overpack, in spite of any remaining cylinder noncompliance.	May be a reasonable option for some, if not all, full and partially filled cylinders containing UF_6 enriched greater than 1.0 wt%.
	4.	Transfer UF_6 from noncompliant cylinders into new or used compliant cylinders and place the compliant cylinders into specification overpacks to create compliant packagings.	Non-regulatory considerations may affect the reasonable ness of this option for full and partially filled cylinders containing UF_6 enriched greater than 1.0 wt%.

TABLE 7.4 (Cont.)

Description of Cylinder Contents		Option	Conclusion
UF_6 enriched greater than 1.0 wt% – empty containing “heels”	1.	Demonstrate that empty cylinders comply “as is” with DOT requirements for transport of enriched “heels” without an overpack.	May be reasonable for some, if not all, empty cylinders containing “heels” enriched greater than 1.0 wt%.
	2.	Obtain an exception from the DOT regulations allowing empty cylinders to be transported without an overpack following repairs, in spite of any remaining noncompliance.	May be reasonable for some empty cylinders containing “heels” enriched greater than 1.0 wt%.
	3.	Clean the empty cylinders such that the cleaned cylinders do not qualify as “radioactive material” for the purpose of shipment under DOT regulations.	Non-regulatory considerations may affect the reasonable ness of this option for empty cylinders containing “heels” enriched greater than 1.0 wt%.

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APPENDIX A:

REPRESENTATIVE TRANSPORTATION ROUTES

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REPRESENTATIVE TRANSPORTATION ROUTES

The transportation route selected for a shipment determines the total potentially exposed population along a route and the expected frequency of transportation-related accidents. For truck and rail transportation, the route characteristics most important to the transportation risk assessment include the total shipping distance between each origin and destination pair of sites (ETTP to either Portsmouth or Paducah) and the fractions of travel in rural, suburban, and urban zones of population density. Federal regulations do not place route restrictions on the movement of depleted UF_6 on U.S. highways or railroads.

For each shipment mode, representative shipment routes were identified by using the routing models HIGHWAY 3.3 (Johnson et al. 1993a) for truck shipments and INTERLINE 5.10 (Johnson et al. 1993b) for rail shipments. The routes were selected to be reasonable and consistent with routing regulations and general practice, but are considered representative because the actual routes to be used will be chosen in the future and are often determined at that time by the shipper. In addition, the predicted routes were benchmarked for reasonableness by comparison with historical routes used by shippers of radioactive material. Route-specific population data were used for the transportation risk assessment.

Data output files for representative highway and rail routes from ETTP to Portsmouth and to Paducah are provided in Tables A.1 through A.4.

TABLE A.1 Representative Truck Route between the East Tennessee Technology Park and the Portsmouth Gaseous Diffusion Plant (HIGHWAY Output File)

```
From: K-25                        TN      Leaving :  6/07/99 at  8:40 EDT
 to  : PORTSMOUTH GDP              OH      Arriving:  6/07/99 at 15:13 EDT

 Route type: Q with  2 driver(s)                      Total road time:  6:33
   Time bias:  1.00  Mile bias:   .00  Toll bias:  1.00   Total miles:  373.0

 The following constraints are in effect:
  1 - Links prohibiting truck use
  6 - HM-164/State preferred routes
  7 - Avoid ferry crossings
 11 - Nonintersecting Interstate Access
 Weighting used with preferred highways: 10.0
 State mileage:
  OH   20.0  KY  262.0  TN   91.0
 Mileage by highway sign type:
     Interstate:  308.0   U.S.:   60.0  State:    5.0  Turnpike:     .0
         County:     .0  Local:     .0  Other:     .0
 Mileage by highway lane type:
     Limited Access Multilane:  308.0  Limited Access Single Lane:     .0
            Multilane Divided:   60.0         Multilane Undivided:     .0
     Principal Highway:     .0    Through Highway:     .0   Other:    5.0


 From: K-25                        TN      Leaving :  6/07/99 at  8:40 EDT
 to  : PORTSMOUTH GDP              OH      Arriving:  6/07/99 at 15:13 EDT


   Routing through:
     .0            K-25                          TN      .0   0:00   6/07 @  8:40
    5.0 S58         KINGSTON       E  I40  X356 TN     5.0   0:06   6/07 @  8:46
   11.0 I40         FARRAGUT       W  I40  I75  TN    16.0   0:16   6/07 @  8:57
   18.0 I40   I75   KNOXVILLE      W  I40  I640 TN    34.0   0:36   6/07 @  9:16
    3.0 I640  I75   KNOXVILLE      NW I640 I75  TN    37.0   0:39   6/07 @  9:19
  167.0 I75         LEXINGTON      E  I64  I75  KY   204.0   3:15   6/07 @ 11:56
  109.0 I64         CATLETTSBURG   S  I64  X191 KY   313.0   5:26   6/07 @ 14:06
   60.0 U23         PORTSMOUTH GDP               OH   373.0   6:33   6/07 @ 15:13


 Population Density from: K-25                        TN
                     to : PORTSMOUTH GDP              OH

          ------------------  Mileage within Density Levels  -------------------
                <0.0   5.0  22.7  59.7   139   326   821  1861  3326  5815
 St Miles    0  -5.0 -22.7 -59.7  -139  -326  -821 -1861 -3326 -5815 -9996 >9996
 -------------------------------------------------------------------------------

 OH  20.0  1.6   3.5   2.2   5.0   3.6    .9   1.8    .5    .8    .1    .0    .0
 KY 262.0 11.1  14.9  12.7  74.7  91.1  29.1  13.1  10.4   3.4   1.5    .0    .0
 TN  91.0 12.2   7.9   8.4   9.9  17.8  18.5   7.6   4.3   3.3    .8    .2    .0

 Totals
    373.0 24.8  26.3  23.3  89.6 112.5  48.5  22.5  15.1   7.6   2.4    .2    .0
 Percentages
           6.7   7.0   6.2  24.0  30.2  13.0   6.0   4.1   2.0    .6    .1    .0
 Basis: 1990 Census


    RADTRAN Input Data      Rural Suburban    Urban
```

TABLE A.1 (Cont.)

Weighted Population				
People/sq. mi.	55.2	683.6	4842.9	
People/sq. km.	21.3	263.9	1869.8	
Distance				Total
Miles	276.5	93.8	2.6	373.0
Kilometers	445.0	150.9	4.2	600.3
Percentage	74.1	25.1	.7	
Basis (people/sq. mi.)	<139	139-3326	>3326	1990 Census

Note: Due to rounding, the sum of the mileages in the individual population categories may not equal the total mileage shown on this report.

TABLE A.2 Representative Railroad Route between the East Tennessee Technology Park and the Portsmouth Gaseous Diffusion Plant (INTERLINE output file)

```
ROUTE FROM:  NS   15316-K 25                TN     LENGTH:   427.2 MILES
        TO:  NS    3177-TEAYS               OH  POTENTIAL:  380.90


   MILEAGE SUMMARY BY RAILROAD           A-M   B-M   A-BR  B-BR  OTHER
                         NS    427.2    301.6 117.1    .0   8.5     .0
                              -  -  -  -  -  -  -  -  -  -  -  -  -  -
                       TOTAL   427.2    301.6 117.1    .0   8.5     .0
    MILEAGE SUMMARY BY STATE
            211.3-KY    139.1-OH     76.8-TN



      RR      NODE            STATE  DIST
     NS   15316-K 25            TN     0.
     NS    7260-HARRIMAN        TN    15.
     NS    6979-DANVILLE        KY   177.
     NS    6850-LEXINGTON       KY   214.
     NS    3228-CINCINNATI      OH   288.
     NS    3234-IVORYDALE       OH   295.
     NS    3237-RED BANK        OH   311.
     NS    3177-TEAYS           OH   427.



    POPULATION DENSITY FROM:  NS   15316-K 25                TN
                         TO:  NS    3177-TEAYS               OH

          ------------------  MILEAGE WITHIN DENSITY LEVELS  -------------------
                <0.0   5.0  22.7  59.7   139   326   821  1861  3326  5815
 St Miles    0  -5.0 -22.7 -59.7  -139  -326  -821 -1861 -3326 -5815 -9996 >9996
 -------------------------------------------------------------------------------

 KY 211.3  3.6   9.5  28.4  89.3  34.4  16.2  10.0   8.7   6.9   3.2   1.1    .0
 OH 139.1 12.3  15.2  24.4  23.0  15.6  13.0  11.4  11.6   7.1   4.0   1.3    .1
 TN  76.8  4.7   6.0  20.8  13.2  24.6   5.2   1.1    .3    .8    .1    .0    .0

 Totals
    427.2 20.6  30.7  73.7 125.6  74.6  34.3  22.4  20.6  14.8   7.3   2.5    .1
 Percentages
           4.8   7.2  17.3  29.4  17.5   8.0   5.3   4.8   3.5   1.7    .6    .0
 Basis: 1990 Census data

    RADTRAN Input Data      Rural Suburban    Urban

    Weighted Population
         People/sq. mi.      42.1    942.1   5459.4
         People/sq. km.      16.2    363.8   2107.9

    Distance                                    Total
         Miles             325.2     92.2      9.8    427.2
         Kilometers        523.3    148.4     15.8    687.5
         Percentage         76.1     21.6      2.3

    Basis (people/sq. mi.)   <139 139-3326    >3326
```

```
    Note:  Due to rounding, the sum of the mileages in the individual population categories
           May not equal the total mileage shown on this report.
```

TABLE A.3 Representative Truck Route between the East Tennessee Technology Park and the Paducah Gaseous Diffusion Plant (HIGHWAY output file)

```
From: K-25                       TN      Leaving :  6/07/99 at  8:40 EDT
 to  : PADUCAH GDP                KY      Arriving:  6/07/99 at 13:06 CDT

 Route type: Q with  2 driver(s)                      Total road time:  5:26
   Time bias:  1.00  Mile bias:   .00  Toll bias:  1.00   Total miles:  309.0

 The following constraints are in effect:
  1 - Links prohibiting truck use
  6 - HM-164/State preferred routes
  7 - Avoid ferry crossings
 11 - Nonintersecting Interstate Access
 Weighting used with preferred highways: 10.0
 State mileage:
  KY  101.0  TN  208.0
 Mileage by highway sign type:
     Interstate:  293.0   U.S.:    8.0  State:    5.0  Turnpike:     .0
         County:     .0  Local:    3.0  Other:     .0
 Mileage by highway lane type:
     Limited Access Multilane:  293.0  Limited Access Single Lane:     .0
            Multilane Divided:     .0        Multilane Undivided:     .0
     Principal Highway:    8.0    Through Highway:     .0   Other:    8.0


 From: K-25                       TN      Leaving :  6/07/99 at  8:40 EDT
 to  : PADUCAH GDP                KY      Arriving:  6/07/99 at 13:06 CDT


   Routing through:
     .0            K-25                     TN      .0   0:00   6/07 @  8:40
    5.0 S58        KINGSTON       E  I40  X356 TN     5.0   0:06   6/07 @  8:46
  145.0 I40        NASHVILLE      E  I24  I40  TN   150.0   2:22   6/07 @ 10:01
    1.0 I24        NASHVILLE      SE I24  I440 TN   151.0   2:23   6/07 @ 10:02
    7.0 I440       NASHVILLE      W  I40  I440 TN   158.0   2:30   6/07 @ 10:10
    1.0 I40        NASHVILLE      W  I265 I40  TN   159.0   2:31   6/07 @ 10:11
    2.0 I265       NASHVILLE      N  I24  I265 TN   161.0   2:34   6/07 @ 10:14
    2.0 I24   I65  INGLEWOOD      W  I24  I65  TN   163.0   2:36   6/07 @ 10:16
  135.0 I24        PADUCAH        W  I24  X4   KY   298.0   5:11   6/07 @ 12:50
    8.0 U60        KEVIL          E  U60  LOCL KY   306.0   5:20   6/07 @ 13:00
    3.0 LOCAL      PADUCAH GDP                 KY   309.0   5:26   6/07 @ 13:06


 Population Density from: K-25                       TN
                     to : PADUCAH GDP                KY

         ------------------  Mileage within Density Levels  -------------------
               <0.0   5.0  22.7  59.7   139   326   821  1861  3326  5815
 St Miles    0  -5.0 -22.7 -59.7  -139  -326  -821 -1861 -3326 -5815 -9996 >9996
 -------------------------------------------------------------------------------

 KY 101.0  2.9   4.5  34.1  24.6  17.5  10.9   2.6   2.8   1.2    .0    .0    .0
 TN 208.0 23.0  24.4  44.5  46.4  24.0  21.2   7.2   7.7   5.2   2.8   1.0    .6

 Totals
    309.0 25.9  28.9  78.6  71.0  41.5  32.1   9.8  10.5   6.4   2.8   1.0    .6
 Percentages
           8.4   9.4  25.4  23.0  13.4  10.4   3.2   3.4   2.1    .9    .3    .2
 Basis: 1990 Census
```

TABLE A.3 (Cont.)

```
RADTRAN Input Data      Rural Suburban    Urban

Weighted Population
     People/sq. mi.      33.4    742.5   6039.6
     People/sq. km.      12.9    286.7   2331.9

Distance                                          Total
     Miles              245.9     58.7      4.4    309.0
     Kilometers         395.7     94.5      7.0    497.3
     Percentage          79.6     19.0      1.4

Basis (people/sq. mi.)   <139 139-3326    >3326   1990 Census
```

```
Note: Due to rounding, the sum of the mileages in the individual population categories
      may not equal the total mileage shown on this report.
```

TABLE A.4 Representative Railroad Route between the East Tennessee Technology Park and the Paducah Gaseous Diffusion Plant (INTERLINE output file)

```
ROUTE FROM:  NS   15316-K 25                TN     LENGTH:   511.8 MILES
            TO:  PAL   7053-KEVIL               KY  POTENTIAL:  832.16


   MILEAGE SUMMARY BY RAILROAD           A-M   B-M   A-BR  B-BR  OTHER
                         NS    276.8    261.8   9.5    .0   5.5     .0
                         PAL   235.0       .0 230.0    .0   5.0     .0
                              -  -  -  -  -  -  -  -  -  -  -  -  -  -
                       TOTAL   511.8    261.8 239.5    .0  10.5     .0
    MILEAGE SUMMARY BY STATE
            435.0-KY     76.8-TN



      RR      NODE            STATE  DIST
     NS   15316-K 25            TN     0.
     NS    7260-HARRIMAN        TN    15.
     NS    6979-DANVILLE        KY   177.
     NS    7008-LOUISVILLE      KY   277.
    - - - - - - - - - - - - - - - - - - - - - - - TRANSFER
     PAL   7008-LOUISVILLE      KY   277.
     PAL  15293-CENTRAL CITY    KY   401.
     PAL   7059-MADISONVILLE    KY   421.
     PAL   7075-PADUCAH         KY   499.
     PAL   7078-MAXON           KY   507.
     PAL   7053-KEVIL           KY   512.



    POPULATION DENSITY FROM:  NS   15316-K 25                TN
                         TO:  PAL   7053-KEVIL               KY

          ------------------  MILEAGE WITHIN DENSITY LEVELS  -------------------
                <0.0   5.0  22.7  59.7   139   326   821  1861  3326  5815
 St Miles    0  -5.0 -22.7 -59.7  -139  -326  -821 -1861 -3326 -5815 -9996 >9996
 -------------------------------------------------------------------------------

 KY 435.0 10.7  21.3  51.0 219.1  77.3  22.1   9.8   8.7   6.0   6.8   1.7    .4
 TN  76.8  4.7   6.0  20.8  13.2  24.6   5.2   1.1    .3    .8    .1    .0    .0

 Totals
    511.8 15.4  27.3  71.8 232.3 101.9  27.3  10.9   9.0   6.8   7.0   1.7    .4
 Percentages
           3.0   5.3  14.0  45.4  19.9   5.3   2.1   1.8   1.3   1.4    .3    .1
 Basis: 1990 Census data

    RADTRAN Input Data      Rural Suburban    Urban

    Weighted Population
         People/sq. mi.      46.3    783.9   5434.3
         People/sq. km.      17.9    302.7   2098.2
```

TABLE A.4 (Cont.)

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Distance                                                   Total
     Miles              448.7     54.0        9.1    511.8
     Kilometers         722.1     86.9       14.6    823.6
     Percentage          87.7     10.6        1.8

Basis (people/sq. mi.)   <139 139-3326    >3326
```

```
Note: Due to rounding, the sum of the mileages in the individual population categories
      may not equal the total mileage shown on this report.
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REFERENCES FOR APPENDIX A

Johnson, P.E., et al., 1993a, *HIGHWAY 3.1, An Enhanced Transportation Routing Model: Program Description, Methodology, and Revised User's Manual*, ORNL/TM-12124, Oak Ridge National Laboratory, Oak Ridge, Tenn., March.

Johnson, P.E., et al., 1993b, *INTERLINE 5.0, An Expanded Railroad Routing Model: Program Description, Methodology, and Revised User's Manual*, ORNL/TM-12090, Oak Ridge National Laboratory, Oak Ridge, Tenn., March.

APPENDIX B:

AMERICAN NATIONAL STANDARD N14.1, *URANIUM HEXAFLUORIDE – PACKAGING FOR TRANSPORT*

APPENDIX B:

AMERICAN NATIONAL STANDARD N14.1,
URANIUM HEXAFLUORIDE – PACKAGING FOR TRANSPORT

Because the U.S. Department of Transportation (DOT) regulations applicable to transport of UF_6 incorporate by reference the provisions of American National Standard N14.1 (ANSI N14.1), it is important to review the requirements of that standard. ANSI N14.1 includes specific information on design and fabrication requirements for the procurement of new UF_6 packages. It also defines the requirements for in-service inspections, cleanliness, and maintenance of UF_6 packages while they are in use. The generic requirements from ANSI N14.1 (1990, 1995, and 2000) are summarized in Table B.1. This summary does not cover the additional more definitive specifications given in ANSI N14.1 for UF_6 cylinder models 1S, 2S, 5B, 8A, 12A, 12B, 30B, 48X, 48Y, and 48G. Also, this summary does not replicate the wording of the standard. Therefore, the applicable version of ANSI N14.1 should always be consulted to ensure accuracy.

When considering the requirements summarized in Table B.1, it should be noted that ANSI N14.1 also makes the following statement regarding UF_6 packages currently in service and not specifically addressed in the standard:

> Packagings currently in service and not specifically defined in this standard are acceptable for use, provided they are used within their original design limitations and are inspected, tested, and maintained so as to comply with the intent of this standard.

TABLE B.1 Summary of Requirements in ANSI N14.1 Applicable to Depleted UF_6 Shipments

Description of Requirement (Section No.)	**ANSI N14.1-2000**	**ANSI N14.1-1995**	**ANSI N14.1-1990**
Quality Assurance (Section 4)			
Quality Assurance (Sec. 4)	The user of a UF_6 package must have a documented quality assurance (QA) program that meets specified requirements, at least for those quality-related activities associated with procurement, maintenance, repair, and use of the cylinder and the protective packaging. The user may demonstrate that quality-related activities (design, fabrication, inspection, testing, modification, and the like) are satisfied by obtaining certificates from cylinder and package suppliers (fabricators).	Same as ANSI N14.1-2000.	Same as ANSI N14.1-2000, except the QA program must meet the applicable criteria of 10 CFR Part 71, Subpart H or ANSI/ASME NQA-1-1986 and ANSI/ASME NQA-1c-1988.
Packaging Requirements (Section 5)			
General UF_6 Packaging Requirements (Sec. 5.1)	UF_6 must be packaged for transport in cylinders meeting the inspection, testing, and in-service requirements of this standard. UF_6 must be shipped in one of the following ways: (1) In a bare cylinder that has a tamper-indicating seal and that qualifies as a “strong, tight package” for low specific activity (LSA) material in accordance with 49 CFR 173.427; or (2) In a bare cylinder that has a tamper-indicating seal and that qualifies as a DOT Specification 7A package; or (3) In a cylinder with an outer protective packaging that has a tamper-indicating seal and that meets DOE Specification 20PF or 21PF or that is authorized by a NRC or DOE certificate of compliance or an IAEA certificate of competent authority.	Same as ANSI N14.1-2000.	Same as ANSI N14.1-2000.

TABLE B.1 (Cont.)

Description of Requirement (Section No.)	**ANSI N14.1-2000**	**ANSI N14.1-1995**	**ANSI N14.1-1990**
Packaging for LSA UF_6 – *Nonexclusive Use Shipments* (Sec. 5.2.1)	Non-fissile and fissile-excepted UF_6 (i.e., natural and depleted uranium, and uranium enriched to a maximum 1.0 wt% U-235), when transported in less than truckload quantities (non-exclusive use), must be packaged in Industrial Packaging Type 2 (IP-2) (49 CFR 173.427(b)(1)), or, for domestic shipments only, DOT Specification 7A packagings (49 CFR 173.427(b)(2)). The packaging shall meet the additional requirements of 49 CFR 173.420. The shipper shall also comply with 49 CFR 173.415(a), “DOT Specification 7A Type A general packaging.” Cylinders covered by this standard qualify as DOT Specification 7A packagings.	Non-fissile and fissile-excepted UF_6 (i.e., natural and depleted uranium, and uranium enriched to a maximum 1.0 wt% U-235), when transported in less than truckload quantities (non-exclusive use), must be packaged in DOT Specification 7A packagings (49 CFR 173.427(b)(2)). Cylinders covered by this standard qualify as DOT-7A packaging meeting the additional requirements of 49 CFR 173.420. The shipper shall also comply with 49 CFR 173.415(a), “DOT Specification 7A Type A general packaging.”	Same as ANSI N14.1-1995.
Packaging for LSA UF_6 – *Exclusive Use Shipments* (Sec. 5.2.2)	Non-fissile and fissile-excepted UF_6 (i.e., natural and depleted uranium, and uranium enriched to a maximum 1.0 wt% U-235), when transported as exclusive use, may be packaged in cylinders covered by this standard (i.e., UF_6 cylinder models 1S, 2S, 5A, 5B, 8A, 12A, 12B, 30B, 48A, 48X, 48F, 48Y, 48T, 48O, 48OM Allied, 48OM, 48H, 48HX, and 48G), which are deemed to satisfy the “strong, tight package” requirements of 49 CFR 173.427(b)(3). These cylinders must also meet the additional requirements of 49 CFR 173.420.	Same as ANSI N14.1-2000, except that cylinders “covered by of this standard” were deemed to satisfy both 49 CFR 173.427(b)(3) [then 49 CFR 173.425(b)] and 49 CFR 173.420.	Same as ANSI N14.1-1995.

TABLE B.1 (Cont.)

Description of Requirement (Section No.)	**ANSI N14.1-2000**	**ANSI N14.1-1995**	**ANSI N14.1-1990**
Packaging for UF_6 Enriched Greater Than 1.0 wt% U-235 (Sec. 5.3)	UF_6 enriched to greater than 1.0 wt%, except “heels,” must be packaged in accordance with 49 CFR 173 and 178, or in other NRC or DOE certified package designs. These packages consist of an inner cylinder (models 1S, 2S, 5A, 5B, 8A, 12A, 12B, 30B, 48A, 48X, 48F, and 48Y) plus an outer protective package. (See Section 8.1.2 for requirements applicable to “heels” enriched greater than 1.0 wt%.)	Same as ANSI N14.1-2000.	Same as ANSI N14.1-2000
Physical Condition of UF_6 (Sec. 5.4)	UF_6 must be in solid form for shipment, and the vapor pressure of the cylinder must have been measured to be below 1 atm (14.8 psia), or the measured purity of the cylinder contents must be within specification.	Same as ANSI N14.1-2000.	Same as ANSI N14.1-2000.
Standard UF_6 Cylinders (Sec. 5.5)	Requirements for cylinder models currently in service are reproduced in this summary as Table B.2. The standard contains additional more definitive specifications for some of the cylinder models in Sections 6.4 through 6.13 (which are not covered by this summary). Cylinders listed in Table B.2 for which no more definitive specifications are provided are acceptable for continued use, provided they are inspected, tested, and maintained in accordance with the intent of ANSI N14.1-2000 and the requirements stated in Table B.2.	Same as ANSI N14.1-2000.	Same as ANSI N14.1-2000.
Cylinders (Section 6)			
Design and Fabrication – ***General*** (Sec. 6.1.1)	Design, fabrication, inspection, testing, and cleaning of UF_6 cylinders must be performed as specified for each cylinder model in Sections 6.4 through 6.15. To minimize points of leakage, it is desirable to install only one valve and one plug. If more are required, they may be provided if installed in accordance with specified requirements for valve and plug installation in Sections 6.10.6, 6.11.6, 6.12.6, and 6.13.6.	Same as ANSI N14.1-2000.	Same as ANSI N14.1-2000, except that ANSI/ASME Code, Section VIII, Division 1 could be used to provide alternative weld fabrication details.

TABLE B.1 (Cont.)

Description of Requirement (Section No.)	**ANSI N14.1-2000**	**ANSI N14.1-1995**	**ANSI N14.1-1990**
Design and Fabrication – ***Reports, Certification, and Records*** (Sec. 6.1.2, 1st paragraph)	For each cylinder fabricated, the manufacturer must supply the purchaser and the National Board of Boiler and Pressure Vessel Inspectors with copies of the Manufacturer's Data Report.	Same as ANSI N14.1-2000.	Same as ANSI N14.1-2000.
Design and Fabrication – ***Reports, Certification, and Records*** (Sec. 6.1.2, 2nd paragraph)	The manufacturer must provide for the purchaser (1) a copy of the "as built" drawing pertaining to the cylinder or cylinders involved and (2) one copy of each radiograph, properly identified with the cylinder and location to which it applies.	Same as ANSI N14.1-2000.	Same as ANSI N14.1-2000.
Design and Fabrication – ***Reports, Certification, and Records*** (Sec. 6.1.2, 3rd paragraph)	The manufacturer must measure the actual water capacity using a prescribed procedure. The certified water capacity must be stamped on the cylinder as part of the nameplate data, except that 1S and 2S cylinders are exempt from this stamping requirement.	Same as ANSI N14.1-2000.	Same as ANSI N14.1-2000.
Design and Fabrication – ***Reports, Certification, and Records*** (Sec. 6.1.2, 4th paragraph)	The cylinder tare weight must be established before the new cylinder is placed in service. The purchaser is responsible for performing this function, but may arrange by agreement for the manufacturer to do it.	Not addressed.	Not addressed.

TABLE B.1 (Cont.)

Description of Requirement (Section No.)	**ANSI N14.1-2000**	**ANSI N14.1-1995**	**ANSI N14.1-1990**
Design and Fabrication – *Reports, Certification, and Records* (Sec. 6.1.2, 5th paragraph)	The manufacturer must retain fabrication and inspection records. The purchaser must retain copies of the Manufacturer's Data Report, drawings, and certifications in accordance with regulatory requirements. Radiographs and other related papers must be retained for a minimum of 5 years. The documents must be transferred with the cylinder upon change of ownership.	Same as ANSI N14.1-2000, except that the purchaser's retention of copies of the Manufacturer's Data Report, drawings, and certification was required throughout use and ownership of the cylinder.	Same as ANSI N14.1-1995.
Cleanliness – *New Cylinders* (Sec. 6.2.1)	New cylinders must be cleaned in accordance with the applicable specifications in Sections 6.4 through 6.15. The cleaning procedure to be used must be described in detail to the cylinder fabricator. This standard provides a cleaning method as an appendix (which is not covered by this summary).	Same as ANSI N14.1-2000.	Same as ANSI N14.1-2000.
Cleanliness – *In-Service Cylinders* (Sec. 6.2.2)	If cylinders containing residual quantities of UF_6 require cleaning prior to refilling to ensure product purity, or to accommodate maintenance or hydrostatic testing, decontamination may be performed using a procedure similar to the example (which is not covered by this summary) provided in this standard.	Same as ANSI N14.1-2000.	Same as ANSI N14.1-2000.
Cleanliness – *Cylinder Outer Surfaces* (Sec. 6.2.3)	Cylinder surfaces must be monitored and cleaned when required to meet applicable radiation requirements.	Same as ANSI N14.1-2000.	Same as ANSI N14.1-2000.

TABLE B.1 (Cont.)

Description of Requirement (Section No.)	ANSI N14.1-2000	ANSI N14.1-1995	ANSI N14.1-1990
Service Inspections, Tests, and Maintenance – ***Routine Operational Inspections*** (Sec. 6.3.1)	UF_6 cylinders must be routinely examined as received and prior to sampling, withdrawal, filling, or shipping to ensure that they remain in a safe, usable condition. Leakage, cracks, excessive distortion, bent or broken valves or excessive distortion, bent or broken valves or plugs, broken or torn stiffening rings or skirts, or other conditions that may affect the safe use of the cylinder shall warrant appropriate precautions, including removing the cylinder from service until the defective condition is satisfactorily corrected. Questionable conditions should be referred to a qualified inspector for evaluation and for recommendations concerning use, repair, or condemnation of the cylinder in question. Examples of acceptable and unacceptable damage are shown in an appendix (which is not covered by this summary).	Same as ANSI N14.1-2000.	Same as ANSI N14.1-2000, except that no appendix containing examples of acceptable and unacceptable damage is provided.
Service Inspections, Tests, and Maintenance – ***Periodic Inspections and Tests*** (Sec. 6.3.2)	All cylinders must be periodically inspected and tested throughout their service lives at intervals not to exceed 5 years, except that any cylinder already filled prior to the 5-year expiration date does not require testing until it is emptied. The periodic inspection shall consist of: – An internal and external examination of the cylinder by a qualified inspector; – A hydrostatic strength test of the type set forth in Section VIII, Division 1, of the ANSI/ASME Code; and – An air leak test.	Same as ANSI N14.1-2000.	Same as ANSI N14.1-2000.

TABLE B.1 (Cont.)

Description of Requirement (Section No.)	ANSI N14.1-2000	ANSI N14.1-1995	ANSI N14.1-1990
Periodic Inspections and Tests (Sec. 6.3.2, continued)	– The hydrostatic test shall be applied at a pressure equal to the original test pressure. – Prior to the air test, all couplings from which valves or plugs were removed shall be thoroughly inspected. – The air test shall be applied after valves and plugs have been installed in the cylinder. – All valves shall meet the current design requirements, including tinning. – At each 5-year recertification, the cylinder should have the tare weight reestablished.	Same as ANSI N14.1-2000.	Same as ANSI N14.1-2000.
Periodic Inspections and Tests (Sec. 6.3.2, continued)	Cylinders that pass the periodic inspection and tests shall be restamped with the month and year in which the hydrostatic test was performed.	Same as ANSI N14.1-2000.	Same as ANSI N14.1-2000.
Periodic Inspections and Tests (Sec. 6.3.2, continued)	Cylinders that have not been inspected and tested within the required 5-year period must be properly reinspected, retested, and re-stamped before being refilled.	Same as ANSI N14.1-2000.	Same as ANSI N14.1-2000.
Periodic Inspections and Tests (Sec. 6.3.2, continued)	Cylinders that have not been recertified within the required 5-year period must be visually inspected for degradation of the cylinder wall. Any questionable conditions should be investigated further, including ultrasonic wall thickness measurements, if appropriate.	Same as ANSI N14.1-2000.	Same as ANSI N14.1-2000.
Periodic Inspections and Tests (Sec. 6.3.2, continued)	After testing, the cylinder may have the outer shell cleaned and repainted.	Same as ANSI N14.1-2000.	Same as ANSI N14.1-2000.
Periodic Inspections and Tests (Sec. 6.3.2, continued)	Records of periodic inspections and tests shall be retained by the cylinder owner for a period of 5 years or until a subsequent period inspection and test have been performed and recorded.	Same as ANSI N14.1-2000.	Same as ANSI N14.1-2000.

TABLE B.1 (Cont.)

Description of Requirement (Section No.)	**ANSI N14.1-2000**	**ANSI N14.1-1995**	**ANSI N14.1-1990**
Periodic Inspections and Tests (Sec. 6.3.2, continued)	A UF_6 cylinder shall be removed from service (for repair or replacement) when it is found to contain leaks, corrosion, cracks, bulges, dents, gouges, defective valves, damaged stiffening rings or skirts, or other conditions that, in the opinion of the qualified inspector, render it unsafe or unserviceable in its existing condition.	Same as ANSI N14.1-2000.	Same as ANSI N14.1-2000.
Periodic Inspections and Tests (Sec. 6.3.2, continued)	Any cylinder with a shell thickness that has decreased below the following applicable value, as interpreted by the National Board Inspection Code, ANSI-NB-23 criteria, must be removed from service: *Cylinder Model* — *Minimum Thickness (inches)* 1S — 1/16 2S — 1/16 5A — 1/8 5B — 1/8 8A — 1/8 12A and B — 3/16 30B — 5/16 48 A, F, X, and Y — ½ 48 T, O, OM, OM allied, HX, H, and G — 1/4 NOTE: Cylinders 48A and 48F are identical to 48X and 48Y, respectively, except that the volumes are not certified.	Same as ANSI N14.1-2000, except that interpretation by the National Board Inspection Code was not specified.	Same as ANSI N14.1-1995.
Service Inspections, Tests, and Maintenance – ***Cylinder Maintenance*** (Sec. 6.3.3)	Cylinder repairs and alternations are authorized provided: (1) They meet the approval of the inspector; (2) They comply with the design, material, fabrication, and welding qualification requirements of the ANSI/ASME Code, Section VIII, Division 1, and Section IX, Welding and Brazing Qualifications, for unfired pressure vessels; and (3) They do not deviate from the intent of ANSI N14.1.	Same as ANSI N14.1-2000.	Same as ANSI N14.1-2000.

TABLE B.1 (Cont.)

Description of Requirement (Section No.)	ANSI N14.1-2000	ANSI N14.1-1995	ANSI N14.1-1990
Cylinder Maintenance (Sec. 6.3.3, continued)	Welded repairs or alterations to ASME code stamped pressure vessel parts shall be required to be conducted by organizations holding a current "R" Stamp from the National Board Inspection Code, ANSI-NB-23, unless specifically approved by the NBIC Jurisdictional Authority.	Welded repairs or alterations to pressure parts shall require the use of welding procedures qualified in Section IX of the ANSI/ASME Code and welders whose qualifications are active.	Same as ANSI N14.1-1995.
Cylinder Maintenance (Sec. 6.3.3, continued)	Welded repairs also must be inspected and accepted by a qualified inspector in accordance with the fabrication inspection requirements in Section VIII, Division 1, of the ANSI/ASME Code.	Same as ANSI N14.1-2000.	Same as ANSI N14.1-2000.
Cylinder Maintenance (Sec. 6.3.3, continued)	Repairs and alterations to pressure parts must be followed by a hydrostatic strength test. Plug and valve replacements should be followed by air leak tests. Repairs to structural attachments do not require pressure or leak tests or the cylinder, unless repairs of torn or deformed areas of pressure-containing material are involved.	Same as ANSI N14.1-2000.	Same as ANSI N14.1-2000.
Service Inspections, Tests, and Maintenance – *Reuse of Cylinder Valves* (Sec. 6.3.4)	Valves removed from cylinders may be reused only after refurbishment to ensure the used valves meet the testing requirements specified in Sections 6.14 or 6.15, as appropriate. Valves that will not pass in-service, shipment, or storage tests must be used only after complete refurbishment. The packing must be replaced and all parts inspected for damage. The refurbishment must be performed in accordance with a documented quality control plan.	Same as ANSI N14.1-2000.	Same as ANSI N14.1-2000.

TABLE B.1 (Cont.)

Description of Requirement (Section No.)	ANSI N14.1-2000	ANSI N14.1-1995	ANSI N14.1-1990
Service Inspections, Tests, and Maintenance – ***Retorque of Used Cylinder Valve Packing Nut*** (Sec. 6.3.5)	The packing nut of cylinder valves procured in accordance with Sections 6.14 or 6.15 may be retorqued to stop leakage: – The torque applied should be the minimum amount required to stop the leak, but must not exceed 100 ft-lb. – Valves that require more than 100 ft-lb to stop leakage must not be heated. – An adjustable or indicating torque wrench shall be required for retorquing. Cylinders with valves that have required retorquing using more than 100 ft-lb shall not be used in feed, withdrawal, or shipment, until after a valve change or replacement of the packing and/or packing nut is completed.	Same as ANSI N14.1-2000.	Same as ANSI N14.1-2000.
Outer Protective Packagings (Section 7)			
General (Sec. 7.1)	The outer protective packaging must be kept structurally sound, provide a tight seal between the cover and base, and be protected from damage to the insulation by moisture.	Same as ANSI N14.1-2000.	Same as ANSI N14.1-2000.
Design – ***Design Certification*** (Sec. 7.2.1)	Outer protective packaging for the transport of non-LSA enriched UF_6 must be designed and fabricated in accordance with the appropriate specification in 49 CFR Part 178 or in accordance with the requirements of an NRC or DOE Certificate of Compliance.	Same as ANSI N14.1-2000.	Same as ANSI N14.1-2000.
Design – ***NRC Certified Outer Protective Packaging Designs*** (Sec. 7.2.2)	A listing of NRC certified designs can be found in the *Directory of Certificates of Compliance for Radioactive Material Packages*, NUREG-0383.	Same as ANSI N14.1-2000.	Same as ANSI N14.1-2000.

TABLE B.1 (Cont.)

Description of Requirement (Section No.)	**ANSI N14.1-2000**	**ANSI N14.1-1995**	**ANSI N14.1-1990**
Fabrication – ***Manufacturer's Qualifications*** (Sec. 7.3.1)	All outer protective packagings must be fabricated in accordance with an NRC-approved quality assurance plan meeting the requirements of 10 CFR part 71, Subpart H, or ANSI/ASME NQA-1c and ANSI/ASME NQA-1, or both.	Same as ANSI N14.1-2000.	Same as ANSI N14.1-1995, except that the 1989 version of the two ANSI/ASME documents was specified.
Fabrication – ***Fabrication Tests and Certifications*** (Sec. 7.3.2)	The manufacturer must fabricate the outer protective packaging in accordance with 49 CFR Part 178 or drawings approved in an NRC or DOE Certificate of Compliance. – The tare weight must appear on the packaging nameplate. – Scales accurate to ±0.1% must be used to certify the weight. – All welding must be performed by welders qualified in accordance with Section IX of the ANSI/ASME Boil and Pressure Vessel Code or Section 5 of ANSI/AWS D1.1.	Same as ANSI N14.1-2000.	Same as ANSI N14.1-2000.
Fabrication Tests and Certifications (Sec. 7.3.2, continued)	The manufacturer must provide certifications of the following: – Weight of each completed packaging. – Weld procedures. – Welder qualifications. – Packaging compliance with 49 CFR Part 178 and ANSI N14.1. The owner must keep all certifications and other manufacturing data provided by the manufacturer throughout the use or ownership of the protective packaging.	Same as ANSI N14.1-2000.	Same as ANSI N14.1-2000.

TABLE B.1 (Cont.)

Description of Requirement (Section No.)	**ANSI N14.1-2000**	**ANSI N14.1-1995**	**ANSI N14.1-1990**
In-Service Inspections and Maintenance – ***Routine Operational Inspections*** (Sec. 7.4.1)	The outer protective packaging must be inspected in accordance with written procedures prior to each use to ensure its integrity: – The inspection must be documented. – Nonconforming conditions found by the inspector must be evaluated by shipper personnel to determine whether the protective packaging is fit for use, requires repairs, or should be condemned. Excessive warping, distortion, or other damage of the liner or shell are nonconforming conditions that warrant evaluation if they would: – Prevent tight closure of the package, – Allow excessive clearance from the inner container with the liner, – Reduce the assembly fastener strength of the container, – Reduce the thermal insulation thickness in any area, or – Otherwise make the integrity of the outer protective package questionable as a fire and shock resistant housing. Evidence of water leakage into the packaging requires evaluation: – The amount of water in the packaging must be determined. – If necessary, the packaging weight must be recertified. – The water must be removed prior to outer packaging repairs.	Same as ANSI N14.1-2000.	Same as ANSI N14.1-2000.
In-Service Inspections and Maintenance – ***Periodic Inspections, Tests, and Recertification*** (Sec. 7.4.2)	In addition to the routine inspections performed prior to each use, each protective packaging must be recertified every 5 years. This recertification must include the elements of the routine inspections plus a detailed inspection for degradation of welds and the presence of rusting of the protective packaging. – Weld defects must be repaired before returning the protective packaging to service.	Same as ANSI N14.1-2000.	Same as ANSI N14.1-2000.

TABLE B.1 (Cont.)

Description of Requirement (Section No.)	**ANSI N14.1-2000**	**ANSI N14.1-1995**	**ANSI N14.1-1990**
In-Service Inspections and Maintenance – *Repairs* (Sec. 7.4.3)	All repairs must be performed by competent sources. – All welding must be performed by welders qualified in accordance with Section IX of the ANSI/ASME Boil and Pressure Vessel Code or Section 5 of ANSI/AWS D1.1. – Insulation replacement must be performed in accordance with an NRC approved quality assurance plan. Recertification of the total outer protective packaging weight should occur if repairs result in a significant weight change.	Same as ANSI N14.1-2000.	Same as ANSI N14.1-2000.
Shipping (Section 8)			
Cylinders – *Full Cylinders* (Sec. 8.1.1)	Full cylinders must be packaged as specified in Section 5, and when shipped by truck, should be shipped on semi-trailers meeting the requirements of ANSI N14.30.	Same as ANSI N14.1-2000.	Same as ANSI N14.1-2000, except that no instructions about truck shipments were given.
Cylinders – *Empty Cylinders* (Sec. 8.1.2)	Empty cylinders with valve protection may be shipped without outer protective packaging provided the UF_6 “heels” do not exceed the following amounts: *Cylinder Model* — *”Heel”(lb [kg])* — *Max. U-235 (wt%)* 5A or 5B — 0.1 [0.045] — 100.00 8A — 0.5 [0.227] — 12.50 12A or 12B — 1.0 [0.454] — 5.00 30B* — 25.0 [11.3] — 5.00 48A** or 48X — 50.0 [22.7] — 4.50 48F** or 48Y — 50.0 [22.7] — 4.50 48G or 48H — 50.0 [22.7] — 1.00 48 T, O, OM, OM allied — 50.0 [22.7] — 1.00 * This cylinder replaces the 30A cylinder. The 30 A cylinder has the same heel and maximum U-235 limit as the 30B. ** Cylinders 48A and 48F are identical to 48X and 48Y, respectively, except that the volumes are not certified.	Same as ANSI N14.1-2000.	Same as ANSI N14.1-2000.

TABLE B.1 (Cont.)

Description of Requirement (Section No.)	ANSI N14.1-2000	ANSI N14.1-1995	ANSI N14.1-1990
Cylinders – *Clean Cylinders* (Sec. 8.1.3)	Clean cylinders, including new cylinders, may be shipped with no special precautions, provided the shipper can assure that contamination remaining in the cylinder has specific activity less than or equal to 0.002 μCi/g (according to 49 CFR 173.403, material with specific activity below this level is not classified as a radioactive material). Without the shipper’s assurance about specific activity levels, a cylinder must be shipped in accordance with 49 CFR 173.427 (applicable to LSA materials and surface contaminated objects), Section 5 of ANSI N14.1, and applicable DOT regulations. All bare cylinders must have a tamper-indicating seal.	Same as ANSI N14.1-2000.	Same as ANSI N14.1-2000.
Valve Protectors and Seals (Sec. 8.2)	Valve protectors are required on all cylinders (except new and cleaned ones) that are not contained in an outer protective package during shipment. All UF_6 packages must have a tamper-indicating seal.	Same as ANSI N14.1-2000.	Same as ANSI N14.1-2000.
Labeling (Sec. 8.3)	Package labels must be selected as follows: – Radioactive White-I Label for radiation not exceeding 0.5 mrem/hr at any point on the external surface of the package, except that the white label is not authorized for Fissile Class II packages. – Radioactive Yellow-II Label for packages exceeding the white-I limits but which have radiation levels not exceeding 50 mrem/hr at the package surface or a transport index exceeding 1.0. – Radioactive Yellow-III Label for packages exceeding the yellow-II limits. – Corrosive Label for all packages containing UF_6, except those transported on exclusive use LSA shipments and clean cylinders (i.e., containing specific activity less than or equal to 0.002 μCi/g).	Same as ANSI N14.1-2000.	Same as ANSI N14.1-2000.

TABLE B.1 (Cont.)

Description of Requirement (Section No.)	**ANSI N14.1-2000**	**ANSI N14.1-1995**	**ANSI N14.1-1990**
Placarding (Sec. 8.4)	“Radioactive” placards must be displayed on all conveyances transporting UF_6 as an exclusive use shipment, and on all conveyances transporting a package labeled “Radioactive Yellow-III.” “Corrosive” placards must be displayed on all conveyances transporting UF_6 for which the gross weight of UF_6 plus packaging exceeds 1000 pounds.	Same as ANSI N14.1-2000.	Same as ANSI N14.1-2000.
Marking – ***LSA UF6 in Nonexclusive Use Conditions*** (Sec. 8.5.1)	LSA UF_6 transported in less than truckload amounts (nonexclusive use) must be marked with: – USA DOT 7A Type A – Radioactive Material – Uranium Hexafluoride, low specific activity – UN 2978 – Name and address of consignor or consignee – Gross weight.	Same as ANSI N14.1-2000.	Same as ANSI N14.1-2000.
Marking – ***LSA UF6 in Exclusive Use Conditions*** (Sec. 8.5.2)	LSA UF_6 transported on exclusive use shipments must be marked “RADIOACTIVE – LSA” in accordance with 49 CFR 173.427(a)(6)(vi).	Same as ANSI N14.1-2000.	Same as ANSI N14.1-2000.

TABLE B.1 (Cont.)

Description of Requirement (Section No.)	ANSI N14.1-2000	ANSI N14.1-1995	ANSI N14.1-1990
Marking – ***Marking of Packages of UF6 Enriched to Greater Than 1 wt% U-235*** (Sec. 8.5.3)	Packages used to transport UF_6 enriched to greater than 1 wt% U-235 must be marked as follows: – Bare cylinders containing “heels” must be marked as follows: (a) USA DOT 7A Type A (b) Radioactive material (c) Uranium hexafluoride, fissile (d) UN 2977 (e) Name and address of consignor or consignee (f) Gross weight – DOT specification outer protective packages must be marked with the DOT specification number in conjunction with “USA-DOT-” (for example, “USA-DOT-20PF-1B”). – NRC and DOE certified outer protective package designs and DOT specification outer protective packages that will be exported must be marked with the package design identification number, such as “USA/9196/AF.” – All outer protective packages must be marked as follows, per DOT regulations: (a) Uranium hexafluoride, fissile (b) UN 2977 (c) Name and address of consignor or consignee (d) Gross weight (e) Type A	Same as ANSI N14.1-2000, except that DOT specification outer protective packages with stainless steel inner shells were required to be marked with the type of stainless steel (for example, “304L-SS”). Also the package design identification number example for outer protective packages that will be exported was “USA/4904/AF.”	Same as ANSI N14.1-1995, except that for bare cylinders, the requirement read as follows: “Bare cylinders containing ‘heels’ shall comply with 8.5.1.”

TABLE B.2 Standard UF$_6$ Cylinder Data (see Section 5.5)

Model Number	Nominal Diameter (inches)	Material of Construction	Minimum Volume (ft^3)	Approximate Tare Weight (Without Valve Protector) (lb)	Maximum Enrichment (wt% U-235)	Maximum Fill Limit (lb UF$_6$)
1S	1.5	Nickel or nickel-copper alloy[a]	0.0053	1.75	100	1[b]
2S	3.5	Nickel or nickel-copper alloy[a]	0.0254	4.2	100	4.9[b]
5A	5	Nickel-copper alloy[a]	0.284	55	100	54.9[b]
5B	5	Nickel	0.284	55	100	54.9[b]
8A	8	Nickel-copper alloy[a]	1.319	120	12.5	255[b]
12A[c]	12	Nickel	2.38	185	5	460[b]
12B	12	Nickel-copper alloy[a]	2.38	185	5	460[b]
30B[d]	30	Steel	26	1400	5 [e]	5020[b]
48A[f]	48	Steel	108.9	4500	4.5 [e]	21030[b]
48X	48	Steel	108.9	4500	4.5 [e]	21030[b]
48F[f]	48	Steel	140	5200	4.5 [e]	27030[b]
48Y	48	Steel	142.7	5200	4.5 [e]	27560[b]
48T[g]	48	Steel	107.2	2450	1	20700[h]
48O[g]	48	Steel	135	2650	1	26070[h]
48OM[g]	48	Steel	140	3050	1	27030[h]
Allied 48OM[g]	48	Steel	135	2650	1	26070[h]
48H, 48HX[g]	48	Steel	140	3250	1	27030[h]
48G	48	Steel	139	2650	1	26840[h]

[a] For example, Monel or the equivalent.

[b] Fill limits are based on 250°F maximum UF$_6$ temperature (203.3 ob UF$_6$ per ft^3), certified minimum internal volumes for all cylinders, and a minimum cylinder ullage of 5%. These operating limits apply to UF$_6$ with a minimum purity of 99.5%. More restrictive measures are required if additional impurities are present. This maximum temperature shall not be exceeded. It should be noted that initial cylinder heating may result in localized pressures above a normal UF$_6$ vapor pressure. This may be evidenced by an audible bumping similar to a water hammer.

[c] This cylinder is presently in service. New procurement should be Model 12B.

[d] This cylinder replaces the Model-30A cylinder, which has a fill limit of 4950 pounds.

[e] These maximum enrichments require moderation control equivalent to a UF$_6$ purity of 99.5%. Without moderation control the maximum permissible enrichment is 1.0 wt% U-235.

[f] Cylinders 48A and 48F are identical to 48X and 48Y, respectively, except that the volumes are not certified.

[g] This cylinder is similar in design to the 48G in that their design conditions are based on 100 psig at 235°F.

[h] Fill limits are based on 250°F maximum UF$_6$ temperature and minimum UF$_6$ purity of 99.5%. The allowable fill limit for tails UF$_6$ with a minimum UF$_6$ purity of 99.5% may be higher but shall not result in a cylinder ullage of less than 5% when heated to the cylinder design temperature of 235°F based on the actual certified volume.

Source: ANSI N14.1-2000, Table 1.

APPENDIX C:

IAEA SAFETY STANDARDS SERIES NO. TS-R-1 (ST-1, REVISED), *REGULATIONS FOR THE SAFE TRANSPORT OF RADIOACTIVE MATERIAL*, 1996 EDITION (REVISED)

APPENDIX C:

IAEA SAFETY STANDARDS SERIES NO. TS-R-1 (ST-1, REVISED), *REGULATIONS FOR THE SAFE TRANSPORT OF RADIOACTIVE MATERIAL*, 1996 EDITION (REVISED)

Periodically, the U.S. Department of Transportation (DOT) harmonizes its hazardous materials regulations (HMR) with international regulations to facilitate the international transportation of hazardous materials. Accordingly, in 1999, DOT published an advance notice of proposed rulemaking (ANPR) requesting comment on a plan to amend the HMR based on the International Atomic Energy Agency (IAEA) Safety Standards Series No. TS-R-1 (ST-1 Revised), *Regulations for the Safe Transport of Radioactive Material*, 1996 Edition (Revised) [referred to as "IAEA ST-1 (Revised)"] (64 *Federal Register* [FR] 72633, December 28, 1999).[1] The most recent DOT regulatory agenda shows that a more detailed notice of proposed rulemaking on this subject is scheduled for April 2001 (65 FR 74308; November 30, 2000). However, DOT has not announced a schedule for publishing the final harmonizing regulations. Nevertheless, it is possible that before the U.S. Department of Energy (DOE) completes transportation of all of the UF_6 cylinders from the ETTP to Portsmouth or Paducah, DOT may have finalized regulations incorporating the IAEA ST-1 (Revised) standards.[2] For this reason, it is important to identify and evaluate the significance of new requirements contained in the IAEA ST-1 (Revised) that apply to UF_6. Table C.1 summarizes such new requirements and compares them with the existing requirements in the HMR and American National Standards Institute (ANSI) N14.1.

On the basis of Table C.1, it appears that the designs for most currently approved fissile UF_6 packagings (including the cylinder and a protective overpack) (especially those which are NRC-certified) probably comply with the new IAEA ST-1 requirements.[3] However, low specific activity

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[1] It should be noted that DOE submitted comments on the DOT ANPR. In its comments, DOE suggested that DOT regulations should treat depleted UF_6 "as the toxic, corrosive chemical that it is, rather than as a radioactive material," and that this should be accomplished by retaining the current HMR requirements for cylinders of depleted UF_6 (Letter from DOE (R.S. Scott [EM-5] and D.G. Huizenga [EM-20]) to DOT (Documents Management System) regarding Docket Number RSPA-99-6283; June 29, 2000).

[2] As was discussed in Section 7.3.1, DOT has proposed that shipments imported into and exported from the United States, and shipments passing through the United States in the course of being shipped between places outside the United States, be required to comply with either IAEA Safety Series No. 6 or IAEA ST-1 (Revised), depending on which requirements have been adopted in the foreign country of origin for the shipment (65 FR 63294, 63306; October 23, 2000). DOT proposed this approach to allow flexibility until future amendments to the HMR are finalized to harmonize them with IAEA ST-1.

[3] The NRC stated its belief that NRC-certified UF_6 packages already comply with the IAEA ST-1 requirements in the proposed rule, "Major Revision to 10 CFR Part 71: Compatibility With ST-1 – The IAEA Transportation Safety Standards – And Other Transportation Safety Issues, Issues Paper, and Notice of Public Meetings," 65 FR 44360, 44363 (July 17, 2000).

(LSA) UF_6 cylinders (i.e., cylinders containing depleted UF_6, natural UF_6, or UF_6 enriched 1 wt % or less) probably do not. Hence, if the DOT finalizes regulations incorporating the IAEA ST-1 (Revised) standards into the hazardous material regulations, it is likely that competent authority (i.e., DOT) approval will be needed for transport of LSA UF_6 cylinders, as allowed by IAEA ST-1, Section 632.

TABLE C.1 Comparison of New IAEA ST-1 (Revised) Requirements for UF_6 Transportation to Existing Requirements

IAEA ST-1 (Revised) Section No.	Summary of IAEA ST-1 (Revised) Requirement	Comparison to Existing Requirements
Section 629	Except under certain circumstances (see Section 632), UF_6 must be packaged and transported consistent with (1) the requirements of ISO 7195, “Packaging of Uranium Hexafluoride (UF_6) for Transport,” (2) the requirements of Sections 630 and 631 of IAEA ST-1 (Revised), and (3) with other IAEA ST-1 (Revised) requirements pertaining to the radioactive and fissile properties of the material.	(1) ISO 7195 is the international equivalent of ANSI N14.1, which is referenced in the existing DOT regulations. For the purpose of this comparison, ISO 7195 was not reviewed for consistency with ANSI N14.1. (2) Sections 630 and 631 requirements are compared with existing requirements elsewhere in this table. (3) In general, new IAEA ST-1 (Revised) requirements pertaining to the radioactive and fissile properties of UF_6.
Sections 630(a) and 718	Each package designed to contain 0.1 kg or more of UF_6 must be designed so that it would withstand, without leakage and without unacceptable stress (as specified in ISO 7195), a hydraulic test at an internal pressure of at least 1.38 MPa (200 psi). However, when the test pressure is less than 2.76 MPa (400 psi), the design shall require multilateral approval.[a]	ANSI N14.1 currently requires most approved UF_6 cylinder models to be designed for an internal pressure of 200 psig. In addition, ANSI N14.1 requires these UF_6 cylinder models to be tested by hydrostatically pressuring them to 400 psig, then reducing the pressure to 300 psig while the cylinder is inspected for leaks. No leaks are allowed.

TABLE C.1 (Cont.)

IAEA ST-1 (Revised) Section No.	Summary of IAEA ST-1 (Revised) Requirement	Comparison to Existing Requirements
Sections 630(b), 717, and 722	Each package designed to contain 0.1 kg or more of UF_6 must be designed to withstand, without loss or dispersal of the UF_6, a free drop test, as follows: The specimen shall drop onto a flat, horizontal surface of such a character than any increase in its resistance to displacement or deformation upon impact by the specimen would not significantly increase the damage to the specimen. The drop shall occur so that the specimen will suffer maximum damage in respect of the safety features to be tested. (a) The height of drop shall be as indicated on the following table, when measured from the lowest point of the specimen to the upper surface of the target.	ANSI N14.1 does not currently require low specific activity (LSA) UF_6 cylinders (i.e., UF_6 cylinders containing depleted UF_6, natural UF_6, or UF_6 enriched 1 wt% or less) transported under exclusive use conditions to be designed to withstand a free drop test. However, LSA UF_6 cylinders transported under nonexclusive use conditions and fissile UF_6 cylinders (i.e., cylinders containing UF_6 enriched greater than 1 wt%), both of which must qualify as DOT Specification 7A packages, are required to be designed to meet essentially the same drop test as specified in ST-1, Section 630(b). The drop test for DOT Specification 7A packages is defined in 49 CFR 173.465.
	Package Mass (kg) — Free Drop Distance (m) Package mass < 5,000 — 1.2 5,000 ≤ Package mass < 10,000 — 0.9 10,000 ≤ Package mass <15,000 — 0.6 15,000 ≤ Package mass — 0.3	

TABLE C.1 (Cont.)

IAEA ST-1 (Revised) Section No.	Summary of IAEA ST-1 (Revised) Requirement	Comparison to Existing Requirements
Sections 630(c) and 728	Each package designed to contain 0.1 kg or more of UF_6 must be designed to withstand the following thermal test, without rupture of the containment system, taking due account for stipulated thermal conditions of the specimen both before and after the test: Exposure for a period of 30 minutes to a thermal environment which provides a heat flux at least equivalent to that of a hydrocarbon fuel/air fire in sufficiently quiescent ambient conditions to give a minimum average flame emissivity coefficient of 0.9 and an average temperature of at least 800°C, fully engulfing the specimen, with a surface absorptivity coefficient of 0.8 or that value which the package may be demonstrated to possess if exposed to the fire specified.	ANSI N14.1 does not currently require LSA UF_6 cylinders to be designed to withstand fire conditions during a transportation accident. However, without specifying test parameters for demonstrating compliance, ANSI N14.1 requires fissile UF_6 cylinders to have an outer protective packaging designed so that "the integrity of the package as a fire and shock resistant housing will be assured." Also, 49 CFR 173.417 indicates that one approved method of packaging fissile materials for shipment is any Type B, Type B(U), or Type B(M)[b] packaging that also meets the standards in 10 CFR Part 71. Such standards include a thermal test (10 CFR 71.73(c)(4)) that is substantially the same as the test specified in IAEA ST-1, Section 728.
Section 631	Packages designed to contain 0.1 kg or more of UF_6 shall not be designed with pressure relief devices.	Neither 49 CFR Part 173 nor ANSI N14.1 contains a prohibition on pressure relief devices on UF_6 cylinders. Notwithstanding, existing designs do not include such devices. Normal valves and plugs are not considered to be pressure relief devices.
Section 632(a)	Subject to approval of the competent authority, packages designed to contain 0.1 kg or more of UF_6 may be transported, even though the packages are not designed to meet ISO 7195 and the requirements of Sections 630 and 631, if the requirements of Sections 630 and 631 are met as far as practicable.	Existing requirements do not contain a comparable provision.

TABLE C.1 (Cont.)

IAEA ST-1 (Revised) Section No.	Summary of IAEA ST-1 (Revised) Requirement	Comparison to Existing Requirements
Section 632(b)	Subject to approval of the competent authority, packages designed to contain 0.1 kg or more of UF_6 may be transported, even though the packages are designed to withstand, without leakage and without unacceptable stress, a test pressure that is less than the 2.76 MPa (400 psi) indicated in Section 718.	Existing requirements do not contain a comparable provision.
Section 632(c)	Subject to approval of the competent authority, packages designed to contain 0.1 kg or more of UF_6 may be transported, even though the packages are not designed to meet the requirements of the thermal test specified in Section 630(c), provided that the packages are designed to contain 9,000 kg or more of UF_6.	Existing requirements do not contain a comparable provision.

[a] "Multilateral approval" means approval by the relevant competent authority both of the country of origin of the design or shipment and of each country through or into which the consignment is to be transported (on the ground).

[b] B(U) refers to the need for unilateral approval of international shipments; B(M) refers to the need for multilateral approval of international shipments.