An Overview of Transportation in the Nuclear Fuel Cycle

by
R. E. Rhoads

May 1977

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PREFACE

This document was prepared as part of a project to characterize nuclear fuel cycle transportation through the Year 2000 and identify potential difficulties that could develop in the fuel cycle transportation system. The information presented serves as a starting point for that study. The fuel cycle description and transportation systems described here have been used as a typical case for the study. It is recognized that future advances in technology and decisions by regulatory agencies and energy policy makers could significantly change the picture presented here. The effect of such changes is being evaluated in other tasks of this study.

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1.0 INTRODUCTION

Currently operating and planned facilities associated with the nuclear fuel cycle are situated in diverse geographic locations. Radioactive materials in a wide variety of physical and chemical forms must be transported between these facilities. Materials such as uranium ore concentrate, uranium hexafluoride, fresh fuel, spent fuel, plutonium and many forms of radioactive waste have been shipped routinely in the U.S. for many years. As the fuel cycle is closed and the nuclear industry expands, transportation requirements for these materials will increase substantially. Other materials requiring transportation are expected to be produced in the future (e.g., solidified high level waste, cladding hulls, plutonium with high heat generation rates, radioactive noble gases and spent fuel from LMFBRs). Although this material has not yet been packaged and shipped on a commercial scale, development of appropriate transportation systems is not expected to pose significant technical difficulties.

This document presents a review of current transportation regulations, a description of transportation systems currently in use, a discussion of systems that are anticipated to be developed in the future and a projection of shipments and shipping distances through the Year 2000. Current regulations for transporting radioactive materials are discussed in Section 2.0 and detailed in Appendix A.

Radioactive materials in the nuclear fuel cycle are transported primarily by truck or train. The packaging and transportation modes used for each step of the nuclear fuel cycle are described in Section 3.0. Shipping containers are usually purchased or leased by nuclear fuel cycle facilities and are shipped by common carrier or specialized haulers. A detailed description of these transportation services can be found in Section 4.0.

Section 5.0 summarizes the projected growth of nuclear power, estimated annual shipments of fuel cycle materials and the projected transportation requirements of the nuclear power industry through the Year 2000.

2.0 TRANSPORTATION REGULATIONS

The safety of transportation of radioactive materials is regulated primarily by the U.S. Department of Transportation (DOT) and the Nuclear Regulatory Commission (NRC). (These regulations are summarized in Appendix A.) Their regulations delineate shipping container design requirements, allowable radiation doses and handling procedures for shipments of radioactive material to insure that there are only minimum risks to the public and transportation workers. The major effort in the development of radioactive material shipping containers is the design of a container to efficiently and economically transport material within the framework of these regulations. The physical properties of some fuel cycle materials can pose unique constraints on the design of shipping containers and/or transport modes that comply with transportation regulations. Spent fuel, for example, requires containers with large amounts of radiation shielding and a large heat removal capacity. Shipment quantities must be limited to keep container weights and dimensions within allowable limits for truck and train transport. Shipments containing more than 2 kg (4.4 lb) of plutonium must be made in special vehicles and under special transport conditions designed to prevent the diversion of fissile radioactive material.

3.0 PACKAGING AND TRANSPORTATION MODES FOR FUEL CYCLE MATERIALS

The principal transport modes for radioactive materials in the nuclear fuel cycle are truck and train. In special cases, shipments by barge have been made. Fuel cycle materials are not routinely shipped by air within the U.S. The majority of radioactive material shipments are presently carried by trucks. They provide a flexible and economic mode for transport of a wide variety of materials. Truck shipments, however, are limited to a maximum payload weight of about 22 metric tons (48,000 lb), without overweight permits. Payloads of 90 metric tons (200,000 lb) or more can be accommodated in train shipments. For shipments in which cask weight is a limiting factor, improved radioactive material-to-shipping container weight ratios can be achieved in train shipments due to the greater size and weight of the shipping containers that can be transported by train.

Figure 1 illustrates the transportation steps in the Light Water Reactor (LWR) fuel cycle using plutonium recycle. It is expected that this fuel cycle will be used extensively in the 1980s and 1990s. The possible introduction of High Temperature Gas-Cooled Reactors (HTGRs) and Liquid Metal Fast Breeder Reactors (LMFBRs) will produce variations in the fuel cycle depicted, but since these reactors are expected to provide only a small percentage of the total nuclear-generated electrical power by the Year 2000, the effect of these variations on transportation requirements will be small. Figure 2 presents the approximate geographic location of existing and some planned facilities in the nuclear fuel cycle.

The fuel cycle depicted in Figure 1 does not exist today. No commercial reprocessing plants are in operation. Mixed oxide fuel is being fabricated only for experimental purposes. Commercial-scale facilities for solidifying high level waste (HLW) have not been built. No facilities for storage or disposal of solidified high level waste or transuranic (TRU) waste have been built. The description of the fuel cycle that follows includes the best available estimates of transportation requirements and transportation systems for a fully-operational fuel cycle using plutonium recycle.

FIGURE 1. Transportation Steps in the Mixed Oxide Fuel Cycle (Dashed Lines Indicate Optional Sources of Uranium for Mixed Oxide Fuel)

FIGURE 2. Reactors and Fuel Cycle Facilities in the U.S.
(as of June 1976)

3.1 URANIUM ORE FROM MINE TO MILL

The uranium fuel cycle begins with the mining of uranium ore and milling the ore to produce U_3O_8 or "yellowcake." Most of the uranium deposits in the U.S. are located in Wyoming, Colorado and New Mexico. Transportation of the ore from the mine to the mills produces only local impacts. Many mills are located at the mine site. The maximum distance for transporting the ore is about 160 km. Uranium ore is designated as "low specific activity" (LSA) material in DOT regulations. It requires no special packaging when transported in an exclusive-use vehicle.^(a) Ore is generally delivered to the mill in dump trucks. The trucks may be owned by the mine operator or contracted from local trucking companies.

3.2 U_3O_8 FROM MILL TO CONVERSION FACILITY

Uranium ore concentrate (U_3O_8) is shipped from the uranium mill to the UF_6 conversion facility in 210-liter (55-gallon) steel drums. Each drum contains about 360 kg (800 lb) of concentrate. Exclusive-use vehicles are generally employed for these shipments. U_3O_8 also qualifies as LSA material. Strong, tight industrial packaging is all that is required to ship this material in exclusive-use vehicles. Rail transport is generally used for U_3O_8 shipments. If there is no rail siding at the uranium mill site, the containers of U_3O_8 are usually trucked to the nearest rail facility. Fifty-five drums of U_3O_8 can be transported in a standard truck van. One hundred ten drum lots are usually shipped in railroad boxcars. There are two UF_6 conversion facilities presently in operation, one at Metropolis, Illinois and another at Sequoyah, Oklahoma. Possible shipping paths between the uranium mills and the UF_6 conversion facilities are depicted in Figure 3. As indicated in Figure 1, some yellowcake may be shipped directly to the fuel fabricator. This material would be used in the production of natural UO_2 to be blended with plutonium for use in mixed oxide fuels for light water reactors or fuel for fast breeder reactors. The amount of material following this pathway is expected to be small through the Year 2000. The tailings produced in the milling operation are disposed of locally. They are usually placed on a tailings pile adjacent to the mill.

^(a) An exclusive-use vehicle is one carrying no other freight. Exclusive-use vehicles are generally used for radioactive fuel cycle materials.

FIGURE 3. Possible Domestic Shipping Pathways for U_3O_8

3.3 UF₆ FROM CONVERSION FACILITY TO GASEOUS DIFFUSION PLANT

Uranium hexafluoride is shipped from the UF₆ conversion plant to the gaseous diffusion plant where it is enriched to about 3% in the isotope ²³⁵U. Natural uranium hexafluoride also qualifies as LSA material. Packaging standards are set by the chemical hazard of the material rather than by its radioactive properties. Natural UF₆ is shipped 9-metric ton (10-ton) UF₆ capacity or 12.6-metric ton (14-ton) UF₆ capacity steel cylinders. The UF₆ is placed in the cylinders as a liquid at about 90°C (200°F). It is cooled to room temperature to form a volatile solid before the cylinders are shipped. The cylinders are transported by truck or rail. In the past, rail shipments were used almost exclusively for shipment between the UF₆ conversion facilities and the enrichment plants. A change in this practice has been evident recently, so that most shipments are now made by truck. Two 9-metric ton (10-ton) or one 12.7-metric ton (14-ton) cylinder can be transported on a truck trailer of standard construction. Four of each type cylinder can be placed on a railroad flatcar. Special cradles and tie-downs are used to secure the cylinders to the transport vehicle. The transport vehicle is usually modified by permanent installation of the cradles and tie-down equipment. A protective device is placed over the filling valve to prevent damage to the valve during handling or transportation operations. Pictures of 9-metric ton UF₆ cylinders loaded on a truck trailer and a railroad flatcar are presented in Figures 4 and 5. Possible transportation pathways between the UF₆ conversion facilities and the enrichment plants are shown in Figure 6. The enrichment plants presently in operation are owned by the federal government. They are located at Paducah, Kentucky; Oak Ridge, Tennessee; and Portsmouth, Ohio.

3.4 TRANSPORTATION OF UF₆ FROM GASEOUS DIFFUSION PLANT

Two products from the gaseous diffusion plant are enriched UF₆ and depleted UF₆. Enriched UF₆ is shipped to a UO₂ conversion plant for use in fabricating reactor fuels. Depleted UF₆ is presently stored onsite at the diffusion plant. It may eventually be shipped to a fuel fabrication facility.

FIGURE 4. 9-Metric Ton UF_6 Cylinders - Rail Transport⁽¹⁾

FIGURE 5. 9-Metric Ton UF_6 Cylinders - Truck Transport⁽¹⁾

FIGURE 6. Domestic Shipping Pathways for Natural UF_6

3.4.1 Enriched UF_6

Enriched UF_6 is shipped from the gaseous diffusion plant to a UO_2 conversion facility. As indicated in Figure 1, the UO_2 conversion facility is generally located at the fuel fabrication facility. Enriched UF_6 , unlike natural UF_6 , is not exempt from classification as a fissile material. Therefore, it cannot be shipped as LSA material. Usually transported quantities constitute a Type B quantity of radioactive material under NRC regulations. Type B packaging in the form of protective overpacks for 2.3-metric ton UF_6 capacity and 9-metric ton UF_6 cylinders are used to satisfy the transportation accident test criteria of 10 CFR 71. Five 2.3-metric ton cylinders with overpack or one 9-metric ton cylinder with overpack can be shipped by truck. Sixteen 2.5-metric ton or four 9-metric ton cylinder can be shipped on a railroad flatcar. Truck shipment in 2.3-metric ton cylinders with overpacks is generally used for enriched UF_6 . A typical shipment is shown in Figure 7. Possible shipping pathways between the enrichment plants and the UO_2 conversion facilities are shown in Figure 8.

FIGURE 7. 2.3-Metric Ton UF_6 Cylinders with Overpack⁽¹⁾

FIGURE 8. Possible Domestic Shipping Pathways for Enriched UF_6

3.4.2 Depleted UF₆

As indicated in Figure 1, depleted uranium (0.2% - 0.3% ²³⁵U) may be shipped from the enrichment plant stockpiles to the fuel fabrication facilities for use in mixed oxide or fast breeder reactor fuels. It is transported in the same manner as natural UF₆.

3.5 UO₂ TO MANUFACTURERS OF FUEL ELEMENTS

There are currently three facilities in operation that produce UO₂ and transport it to other facilities for the manufacture of fuel elements. These facilities are located at Erwin, Tennessee; Cimarron, Oklahoma; and Hematite, Missouri. Enriched UO₂ can be shipped in DOT specification 6L or 6M containers, or containers approved by NRC. Truck transport is generally used.

3.6 FRESH FUEL ELEMENTS FROM FUEL FABRICATION PLANT TO REACTOR

At the fuel fabrication plant, UO₂ (or mixed UO₂ and PuO₂) pellets are placed in zircaloy (for LWRs) or stainless steel (for LMFBRs) tubes. These tubes are banded together to form fuel elements for nuclear reactors. These fresh fuel elements are transported to the reactor in protective outer packages designed to prevent damage to the fuel elements in transit. Typically, one PWR or two BWR fuel elements are placed in a protective overpack designed to protect the valuable fuel element from damage during transport. These overpacks are usually shipped to the reactor by truck. Six containers of PWR fuel or sixteen containers of BWR fuel are typically placed on a standard truck trailer. Normal tiedown techniques are used. A fresh fuel shipment is pictured in Figure 9. Shipments of mixed oxide fuel may require special transport equipment or procedures to guard against theft of the fuel.

3.7 SPENT FUEL ELEMENTS FROM REACTOR TO REPROCESSING PLANT

After irradiation in the reactor, nuclear fuel contains residual uranium (about 0.9% enrichment at anticipated exposures), plutonium and highly radioactive fission products. The radioactive decay processes

FIGURE 9. Fresh Fuel Shipment⁽²⁾

also generate large amounts of decay heat. The spent fuel elements are stored at the reactor a minimum of 120 days to allow radioactivity and heat generation levels to decrease before they are transported to the reprocessing plant.

Shipments of spent fuel have been made in the U.S. for many years. The physical properties of spent fuel (large gamma and neutron radiation doses, large heat generation rates, typically 3.6-m length of the elements) combine with the constraints of the transportation regulations to place stringent requirements on spent fuel shipping casks. Shielding from fission product gamma rays is provided by a thick (typically 10- to 20-cm) layer of lead or depleted uranium. Neutron shielding is provided by water or a hydrocarbon such as epoxy resin. Heat removal is accomplished either by natural convection cooling fins or by diesel-driven blowers.

These factors make spent fuel casks large and very massive. Casks that can be shipped by truck without overweight permits (cask weight about 22-metric tons) are limited to 1 PWR or 2 BWR fuel elements. Overweight truck casks (cask weight about 36-metric tons) can handle up to 3 BWR or 7 BWR elements. Rail casks have been designed that can haul up to 12 PWR or 32 BWR assemblies. A picture of a legal weight truck cask is presented in Figure 10. This cask is cooled by natural convection. The IF 300 rail cask is shown in Figure 11. The inner cavity of this cask is filled with water. Heat is transferred from the fuel to the outer surface of the cask by natural convection. The cask is ultimately cooled by two diesel-driven blowers.

Spent fuel casks must conform to handling requirements at the reactor fuel storage basin and at the fuel storage pool at the destination. Fuel is loaded and unloaded under water to provide radiation shielding to workers during these operations. The cask is in a horizontal configuration. The spent fuel cask must have lifting points for the cask handling cranes at these facilities and its weight cannot exceed the capacity of the cranes. Casks must also be designed to facilitate decontamination before the loaded cask is shipped to the reprocessing plant and before the empty cask is returned to the reactor. Special cradles and tie-downs are required on the transport vehicle to hold the massive cask in position during transportation. Usually a dedicated transport vehicle^(a) is provided with the cask.

The choice of transport mode for spent fuel is largely one of economics and convenience. Some reactors do not have rail sidings. Although inter-modal shipments are possible from these sites, rail shipments are not expected to be made unless a rail siding is relatively close to the site. Rail shipments appear to have economic advantages,^(b) since larger casks

(a) A dedicated transport vehicle is used exclusively to transport radioactive fuel cycle materials.

(b) Proposed regulations of the American Association of Railroads would require that spent fuel be carried in "special trains" that carry no other freight and travel at speeds less than 35 mph. The additional charges made for this service may erase the economic advantages of rail shipment of spent fuel.(6)

FIGURE 10. Spent Fuel Cask on Truck Trailer⁽³⁾

FIGURE 11. The IF 300 Spent Fuel Cask on Rail Car⁽³⁾

provide better payload-to-weight ratios. Truck casks using overweight permits also appear attractive economically, although shipment of overweight casks through several states can be difficult because of variations in the policies of the states regarding issuance of overweight permits.

3.8 REPROCESSING

Spent fuel is not currently being reprocessed. In the completed fuel cycle, the fuel bundles are chopped into short sections and the fuel material is acid-leached from the cladding at the reprocessing plant. The fission products are separated from the uranium and plutonium and stored as liquids in underground tanks for up to 5 years, at which time they will be solidified by an as yet undetermined process.

3.8.1 Solidified High Level Waste

High level waste will be solidified in stainless steel containers 30 cm (12 in.) to 60 cm (24 in.) in diameter and 3 m (10 ft) to 4.5 m (15 ft) in length. These containers will be stored on site for up to 5 years before being transported to a federal facility for storage and eventual disposal. Although solidified high level waste shipping casks have not been built, conceptual studies have identified important design parameters. Solidified high level waste has radiation and heat generation properties that are similar to spent fuel and the shipping casks for solidified high level waste are expected to be similar to the spent fuel casks presently in use. One proposed design for a high level waste shipping cask^(4,5) would be about 3 m (10 ft) in diameter and 4.6 m (15 ft) long and would accommodate 9 canisters of solidified high level waste. (Each waste canister is about 30 cm in diameter and 3 m long.) Gamma shielding is provided by 20 cm (8 in.) to 36 cm (12 in) of lead or depleted uranium and neutron shielding would be furnished by 10 cm (4 in.) of borated water. The cask would be cooled by natural convection cooling fins. The loaded cask would weigh about 90 metric tons and would be transported on a dedicated railroad flatcar. A conceptual drawing of a high level waste shipping cask on a railroad flatcar is presented in Figure 12.

FIGURE 12. High Level Waste Shipping Cask and Railcar⁽⁷⁾

3.8.2 Plutonium

Plutonium will be separated from the spent fuel at the reprocessing plant and converted to PuO_2 powder before it is shipped. Plutonium has been transported for many years for research and weapons programs. This plutonium is shipped in DOT specification 6M shipping containers or an approved equivalent. A typical 6M container consists of a 5-liter (15-gallon) steel drum with a 12.7-cm (5-in.) inner container of schedule 80 steel pipe closed at the bottom by a welded 1.2-cm (1/2 in.) steel plug. The containers are separated by Celotex[®] insulating material. The plutonium is prepackaged in two metal cans each containing about 2.2 kg (5 lb) of plutonium dioxide. These cans are placed inside the inner container which is sealed with a gasketed pipe plug for transport. Most plutonium shipments in the U.S. are made by truck. One hundred twenty 6M containers can be transported in a standard sized truck van. (If the number is not limited by criticality safety considerations or radiation dose limitations.)

Federal Regulations (Title 10, Code of Federal Regulations, Part 73) require that shipments of over 2 kg of plutonium be protected in transit from diversion of the fissile material or sabotage. The regulations require that truck shipments follow procedures that have been approved by NRC. Containers must have tamper-indicating seals and no cargo transfers are permitted en route. Transport vehicles must be equipped with radio-telephones and the driver must make periodic reports to his dispatcher. Two persons must ride in the transport vehicle. If the transport vehicle is not equipped with special features to immobilize the trailer and provide physical deterrents to entry into the cargo compartment, the shipment must be accompanied by an escort vehicle with two armed guards. Systems currently under development include armored cabs and cargo compartments, special hinges and locking devices on cargo compartment doors, cargo compartment intrusion penalties (toxic gas or liquids, for example) and vehicle immobilization features (wheel or steering mechanism locks or engine or drive line disability mechanisms). These features can substantially increase tractor and trailer weights.

The contents of the 6M shipping container are limited to a maximum heat generation rate of 10 watts. Plutonium that is expected to be separated from discharged plutonium recycle fuel is expected to generate heat at a rate of about 20 watts/kg and to produce a radiation dose requiring shielding because it contains greater percentages of the isotopes ^{238}Pu and ^{241}Pu . A conceptual design has been developed for a container that can carry 32 kg of Pu from second generation Pu recycle fuel.⁽⁸⁾ The package consists of an inner and outer container separated by about 28 cm (11 in.) of hydrogenous material providing thermal insulation, neutron shielding and some impact protection. Plutonium dioxide is prepackaged in four 15-cm (6-in.) diameter by 30-cm (12-in.) high stainless steel canisters. The canisters are placed in an inner stainless steel pressure vessel 16 cm (6 1/2 in.) in diameter by 1.3 m (53 in.) high. The outer container is also a pressure vessel. It is approximately 7.5 cm (30 in.) in diameter and 1.8 m (72 in.) high. The loaded container weighs about 1360 kg (3000 lb). About 7 of these containers could be transported in a safeguards equipped truck without the use of overweight permits.

3.8.3 Slightly Enriched UF₆

The uranium separated from the spent fuel at the reprocessing plant is slightly enriched (about 0.9%)⁽⁹⁾ in ²³⁵U. It is expected that the uranium will be converted to UF₆ at the reprocessing plant before it is shipped. Most of this UF₆ is expected to be transported to the enrichment plant to be used as feed stock. As indicated in Figure 1, some of this material may be sent to the mixed oxide fuel fabrication plant for use in plutonium recycle or LMFBR fuels. Uranium of less than 1% enrichment is exempt from classification as a fissile material and can be shipped as LSA material. The slightly enriched UF₆ from the fuel reprocessing plant can therefore be transported in the same 9-metric ton (10-ton) and 12.7-metric ton (14-ton) cylinders used to ship natural UF₆.

3.9 TRANSPORTATION OF RADIOACTIVE WASTES FROM FUEL CYCLE FACILITIES

Radioactive wastes are generated at all fuel cycle facilities. These wastes include an assortment of materials with a wide range of contamination levels. The waste includes such items as cladding hulls and radioactive gases from reprocessing plants, resins and filter cartridges from liquid cleanup systems at reactors and fuel storage pools in reprocessing plants, HEPA filters and a wide variety of radioactive trash from all facilities including contaminated failed or obsolete equipment, plastic bags, gloves, protective clothing and other articles of wood, paper, plastic and rubber. Some of the waste is contaminated with transuranic (TRU) elements and under currently proposed regulations⁽¹⁰⁾ will require transportation to a federal repository for such wastes. Under current regulations, non-transuranic (Non-TRU) wastes can be disposed of at a commercial burial ground. In general, wastes from reactors, mills, UF₆ conversion and uranium enrichment plants are Non-TRU. Waste from mixed oxide fuel fabrication facilities is almost entirely TRU contaminated. Approximately 70% (by volume) of reprocessing plant wastes are contaminated with TRU elements (as well as other radioactive contaminants).⁽¹¹⁾

A variety of treatment processes are available or under development to stabilize the contamination on the waste and/or to reduce waste volumes. Contaminated liquids, for example, may be fixed in a solid such as bitumen, urea-formaldehyde or cement. This will increase waste volumes, but stabilize the contamination for burial. The volume of solid radioactive trash can be reduced in many ways including mechanical compaction, burning, pyrolysis or chemical digestion. These processes generally decrease the volume of the material to be shipped and in many cases the weight as well. Transportation and waste disposal costs are thereby reduced.

An assortment of shipping containers will be used for radioactive wastes. Container requirements depend on the physical form of the waste, the waste treatment process used, the radiation levels of the waste and the shipping destination. An outline of the containers and transportation modes in use or anticipated to be used for various waste forms is presented below.

3.9.1 Cladding Hulls

Cladding hulls consist of the chopped sections of Zircaloy tubing with some residual fuel and stainless steel inconel fuel element hardware removed from the head end process at the reprocessing plant after the acid-leach operations are completed. The hulls are highly radioactive and are contaminated with transuranic elements. A variety of treatments have been proposed for cladding hulls. Shipping container requirements are highly dependent on the treatment selected. The treatments include mechanical compaction or melting to reduce waste volumes and interim storage at the reprocessing plant for periods of up to ten years to allow the radioactivity levels to decrease. Cladding hulls are not currently a transportation requirement in the U.S. Conceptual designs have been developed for shipping containers to transport the hulls from the reprocessing plant to a federal repository for transuranic waste. In one proposed design,⁽¹²⁾ the hulls would be compacted and placed in stainless steel cans about 23 cm (9 in.) in diameter by 3 m (10 ft) long. Twenty-seven of these cans would be carried in a cask 1.8 m (6 ft) in diameter by 3.6 m (12 ft) long, weighing 80 metric

tons (180,000 lb). The cask has about 14 cm (5 1/2 in.) of lead gamma shielding and an unspecified amount of hydrogenous neutron shielding. It is cooled by natural convection cooling fins. The cask carries the hulls from about 45 metric tons of LWR fuel cooled 1 year after reactor discharge. A cask design proposed by Allied General Nuclear Services⁽¹²⁾ would transport untreated hulls in stainless steel cylinders 1.1 m (42 in.) in diameter by 2.4 m (8 ft) long. A filled cylinder is shipped in a finned cylindrical cask with a 2.5 cm (1 in.) steel inner wall, 17 cm (6.5 in.) of lead shielding and a 5 cm (2 in.) thick outer steel shell. Because of the cask weights, both must be transported by rail.

3.9.2 Radioactive ^{85}Kr Gas

The radioactive noble gas ^{85}Kr is a byproduct of spent fuel reprocessing. Although current regulations permit release of ^{85}Kr to the atmosphere, future developments may require its collection and transportation to a federal repository.⁽¹³⁾ It has been proposed that this gas be collected in 50-liter gas cylinders 23 cm (9 in.) in diameter by 1.3 m (52 in.) high at a pressure of 150 atmospheres and shipped to a federal repository for storage. Three of these cylinders would be shipped in a cask weighing about 6.3 metric tons (14,000 lb). The cask is filled with water that acts as shielding and a heat transfer media. It is cooled by natural convection. Six of these casks could be carried on a standard railroad flatcar.⁽¹⁴⁾

3.9.3 Radioactive Iodine

Radioactive iodine will be removed from spent fuel at the reprocessing plant and fixed as a solid, possibly as potassium iodide. The amount of waste generated annually is small. Only one 450-kg (1000-lb) shipment/yr is anticipated from each 1500 MTHM/yr reprocessing plant. The shipping container will probably be a 210-liter (55-gallon) drum with an overpack.

3.9.4 Radioactive Tritium Gas

Radioactive tritium gas may also be collected at the reprocessing plant and fixed as a solid (possibly $\text{Ca}(\text{OT})_2$). Several available shipping containers could be used, including the DOT specifications 6M container.

The tritiated calcium hydroxide could also be put in drums and transported in Type B overpacks such as the NECO B2⁽¹⁵⁾ or the Protective Packaging, Inc. Super Tiger.⁽¹⁶⁾ The Super Tiger can accommodate forty-two 210-liter drums and has a maximum payload weight of 2.2 metric tons (5000 lb). The outside dimensions of the overpack are 1.3 m x 2.3 m x 3.5 m (54 in. x 91 in. x 142 in.).

3.9.5 Low Level Waste

Low level wastes are produced at all fuel cycle facilities. They include a wide variety of materials that generally do not require shielding during transportation. Combustible low level wastes will probably be compacted before they are transported. Much low level waste meets the requirement of Low Specific Activity (LSA) material, requiring strong tight industrial packaging when shipped in exclusive-use vehicles. Two hundred ten liter drums have been widely used for such shipments. Type A quantities of low level waste must be shipped in containers meeting the requirements of DOT specification 7A packaging. A variety of DOT specification metal drums, plywood boxes, fiberboard boxes and fiberboard drums have been determined to meet the Spec 7A requirements.⁽¹⁷⁾ The most common shipping containers for these wastes are 210-liter (55-gallon) drums. Wastes that are not contaminated with transuranic elements will be shipped to a commercial burial ground. The wastes that are contaminated with TRU elements will be shipped to a federal repository. The shipping containers used for these wastes must also meet as yet unspecified repository requirements as well as satisfy DOT transportation regulations. Low level wastes can be shipped by truck or railcar. Typical truck shipments contain sixty-four 210-liter (55-gallon) drums in a 10 m (33 ft) enclosed trailer. The ATMX-600 series railcar⁽¹⁸⁾ in use at ERDA's Rocky Flats facility has been very effective in transporting large quantities of low-level TRU waste. These cars are specially reinforced to satisfy the requirement of a Type B package. The interior dimensions of the car are 2.7 m x 2.7 m x 15.2 m (9 ft x 9 ft x 50 ft) and it has a useful load of 45.8 metric tons (101,000 lb). The car can carry two hundred sixteen 210-liter drums or two 2.4 m x 2.4 m x 6.1 m (8 ft x 8 ft x 20 ft) cargo containers each containing 70 drums or plywood boxes of various sizes. The Type B overpacks described in the previous section can also be used for Type B quantities of low level waste.

3.9.6 Intermediate Level Waste

Intermediate level wastes require shielding during transportation. Typical intermediate level wastes are coolant cleanup system resins and evaporator bottoms from reactors and HEPA filters and contaminated failed or obsolete equipment from reprocessing plants. Liquid wastes are generally immobilized by mixing them with concrete, bitumen or urea-formaldehyde before they are transported for disposal. Some of the reprocessing plant wastes will be contaminated with TRU elements and will be transported to a federal repository. The reactor wastes and the remainder of the reprocessing plant wastes will be shipped to a commercial burial ground.

Intermediate level wastes, just as low level wastes, can be either LSA, Type A, Type B, or large quantities of radioactive material. In the past, much of the dry intermediate level waste and immobilized liquids have been packaged in 210-liter drums and transported in shielded overpacks or shielded truck vans. The inexpensive drums are disposed of with the waste and the more expensive overpacks are reused. Shielded containers meeting the requirements of DOT Specification 7A are required for Type A quantities of intermediate level waste. Shielded containers meeting the Spec 7A requirements are available in various sizes with a variety of thicknesses. In recent years, shipments of reactor wastes, which are mostly Type A or LSA quantities of radioactive material have been made in large, 1.4 to 5.6 m³ (50-200 ft³), cylindrical steel drums placed in shielded shipping casks. Indications are that the current trend is toward more extensive use of these larger waste containers. It is felt that these containers reduce personnel exposure in packaging and handling the waste, and make more efficient use of the shielded overpack.⁽¹⁹⁾ A waste shipping cask on a truck trailer is shown in Figure 13.

Type B overpacks are required for Type B and large quantities of radioactive material. Available overpacks range in size from containers for one 210-liter (55-gallon) drum to large casks requiring overweight permits. A variety of shielding thicknesses are available and the shielding thickness can be varied in some containers by means of removable lead inserts.

FIGURE 13. Radioactive Waste Shipping Cask on Truck Trailer⁽²⁰⁾

3.10 IMPORT/EXPORT ACTIVITIES

The previous discussion has dealt with domestic shipments of fuel cycle materials. There are also some import and export shipments of these materials. These shipments occur primarily in the front end of the fuel cycle and are usually associated with ERDA sales of enriching services to foreign customers. U_3O_8 and natural UF_6 are imported and enriched UF_6 and UO_2 powder and pellets are exported. For the most part, the containers previously described are used for these materials. They are carried almost exclusively on cargo vessels, so the container must be approved for water-borne transport. Usually, to meet the requirements of the transportation regulations in both the shipping and receiving country, the container must be approved by the International Atomic Energy Agency. Most containers that have been approved by DOT and NRC meet the IAEA requirements.

4.0 TRANSPORTATION SERVICES

The trend in transportation of radioactive materials is for fuel cycle facilities to hire a specialized company to arrange transportation services for their radioactive material. This trend is due to a variety of factors. Transportation regulations are complicated. Expert interpretation of the regulations is often required. Shipping requirements at an individual site are usually not sufficient to warrant full time employment of a transportation expert. Specialized equipment is necessary for packaging and transporting radioactive material. It is not economically attractive for an individual facility to own a shipping container unless it can use the container continuously. The nuclear industry presently supports one dedicated fleet of trucks and specially trained drivers (Tri-State). As nuclear transportation requirements grow, it is expected that other common carriers will also develop special capabilities for transporting radioactive materials.

Some fuel cycle facilities own or lease shipping containers (many times with specialized truck trailers) and deal directly with common carriers, contract carriers, or specialized haulers to transport their material. This is the typical case in the front end of the fuel cycle (mining, milling and fuel preparation activities) where materials of relatively low hazard potential are shipped and shipping container requirements and regulations are relatively straightforward.

Companies specializing in spent fuel shipments typically design, obtain licenses for, build and lease spent fuel shipping casks. The casks are usually furnished with a specially designed transport vehicle. Companies engaged in the transportation of spent fuel include General Electric, Nuclear Fuel Services, Transnuclear, National Lead and Nuclear Assurance Corporation.

Waste shipments are usually handled by a company specializing in waste disposal operations. These companies contract with the fuel cycle facility to furnish the proper shipping container for the waste, make appropriate arrangements with disposal site and transport the waste. The three

major companies in the U.S. providing this service are Chem-Nuclear Systems with headquarters in Bellevue, Washington; Nuclear Engineering Company (NECO) in Louisville, Kentucky; and Hittman Nuclear and Development Corporation of Columbia, Maryland. Chem-Nuclear and NECO also operate low level waste burial grounds. Chem-Nuclear's facility is located in Barnwell, South Carolina. NECO operates facilities at Beatty, Nevada; Richland, Washington; Moorehead, Kentucky and Sheffield, Illinois.

Although many trucking companies act as common carriers of radioactive materials, there are three companies that as a group haul a large percentage of the fuel cycle shipments in the U.S. The largest company in this field is Tri-State Motor Transit with headquarters in Joplin, Missouri. By their own estimates, Tri-State hauls about 70% of the radioactive materials shipped annually in the U.S. They have a dedicated fleet of trucks and drivers for radioactive material. They also own some specialized equipment such as trailers with cradles for UF_6 cylinders or spent fuel casks permanently attached and armored tractors for safeguards shipments. They can also furnish armed drivers and armed escorts for safeguards shipments. Their drivers receive special training for hauling radioactive materials. Other companies engaged in the truck transport of radioactive materials include Davis Transport, Moss Trucking and Home Transport. Several other companies do a relatively large business in localized areas.

There are other companies in the U.S. providing a variety of transportation services. ATCOR, Inc. of Peekskill, New York, among others, provides shipping casks for rent. Many companies provide design and manufacturing services for shipping casks and there are a number of companies that supply radioactive material packaging.

In the past, most U.S. railroads have acted as common carriers of radioactive materials and shipped them, using the same procedures followed for routine shipments of other (non-radioactive) hazardous materials. Recently, however, the railroad industry has changed the way they propose to handle radioactive materials. Many eastern and southern railroads have refused to act as common carriers of radioactive materials. They will continue to handle these materials only on a

contract basis. The American Association of Railroads has proposed amendments to Uniform Freight Classification 12 that would require that all shipments of spent fuel, radioactive waste, and empty shipping containers be carried only in special train service. They have also proposed a set of operating practices that would prohibit carriage of non-radioactive materials in the same train with radioactive materials, require a maximum speed of 35 mph for special trains carrying radioactive materials, and require that one train be standing when a radioactive material special train meets, passes or is passed by another train. These operating practices would substantially increase the cost of shipping radioactive materials by rail. The final fate of these proposals is not known. They are currently being discussed in hearings before the Interstate Commerce Commission.

Most of the import/export shipments of radioactive material in the U.S. are handled under contract to shipping companies such as Edlow International, Inc., Transnuclear, Inc. or Mitsubishi International. Most customers purchasing services from these companies are foreign companies buying enrichment services from ERDA. The service company typically obtains necessary permits and licenses and arranges for transportation of the material to and from the U.S. (usually in cargo vessels) and transportation within the U.S. The customer usually owns and furnishes the shipping container. Some large companies such as General Electric and Westinghouse provide their own transportation services.

5.0 PROJECTIONS OF TRANSPORTATION REQUIREMENTS

This section gives a projection of the number of shipments, shipping distances and transportation requirements through the Year 2000.

Table 1 illustrates the current and projected transportation requirements of the nuclear power industry, the approximate number of shipments for each step in the fuel cycle in 1976 and projections for materials shipped in 1990 and 2000. The material flows are based on recent projections prepared for the Energy Research and Development Administration (ERDA).⁽²¹⁾ A mid-growth case has been used. This case is based on the installed nuclear generating capacity presented in Table 2.

The projection assumes that reprocessing begins in 1981, recycle of plutonium in light water reactors begins on a limited basis in 1982 and that the fast breeder reactor is commercialized in 1995. An average plant capacity factor of 70% has been assumed.

The estimated number of shipments presented in Table 1 for each type of material transported in the fuel cycle are based on the reference shipping containers and transport modes listed in the table. The shipping containers and modes selected are believed to be typical of current practice or representative of methods that will be used in the future. Changes in the reference shipping system can significantly affect the number of shipments. Total shipping distances, using assumed average shipping distances, are also included. Shipping distances include return of empty containers and special equipment. Details concerning the table entries are given in the footnotes following the table.

TABLE 1. Summary of Information on Projected Shipments of Radioactive Fuel Cycle Materials in the U.S.

Fuel Cycle Step	Material Shipped	Physical/Chemical Form	Typical Shipping Container	Quantity/Container	Transport Mode	Quantity/Shipment	Quantity Shipped/Yr			Shipments/Yr			Destination	Estimated Avg. Shipping Distance (km)	Total Shipping Distance/Yr (Thousands of km) ^(a)			Special Equipment/Personnel Requirements
							1976	1990	2000	1976	1990	2000			1976	1990	2000	
Milling	U ₃ O ₈	Fine Yellow Powder	Steel Drums	360kg	Rail	110 Drums	13,000MT ^(b)	52,000MT	82,000MT	350	1300	2100	UF ₆ Conversion	2500	880	3300	5200	None
UF ₆ Conversion	Natural UF ₆	Volatile Solid	10-Ton Cylinder	9MT	Truck	2 Cylinders	13,000MT ^(c)	55,000MT	87,000MT	700	3100	4800	Enrichment Plant	800	1100	5000	7700	Cylinders, Cradles, Tiedowns (Usually Dedicated Trailer)
	Waste	Various Contaminated Solids	Steel Drums	210 ℓ	Truck	64 Drums	3,000m ^{3(d)}	10,000m ³	15,000m ³	220	750	1100	Burial Ground	800	180	600	880	None
Enrichment	Enriched UF ₆	Volatile Solid	2 1/2-ton Cylinder with Overpack	2.3MT	Truck	5 Cylinders	2,300MT	10,000MT	16,000MT	200	900	1400	Fuel Fabrication Plant	800	320	1400	2200	Cylinders, Overpack, Tiedowns (Usually Dedicated Trailer)
	Depleted UF ₆ ^(e)	Volatile Solid	10-Ton Cylinder	9MT	Truck	2 Cylinders	0	1,400MT	2,100MT	0	80	120	Fuel Fabrication Plant	800	0	130	190	Cylinders, Cradles, Tiedowns (Usually Dedicated Trailer)
	Waste	Various Contaminated Solids	Steel Drums	210 ℓ		64 Drums	2,000m ^{3(d)}	5,700m ³	11,000m ³	150	420	850	Burial Ground	800	120	330	680	None
Fuel Fabrication	UO ₂ Fresh Fuel	UO ₂ Pellets in Zircaloy Tubes	Protective Overpack	1 PWR or 2 BWR Elements	Truck	6 PWR or 16 BWR Containers	1,500MT ^(f)	7,000MT	11,000MT	270	1200	2000	Reactor	1000	540	2500	4000	Overpacks
	Waste	Various Contaminated Solids	Steel Drums	210 ℓ	Truck	64 Drums	1,200m ^{3(d)}	5,700m ³	9,000m ³	90	420	670	Burial Ground	800	70	340	540	None
	PuO ₂ -UO ₂ Fresh Fuel	PuO ₂ -UO ₂ Pellets in Zircaloy Tubes	Protective Overpack	1 PWR or 2 BWR Elements	Truck	6 PWR or 16 BWR Containers	0	1,000MT	1,500MT	0	180	260	Reactor	1000	0	360	520	Overpacks, Security Personnel
	Wastes	Various TRU-Contaminated Solids	Steel Drums	210 ℓ	Truck	64 Drums	0	2,300m ^{3(g)}	3,500m ³	0	170	260	Federal Repository	2500	0	430	650	None
Power Production	Spent Fuel	Fuel Pellets and Fission Products in Zircaloy Tubes	Shielded Cask	2 PWR or 4 BWR Elements	Truck	1 Cask	50MT	1,200MT ^(h)	2,200MT	110	1300	2400	Reprocessing Plant	1600	350	4200	7700	Casks, Tiedowns, Dedicated Transport Vehicle
	Spent Fuel	Fuel Pellets and Fission Products in Zircaloy Tubes	Shielded Cask	10 PWR or 24 BWR Elements	Rail	1 Cask	100MT	4,800MT	8,800MT	30	1100	2000	Reprocessing Plant	1600	100	3500	6400	Casks, Tiedowns, Dedicated Transport Vehicle
	Waste	Various Contaminated Solids	Steel Drums, Some in Shielded Overpacks	210 ℓ	Truck	64 Drums	12,000m ³⁽ⁱ⁾	60,000 ⁽ⁱ⁾	120,000m ³⁽ⁱ⁾	900	4500	9000	Burial Ground	800	720	3600	7200	Shielded Overpacks (Some Shipments)
Reprocessing	Plutonium	PuO ₂ Powder	Shielded Container	32kg	Truck	7 Containers	0	40MT ^(j)	100MT	0	160	450	Fuel Fabrication Plant	1200	0	380	1100	Armored vehicle, Armed Escort, Communication Equipment
	Solidified High Level Waste	Boro-silicate Glass in Stainless Steel Canisters	Shielded Cask	2m ³	Rail	1 Cask	0	130m ^{3(k)}	600m ^{3(k)}	0	70	300	Federal Repository	2500	0	350	1500	Cask, Tiedowns, Dedicated Flatcar
	Cladding Waste	Zircaloy Tubing, Stainless Steel and Inconel Fittings	Stainless Steel Cylinder in Shielded Cask	4.2 m ³	Rail	1 Cask	0	1,600m ³	3,500m ³	0	400	880	Federal Repository	2500	0	2000	4400	Cask, Tiedowns, Dedicated Flatcar
	Noble Gases ^(l)	⁸⁵ Kr Gas	50- ℓ Cylinder in Shielded Cask	3 Cylinders/Cask	Rail	6 Casks	0	1MT ^(m)	3MT	0	2	6	Federal Repository	2500	0	10	30	Casks, Tiedowns, Dedicated Flatcar
	Tritium ^(l)	Ca(OT) ₂	Steel Drums in Overpack	210 ℓ	Truck	42 Drums in Overpack	0	65m ³⁽ⁿ⁾	170m ³	0	7	20	Burial Ground	800	0	10	30	Overpack
	TRU Waste	Various Contaminated Solids	Steel Drums, Plywood Boxes, Some in Protective Overpacks	210 ℓ	Rail	140 Drums	0	13,000m ^{3(o)}	30,000m ^{3(o)}	0	450	1000	Federal Repository	2500	0	1100	2500	Overpack, (Some Shipments)
	Non-TRU Waste	Various Contaminated Solids	Steel Drums, Plywood Boxes, Some in Protective Overpacks	210 ℓ	Rail	140 Drums	0	3,500m ³	7,800m ³	0	120	260	Burial Ground	800	0	100	200	Overpack, (Some Shipments)
	Slightly Enriched UF ₆	Volatile Solid	14-Ton Cylinder	12.7MT	Rail	4 Cylinders	0	7,200MT	17,000MT	0	140	330	Enrichment Plant	800	0	220	530	Cylinders, Cradles, Tiedowns,

(a) Shipping distances include round trip for casks and special containers.
(b) Calculated assuming that no losses occur in conversion from "yellowcake" to UF₆. Material shipped is assumed to be "yellowcake", with an average U₃O₈ content of 85%.
(c) Reference 21. An enrichment tails assay of 0.25% has been assumed.
(d) Waste volumes based on information in Reference 22.
(e) Mixed oxide fuel is assumed to be manufactured from PuO₂ and depleted uranium dioxide.
(f) Reference 21.
(g) Waste volumes based on Reference 11. Waste treatment assumptions same as note i.
(h) Assumes that 80% of all spent fuel is shipped by rail in 1990 and 2000.
(i) Waste volumes based on information in Reference 11. Reactor coolant cleanup systems are assumed to be 75% deep bed demineralizer systems and 25% powdered resin filter-demineralizer systems. Waste volumes for 1976 are untreated volumes. In 1990 and 2000, all combustible and wet wastes are assumed to be treated before being shipped for disposal. Combustible wastes are assumed to be compacted with a volume reduction factor of 5. Wet wastes are assumed to be immobilized in concrete, bitumin or urea-formaldehyde with a volume increase factor of 2. Noncombustible solids are assumed to be packaged without treatment. A packing factor of 60 was used for noncombustible solids.
(j) Same as c.
(k) Based on information in Reference 11. High level liquid waste is assumed to be solidified shortly after being generated and stored as a solid for 5 yr before being transported.
(l) Collection and transportation of these materials is not currently required. These materials are included because transportation of these materials may be required in the future.
(m) Based on information in Reference 11. Kr is assumed to be cooled 1 yr before being transported.
(n) Based on information in Reference 23.
(o) Waste volumes based on Reference 11. Waste treatment assumptions same as note i except volume reduction factor for combustible TRU wastes assumed to be 2.

TABLE 2. Projected Growth of Nuclear Power

		<u>1976</u>	<u>1990</u>	<u>2000</u>
PWR	(GWe)	27	167	312
BWR	(GWe)	17	84	156
LMFBR	(GWe)	<u> </u>	<u> 1 </u>	<u> 32 </u>
	TOTAL	44	252	500

Table 3 presents an estimate of the number of shipments of various types from typical fuel cycle facilities. These estimates assume that the fuel cycle as depicted in Figure 1 is fully operational in a relatively steady state. Waste shipments are based on the waste treatment assumptions for 1990.

TABLE 3. Estimated Annual Shipments from Typical Fuel Cycle Facilities (Steady State Fuel Cycle Operation)

<u>1000 MWe Light Water Reactor</u>	<u>Shipments/Yr</u>
Spent Fuel (Truck)	5
(Rail)	5
Waste (Truck)	<u>20</u>
TOTAL	30
<u>1500 MTHM/yr Reprocessing Plant</u>	
Plutonium	40
Solidified High Level Waste (Rail)	20
Cladding Waste (Rail)	100
Noble Gases (Rail)	1
Iodine (Truck)	1
Tritium (Truck)	2
TRU Waste (Rail)	110
Non-TRU Waste (Rail)	30
UF ₆ (14-Ton Cylinder by Rail)	<u>30</u>
TOTAL	330
<u>1500 MTU/yr UO₂ Fuel Fabrication Plant</u>	
Fresh Fuel (Truck)	260
Waste (Truck)	<u>90</u>
TOTAL	350
<u>300 MTHM/yr Mixed Oxide Fuel Fabrication Plant</u>	
Fresh Fuel (Truck)	50
Waste (Truck)	<u>50</u>
TOTAL	100
<u>15,000 MTU/yr UF₆ Conversion Facility</u>	
Natural UF ₆ (10-Ton Cylinders By Truck)	900
Waste (Truck)	<u>220</u>
TOTAL	1120
<u>1800 MT Ore/day Uranium Mill</u>	
U ₃ O ₈ (Rail)	30
<u>18.75 MT SWU/yr Uranium Enrichment Plant</u>	
Enriched UF ₆ (2 1/2-Ton Cylinder by Truck)	300
Waste (Truck)	<u>140</u>
TOTAL	440

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APPENDIX A

GOVERNMENT REGULATIONS PERTAINING TO THE TRANSPORTATION OF RADIOACTIVE MATERIALS

FEDERAL REGULATIONS

Regulations governing the transportation of radioactive materials have been established to prevent the loss or dispersal of material during shipment and to insure the safety of the public and transportation workers. There is overlapping responsibility for regulating the safe transport of radioactive materials. Primary responsibility at the federal level for the safety of radioactive shipments lies with the Department of Transportation (DOT) Materials Transportation Bureau and the Nuclear Regulatory Commission (NRC). A "Memorandum of Understanding" between the two agencies was signed in 1966 and revised in 1973.⁽¹⁾ This memorandum calls for cooperation between DOT and NRC and delineates the responsibilities of each agency. DOT is responsible for promulgating and enforcing safety standards governing packaging and shipping containers and for the labeling, classification and marking of all packages. DOT also implements safety standards for the mechanical condition of carrier equipment and qualifications of carrier personnel. NRC develops performance standards for package designs and reviews package designs for Type B, fissile and large quantity packages (defined below). DOT requires NRC approval to use these packages.⁽²⁾ The Federal Aviation Administration, the Interstate Commerce Commission, the Civil Aeronautics Board, the U.S. Coast Guard and state regulatory agencies also exercise some regulatory authority over the shipment of radioactive materials.

The transportation or packaging for transport of radioactive material is subject to issuance of the appropriate licenses. Applicants for a license to package or to transport radioactive material must show by a combination of analysis and experiment that the proposed package or transport vehicle satisfies all the requirements set forth in the Code of Federal Regulations. The application must describe proposed controls or precautions to be used in the loading, unloading, handling and transport of radioactive material and the procedures to be followed in the event of an accident or delay in shipment. Inspection and accountability procedures must also be described.

The following Federal Regulations are applicable to the transportation of radioactive materials:

- Title 49 Code of Federal Regulations Parts 170-199 (49 CFR 170-199) - Department of Transportation regulations governing the transport of hazardous materials.
- 10 CFR 71 - Nuclear Regulatory Commission regulations governing the packaging and shipment of radioactive materials.
- 14 CFR 103 - Federal Aviation Administration regulations for shipment of radioactive materials by air.
- 46 CFR 146 and 149 - U.S. Coast Guard regulations governing the shipment of radioactive materials by water.
- 10 CFR 73 - Nuclear Regulatory Commission regulations for the protection of special nuclear material in transit.

DOT and NRC regulations are the most important for shipments in the Nuclear Fuel Cycle. These regulations will be reviewed here.

Transport Group

Radioactive materials are classified for transportation purposes into one of seven transport groups according to their radiotoxicity and potential hazard if released to the environment.^(a) Transport Group I is the most restrictive. Materials such as plutonium are placed in this group. Materials such as tritium gas with a relatively low hazard potential are placed in Transport Group VII.

Quantity Designations

A shipment of radioactive material is classified as Type A, Type B, or Large Quantity of Radioactive Material depending on the amount of radioactivity it contains. The dividing line between the quantity types is dependent on the Transport Group of the material being shipped. (See Table A-1.)

^(a) It is anticipated that the U.S. Regulations will be changed in the near future to agree in substance with 1973 IAEA Regulations. The transport group designation has been replaced with a different system in these regulations. (See References 3 and 4.)

If a shipment contains materials from more than one Transport Group, the most restrictive group will generally apply for the determination of quantity type. (See 10 CFR 71.4(p).)

TABLE A-1. Maximum Activities for Normal Form^(a) Type A and B Quantities of Radioactive Material by Transport Group

<u>Transport Group</u>	<u>Type A Quantity (Ci)</u>	<u>Type B Quantity (Ci)</u>
I	0.001	20
II	0.05	20
III	3	200
IV	20	200
V	20	5000
VI and VII	1000	50000

NOTE: Any quantity greater than Type B is defined as a "Large Quantity" of radioactive material.

(a) Normal form material is everything that does not meet the "Special Form" criteria outlined below.

Low Specific Activity (LSA) Materials

Some shipments of material with a relatively low hazard potential are exempted from certain of the requirements in the regulations even though they may contain Type A or B quantities of radioactive materials. LSA materials include uranium or thorium ores, unirradiated depleted or natural uranium, unirradiated thorium; aqueous solutions of tritium oxide containing less than 5 mCi/ml; and materials having uniformly distributed activity in which the concentrations per gram does not exceed the following:

- 0.1 μ Ci of Group I materials
- 5.0 μ Ci of Group II radionuclides
- 300 μ Ci of Group III and IV materials.

Externally contaminated non-radioactive materials may be considered LSA provided the contamination is not readily dispersible and the average surface contamination per square centimeter does not exceed the following:

- 0.1 μCi for Group I radionuclides
- 1.0 μCi for other materials.

Special Form Material

Radioactive material in special form may be transported as if it were Transport Group V regardless of the radioactive species present. Special form material meets one of the following criteria:

1. Radioactive material in solid form having no dimension less than 0.5 mm (or one dimension greater than 5 mm). Will not sublime, melt or ignite in air at 538°C. Remains non-dispersible after immersion for one week in water at 20°C or air at 30°C.
2. Radioactive material contained in a capsule that will satisfy the above requirements.

Special form material must remain intact after a test that includes a 9.1-m drop, impact of 1.4-Kg steel rod dropped from a height of 1 m, heating to 800°C for 10 minutes and immersion in water for 24 hours.

Fissile Classification

A shipment containing fissile materials (^{233}U , ^{235}U , ^{238}Pu , ^{239}Pu , ^{241}Pu) is classified according to the amount of control which must be exercised to prevent nuclear criticality in shipment.

- Fissile Class I packages may be shipped in unlimited numbers in any arrangement, requiring no nuclear criticality considerations.
- Fissile Class II packages may be shipped together in any arrangement but their numbers are limited to an aggregate Transport Index (see definition below) of 50. For purposes of nuclear criticality safety, individual packages must have a transport index between 0.1 and 10.

- Fissile Class III packages must be controlled in transport by special arrangements between the shipper and the carrier to provide nuclear criticality safety.

Certain shipments of fissile materials are exempt from the normal requirements for packages containing fissile material. These packages meet one of the following criteria (among others - see 10 CFR 71.9):

1. Contain less than 15 g fissile material
2. Contain Th or U with less than 0.72% fissile material
3. Contain less than 350 g fissile material with a maximum of 5 g in any 0.028 cubic meter (1 ft³) of the package.

Transport Index

The transport index is a number placed on a package of radioactive material to designate the degree of control to be exercised by the carrier during transportation. The transport index is the larger of the following numbers:

1. The highest radiation dose rate in millirem/hr at 1 m from any accessible external surface of the package; or
2. For Fissile Class II packages the number 50 divided by the maximum number of such packages which may be transported together with criticality safety considerations.

Except in a exclusive use vehicle, the aggregate transport index of all packages in any storage area during transportation must be exceed 50. (Shipments of Fissile Class II packages can never exceed an aggregate transport index of 50. A total transport index of 100 is permitted for fissile Class III shipments.) The transport index also determines the labeling requirements for the package.

Special Nuclear Material (SNM)

A shipment of radioactive material is designated special nuclear material if it contains 5000 grams or more of ²³⁵U (contained in uranium enriched to 20 percent or more), ²³³U or plutonium or any combination of the three computed by the formula

$$\text{grams} = \text{grams } ^{235}\text{U} + 2.5 (\text{grams } ^{233}\text{U} + \text{grams Pu}).$$

10 CFR 73 requires that shipments of special nuclear material be afforded additional physical protection in transit to prevent theft or sabotage. These protective measures include:

- Carrier procedures NRC approved pre-planned
- Hand-to-hand receipts
- Tamper-indicating seals on all containers
- Minimum container weights of 227 kg for shipments in open vehicles
- No cargo transfers enroute
- Periodic radio communication between transport vehicle and carrier dispatcher
- Armed escorts or specially designed transport vehicles with disabling features

Radiation Dose Requirements

Radiation dose rates from shipments of radioactive materials are also limited by the regulations. Larger maximum radiation dose levels are allowed for vehicles being used exclusively to transport radioactive materials than for non-exclusive use vehicles. For vehicles not in exclusive use the following limits apply

- 200 millirem/hr at any point on the external surface of the package
- 10 millirem/hr at 1 m from the package

For vehicles being used exclusively for the transport of radioactive materials the limits are as follows:

- 1000 millirem/hr at 1 m from the external surface of the package (closed transport vehicle only)
- 200 millirem/hr at any point on the external surface of the vehicle (closed transport vehicle only)
- 10 millirem/hr at 2 m from the external surface of the vehicle
- 2 millirem/hr in any normally occupied position in the vehicle.

These dose limits are illustrated in Figure A-1 for truck transport.

FIGURE A-1. Radiation Dose Limits (Reference 5)

Packaging

The type of packaging required for a shipment of radioactive material is dependent on the type, quantity, form and fissile classification of the material to be shipped. 49 CFR allows shipment of radioactive materials in DOT specification containers, in containers licensed by NRC or in containers authorized by special permit from DOT.^(a) The specification containers are described in the regulations. All radioactive material shipping containers must meet the general package requirements for radioactive material shipping containers 49 CFR 173.393 and the general requirements for all packaging used in interstate commerce contained in 49 CFR 173.24.

Low specific activity material shipped in exclusive use vehicles is exempt from most of the packaging requirements of 49 CFR. Basically only strong, tight packaging is required. The radiation dose limits discussed previously are still applicable, however.

Type A quantities of radioactive material must be shipped in DOT specification 6M packaging, approved Type B packaging or packaging that meets the requirements of DOT specification 7A (See 49 CFR 178.350). In addition to meeting the general packaging requirements of 49 CFR 173.24 and 49 CFR 173.393, specification 7A packaging must be capable of maintaining its shielding integrity and preventing the dispersal of its contents during a test simulating conditions normally incident to transportation. These test conditions are outlined below.

Test Representing Conditions Normally Incident To Transportation

- Heat - direct sunlight at an ambient temperature of 54°C in still air.
- Cold - an ambient temperature of -40°C in still air and shade.
- Pressure - one half standard atmospheric pressure.
- Vibration - normally incident to transport.

^(a) Special permits are no longer issued for radioactive material shipping containers. The special permits now in effect will be allowed to expire without renewal. In the future all radioactive material will be shipped in DOT specification or NRC licensed containers.

- Water spray - sufficient to keep the exposed surfaces of the package except the bottom wet for 30 minutes.
- Free drop - 1 1/2 to 2 1/2 hours after the water spray test at a distance of 1.3 to 1.2 m (depending on package weight) onto an unyielding surface.
- Corner drop - onto each corner in succession (each quarter of each rim for cylinders) from a height of 30 cm onto an unyielding surface (applies only to wood or fiberboard containers of less than 45 kg and to all Fissile Class II Packages).
- Penetration - impact of the hemispherical end of 5.9 kg steel cylinder 3.2 cm in diameter dropped from a height of 1 m onto the most vulnerable surface of the package.
- Compression - a compressive load against the top and bottom of the package in its normally transported condition. The load is the greater of 5 times the weight of the package or $1.38 \text{ neutrons/cm}^2$ times the minimum horizontal cross section of the package. (This test applied only to packages weighing less than 4535 kg.)

Type B quantities of radioactive material may be shipped in DOT specification 6M containers, in packaging authorized by NRC or in packaging meeting the 1973 IAEA requirements (provided DOT has validated the approval of the foreign competent authority). Type B packaging submitted to NRC for approval must be able to maintain its integrity through the test conditions outlined below simulating transportation accident environments as well as the test simulating conditions normally incident to transportation outlined above.

Test Conditions Simulating Severe Transportation Accident Environments

(Tests applied sequentially to determine cumulative effect on the package.)

- Free drop - through a distance of 9.1 m onto an unyielding surface striking the surface in the position which would produce maximum damage.

- Puncture - a free drop through a distance of 1 m onto a cylindrical steel bar 15.2 cm in diameter with the edge rounded to a radius of 6.4 mm. The length of the bar is selected for maximum damage (minimum length is 20.3 cm). The bar is mounted on an unyielding horizontal surface and the package is dropped in a position expected to produce maximum damage.
- Thermal - exposure to the equivalent of a 800°C fire for 30 minutes with no artificial cooling for 3 hrs after the exposure.
- Water immersion - (fissile material packages only) at a depth of 91 cm for 8 hours.

Large quantities of radioactive materials are shipped in Type B packaging. The packaging used must provide adequate shielding and heat removal capabilities for the radioactive material to be transported.

Fissile material may be shipped in DOT specification 6L (Type A quantities only) or 6M packaging or in packaging approved by NRC. Packaging approved by NRC for fissile materials must meet some requirements not posed on containers for other radioactive materials (See 10 CFR 71.38 - 71.40). These conditions insure a wide margin of safety on the number of packages which can be shipped at one time. They also insure that a critical mass could not be assembled in the event of a transportation accident.

Special Regulations Applying to Plutonium

Because of its hazardous nature, there are some special regulations in effect for the shipment of plutonium. Plutonium may presently be shipped as a liquid (in nitrate solution) or as a solid (plutonium oxide). After June 1978, plutonium in excess of 20 Ci per package must be shipped as a solid. (10 CFR 71.42). The plutonium must be double packaged and the inner container must maintain its containment integrity as the outer container undergoes the tests for Type B packaging. The separate outer container must meet the requirements for packaging of material in normal form.

Federal regulations prohibit shipments of plutonium in passenger aircraft in quantities exceeding 20 grams or 20 Ci, whichever is less (10 CFR 71.42). However, a recently enacted federal statute has placed an embargo on shipments of plutonium by air until it is shown that the shipping containers will not release their contents in an airplane crash environment.

State Regulations

Although federal agencies dominate the regulatory process for the transportation of radioactive materials, state governments also exercise some control over these shipments. State highway departments regulate gross vehicle weights, vehicular dimensions and other parameters for radioactive shipments just as they do for other kinds of shipments. About one half of the states have adopted the U.S. DOT Hazardous Materials Regulations to cover intra-state shipments. Several states have adopted or proposed additional regulations concerning radioactive materials.^(1,6) These include:

- Special routing of radioactive shipments
- Advance notification for shipments of large quantities of materials
- State inspections of some types of radioactive shipments
- Prohibition of certain types of shipments within the states
- Prior approval for radioactive shipments
- Requirement of exclusive use vehicle for radioactive shipments
- Use of pilot vehicles
- Speed restrictions for radioactive shipments
- Specific hours of movement
- Accompaniment of all shipments by radiation monitoring personnel.

The variation of regulations between adjacent states can often require special considerations for interstate shipments.

There is a potential conflict between some of the proposed state laws and the provisions of the National Transportation Act of 1974. (Public Law 93-633 signed in 1975). This law prohibits the states from adopting laws or regulations more stringent than Federal regulations unless the state regulations improve transportation safety. Even in this case, such rules can be adopted only if they do not unreasonably burden commerce.

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