Transportation Requirements for the Disposition of Excess Weapon Plutonium by Burning in Fission Reactors*

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INTRODUCTION

Both the United States and Russia, as part of a mutual program to ensure peaceful intentions (to one another and the international community), are planning to dispose of about 50 Mg of excess weapon plutonium over a 25-year period. One option is to transfer the plutonium to Advanced Light Water (power) Reactors (ALWRs) for use as fuel. Subsequent disposal would then be considered "commercial" spent fuel. This disposition option, like others, involves the transportation of plutonium in various material forms as it proceeds through various points in the recovery operation. This paper examines both the disposition option and the issues surrounding the transportation of 50 Mg of excess plutonium within the United States under current regulatory and infrastructure constraints.

Transportation of plutonium and associated wastes will be subject to government regulations and Department of Energy (DOE) orders. At its discretion, DOE may adopt national-security exemptions for transporting sensitive forms of special nuclear materials. Such instances have become increasingly rare. Different regulations may apply for different portions of the plutonium-recovery operation, which generally starts with weapon pits and ends with feed material for fuel-element fabrication. Following the fuel-element fabrication, the fresh fuel assemblies will be shipped to the reactor site where they will be fissioned in ALWRs. The spent fuel will be stored on site for some specified time prior to shipment to a disposal facility.

Transportation issues include criticality control, shielding, and containment of the contents. Allowable limits on each of these issues are specified by the applicable (or selected) regulation. The composition and form of the radioactive materials to be transported will determine, in part, the applicable portions of the regulations as well as the packaging design. The regulations and the packaging design, along with safeguard and security issues, will determine the quantity of plutonium or fuel assemblies per package as well as the number of packages per shipment and the type of highway carrier. For the disposition of 50 Mg of weapon plutonium using ALWRs in a 25-year campaign, the annual shipment rates are determined for the various types of carriers.

PACKAGING ISSUES

Packaging design and transportation of a package containing radioactive material must ensure that the contents of the package remain subcritical, that the dose rate at the surface of the package

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is at an acceptable level, and that the release rate of the contents remains below specified allowable levels during storage and normal shipment and in the event of an accident.

Criticality

Criticality control may be the limiting factor in packaging design and transportation plans for plutonium in its various forms at various points in the recovery operation. Criticality criteria are applied to a package as well as a shipment of packages. Criticality is not an issue for shipment of low level waste (LLW) from recovery operations.

Shielding

The allowable surface dose rate and the radionuclide contents of the package dictate the shielding that must be provided by the packaging. Additional shielding for pure plutonium metal is required for shipments containing americium impurities or plutonium oxide. The most challenging shielding requirements are for spent fuel packages and shipments.

Containment

The radionuclide content of the package and the form of the material dictate the containment criteria. Material in a nondispersable form, such as a solid metal, is easier to contain than a potentially dispersible form, such as PuO_2 powder. Solid plutonium metal and reactor fuel elements can be shipped in packages with a single containment system. However, PuO_2 powder, unless exempted, must be doubly contained (i.e., in a sealed inner container that is wholly within a sealed outer container).

REGULATIONS

Packaging and transportation of radioactive materials are subject to regulation by various government agencies, such as the Nuclear Regulatory Commission (NRC), the Department of Transportation (DOT), or DOE. For defense program activities, DOE may either comply with NRC regulations or select to transport materials under a national-security exemption.

National-Security Exemption

For the purpose of national security, DOT regulation 49 CFR 173.7(b) allows DOE to ship radioactive material under escort by personnel designated by DOE, thus waiving DOT regulations in 49 CFR 170-189 (49 CFR Subchapter C).

Nuclear Regulatory Commission Regulations

The NRC regulation 10 CFR 71 establishes the requirements for packaging, preparation for shipment, and transportation of licensed material and for the procedures and standards for obtaining NRC approval of packaging and shipping procedures for fissile material and Type B quantities of other licensed materials. (A quantity of weapon plutonium in excess of approximately 25 mg constitutes a Type B quantity per 10 CFR 71.) This regulation incorporates, by reference, DOT regulation 49 CFR 170-189. Wherever possible, DOE transports radioactive materials under NRC regulations.

Nonconforming Shipments

All DOE shipments of materials, components, and assemblies must meet the normal transport conditions described in 10 CFR 71. If the shipment does not meet the hypothetical accident condition stated therein, however, the DOE may, based on DOE Order 5610.12, require that a risk assessment be performed. The DOE may then authorize the shipment subject to restrictions determined by the results of the risk assessment. These may include restrictions on the mode of transport, type of vehicles, freight container, or supplementary operational requirements and may require a DOT exemption from some part of the DOT regulation.

DOE ORDERS

The current DOE order covering the shipment of hazardous material is DOE Order O 460.1. This order contains the special requirements for radioactive material packaging, including plutonium packaging. All current DOE shipments of nuclear explosives, nuclear components, and special assemblies are performed under DOE Order 5610.12. This order requires that nuclear explosives, nuclear components, and special assemblies must be packaged and transported to provide a level of safety at least equal to that provided by packaging and shipping in accordance with regulations applicable to other radioactive material. Note that PuO_2 powder does not meet the definition of a nuclear component under DOE Order 5610.12 and will probably never be shipped under 49 CFR 173.7(b) even in a safe secure trailer (SST).

GENERAL LOGISTICS

Routes between the various plant locations in the plutonium recovery operation will determine the general logistics. The transportation index (TI) of a package with fissile contents is based on nuclear criticality control (as determined by regulations). The limit of the number of packages (and hence the contents) per shipment is based on the TI. The minimum number of shipments for a campaign is simply the amount of material to be shipped divided by the maximum amount of material allowed per shipment. Safeguards and security must be in place to ensure that diversion of plutonium does not occur.

Location of Transportation End Points

Figure 1 shows the transportation end points being considered for the purpose of providing a definitive framework in which to evaluate transportation issues. This figure depicts several possible scenarios to illustrate the transportation issues involved. Collocation of the necessary facilities would avoid or minimize the need for transportation. Plutonium pit parts are assumed to be isolated from their weapons at Pantex (Point P). Plutonium recovery that converts the weapon plutonium into feed material for nuclear reactors could be done at Pantex, or the pits could be shipped to a fuel-processing facility at Hanford (Point H), the Nevada Test Site (Point N), or the Savannah River Site (Point S).

In the first case, the plutonium feed material could be shipped to the standard (hypothetical) Electric Power Research Institute (EPRI) power station in the Great Lakes region (which is used as the baseline location for "greenfield" cost estimates of the disposition reactor(s) in the DOE Plutonium Disposition Study). The feed material would be delivered to a fuel-fabrication facility located adjacent to the reactor. Alternatively, the pits could be processed at Hanford, the Nevada Test Site, or the Savannah River Site, and the feed material subsequently shipped to the fuel-fabrication facility.

In another scenario, the fuel-fabrication facility and reactor(s) are located at Hanford, the Nevada Test Site, or the Savannah River Site. The only transportation required would be to move pits from Pantex to one of these three sites. At the recovery-process site, the resulting radioactive waste would be properly transported to the appropriate waste repository.

Collocation of facilities at a DOE site would simplify transportation issues. Onsite transportation would be subject to DOE Order O 460, which requires that transportation must meet DOT requirements of 49 CFR 170-189 or equivalent safety standards for any deviation from the DOT regulations. Site safeguards and security would ensure that the material transported onsite is secure.

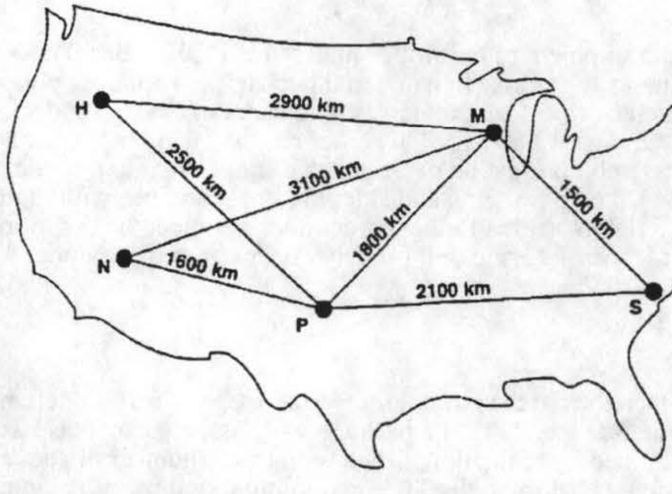

Figure 1. Transportation end points being considered for the purpose of providing a definitive framework in which to evaluate transportation issues. Route distances are approximate and are subject to change, depending on results of risk analysis. (H = Hanford, N = Nevada Test Site, P = Pantex, M = "Midtown" standard (hypothetical) EPRI site, S = Savannah River Site.)

Transportation Route

Transportation of plutonium from one facility to another is more complex than onsite transportation. If the DOE decides to transport plutonium using the national-security exemption of 10 CFR 173.7(b), selection of a route that will minimize the probability and consequences of an accident is necessary. Codes such as RISKIND (Yuan et al. 1993) or RADTRAN (Nuehauser and Kanipe 1992) can be used to calculate the radiological consequences of incident-free transportation and the accident risk of transporting radioactive materials. The accident risk is based on (1) how the radioactive material is dispersed in various types of accidents and (2) the health and economic effects of dispersing the material.

Amount of Material per Shipment

The amount of fissile material contained in a package may be determined by criticality, decay-heat, or radiation-dose considerations. The package must remain subcritical during normal and abnormal "accident" conditions of transport, as defined by regulations such as 10 CFR 71.55 or International Atomic Energy Agency (IAEA) Safety Series No. 6. The amount of fissile material per package and the maximum number of packages per shipment—based on criticality and external radiation-level considerations—will determine the amount of material per shipment. For exclusive-use shipments of fissile material, the number of packages may be double the number used to establish the transport index (TI), as defined below. The radiation dose rate must not exceed 2 mSv/h on the outer surfaces or 0.1 mSv/h at any point 2 m outside the outer surfaces of the conveyance used for exclusive shipment.

Transport Index (TI)

For exclusive-use shipment of fissile material (as would be the case here), the sum of the TIs of the packages in the shipment, based on criticality control, must be no more than 100.

The TI for criticality control is obtained by dividing 50 by the allowable number, N, of the packages that can be stacked together such that:

(a) if the undamaged packages are stacked together in any arrangement and closely reflected on all sides of the stack by water, 5 times the allowable number of the packages would be subcritical *or*

(b) if the packages damaged by the application of a series of hypothetical regulatory tests are stacked together in any arrangement and closely reflected on all sides of the stack by water and with optimum interspersed hydrogenous moderation, 2 times the allowable number of damaged packages would be subcritical.

Number of Shipments

The minimum number of shipments required to ship 50 Mg of plutonium to the feed fabricators (over public roads) depends on the number of packages allowed per shipment. The required rate of shipments will be determined by the rate capacities at the plutonium-recovery and fuel-fabrication points, the fuel requirements for the reactor, and the storage capacity at each facility.

Safeguards and Security

Because plutonium is a strategic special nuclear material, shipment of plutonium is subject to regulations which safeguard and secure the plutonium from diversion. The NRC regulation that covers the safeguards and security of shipments of plutonium are given in 10 CFR 73. The DOE safeguards and security program is covered by DOE Order O 470.1. The transportation safeguard system program operations are covered in DOE Order 5610.14 which incorporates, by reference, DOE Order 5633.3B covering control and accountability of nuclear materials. The NRC transportation safeguards and security regulations for spent fuel are given in 10 CFR 73.37. The DOE protection of unclassified irradiated reactor fuel in transit is covered in DOE Order 5632.11.

All unirradiated plutonium, including fresh fuel assemblies, must be shipped as an exclusive-use shipment by safe secure trailers (SST) to minimize the potential for diversion of the material. The spent fuel can be shipped as an exclusive use shipment on a flatbed truck. However, the shipment of the spent fuel must conform to safeguard and security regulations or DOE orders identified above.

Packages Required for Each Fuel Type

Several packages in various stages of the certification or recertification process will be available to ship plutonium metal or plutonium oxides. These packages include, but are not limited to, the SAFKEG 2863B packaging to be certified as Docket No. 94-14-9517 and the Savannah River 9960 and 9970 series of packages (WSRC-SA-7 1994). The shipment of plutonium in the solid-metal form requires only a single containment system while the shipment of plutonium in the powder or oxide form requires that the plutonium contents be doubly contained (a containment vessel within another containment vessel). Another package that could be used for the shipment of plutonium oxide is a DOT-specification 6M package (49 CFR 173,178; Giersch et al. 1995). The limit of plutonium in the oxide form that could be placed in this package is about 4.5 kg, based on the 10-W decay heat limit of the packaging design. The plutonium oxide must be doubly contained, with the outer container being a DOT-specification 2R containment vessel (49 CFR 173,178). Thus, about 11,000 packages would be needed to transport 50 Mg of weapon plutonium as oxide unless a strategy for the reuse of the packaging and containment vessels is developed.

Packages for Plutonium as Oxide

The TI for fissile Class II plutonium contents in the 6M package is a function of the form of the plutonium (metal, alloy, or compound) and the ratio of hydrogen-to-fissile atoms with all sources of hydrogen in the containment considered. For a package containing 4.5 kg of plutonium as oxide with a ratio of hydrogen atoms to fissile atoms of 3, the TI is 0.5 per 49 CFR 173.417. For an exclusive-use shipment such as in the SST, the allowable number of packages containing 4.5 kg of plutonium as oxide per shipment is 200. Sufficient room (25 cubic meters) exists for 100 packages in the SST. However, the SST can only carry between 25 and 35 of the 140 kg (loaded weight) 30-gallon 6M packages based on the floor area and tiedown constraints and the gross vehicle weight and axle loading constraints respectively (Moyer 1994). The total decay heat from 25 packages in a shipment is 250 W. If the external radiation level remains below the regulatory limit, the mass of plutonium (in oxide form) per shipment would be 110 kg. Thus, transport of 50 Mg of plutonium as oxide would require about 450 shipments or about two shipments per month over 20 years. For a package of plutonium metal instead of oxide, the TI would be 1. This will not increase the number of shipments which are mass- rather than TI-limited.

Packages for Fresh MOX Fuel

Fresh fuel assemblies for LWRs are packaged and shipped as a Type A fissile class material. However, the presence of plutonium in fresh mixed oxide (MOX) fuel results in the fresh fuel becoming a Type B radioactive material. Thus the packaging for the fresh MOX fuel must comply with the requirements of 10 CFR 71. Therefore, the packaging for the shipment of fresh MOX fuel would be more robust than the packaging of the fresh low-enriched uranium (LEU) fuel. The fresh MOX fuel would be shipped in more massive packages in the more restrictive cargo-weight-limited SST. This results in fewer MOX fuel assemblies per shipment than is allowed for fresh LEU fuel assemblies in lighter packages on flatbed trailers. Currently, no packagings are certified for the shipment of fresh MOX fuel. However, for an assumed cargo weight restriction of 4600 kg in an SST, a shipment will consist of one package containing two pressurized water reactor (PWR) fresh MOX fuel assemblies. A shipment of boiling water reactor (BWR) fuel assemblies will consist of five packages each containing two BWR fresh MOX fuel assemblies (GE Nuclear Energy 1994).

Packages for Spent MOX Fuel

Spent MOX fuel can be shipped using the same packaging and transport systems as conventional spent fuel from LWRs. These shipments can be made on flatbed trailers. Currently, packagings for the highway transport of spent fuel are under development. These packages may carry 4 PWR fuel assemblies (GA-4 1994a) or 9 BWR fuel assemblies (GA-9 1994b). Weight considerations will result in only one package per highway shipment.

Table 1 shows the amount of material per shipment for the various shipment forms. The plutonium in the metal and oxide form as well as the fresh MOX fuel would be shipped in an SST. The spent fuel would be shipped on a flatbed trailer.

Table 1. Amount of Material Per Shipment for the Various Shipment Forms

Form	*Package*	*Mass/ Package(kg)*	*Assemblies/ Package*	*Packages/ Shipment*
Plutonium	DOT 6M-2R	4.5	–	25
Fresh Fuel				
BWR	–	–	2	5
PWR	–	–	2	1
Spent Fuel				
BWR	–	–	9	1
PWR	–	–	4	1

Shipments Required for Each ALWR Type

Several ALWRs are proposed for the disposition of the 50 Mg of excess weapon plutonium. These include the CE System 80+ (Combustion Engineering 1994) and the Westinghouse PDR 1400 and PDR 600 (Westinghouse Electric 1994) advanced PWRs and the GE ABWR (GE Nuclear Systems 1994) advanced BWR. The number of shipments required for the disposition of 50 Mg of weapon plutonium for each of the ALWR types are given in Table 2.

Table 2. Shipments Required for the Disposition of 50 Mg of Weapon Plutonium for Each ALWR Type

	PWR			*BWR*
	System 80+	***PDR 1400***	***PDR 600***	***ABWR***
Power, Mwe	1256	1400	600	1300
Number of Reactors	2	2	4	2
Total Fuel Assemblies	1900	1700	1700	5400
Total Pu Shipments	450	450	450	450
Total Fresh Fuel Shipments	950	850	850	540
Total SST Shipments	1400	1300	1300	990
Total Spent Fuel Shipments	480	430	430	600

The packaging and SST availability may pose constraints on the transportation aspects of using the 50 Mg of excess weapon plutonium as fuel for AWLRs. These constraints can be mitigated by stretching the duration of the disposition campaign or making the shipments more uniform over a campaign duration by starting recovery of plutonium from pits and production of the fresh MOX fuel assemblies substantially before they are needed in the reactor. This strategy will require storage facilities for the fresh fuel at either the production facility or at the reactor site. This strategy will need to be implemented for the initial core loads for each of the reactors used for disposition of the excess weapon plutonium. The annual number of SST shipments for a 25-year campaign (which includes the time from the project start through construction and first operation of the reactors) depends on the reactors used as well as the fuel management strategy adopted by each reactor operator. The annual number of SST shipments for a uniform fuel-delivery schedule for various reactor types is given in Table 3.

Table 3. Annual Number of SST Shipments for a Uniform Fuel-Delivery Schedule for Each ALWR Type

	PWR			*BWR*
	System 80+	***PDR 1400***	***PDR 600***	***ABWR***
Power, Mwe	1256	1400	600	1300
Number of Reactors	2	2	4	2
Assemblies/year	122	122	116	315
Pu(kg)/Assembly	28	31	31	10
Pu Shipments/year	30	34	32	28
Fuel Assembly Shipments/year	61	61	58	32
Total SST Shipments/year	91	95	90	60

Ample SST fleet capacity exists to transport the plutonium feed material and the fresh MOX fuel for the disposition of 50 Mg of excess weapon plutonium over a 25-year campaign. The use of the SST will satisfy the safeguard and security requirement for the transportation of unirradiated plutonium metal and oxide. The number of Type B packages containing fresh MOX fuel assemblies that can be shipped at one time in an SST is currently unknown as a Type B package for fresh MOX reactor fuel has not yet been designed or certified.

The shipment of spent MOX fuel is not subject to the same constraints as that of (1) the plutonium feed material in either the solid metal or oxide form or (2) the fresh MOX fuel. Because the safeguards and security issues are partially mitigated due to the radiation levels from the spent fuel, SSTs are not required for shipment. This means that the fleet size is not a constraint and the cargo weight can be greater than 4600 kg per shipment. In addition, the spent MOX fuel will be cooled prior to transport to a disposal site to reduce the radiation dose rate during shipment. The onsite storage of the spent fuel will allow the shipping schedule to be stretched over time, reducing the demand for transportation vehicles. However, this strategy will result in an increase in the number of casks for the onsite storage of spent fuel.

WASTE SHIPMENTS

All offsite shipments of radioactive waste from the weapon-plutonium recovery operations, including both LLW and transuranic waste (TRU), as well as the waste from the reactor, including both LLW and high level wastes (HLW) must be packaged and shipped in accordance with 10 CFR 71.

CONCLUSION

Transportation issues surrounding the reactor fuel option for the disposition of 50 Mg of excess weapon plutonium over a 25-year campaign appear to be manageable. Ample transportation infrastructure with safeguards and security exists. A regulatory framework covering packaging, transportation, and safeguards and security for the shipment of plutonium feed stock as well as fresh and spent MOX fuel is in place.

However, packaging issues remain. The appropriateness of the DOT 6M-2R package for the shipment of plutonium metal and oxide has been challenged because of the inability to leak-test the containment vessels. The certification of the SAFKEG packaging and the recertification of the Savannah River 9960 and 9970 series of packages for plutonium shipments is still in process. A certified Type B packaging for shipping fresh MOX fuel assemblies in an SST does not currently exist. Several designs of packagings for the highway shipment of spent fuel assemblies are underway. A package design for the highway shipment of PWR spent fuel has a capacity of four assemblies while a package design for the highway shipment of BWR spent fuel has a capacity of nine assemblies. The certification of these packages are expected to be complete prior to the beginning of the disposition campaign.

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