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Transportation Considerations Related to Waste Forms and Canisters for Defense TRU Wastes

**K. J. Schneider
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September 1981

**Work supported by the U.S. Department of
Energy through the Transportation Technology
Center at Sandia National Laboratories
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**Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
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TRANSPORTATION CONSIDERATIONS RELATED TO WASTE
FORMS AND CANISTERS FOR DEFENSE TRU WASTES

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ABSTRACT

This report identifies and discusses the considerations imposed by transportation on waste forms and canisters for contact-handled, solid transuranic wastes from the U.S. Department of Energy (DOE) activities. The report reviews 1) the existing raw waste forms and potential immobilized waste forms, 2) the existing and potential future DOE waste canisters and shipping containers, 3) regulations and regulatory trends for transporting commercial transuranic wastes on the ISA, 4) truck and rail carrier requirements and preferences for transporting the wastes, and 5) current and proposed Type B external packagings for transporting wastes.

Transportation requires waste forms to be solid and the canisters to be sized for handling and movement on conventionally-sized vehicles. Additional transportation impacts on transuranic waste forms and canisters are typically accommodated by external packagings. Some impact of waste forms and canisters may occur if canisters would be designed to meet regulations for disposable Type B packagings for immobilized wastes or to provide the second containment level when using Type B external packagings. Currently proposed regulations would allow a larger range of options for regulatory shipping categories. In some of these cases, external packagings for transportation would be simplified if credit could be taken for waste form characteristics and waste canisters.

Carrier considerations are primarily related to effects of full waste containers on the external packagings to maintain acceptable load weights and dimensions. Carriers strongly prefer: 1) the canisters or other containers to be nonflammable and to be stable with respect to shifting and overturning, including a low center of gravity (i.e., low height, high density) of a load; 2) the containers to be handled readily and efficiently at terminals to minimize turnaround time and 3) to allow even distribution of the load on a vehicle. Rail carriers want high assurance that an accident would not shut down a main rail line for an extended time.

Potential impacts on transportation hardware are primarily related to external packagings typically used for transporting Type B wastes. Preferably

the waste canisters or other containers should make efficient use of the space available in a packaging. They should meet the dimensional limitations of the packagings, and should not exceed the weight limits or weight concentration limits of the packagings. The containers should be compatible with handling systems that can be used with the packagings, including contribution to control of radiation exposure to the waste handlers.

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1.0 INTRODUCTION

The current policy in the United States requires that geologic repositories be utilized for the disposal of transuranic (TRU) wastes produced from past and continuing U.S. Department of Energy (DOE) activities. It is important that the collection, handling, processing, packaging, storing and disposal of these wastes be done safely and efficiently and in accordance with applicable regulations and other requirements. Transportation of these wastes from sites of origin to sites for treatment/storage/disposal is an indispensable component of the management of these wastes, and must also be done safely and efficiently as well as be acceptable to the public.

The appropriate storage and disposal of TRU wastes can impose severe restrictions on the waste form and on the waste canister. Criteria for these components are being developed. Similarly, there are additional considerations regarding the waste forms and canisters to accommodate transportation needs. The purpose of this report is to identify and discuss the considerations imposed by transportation on the waste forms and canisters for contact-handled transuranic wastes (CH-TRU wastes), including processed transuranic wastes (PTRU wastes), from DOE activities. Information in this report will be combined later with the comparable information on waste collection, handling, treatment, packaging, storage and disposal to identify the total form and canister requirements for managing these DOE CH-TRU and PTRU wastes. The integration of this information will be performed by the Transuranic Waste Systems Office (TWSO) operated by Rockwell International for the DOE. From all related information, the TWSO will develop a set of design criteria for the waste forms and canisters that will satisfy all the requirements.

This report covers the considerations for the CH-TRU and PTRU wastes from DOE activities that currently exist in retrievable and buried storage and those that are expected to be generated in the next 20 years that are generally similar to those currently generated. Transuranic wastes that emit enough penetrating radiation to require remote handling (RH-TRU wastes) are not addressed directly in this report and may have some different considerations. Transportation of the wastes by either rail or truck is considered in this report. Transportation

can be required from sites of waste origin to sites of treatment, storage and/or disposal. Similarly, transportation can be required from sites of treatment and/or storage to disposal sites.

The report first presents a review of current waste and canister characteristics. Then, requirements imposed by regulations, by the carriers, and by transportation hardware needs are presented sequentially. Finally all of these requirements are summarized and their total impacts are identified. A glossary of terms used in this report is given in the appendix.

2.0 CHARACTERISTICS OF WASTES AND CANISTERS

An overview of the characteristics of the wastes and canisters is given in this section to provide background for the subsequent sections.

2.1 WASTES

Transuranic wastes generally consist of a myriad of conventional materials that are contaminated with trace amounts of transuranic radionuclides. While the amounts of transuranic radionuclides are typically small relative to the other physical materials in the wastes, their radioactivity levels are high enough to qualify the wastes as transuranic wastes.

Contact-handled transuranic (CH-TRU) wastes comprise over 98% of the defense transuranic (TRU) waste volume in retrievable storage. The greatest amount of retrievably stored CH wastes is located at the Idaho National Engineering Laboratory (INEL). Thus, characteristics of the wastes in the INEL can be taken as representative of the characteristics of the total inventory of defense CH-TRU wastes.

Table 2.1 lists eight types of materials that comprise about 60 volume percent of the wastes stored at the INEL from September 1971 through December 1978 and contain 46 weight percent of the total plutonium in those wastes. Other TRU waste materials at INEL include:

- leaded rubber gloves
- leached metals
- insulation
- graphite
- organic setups (solidified oils)
- concrete and asphalt
- glass
- low specific activity (LSA) metals and glass
- high specific activity sludge/concrete
- plastics and rubber.

TABLE 2.1. TRU Wastes Stored at Idaho from September 1971 Through December 1978 (Shefelbine 1978, Bryan and Palmer 1980)

Waste Materials	Volume % of Total	Plutonium Content		Bulk Density kg/m ³
		wt% of Total Pu in Wastes	Avg. mg/m ³ of Waste	
Metal Scrap	30	13	3.2	417
Paper and Rags, Dry	10	3	1.3	353
Paper and Rags, Moist	5	1	1.4	433
Second Stage Sludge	5	1	1.1	1138
Filters, CWS	5	2	3.7	272
First-Stage Sludge	4	13	24	1074
Rashig Rings, Unleached	1	5	49	433
Incinerator Ash, Leached	<0.1	8	271	NA

Tables 2.2 and 2.3 present radionuclide data for wastes stored at the INEL in 55-gallon drums and Rocky Flats boxes, respectively. The TRU nuclide contents given are overall averages for wastes from primarily two sources: weapons grade plutonium (by far the largest quantities); and heat-source plutonium to supply power for defense-related devices. Additional information on the radionuclides in each waste source is given in Section 3.1.1.

TABLE 2.2. Radionuclide Content in Defense Contact-Handled TRU Wastes Stored at the INEL in DOT-17C 55-gal Steel Drums (U.S. Department of Energy 1980)

Radionuclide	Average Mass Present (a) (grams)	Average Radioactivity Content (b)		External Surface Contamination (Ci/drum)
		Ci/drum	Ci/liter	
²³⁸ Pu	2.5E-3 ^(c)	4.2E-2	2.0E-4	7.0E-10
²³⁹ Pu	7.5	4.6E-1	2.2E-3	7.5E-9
²⁴⁰ Pu	5.0E-1	1.1E-1	5.3E-4	1.8E-9
²⁴¹ Pu ^(d)	2.7E-2	2.8	1.3E-2	1.0E-7
²⁴² Pu	2.4E-3	9.4E-6	4.5E-8	1.6E-13
²⁴¹ Am	1.5E-3	5.2E-3	2.5E-5	8.5E-11
Total	8 ^(e)	3.4	1.6E-2	1.1E-7
Total fissile content 7.5 g				
Total Pu 8 g				

(a) Maximum fissile content is 200 grams, based on transportation regulations.

(b) For maximum activity in container, multiply by 25 (or 200/8).

(c) 2.5E-3 = 2.5 x 10⁻³.

(d) Primarily a beta emitter; values given are for total radioactivity content.

(e) Total Ci/g TRU elements = 0.445; α Ci/g TRU elements = 0.0756.

TABLE 2.3. Radionuclide Content in Defense Contact-Handled TRU Wastes Stored at the INEL in DOT-7A 4 x 4 x 7-ft Plywood Boxes (U.S. Department of Energy 1980)

Radionuclide	Average Mass Present ^(a) (grams)	Average Radioactivity Content ^(b)		External Surface Contamination (Ci/Box)
		Ci/Box	Ci/Liter	
²³⁸ Pu	4.0E-3 ^(c)	6.8E-2	2.4E-5	4.5E-9
²³⁹ Pu	1.2E+1	7.5E-1	2.7E-4	5.0E-8
²⁴⁰ Pu	8.1E-1	1.8E-1	6.5E-5	1.2E-8
²⁴¹ Pu ^(d)	4.4E-2	4.5	1.6E-3	6.5E-7
²⁴² Pu	3.9E-3	1.5E-5	5.4E-9	1.0E-12
²⁴¹ Am	<u>2.5E-3</u>	<u>8.4E-3</u>	<u>3.0E-6</u>	<u>5.5E-10</u>
Total	13 ^(e)	5.5	2.0E-3	7.0E-7
Total Fissile Content 12.2 g				
Total Pu 13 g				

(a) Maximum fissile content is 350 grams but not exceeding 5 grams in any 0.0283 cubic meters (1 cubic foot), based on transportation regulations.

(b) For maximum activity container, multiply by approximately 27 (or 350/13).

(c) $4.0\text{E}-3 = 4.0 \times 10^{-3}$.

(d) Primarily a beta emitter; values given are for total radioactivity content.

(e) Total Ci/g TRU element = 0.452; α Ci/g TRU element = 0.0757.

2.2 IMMOBILIZED WASTE FORMS

Wastes can be converted to more durable forms to immobilize the radionuclides. A general list of a number of possible immobilized waste forms and some general characteristics of these forms is given in Table 2.4.

The original wastes can be 10 to 100% by weight of the final waste form, with most in the range of 30 to 60%. The resultant volumetric concentration of wastes in the final waste forms can typically vary by about a factor of 3.5. Of these immobilized waste forms, cement has the lowest waste content (i.e., highest volume); glasses and ceramics have intermediate waste content; and salt cakes and calcines have the highest waste content (i.e., lowest volumes).

TABLE 2.4. Possible Immobilized Forms for TRU Wastes

Form	Description	Bulk Specific Gravity	Range of wt% Wastes	Relative Conc. TRU/Vol. Waste Form ^(a)	Leachability ^(b)	Combustible?
Bitumen	Monolithic bitumen with incorporated wastes	1.0-1.3 ^(c,d)	40-60 ^(c)	1.0	med ^(c,d)	yes ^(e)
Cast Cement	Cement with noncombustible embedded waste with possible steel reinforcements	1.6-2.0 ^(c,d)	12-50 ^(c)	0.9	med ^(c,d)	no
Ceramic	Glass ceramic blocks formed from calcined wastes and glass frit	2.5-5.0 ^(f)	15-80	2.7	low ^(f)	no
Sintered Clay	Fired bricks with chemically combined sodium-salt solutions of wastes and clay	2.0-2.8	25-50	1.6	med	no
Glass (solution)	Monolithic glass blocks with dissolved wastes	2.3-3.6	30-60 ^(f)	2.3	low ^(d,f)	no
Glass (encapsulation)	Monolithic glass blocks with incorporated waste pieces	2.3-3.6	30-60	2.3	low ^(f)	no
Glass Ceramic	Monolithic metal blocks with controlled fine grained crystals	2.5-3.1	20-40 ^(f)	1.5	low ^(f)	no
Metal Matrix	Monolithic metal blocks with incorporated calcined wastes	3.5-7.4 ^(f)	20-34 ^(f)	2.6	low	no
Sintered Pellets	Sintered, pelletized powder of waste ash and high-alumina cement	2.5-3.2 ^(f)	30-80 ^(f)	1.6	low	no
Plastic	Monolithic resin or plastic matrices with incorporated waste ash, salts or oxides	1.0-1.3 ^(c)	50-70	1.2	med ^(c)	yes ^(e)
Salt Cake	Cast salt cake from molten-salt incinerator or acid-digestion with incorporated waste ash	2.0-2.5 ^(c)	70-100	3.3	high ^(c)	no
Slag	Granular basalt-like glassy slag from slagging incinerator with incorporated wastes	2.5-3.1 ^(d)	35-63	2.3	low ^(d)	no

(a) The concentrations are relative to bitumen, which is assigned a value of 1.0. The reciprocal of the values are the relative volumes of the waste forms. The relative concentrations shown are taken at mid-range of bulk specific gravity and wt% of wastes in final waste form.

(b) For leaching of actinides from waste form materials leached in 100°C distilled water. Ranges for leach rates can be as much as 3 orders of magnitude. General classification only is intended here:

low = $<10^{-6}$ g/cm²/d
 med = $<10^{-3}$ and $>10^{-6}$ g/cm²/d
 high = $>10^{-3}$ g/cm²/d

(c) Energy Research and Development Administration 1976.

(d) Grisler 1980.

(e) Can flash burn at $\sim 300^\circ\text{C}$.

(f) Rusin 1980.

(g) Values shown without references were obtained from a number of sources.

Leachability of the wastes may be important in the event that a very serious accident should result in the breaching of the containment and the wastes are exposed to water. Leachability is also of potential concern if credit is to be taken for the waste form as a special form material as defined in transportation regulations. The transuranic leach rates of the waste forms produced at high temperatures (on the order of 1000°C) are typically low; cement, bitumen and plastic leach rates are intermediate; and salt cakes and calcines are high.

Combustibility of waste forms may also be of concern in a very serious accident involving a fire. All waste forms indicated in Table 2.4 are not combustible except bitumen and plastic (and these require elevated temperatures of about 300°C for combustion).

2.3 CANISTERS

A wide variety of canisters has been used for waste storage and transportation. Table 2.5 does not include every type of canister; however, it does list some of the most common types used. Two of the most commonly used waste containers are the Rocky Flats box and the 55-gallon drum. Special wastes sometimes require other containers. For example, Hanford has used 2.44 m x 2.44 m x 6.1 m (8 ft x 8 ft x 20 ft) and 3.66 m x 3.66 m x 2.44 m (12 ft x 12 ft x 8 ft) concrete boxes for large equipment. Savannah River has used 1.98 m x 2.57 m x 3.51 m (6.5 ft x 8.5 ft x 11.5 ft) concrete boxes filled with wastes that contain ^{238}Pu . These special containers hold only a small portion of the total wastes but their dimensions and weights will make them difficult to transport.

The weights for full 55-gallon drums stored at the INEL from September 1971 through December 1976 range from 43.6 to 500 kg (100 to 1100 lbs) (Shefelbine 1978, Energy Research and Development Administration 1976) with the average weight being about 145 kg (330 lbs). The heavier drums typically contain sludges. The Rocky Flats boxes full of wastes range from 436 to 2180 kg (1000 to 5000 lbs) with the average weight being about 1230 kg (2830 lbs). More than half of the drums and boxes of CH-TRU wastes contain less than 0.5 g of plutonium, but a few contain 100 g or more (Shefelbine 1978).

TABLE 2.5. Types of Canisters Used for CH-TRU Wastes (Shefelbine 1978)

Package Description	Package Dimensions		Maximum Gross Weight		Package Volume		% of Known Volume Stored(a)
	m	ft	kg	lbs	m ³	ft ³	
Rocky Flats FRP ^(b) Box	1.22 x 1.22 x 2.13	4 x 4 x 7	2,270	5,000	3.17	112	45
55-gal Drum ^(c)	0.61 x 0.89	2d x 2.92	500	1,100 ^(d)	0.21	7.4	48
83-gal Drum	0.66d x 1.09	2.17d x 3.58	NA	NA	0.31	11.1	3.3
30-gal Drum	0.48 x 0.74	1.58d x 2.42	NA	NA	0.11	4.0	0.03
Welded Steel Box	Random	Random	NA	NA	NA	NA	NA
FRP ^(b) Box	Random	Random	NA	NA	NA	NA	1.9
Concrete Boxes	0.91 x 0.91 x 1.22	3 x 3 x 4	NA	NA	0.74	26	NA
Corrugated Metal Pipe	0.76d x 6.08	2.5d x 20	NA	NA	2.78	98	NA
Concrete Culvert ^(e)	2.13d x 2.28	7d x 7.5	8,620	19,000	5.10	180	NA
Steel Bin ^(e)	1.22 x 1.52 x 1.83	4 x 5 x 6	1,450	3,200	3.40	120	1.6

(a) Based on total amount in retrievable storage through December 1977 excluding those for which data are not available (NA), which constitute a small fraction.

(b) FRP = Fiberglass Reinforced Polyester.

(c) The interior and exterior surface treatment and the empty weight of the drum (DOT-17C or 17H) varies with the user.

(d) Comment letter from L. E. Romesburg, Sandia National Laboratory to K. J. Schneider, Pacific Northwest Laboratory, April 15, 1981.

(e) The concrete culvert and the steel bin are commonly used as secondary containers; wastes packaged in either drums or boxes are usually placed in these outer containers.

A new waste container for unprocessed waste, called the modular box, was developed at Sandia Laboratories and is currently being tested at Rocky Flats to qualify it as a Type A canister or an overpack for canisters (Jefferson 1980). This box is approximately 1.91 m x 1.30 m x 0.94 m (6.25 ft x 4.25 ft x 3 ft) and can also be used to overpack 55-gallon drums in a 2-by-3 array. The modular box is constructed from corrugated sheet steel. Another box of similar construction is under development at Rocky Flats for use as an overpack for the Rocky Flats FRP box. A third type of steel box is also being considered as a compromise between these two proposed boxes. This box would measure 1.1 m x 1.3 m x 1.9 m (3.7 ft x 4.2 ft x 7 ft), h x w x l, and could be used for transporting wastes which may or may not be packaged in smaller canisters.

3.0 REGULATIONS APPLICABLE TO THE TRANSPORT OF TRANSURANIC WASTES

Regulations governing the packaging and transportation of radioactive materials exist at federal, state and local levels of government. This large body of rules is generally consistent on packaging requirements, with both the U.S. Nuclear Regulatory Commission (NRC) and U.S. Department of Transportation (DOT) being active at the federal level. NRC regulations focus on shipments with higher potential hazards than DOT regulations. State and local regulations, in general, reinforce federal rules and apply further restrictions on the operation of carriers within their jurisdiction.

Federal regulations are applied to packaging for transportation of defense wastes between federal government (typically DOE) facilities through the use of self-imposed requirements. Packaging is currently controlled by DOE requirements and agreements among the DOE, NRC and DOT. Historically, DOE packaging requirements have been similar to those of the NRC and the DOT. Thus, for future DOE packages, criteria and designs for "licensable" instead of "licensed" packagings can be developed based on studies of transportation regulations. Existing and proposed regulations are discussed in this report as an indicator of present and future package requirements for DOE approval.

The remainder of this section is divided into three subsections on packaging regulations, operational restrictions and interpretation of rules for CH-TRU defense wastes. Additional regulations, which are applicable to transport vehicles carrying any hazardous materials, also apply to radioactive materials. These regulations are not pertinent to the contents of this report and are not included.

3.1 TRANSPORTATION PACKAGING REGULATIONS

Regulations by the DOT (49 CFR 173) and NRC (10 CFR 71) provide for a range in package integrity based on the hazard, nuclear characteristics and form of the materials to be shipped. This section discusses separately the existing and the proposed revisions to regulations applicable to the packaging of TRU wastes for transportation.

3.1.1 Existing Regulations

Existing regulations are based on two philosophies. The first allows the use of specified performance tests to demonstrate that radioactive material packagings meet acceptable safety criteria. A case by case evaluation is required. Both the NRC and the DOT provide guidance on packaging to meet these regulations. The second regulatory philosophy, practiced by the DOT and referenced by the NRC, provides packaging specifications, that, if followed, require no additional licensing action. Both philosophies are discussed in this subsection.

All packagings for the transportation of radioactive materials must meet general design criteria for their use under DOT and NRC rules. Rules applicable to solidified nonpyrophoric TRU wastes require the use of compatible materials in package construction, providing a tamper-indicating package closure, minimum acceptable tie-down performance, minimum acceptable structural support, maximum acceptable surface dose rates, minimum acceptable heat dissipation and appropriate lifting devices.

Lifting devices must be capable of lifting three times the package weight without compromising package shielding in any failure mode of package handling. Tie-downs between the package and the transport vehicle must restrain the package under accelerations of 2 g in the vertical direction, 10 g horizontally in the direction of travel and 5 g transverse to the direction of travel. Tie-down failure modes must not impair package performance. NRC rules require the transportation package structure to withstand a distributed load of five times the full package weight when supported as a simple beam and to withstand external isostatic pressures of 25 psig without loss of contents [10 CFR 71.32(b)].

Maximum radiation dose rates are limited to 200 mr/hr at the surface of an exposed package shipped as general freight. Packages shipped as a full load are limited to 1000 mr/hr at 0.9 m (3 ft) from the surface of a package inside an enclosed transport vehicle, 200 mr/hr at any outside package or vehicle surface and 10 mr/hr at 1.8 m (6 ft) from the transport vehicle or package outside surface. Normally occupied areas of a transport vehicle such as the driver's cab are limited to a maximum dose rate of 2 mr/hr. Heat generation of the waste

cargo must be limited to avoid transport package damage under normal conditions of transport for certain classes of radioactive materials and under accident conditions for more hazardous classes.

Compliance with general packaging rules for transportation of TRU wastes requires reasonable design practices and supporting analyses. Analyses to verify package performance under the regulatory structural loadings, surface dose rate limits, and assumed waste heat generation rates are required for all transportation packaging.

Three classes of packaging are allowed for transport under current regulations; Type B, Type A and Low Specific Activity (LSA). Packages not designed to DOT specifications in each of these categories must meet, in addition to general requirements previously discussed, specific performance tests. All packagings are limited to their use by the quantity, physical form and isotopic content of the materials to be carried. Regulation of Type B packaging (that with the most severe performance standards) is generally the responsibility of the NRC. Type A and LSA packages are generally regulated by the DOT, with some overlap of regulations from NRC. For example, Type B quantities of materials with LSA radionuclide concentrations are regulated by the NRC.

LSA package requirements are the least restrictive in terms of package integrity but the most restrictive in terms of the radioactive materials for which they are applicable. Materials meeting LSA requirements can be shipped in "strong, tight packages so that there will be no leakage of radioactive material under conditions normally incident to transportation" (49 CFR 173.392). The NRC requires Type B quantities of materials with LSA concentrations of radionuclides to be shipped in Type A packagings.

Type A packages must retain their integrity after being subjected to a series of tests and environmental conditions considered to be representative of normal transportation and handling conditions. Acceptance is based on the following criteria [49 CFR 173.389(j)]:

- There would be no release of radioactive material from the package;
- The effectiveness of the packaging would not be substantially reduced;
- There would be no mixture of gases or vapors in the package which could reduce the effectiveness of the package.

The environmental conditions that are mentioned above include:

1. Heat. Direct sunlight at an ambient temperature of 54°C (130°F) in still air.
2. Cold. An ambient temperature of -40°C (-40°F) in still air and shade.
3. Reduced pressure. Ambient atmospheric pressure of 0.5 atmosphere absolute pressure (or 7.3 psia).
4. Vibration. Vibration normally incident to transportation.

The package must also pass all of the following tests with any two being applied in sequence [49 CFR 173.398(b)]:

1. Free drop. A free drop through a distance of 1.22 m (4 ft) onto a flat, essentially unyielding horizontal surface, striking the surface in a position for which maximum damage is expected.
2. Penetration. Perpendicular impact of the hemispherical end of a vertical steel cylinder 3.2 cm (1.25 in.) in diameter and weighing 5.9 kg (13 lb), dropped from a height of 1.0 m (40 in.) onto the exposed surface of the package that is expected to be most vulnerable to puncture.
3. Compression. For packages not more than 4,535 kg (10,000 lb) in weight, a compressive load equal to either five times the weight of the package or 0.14 atmosphere (2 psi) multiplied by the maximum horizontal cross section of the package, whichever is greater. The load shall be applied during a period of 24 hours, uniformly against the top and bottom of the package in the position in which the package would normally be transported.

FRP boxes and 55-gallon drums are examples of packages that meet these criteria.

Type B packagings are designed to withstand the more severe environments of transportation accident conditions. Type B packagings are applicable to the widest variety of radioactive contents of the three package types. Requirements for a Type B container to transport TRU wastes are that it meet applicable Type A standards and hypothetical accident conditions without:

1. A reduction of shielding that would be enough to increase the radiation dose rate at 0.91 m (3 ft) from the external surface of the package to more than 1,000 mr/hr.
2. A radioactive material release.

Hypothetical accident conditions for Type B packages are applied sequentially and consist of:

1. Free drop. A free drop through a distance of 9.1 m (30 ft) onto a flat and essentially unyielding horizontal target surface, striking the surface in a position for which maximum damage is expected.
2. Puncture. A free drop through a distance of 1.0 m (40 in.) striking, in a position for which maximum damage is expected, the top end of a vertical cylindrical mild steel bar that is 15 cm (6 in.) in diameter and is mounted on an essentially unyielding horizontal surface.
3. Thermal. Exposure to a thermal test in which the external heat input to the package is no less than that which would result from exposure of the whole package to a thermal radiation environment of 802°C (1,475°F) for 30 minutes with a radiant emissivity coefficient of 0.9, assuming the surfaces of the package have an absorption coefficient of 0.8.
4. Water immersion (for packages containing quantities of fissile material in excess of certain limits only).

It is not necessary to actually conduct the tests prescribed in this section if it can be clearly shown, through engineering evaluations or comparative data, that the material or item would be capable of performing satisfactorily under the prescribed test conditions.

Examples of current systems that meet these criteria are spent fuel casks used in commercial power plants. The ATMX rail car has not been certified to these tests and operates on a special exemption granted by the DOT, (Adcock 1974). Periodic relicensing is required for continued use of Type B packages. The operating license for the Super Tiger® package has currently expired. Existing Super Tiger® packages are being used to provide accident protection for shipments approved by the NRC under special exemptions where the canisters provide containment barriers.

Waste forms are differentiated in current regulations as Normal (49 CFR 173.395) and Special Forms (49 CFR 173.394). Special Form material is defined to be material that if released from a package might present some direct radiation hazard but would present little hazard due to radiotoxicity or dispersion. Materials not shown to meet Special Form tests are considered to be Normal Form. Qualifying a material for Special Form under current regulations could be advantageous because it allows a greater curie content per package than quantities acceptable for Type A packaging.

To qualify as Special Form material, the radioactive material must either be in massive solid form or encapsulated in a high integrity capsule. The waste form or capsule (if used) material must not dissolve or convert into dispersible form to the extent of more than 0.005 weight % by immersion for 1 week in water at pH 6 to 8 and 20°C (68°F) and a maximum conductivity of 10 microhm/cm, and by immersion in air at 30°C (86°F). If encapsulated, the capsule must also retain its contents when subjected to all of the performance tests described below and must not melt, sublime, or ignite at temperatures below 802°C (1,475°F). If in massive solid form, the material must not break, crumble or shatter when subjected to the percussion test described below and must not melt, sublime or ignite below 540°C (1000°F).

1. Free drop. A free drop through a distance of 9.1 m (30 ft) onto a flat, essentially unyielding horizontal surface, striking the surface in such a position as to suffer maximum damage.
2. Percussion. Impact of the flat circular end of a 2.5-cm (1-in.) diameter steel rod weighing 1.36 kg (3.0 lbs), dropped through a distance of 1.0 m (40 in.). The capsule or material shall be placed on a sheet of lead, supported by a smooth, essentially unyielding surface.
3. Heating. Heating in air to a temperature of 802°C (1,475°F), and remaining at that temperature for a period of 10 minutes.
4. Immersion. Immersion for 24 hours in water at room temperature. The water shall be at pH 6 to 8, with a maximum conductivity of 10 microhm/cm.

Radionuclides are placed, for regulatory purposes, into seven transport groups. Allowable package contents for shipment in each category depend on the type and quantity of radionuclides present. Table 3.1 shows the general regulatory strategy in making group assignments for isotopes commonly found in TRU wastes. Specific nuclides and those not covered by Table 3.1 in Groups IV, V, VI and VII are assigned to groups in 49 CFR 173.390.

TABLE 3.1. Transport Group Designation for Radionuclides

Radionuclide	Radioactive Half-Life		
	0 to 1000 Days	1000 Days to 10 ⁶ Years	Over 10 ⁶ Years
Atomic Number 1-81	Group III	Group II	Group III
Atomic Number 82 and over.	Group I	Group I	Group III

Activity limits for each transport group are defined for each package category. Table 3.2 is a summary of limits for the three packaging categories. In addition to the specific activity restrictions given in Table 3.2, LSA shipments have the additional requirement that the activity must be uniformly distributed in the package or fixed to nonradioactive objects. The numbers in the table are upper limits. Exceeding the listed limit requires shipment under rules applicable to the next higher category. Quantities of material that exceed Type B limits are shipped in Type B packages as "large quantity" shipments.

TABLE 3.2. Transport Group Package Limits

<u>Transport Group</u>	<u>Low Specific Activity (in maximum curies/g of package contents)</u>	<u>Type A Maximum Quantity (in curies)</u>	<u>Type B Maximum Quantity (in curies)</u>
I	1E-7	1E-3	2E+1
II	5E-6	5E-2	2E+1
III	3E-4	3E 0	2E+2
IV	3E-4	2E+1	2E+2
V	--	2E+1	5E+3
VI and VII	--	1E+3	5E+4
Special Form	--	2E+1	5E+3

The distinction between "Type B" and "large quantity" shipments was designed to accommodate shipments of irradiated fuel. Special provisions are made in this category to consider the possible escape of fuel coolant under accident conditions. These provisions do not apply to TRU waste shipments and thus "Type B" and "large quantity" can be used interchangeably in this report.

Additional package criteria apply to shipments containing more than certain amounts of fissile material and, in particular, plutonium. For packages containing more than 350 grams of fissile material, or more than 5 grams of fissile material per 0.028 m^3 (1 ft^3), a criticality assessment is required [10 CFR 71.9(e)]. The package must remain subcritical following the hypothetical Type B accident tests including immersion assuming:

1. The fissile material is in the most reactive credible configuration consistent with the damaged condition of the package and the chemical and physical form of the contents
2. Water moderation occurs to the most reactive credible extent consistent with the damaged condition of the package and the chemical and physical form of the contents.
3. There is reflection by water on all sides and as close to the package as is consistent with the damaged condition of the package.

If more than one such package is used in a single shipment, a criticality assessment is required for the array assuming all packages have been subjected to the Type B accident conditions.

NRC regulations make special provision for the shipment of plutonium (10 CFR 71.42). Plutonium shipments in excess of 20 Ci must be shipped as a solid and doubly contained, unless otherwise exempted. Double containment rules require a separate container be used inside of a shipping packaging that meets the Type B package requirements. The regulations point out that the inner containment is required to prevent the release of plutonium when the assembled inner and outer containments are subjected to the Type A and Type B package tests. From the above discussion on package content limits, this rule will apply to all large quantity shipments.

DOT regulations provide package specifications for Type B, Large Quantity and Fissile Type B shipments. All of these packages utilize a specification 2R (49 CFR 178.34) inner containment vessel and various specification overpacks to meet requirements in each category.

The 2R specification vessel is a cylindrical pressure vessel with a threaded closure. It has a maximum volume of 0.13 m^3 but has a smaller limit in more restrictive shipping categories. Table 3.3 lists the maximum dimensions of the 2R vessel in each category.

TABLE 3.3. DOT Package Specification Summary

Radioactive Material Category	Specification Category		Maximum Interior 2R Vessel Dimensions (cm)		Maximum Interior Volume (m^3)	Maximum Heat Load (watts)
	Outer Container	Inner Container	Diameter	Length		
Nonfissile Type B	20 WC	2R	30	183	0.13	None Specified
Nonfissile Large Quantity	6 M	2R	13.3	183	0.03	10
Fissile Type B	6 L	2R	13.3	127	0.02	5

3.1.2 Regulatory Trends

Regulatory trends which impact canister design can occur from actual changes in the regulations and from regulatory interpretations during transportation package licensing. The following two sections discuss each of these issues.

3.1.2.1 Proposed Regulations

Revisions to current radioactive material transportation regulations have been proposed in Federal Register Notice on January 8, 1979 for Part 49 Code of Federal Regulations (DOT) and August 17, 1979 for 10 CFR 71 (NRC). The effects of these rules, if adopted, on TRU waste transportation could be significant. Major differences from the existing rules are discussed in this section.

The proposed regulations eliminate the use of transport groups and instead assign each nuclide two values, A_1 and A_2 which are the maximum number of curies permitted in Type A packages, in special form, and normal form respectively.

The distinction between "Type B" and "Large Quantity" shipments is eliminated under the proposed rules. Type B classification is subdivided into two

classifications, B(U) and B(M). Type B(U) has specific design and performance features similar to those under existing rules for Type B shipments and requires no special conditions of shipment. Type B(M) packages can have less stringent designs but may be subject to specific restrictions in transport to compensate for the reduced design features. Thus, shipment of wastes that meet the requirements of the proposed Type B(M) appears to be simpler than for the current Type B needs. Type B shipments under the proposed regulations, unless official exemption is authorized, will still be subject to double containment requirements if the shipment size exceeds 20 Ci of plutonium. The shipment packagings will also need assessment for nuclear criticality safety if the fissile material concentration exceeds 5 g per 10 liter volume.

A new classification of radioactive material, Low Level Solid (LLS) was added to the proposed regulations. It is similar to LSA material except that a higher concentration of radioactive material is allowed while imposing greater restrictions on the dispersability of the waste form in exclusive-use vehicles. There are cost incentives to ship qualifying wastes as proposed LLS category rather than as current Type B.

Package design requirements are proposed to be modified slightly for LSA and Type A Special Form containers. The use of "strong, tight" packages for LSA shipments would be discontinued in favor of Type A packaging. An additional bending test of the waste package was added to the special form requirements. This test is not significant for large waste packages.

General design criteria were modified to eliminate specific design limits for lifting attachments. Safe stress levels during an abrupt lift must be maintained. Tie-down performance limits for Type B packages were deleted in favor of tie-down evaluations that are specific to the transport mode.

Table 3.4 presents the proposed A_1 and A_2 quantities of material for isotopes in weapons and heat source plutonium. In general, limits for Special Form material (A_1) would be lowered by up to a factor of 10 for all plutonium isotopes except ^{241}Pu . Allowable limits for ^{241}Pu are 50 times higher in the proposed rules. Proposed quantity limits for individual isotopes in Normal Form (A_2) would be 2 to 100 times higher than under existing rules.

TABLE 3.4. A_1 and A_2 Material Limits for One Canister

	Special Form Limits, A_1 (Ci)	Normal Form Limits, A_2 (Ci)
^{238}Pu	3	3E-3
^{239}Pu	2	2E-3
^{240}Pu	2	2E-3
^{241}Pu	1E+3	1E-1
^{242}Pu	3	3E-3
^{241}Am	8	8E-3

In the proposed DOT rules, wastes in the Low Level Solids category can be transported only in exclusive-use vehicles and must be contained in packages that pass Type A performance tests. In addition, the waste form must meet the following criteria: 1) the activity under normal transportation conditions is distributed throughout a solid or a collection of solid objects, or is and remains uniformly distributed in a solid compact binding agent (such as concrete, bitumen, or ceramic); 2) the activity remains sufficiently insoluble so that, even under loss of canister, the loss of radioactive material per canister resulting from the effects of wind, rain, other effects of weather, or from total immersion in water is limited to less than $0.1 A_2$ in a period of one week; 3) the estimated activity averaged throughout the material does not exceed $2\text{E-}3 A_2/\text{g}$. Objects of nonradioactive materials contaminated with radioactive materials can be classed as LLS, when the radioactive contamination is in a form that is not readily dispersible, and the level of contamination averaged over 1 m^2 (10.8 ft^2), or the area of the object surface if it is less than 1 m^2 , does not exceed $20 \mu\text{Ci}/\text{cm}^2$ for beta and gamma emitters and low toxicity alpha emitters (i.e., natural or depleted uranium and natural thorium); or $2 \mu\text{Ci}/\text{cm}^2$ for other alpha emitters.

To determine the shipping classification of TRU wastes under the proposed rules, it is necessary to determine the single A_1 and A_2 values for mixtures of isotopes. Interpretation of the regulations is required for LSA and LLS shipments. Three alternative methods were considered for this report: isotopic "A" values weighted by the mass fractions of the mixture, "A" values weighted by

the activity fraction of individual isotopes, and the "unity rule." The "unity rule" is applicable to Type A and Type A Special Form determinations. This rule allows mixtures of isotopes to be transported in a particular category as long as the sum of the ratios of individual isotope activities to their respective isotope "A" values are less than unity. An apparent "A" value can be calculated using this method. The accepted interpretation of this question for LSA and LLS shipments will have significant impact on TRU waste transportation. No official interpretation or precedent is currently available on this issue.

Proposed DOT regulations define LSA material on both a bulk activity and contamination basis. Waste forms with a bulk nuclide concentration of less than $1\text{E-}4 \text{ A}_2/\text{g}$ with a uniform distribution of the radioactivity meet the proposed criteria. Objects of nonradioactive materials contaminated with radioactive materials shipped in an exclusive-use vehicle may qualify as LSA material if nonfixed surface contamination (using the wipe test) is not more than $1\text{E-}4 \text{ }\mu\text{Ci}/\text{cm}^2$ for alpha emitters and "the contaminated object or the contamination on the object, if reduced to the minimum volume under conditions likely to be encountered during transportation, including dissolution in water with subsequent recrystallization, precipitation, evaporation, combustion and abrasion would have an average estimated specific activity of no more than $1\text{E-}4 \text{ A}_2/\text{g}$ " (49 CFR 127[f]). Objects contaminated with nondispersible radioactive materials are considered to be LSA material if the level of contamination averaged over 1.0 m^2 of surface (or the total surface area if it is less than 1.0 m^2) is not more than 1) $1.0 \text{ }\mu\text{Ci}/\text{cm}^2$ for beta and gamma emitters and the low toxicity alpha emitters (natural or depleted uranium and natural thorium) or 2) $0.1 \text{ }\mu\text{Ci}/\text{cm}^2$ for other alpha emitters.

In their proposed regulations, the NRC specifies Type B package normal and post-accident leakage rates in terms of fraction of the curie content per unit-time as shown in Table 3.5.

TABLE 3.5. Proposed NRC Release Limits for Type B Packagings

Package Type	Transportation Conditions	
	Normal	Accident
B(U)	$1\text{E-}6 \text{ A}_2/\text{hr}$	$1\text{E-}3 \text{ A}_2/\text{wk}$
B(M)	$1\text{E-}6 \text{ A}_2/\text{hr}$	A_2/wk $1\text{E+}4 \text{ Ci}/\text{wk}$ (Kr-85 only)

THE DOT has no current or proposed specific leak rates for Type A, LLW or LSA containers other than the statement in 49 CFR 127.105(m) that the normal conditions of transport will not result in "loss or dispersal of the radioactive contents." This implies that it is up to the applicant to propose a test that meets the intent of DOT regulations.

The only applicable leakage testing standard is ANSI N14.5. This document has been adopted by the NRC in Regulatory Guide 7.4. There has been some difficulty experienced in the interpretation of ANSI N14.5 and its conservatism has not been assessed, but it represents a good starting point for leakage evaluation.

3.1.2.2 Regulatory Interpretations

Regulatory interpretations are required following the development of new standards or changes in regulations and the identification of design problems that need to be addressed in analyses to show compliance with package performance tests. Current topics requiring interpretation are in the areas of brittle fracture analysis, leak rate testing and licensing requirements for Type B(U) packages are discussed in this section.

NRC and DOT regulations specify temperature ranges within which packages must retain their integrity. The lowest temperature for consideration of structural behavior are -40°C (-40°F) under NRC and DOT regulations. NRC rules do not specifically mention brittle fracture analysis. However, NRC's Regulatory Guide 7.9 states that for the structural analysis of packages under normal and accident conditions, "brittle fracture should be considered." Proposed DOT regulations (49 CFR 127.105(d)) state that for temperatures from -40°C to 70°C (158°F), "... special attention must be given to brittle temperature range." This DOT requirement is part of the Type A package performance tests but is excluded under proposed rules for LSA and LLS packages.

Lawrence Livermore Laboratory (LLL) has recently developed primary containment brittle fracture guidelines (Holman and Langlad 1981) for package material thicknesses up to 10 cm (4 in.) under NRC sponsorship. This thickness range would include essentially all CH-TRU waste packaging. The preliminary guidelines define three categories. The first and most stringent will provide

a very large margin of safety by assuring no crack propagation at the lowest service temperature; the second category will provide a large margin of safety by preventing fracture initiation under dynamic loading at pre-existing cracks. Category 3 provides an adequate margin of safety and will prevent fracture initiation at minor flaws that are typical of good fabrication practices. Packages will be required to meet the rules of one or the other category based on the hazard, form and quantity of the radioactive materials within the package. For example, spent fuel casks would be in the first category while medical isotopes and TRU wastes would likely be in the second. It should be emphasized that these guidelines have not yet been adopted as NRC policy. The DOT policy on brittle fracture is unknown although it is assumed that whatever is developed by NRC will also be acceptable to DOT.

For carbon steel sections thicker than 6.4 cm (2.5 in.) used in packagings required to meet the first category, brittle fracture considerations will severely limit the available materials. As the section thickness decreases and/or the package category changes to a less restrictive one, more materials become available. Unfortunately, some of the least expensive and most available carbon steels (such as ASTM A36) will probably be unacceptable at the regulatory minimum temperatures regardless of section thickness due to their poor brittle fracture characteristics. This may force designers to utilize the more expensive alloy steels or austenitic stainless steels that have acceptable brittle fracture characteristics.

The American Society for Mechanical Engineers (ASME) has created a nuclear packaging (NUPACK) committee which is writing primary containment design rules for high-level radioactive material packagings. Brittle fracture is also a consideration of this group and the LLL/NRC guidelines are under review and analysis for consistency with existing ASME codes.

The leak testing requirement in the proposed regulations is one of the few major changes from the current 10 CFR 71, and the one that may cause licensees the most difficulty in demonstrating compliance for both new and existing packages. This is due to the interpretation required to determine "A" values and the use of ANSI N14.5 to convert these values to the allowable volumetric flow (leak) rates. In addition, waste canisters will have to meet leakage criteria

and testing strategies must be proposed and developed for use by the waste repository operator. These criteria should be coordinated with the in-transit requirements.

The distinction between Type B(U) and Type B(M) packaging was made previously in Section 3.1.2.1. This discussion emphasizes the selection and approval processes and is related to the leakage testing discussed previously. It is clear from Table 3.5 that the post-accident allowable leakage rate for Type B(M) is significantly greater than that for Type B(U).

Recent discussions among cask designers and analysts have speculated on the difficulty of demonstrating compliance with the B(U) post-accident leak-rate limit (by either analysis or testing). It is intended by the NRC that proposed regulations for Type B(M) packagings with their more liberal leakage rate limits apply to domestic use only. A question remains, however, as to differences in transport restrictions applied to Type B(M) packages for domestic use compared to Type B(U) for multinational use. If there are none, then there is little incentive for a domestic licensee to even consider Type B(U) package.

In summary, current regulatory trends could allow for somewhat more variable and less restrictive shipping strategies not allowed under the existing regulations for TRU wastes. Cost incentives exist to minimize transportation packaging by shipping under proposed LSA or LLS rules. Proposed limits for LLS and Type A Normal Form categories are more favorable to transporting TRU wastes than existing rules.

3.2 OPERATIONAL REGULATIONS

The DOT, the NRC and local governments regulate the operation of radioactive material transportation to assure continued compliance of the packages with performance standards, to prevent the contamination of transport vehicles and personnel, and to minimize potential adverse radiological consequences of radioactive material transportation to the public. These operational regulations apply to the shipment of TRU wastes in the areas of package quality assurance (QA), surface contamination control and routing of radioactive material shipments. Discussion on each of these points is provided in this section.

Package QA requirements depend on the degree of potential hazards that the waste presents and the expected life of the package. Type A packages are generally disposable. They are controlled for quality of manufacture, adequacy of design and allowable contents. Design adequacy can be determined based on an approved analysis or testing program of prototypes built to a specific standard. Specifications for the 17 C drum, which is used extensively for Type A shipments, cover materials of construction, seams, dimensions, heads, closures repair, marking, testing requirements etc. Records must be maintained to show compliance of each drum with all design and manufacturing criteria. In addition, records must be maintained on the contents of each drum as to its form and radionuclide content. This information is used to determine the proper shipping category. If unknowns exist on the package contents, conservative assumptions must be made that will probably place the canister in a more restrictive shipping category. This activity is the responsibility of the waste generator, who certifies that the information is correct. It is not generally checked by other organizations.

Type B packages are usually reusable. QA requirements for Type B packages under 10 CFR 71 Appendix E are more specific than for Type A packages. Records must be kept for the design, fabrication, assembly, testing, use and maintenance of each individual package. Records of each shipment must be maintained by the package licensee for two years.

Surface contamination limits are established to control spread of contamination onto transport vehicles, to other cargo carried on the vehicle, to the public and to transportation workers. Decontamination procedures should be considered in the design of a transportation package to minimize operational problems. Removable contamination is considered significant if the level averaged over any 300 cm^2 of the package surface is in excess of levels shown in Table 3.6. Wipe tests using absorbent material are an accepted test procedure. Measured activity on the wipe cannot exceed 10% of the permissible level. (That is, removable activity is considered to be 10 times that on the wipe cloth.)

Surface contamination limits for packages shipped in exclusive-use vehicles unloaded in the presence of the consignor, consignee or a designated agent are allowed to be 10 times the levels listed in Table 3.8. Vehicles used exclusively for radioactive materials must be surveyed following each shipment to assure dose rates at any accessible surface are less than 0.5 millirem per hour and contamination levels are below those in Table 3.6.

TABLE 3.6. Readily Removable Surface Contamination Limits
for Transportation Packages

Contaminant	Maximum Permissible Level	
	$\mu\text{Ci}/\text{cm}^2$	dis/min cm^2
Natural or Depleted Uranium and Natural Thorium		
Beta-Gamma	1E-3	2.2E+3
Alpha	1E-4	2.0E+2
All Other Beta-Gamma Emitting Radionuclides	1E-4	2.2E+2
All Other Alpha Emitting Radio- nuclides	1E-5	2.2E+1

Over the last few years numerous local bans and restrictions have been placed on the transport of radioactive materials. Recent DOT and NRC studies have indicated that these rules were not consistent with historic and potential hazards from these materials. Federal DOT regulations preempting local laws for highway transport were published in the January 19, 1981 Federal Register and will take effect February 1, 1982. The rules have two major provisions. The first is a general routing requirement and would apply to LSA, LLS and Type A shipments of TRU wastes. Under this rule, carriers of this material must examine all available highway routes and choose a route that minimizes potential radiological risk to the public. The second provision regulates "large quantity" shipments and would apply to Type B TRU waste shipments. This material must be transported only on designated "preferred" routes. In the absence of action by state governments, the interstate highway system has been designated by DOT to be acceptable. State governments are allowed, under the rules, to remove sections of highway from preferred status, but an alternative route must be made available. In designating the alternative or optional routes, state governments must consider overall risks to the public including dose from normal transport and transportation accidents. No regulations have been published on routing of rail shipments. The limited number of available rail alternatives may make rail routing impractical.

In conclusion, operational regulations apply to TRU wastes in the areas of package QA, surface contamination and routing. These rules will impact waste canister criteria only if credit is taken for waste canister characteristics in the transportation package design. Characteristics assumed must be verified by a QA program. Contamination is a concern in transportation for only outside surfaces. Routing restrictions do not appear to be severe and can be minimized by controlling canister contents to avoid "large quantity" shipments.

3.3 INTERPRETATION OF REGULATIONS AS APPLIED TO TRU WASTE FORMS AND CANISTERS

This section presents results of an analysis to determine potential shipping package requirements for TRU waste forms. The section discusses the implications of existing and proposed regulations described in Sections 3.1 and 3.2.

3.3.1 Interpretation of Existing Regulations

Defense TRU wastes can contain weapons plutonium, heat-source plutonium, heat-source curium and thorium fuel cycle materials including thorium or uranium-233. All radioisotopes in these wastes with the possible exception of thorium and uranium fall in the Transport Group I described in Table 3.1, or the most restrictive category. No breakdown of isotopes is available for the thorium wastes, so under the regulations they would have to be assigned to the most restrictive groups that could not be positively excluded. Existing regulations limit Group I isotopes to less than $1\text{E-}7$ Ci/g for LSA materials, $1\text{E-}3$ curies per package for Type A Normal Form shipments and 20 curies per package for Type A Special Form shipments. Packages with material in excess of these limits must meet Type B requirements.

Performance standards for packaging described in Section 3.1 increase according to shipping classification in the following order: LSA, Type A, Type A Special Form, and Type B. Increased costs of higher integrity packages provide incentive to qualify waste shipments in the least cost/restrictive category. The following discussion will evaluate TRU wastes in each of the above categories.

The allowable package categories for TRU defense waste shipments can be determined by multiplying the estimated curies per gram of plutonium by the grams of plutonium per shipment. Because of the significant difference in the specific activity of TRU wastes from weapons manufacture and TRU wastes from defense heat sources, the two types of wastes are considered separately in the example applications of the regulations that follow. Isotopic characteristics of heat-source and weapons-grade plutonium (Shelfelbine 1978) are shown in Table 3.7. The specific activities of weapons and heat source plutonium are 0.424 and 14.7 Ci/g respectively.

TABLE 3.7. Isotopic Mixture in Weapons-Grade and Heat-Source Plutonium

Isotope	Weapons-Grade Pu		Heat-Source Pu	
	Weight Fraction	Ci/g	Weight Fraction	Ci/g
^{238}Pu	3.0E-4	5.0E-3	8.0E-1	1.4E+1
^{239}Pu	9.4E-1	5.8E-2	1.6E-1	1.0E-2
^{240}Pu	5.7E-2	1.4E-2	3.0E-2	7.0E-3
^{241}Pu	3.0E-3	3.5E-1	6.4E-3	7.2E-1
^{242}Pu	3.0E-4	~ 0	1.3E-3	~ 0
^{241}Am	2.0E-4	<u>6E-4</u>	0	<u>--</u>
Total (Ci/g)		4.24E+1		1.5E+1

To determine the applicability of LSA packaging for TRU waste shipments on a bulk activity basis the characteristics of second-stage sludge were used for analysis because it has a low plutonium content per gram of waste material. A weapons plutonium concentration of 1E-6 g/g of sludge from Table 2.1 results in a specific activity of 4.1×10^{-7} Ci/g, which is in excess of the LSA limit for Group I isotopes. Thus, LSA shipments of typical untreated TRU wastes would not be allowed.

Alternative criteria are available in the LSA category for nonradioactive objects that are externally contaminated with radioactive materials that are not readily dispersible. Scrap metal and glass wastes may meet these criteria. Surface contamination levels are limited to 1E-4 mCi/cm^2 of Group I isotopes.

This limit is $4.2\text{E-}8 \text{ g/cm}^2$ for weapons wastes and $6.8\text{E-}9 \text{ g/cm}^2$ for heat-source wastes. Surface area information was not available to evaluate TRU wastes on this basis.

Processing to assure a homogeneous waste mixture and dilution to LSA limits is one possible strategy to minimize transportation packaging requirements. From Table 2.2, the wastes stored in 55-gallon drums at Idaho Falls contain an average of $5.5\text{E-}5 \text{ g Pu/g}$ of waste. To meet LSA limits the waste mass of the nonradioactive waste matrix would need to be increased by a factor of about 230 for weapons wastes and a factor of 8100 for heat-source wastes. From the viewpoint of total system cost for waste treatment, transportation and disposal, this strategy appears to be impractical.

Normal Form Type A package limits allow $1\text{E-}3 \text{ Ci}$ of Group I isotopes. This is equivalent to $2.4\text{E-}3 \text{ g}$ of weapons plutonium and $6.8\text{E-}5 \text{ g}$ of heat-source plutonium. The waste form with the lowest concentration of weapons plutonium stored at Idaho is LSA metal and glass (Shefelbine 1978). A 55-gallon drum of this material contains $1.3\text{E-}2 \text{ g}$ of plutonium and exceeds the Type A limits by a factor of 52. Thus, no untreated defense waste shipments in Type A packages would be allowed under the existing regulations.

If defense wastes are to be treated and/or repackaged, it would be possible to control the package size and performance characteristics to meet either Type A Normal Form or Type A Special Form activity limits. If untreated wastes of average plutonium content and density are repackaged to meet Special Form requirements, a maximum package size of 7 m^3 would be allowable for the average weapons waste concentrations. The corresponding volume would be 0.2 m^3 for heat-source wastes. If defense wastes are treated using the Slagging Pyrolysis Incineration (SPI) process under development at the INEL, a product results with a plutonium concentration of about 40 g/m^3 of waste form. Normal Form package sizes of $5.9\text{E-}5 \text{ m}^3$ and Special Form package sizes of 1.2 m^3 would be allowable for weapons wastes. These sizes would be reduced to $1\text{E-}5 \text{ m}^3$ and $3.4\text{E-}2 \text{ m}^3$ for Normal Form and Special Form heat-source wastes respectively. Package sizes appear to be practical for repackaged and/or treated weapons plutonium contaminated wastes under Special Form rules.

Untreated TRU wastes would require two additional disposable containers to qualify as Type A special Form material. The first is required to meet Special Form requirements and the second to meet Type A requirements. In the case of treated wastes, only the additional outside Type A container would be required if the waste canister is designed to meet Special Form requirements. One possibility is to qualify the combination of waste form and canister by taking credit for the waste-form structure.

A criticality assessment will be required under some strategies for defense TRU waste transportation. Single drums or boxes of untreated wastes containing up to 350 g of fissile materials in Type B packages could be shipped without this assessment. Packages carrying multiple waste canisters, such as the ATMX rail car have been evaluated under these basic requirements. ATMX specifications (Adock 1974) limit the maximum plutonium content to 200 g per 55-gallon drum, and 5 g per 0.028 m³ in boxes. The transuranic Package Transporter (TRUPACT) under development at the Transportation Technology Center (TTC) will be evaluated under both the single and multiple package rules. The effect of fissile material considerations on the transport of treated TRU wastes will depend on the plutonium loading of the final waste form. Up to 8.7 m³ (40 grams of Pu/m³) of SPI processed wastes could be transported under the existing rules as a nonfissile shipment. Wastes with higher fissile material concentrations will reduce the maximum shipment size.

Double containment is required for TRU waste shipping packages containing more than 20 Ci of plutonium. This rule may be implemented by either providing a separate inner containment as part of the shipping package design or providing disposable overpacks for waste canisters. The ATMX system does not meet double containment requirements (but serves as accident protection) and is currently operated under an exemption to this rule. Drums and boxes of untreated wastes will not provide sufficient containment inside transport packagings under Type B conditions to meet the intent of 10 CFR 71.42(b). The TRUPACT shipping packaging is being designed with a single level of containment. It is proposed on the conceptual design that the inner skin is a containment boundary and that the TRU waste forms will be exempted from the double containment requirement. Regulatory interpretation of this approach will be required. Canisters

for treated wastes have potential for providing the second level of containment, thereby meeting double containment rules. It is anticipated that engineering problems for canisters containing monolithic waste forms are relatively small due to the structural support of the waste canister provided by the waste form.

Three DOT specification transport packages are described in Table 3.3 with the potential to carry CH-TRU defense wastes. All utilize an inner vessel built to specification 2R and various overpacks depending on the package contents. For Type B shipments, the 2R vessel is transported in a 20WC (49 CFR 178.194) overpack. The maximum 2R dimensions (0.13 m^3) are allowed. Heat dissipation must be limited to preclude damage in normal transport. This package could be used for most treated and untreated waste forms provided they contain less than 20 Ci of Group I isotopes and contain less than the $5 \text{ g per } 2.8\text{E-}2 \text{ m}^3$ (1 ft^3) fissile material limit. The small dimensions of the 2R vessel limit the utility of this package for untreated wastes. The package volume is constraining for treated wastes.

The interior volume for large quantity nonfissile shipments in specification containers is limited to $3\text{E-}2 \text{ m}^3$. In this case, the 2R containment vessel is part of the 6M specification package (49 CFR 178.104). Exceeding the Type B 20-Ci limit in a volume of 0.03 m^3 would make the shipment fissile and preclude the use of the 6M package.

Waste forms with plutonium concentrations in excess of 250 g/m^3 would be shipped in the 6L container (49 CFR 178.103). This container has a maximum interior volume of 0.02 m^3 and an allowable heat loading of 5 watts. It is anticipated that heat generation is limiting for shipments containing large quantities of plutonium, thereby restricting allowable packages to impractical sizes.

In summary, existing transportation regulations allow practical package volumes in the categories of Types A Special Form and Type B shipments for defense wastes. LSA rules may apply to some solids with fixed-surface contamination, but additional waste characterization is required to evaluate this alternative. Finally, none of the DOT-approved containers that meet specifications for Type B shipments appear practical for CH-TRU defense wastes due to their small internal dimensions. Transportation packages designed to applicable performance standards are required.

3.3.2 Interpretation of Regulatory Trends

Discussion of regulatory trends in this section includes proposed revisions to NRC and DOT regulations and potential impacts of standards development.

A basic issue in the proposed regulations is the interpretation of A_1 and A_2 quantities for mixtures of isotopes. Apparent A values are calculated in this report by weighting the individual isotope A values by the mass fraction and activity fractions in the mixture and "unity rule." Table 3.8 shows the A_1 and A_2 values for heat-source and weapons plutonium under each of the three evaluation strategies. As shown, the A_2 values can vary by a factor of 37 depending on which basis is accepted for mixture of TRU nuclides. No precedent exists in this area at the present time.

The following is a discussion of the applicability of proposed shipping categories to CH-TRU defense waste. "A" values using the three methods of calculation for weapons and heat-source plutonium are considered.

TABLE 3.8. "A" Values for Isotopic Mixtures of Plutonium

Evaluation Strategy	Weapons Plutonium		Heat-Source Plutonium	
	A_1 (Ci)	A_2 (Ci)	A_1 (Ci)	A_2 (Ci)
Weight Fraction ^(a)	NA ^(b)	2.3E-3	NA	3.43E-3
Unity Rule ^(c)	1.11E+1	1.03E-2	3.15E0	3.15E-3
Activity Fraction ^(d)	NA	8.21E-2	NA	7.75E-3

(a) Determined by: (mass fraction of nuclide "a" in mixture) • (A_1 or A_2 for nuclide "a").

(b) NA = Not applicable.

(c) Determined by: (Ci nuclide "a"/ A_1 or A_2 for nuclide b) = 1.0.

(d) Determined by: (activity fraction of nuclide "a" in mixture) • (A_1 or A_2 for nuclide "A").

Proposed regulations allow a bulk concentration of $1E-4 A_2/g$ for LSA materials. This limit ranges from $2.3E-7 Ci/g$ to $8.2E-6 Ci/g$ for weapons wastes under the three interpretations and from $3.4E-7 Ci/g$ to 7.7×10^{-7} for heat-source wastes.

Concentrations of transuranics in weapons TRU wastes for untreated waste forms in Table 2.1 range from $3.3\text{E-}7$ Ci/g for second-stage sludge to $3.3\text{E-}5$ Ci/g for first-stage sludge. If these waste forms were contaminated with heat-source plutonium, their specific activities would be $1.2\text{E-}5$ Ci/g and $1.1\text{E-}3$ Ci/g respectively. Thus, some untreated TRU wastes may qualify with regard to overall TRU concentrations as LSA material if contaminated with weapons plutonium but not with heat-source plutonium under the activity-weighted interpretation of A_2 in the proposed rules. Wastes meeting the LSA criteria could possibly be shipped in their existing Type A canisters with no additional packaging.

Some treated TRU waste may also qualify as LSA material. The SPI waste form (40 g plutonium/ m^3) is estimated to have a specific activity of $6.1\text{E-}6$ Ci/g for weapons plutonium and $2.1\text{E-}4$ Ci/g for heat-source plutonium. Again, the SPI waste form would qualify under the activity-weighted interpretation of the regulations as LSA material for weapons plutonium. Heat-source plutonium wastes would not qualify as LSA material if treated with the SPI process.

Objects of nonradioactive material contaminated with radioactive material may qualify as LSA if nonfixed contamination is not more than $1\text{E-}4$ $\mu\text{Ci}/\text{cm}^2$ for alpha emitters ($1.3\text{E-}9$ g/ cm^2 for weapons waste) and nonfixed contamination, concentrated by processes in transit will have bulk activity less than $1\text{E-}4$ A_2/g . Waste forms such as leached metal and glass may meet one of these criteria, but additional data on surface contamination is required to make a final determination.

After LSA, the next most desirable shipment category in the proposed regulations is LLS. LLS packages of uniformly distributed material are allowed to contain $2\text{E-}3$ A_2/g concentrations of material. For weapons plutonium, this limit ranges from $4.6\text{E-}6$ Ci/g to $1.6\text{E-}4$ Ci/g and for heat-source plutonium it is $6.3\text{E-}6$ Ci/g to $1.5\text{E-}5$ Ci/g. Comparing these limits to the average concentrations for untreated TRU wastes in the LSA evaluation above, it can be seen that, with regard to nuclide concentrations, a greater fraction of untreated wastes meet the activity limit for LLS material than for LSA, including some heat-source wastes. However, the leachability and uniform distribution criteria for this type of LLS material would probably preclude any untreated wastes

in this category. If the SPI waste form is assumed to meet the leachability and activity distribution criteria, it will meet the activity limits under both the activity weighted and unity rule strategies for weapons plutonium. SPI produced waste forms would not be classified as LLS for heat-source plutonium.

A second type of LLS material includes solid objects with nondispersible surface contamination. Surface contamination is limited to $20 \mu\text{Ci}/\text{cm}^2$ for beta and gamma emitters and $2 \mu\text{Ci}/\text{cm}^2$ for alpha emitters. Because of the presence of ^{241}Pu which is primarily a beta emitter, 18% of the total curies in weapons Pu and 95% of those in heat-source Pu are from alpha radiation. The $2 \mu\text{Ci}/\text{cm}^2$ alpha limit appears to be controlling for both waste sources. Allowable surface contamination for weapons waste would be $2.6\text{E-}5 \text{ g}/\text{cm}^2$. For heat-source it would be $1.4\text{E-}7 \text{ g}/\text{cm}^2$. Additional information on surface area and contamination levels of actual wastes is required to determine if specific untreated waste forms can meet the LLS requirements. Scrap metal and glass would appear to have a good chance of meeting these limits.

The next more restrictive packaging category after LSA and LLS is Type A Normal Form. The quantity limits under the unity rule are about 10 times those under existing rules for weapons plutonium. Limits for heat-source plutonium are about three times higher. Waste packages of metal and glass would meet the Type A limits if the canisters are less than 0.38 m^3 in volume. Most other forms of weapons TRU wastes and all heat-source wastes exceed the proposed Type A package concentration limits.

The allowable concentrations for Type A Special Form materials may allow weapons wastes to be transported in packages of significant volume under existing and proposed rules. The proposed rules and application of the unity rule limits the maximum allowable canister size to 3.9 m^3 for the average untreated weapons wastes and 0.032 m^3 for untreated heat-source wastes.

Many TRU wastes must still be shipped as Type B materials under proposed revisions to DOT and NRC regulations. The numbers of shipments required will depend on the final interpretation of the package activity limits and the amount of verification needed to assure that waste form characteristics comply with LSA, or LLS Type A criteria.

The proposed revisions to the transportation regulations may be an advantage in TRU waste transportation. In the least conservative interpretation of the proposed regulations, assuming package contents and integrity can be verified, many wastes could be shipped in the LSA, LLS and Type A categories. More conservative interpretation of the regulations or inadequate documentation on package contents could limit shipments to Type B packaging.

4.0 CARRIER REQUIREMENTS AND PREFERENCES

This section addresses 1) TRU waste trucking and railroad operations, and 2) the concerns, preferences, and requirements of truck and rail carriers regarding TRU waste canister and packaging design.

It is difficult to completely separate carriers' interest in canister design from their interest in overall package design. Thus, some of the discussion in this section bears on the design features of the overall packaging.

This section of the report has been subdivided into three parts. The first and second parts of the section describe TRU waste transportation by the truck and rail modes, respectively. The third part summarizes truck and rail carrier considerations and preferences regarding the TRU waste form and canister design.

4.1 REVIEW OF TRUCKING OPERATIONS RELATED TO TRU WASTE SHIPMENTS

Although only modest amounts of TRU wastes are currently being transported by truck, more shipments are expected in the future. Such shipments are expected to employ trucking practices similar to those presently used for transporting low-level wastes (LLW) and spent fuels.

The information in this study on perspectives of truck carriers was obtained through 1) a review of the Proceedings of the Nuclear Material Truck Transportation Workshop (BMI 1980), 2) field interviews of truck carriers presently hauling nuclear materials, and 3) a review of literature pertaining to nuclear and hazardous material transportation. The trucking firms are inclined to view the properties of TRU wastes from the shipping standpoint as being very similar to those of LLW and therefore require similar handling methods. They also feel that the public and its government representatives consider TRU wastes to be more hazardous than low-level wastes, and would therefore suggest trucking practices more closely resembling those used to transport spent fuel.

Over the course of several interviews the following perceptions by truckers emerged of possible trends for future TRU waste trucking operations: shipments

using specially equipped, dedicated flatbed or low-boy trailers; shipments may be regularly scheduled; two drivers may man the vehicles; constant two-way communications capability may be used between the truck and control stations; and vehicles may have automatic disabling features to thwart hijackers. The application of all these options to TRU waste transportation operations would be more expensive than current practices for low-level waste shipments but economies could be achieved if equipment and driver time is intensely utilized with minimal detention periods at terminals.

4.1.1 Dedication and Scheduling

Dedicated operations can be cost-effective if there is a sufficient volume of TRU wastes moving between fixed points to permit one or more trucks/tractors to be fully utilized. TRU waste movements are expected to satisfy this need because they exist in substantial quantities at a few sites and they will be transported to a limited number of repositories or processing sites.

Shipping of TRU wastes requires specialized packagings and perhaps truck trailers and canisters. For example, truck trailers may be reinforced to better enable them to carry concentrated loads, or they may have special provisions for tie-down of loads. Truck drivers may be required to have special training and relatively high experience levels. Hence both capital and manpower costs could be high for TRU waste transport. In this case, the desirability for dedicated operations would be reinforced by the incentive to reduce costs.

Maximum vehicle utilization could theoretically be achieved by a continuous turnaround operation without schedule constraints at the terminals. A regular schedule (i.e., loading and unloading at fixed times with some time allowances) could result in a delay between the completion of one trip cycle and the beginning of the next. On the other hand, the scheduling of TRU waste truck movements can also permit synchronized scheduling of loading/unloading operations at the terminals, thereby simplifying terminal operations, reducing terminal requirements, and minimizing truck detention times. Regular scheduling of shipments would allow truckers to more readily meet prenotification requirements if any are in effect. Also, truck drivers have a strong preference for regularized driving schedules.

4.1.2 Truck Trip Cycles

Four possible TRU waste truck trip cycles were identified. In every case the shipper is expected to load the truck trailer and the receiver is expected to unload it while the driver may only observe loading and unloading operations. Each method involves a continuous cycle in which a dedicated vehicle transports a full packaging and returns an empty one on the return trip. Use of disposable packagings would obviously eliminate the return trip of the packagings.

At the waste shipping source, a tractor unit may pick up a TRU waste load immediately after returning an empty packaging, or it may wait for a load, or it may go to another originating point to provide service to other shippers until another TRU waste load is available. From the truckers' standpoint the first is desirable, the second is less desirable and more expensive, and the last is least efficient and will significantly increase costs. Because of the disadvantages of the last schedule, it will not be discussed further. However, the four other trip cycles involving a continuous movement of empty and loaded trailer movements are:

- Cycle 1: Exchange Packages - The packaging is preloaded with TRU wastes at the source before the truck's arrival. The truck arrives carrying an empty packaging. Upon arrival the empty packaging is removed from the trailer. The full package is then loaded onto the trailer and secured. After necessary inspections the truck departs. Upon arrival at the destination the process is reversed. The package is removed and an empty one takes its place. The truck then returns to the originating terminal where a new shipment cycle commences.
- Cycle 2: Exchange Trailers - The truck arrives at the originating terminal with an empty packaging. Upon arrival the incoming trailer is detached. Then an outgoing trailer with a loaded packaging that was prepared prior to the rig's arrival is attached to the tractor unit. After necessary inspections the rig departs. At the destination the process is reversed. The trailer with the loaded packaging is exchanged for a trailer with an empty packaging.

- Cycle 3: Pack/Unpack Affixed Packaging - The truck arrives at the originating terminal carrying an empty packaging. The truck driver waits with the tractor while the packaging is loaded and inspected. At the destination, the driver waits while the packaging is unloaded. Both loading and unloading operations are performed with the packaging affixed to the trailer.
- Cycle 4: Remove Package, Pack/Unpack. Cycle 4 is identical to cycle 3 except that the packaging is removed from the trailer for its loading and unloading. It is subsequently mounted onto the trailerbed. The truck driver and tractor are detained throughout these operations.

The operating approaches used may be hybrids of the above cycles. It would be possible to employ one loading or unloading technique at the originating terminal and another at the destination repository.

It is also possible that one or more intermediate stopovers may occur at carrier-owned facilities between the origin and destination. The stopovers would a) provide buffer periods that could allow pickup and delivery schedules to be rigidly maintained, and/or b) permit a thorough pre-inspection of vehicles loads before the destination is reached.

4.1.3 Truck Transportation Resource Utilization

The four trip cycles cited above vary in terms of the intensity of time utilization of truck drivers, truck tractors, truck trailers, and packagings. The cost-effectiveness of each alternative can be appraised in terms of time utilization of each of these transportation resources.

Table 4.1 describes qualitatively the advantages and disadvantages of each cycle in terms of transportation resource utilization availability of backup equipment and scheduling flexibility. No single method is clearly superior to all the others although it does appear that cycle 4 is the least desirable for truckers. Present detention charges are regarded by truckers to be marginally remunerative at best. The truckers prefer cycles 1 or 2, which minimize detention time. The merits of cycles 1 and 4 would be impacted by the ease of removing the exterior packagings from the trailers. The merits of cycles 3 and 4 would be affected by the ease of loading/unloading waste canisters within the exterior packagings.

TABLE 4.1. Merits of Alternative Trip Cycles to Truckers

	Quantitative Favorability to Truckers			
	Cycle 1 <u>Exchange Packages</u>	Cycle 2 <u>Exchange Trailers</u>	Cycle 3 <u>Pack/Unpack Affixed Package</u>	Cycle 4 <u>Remove Package, Pack/Unpack</u>
Transportation Resource Utilization				
Driver	High	High	Medium	Low
Tractor	High	High	Medium	Low
Trailer	High	Low	High	Medium
Packaging (Overpack or Cask)	Low to High	Low	High	Medium
Availability of Backup Equipment ^(a)				
Tractor	Low	Low	Low	Low
Trailer	Low	High	Low	Low
Packaging (Overpack or Cask)	High	High	Low	Low
Scheduling Flexibility	Medium	High	Low	Low

(a) Trailers, overpack and casks that are idle between trip cycles would also provide backup capacity in the event of equipment failure if cycles 1 or 2 are employed.

Despite their advantages to truckers, cycles 1 and 2 have their drawbacks--relatively high trailer and packaging capital costs. The total cost-effectiveness of alternative trip cycles, however, must also take into account the operating costs of the total system.

Cycle 2 is clearly the superior alternative with regard to availability of backup equipment and flexibility of shipping schedules. The additional trailer and packaging capacity in cycle 2, which minimize turnaround times, also provides backup capacity in the event of equipment failures. Both cycles 1 and 2 would allow flexible scheduling of truck and terminal operations because the loading/unloading of waste containers within the exterior packaging could be done independently of the presence of the truck driver and tractor.

A smoothly operated dedicated truck operation can produce 29,000 to 32,000 kilometers (18,000 to 20,000 miles) of freight transportation service per tractor per month. This is a practical target, not a theoretical one. It can be achieved if shipments are regularly scheduled and if fast turnarounds are achieved at the terminals. It allows provisions for a) downtimes during vehicle maintenance, b) downtime between trip cycles, and c) driver rest and sleep periods.

4.1.4 Truck Carrier Equipment

The types of truck trailers currently available for transporting TRU wastes include:

- Flatbed or step-deck trailers
- Low-boy trailers
- Tractor-trailer enclosed vans.

Figure 4.1 provides illustrations of flatbed and low-boy trailers that could be used for transporting TRU wastes (Home Transportation Company 1981). Table 4.2 shows dimensions of van trailers manufactured in 1978.

Overpack or cask shipments typical of TRU wastes usually make use of a step-deck, flatbed, or low-boy trailer. Vans are often used for shipments of other nuclear materials, and may be made usable for some TRU waste shipments. In the past, some carriers have made modifications to general service equipment for use in transporting nuclear materials. Modifying the equipment can be costly and add substantially to the empty weight of the vehicle.

Carriers may utilize air-ride suspension systems in TRU waste transport vehicles. This system allows a smoother ride than the conventional spring system and reduces structural fatigue and cracking caused by road vibrations and road hazards.

4.1.5 Distributing the Load and Securing it to the Trailer

From the trucker's standpoint the most serious technical problems posed by nuclear material transportation relate to load distribution. Casks (and to a lesser degree overpacks) concentrate loads at the center of the trailer. This can result in substantial flexing of the trailer structure, accelerated metal fatigue and cracking, reduced vehicle control, difficulty in securing the package to the trailer, and harsh ride quality for the driver.

To handle heavy or concentrated loads, heavy duty or reinforced trailers can be used but they are more expensive than standard trailers, and more importantly, legal payload capacity is reduced. Tie downs can be extended to the corners of the trailer to increase load secureness, but this localizes the flexing of the trailer, resulting in increase of potential for structural cracking. Packages may be bolted to the trailerbed to secure the load but may weaken the structure. Steel base plates may be positioned beneath the package to help redistribute the load but will reduce the load capacity.

Stretch Flatbeds Available. Maximum Length 65'. Maximum Height 66'.
Aluminum Flatbeds Available.

FLATBED

Stretch Step Deck Available. Maximum Length 37' to 40'.
Maximum Height Step Deck Max. 39'.

STEP DECK

LEVEL DECK LOW BOY

LEVEL DECK LOWBOY - 3 Axles

* Available with 38' Expandable Center.

REMOVABLE GOOSENECK DROP CENTER LOW BOY

* Available with 34' Expandable Center.
Manual and Hydraulic Cents Available.

REMOVABLE GOOSENECK LOW BOY - 3 Axles

REMOVABLE GOOSENECK BEAM TYPE LOWBED - 3 and 4 Axles

NOTE: 1 ft = 0.3048 m
1 in. = 0.0254 m

Source: Courtesy of Home Transportation
Company, Inc., Marietta, Georgia

FIGURE 4.1. Flatbed, Step Deck, and Low-Boy Trailers Used to Transport
Nuclear Materials (Home Transportation Company 1981)

TABLE 4.2. Dimensions of Van Trailers Manufactured in 1978 (Van Trailer Manufacturers Association 1978)

Dimensions		Percent of 1978 Manufacturers	Dimensions		Percent of 1978 Manufacturers
Minimum	Maximum		Minimum	Maximum	
<u>Length, (ft)</u>			<u>Interior Load Height (ft)</u>		
--	27	2.76	--	7-1/2	1.68
27	27-1/2	4.18	7-1/2	8	12.89
27-1/2	40	0.97	8	8-1/2	25.03
40	42-1/2	32.68	8-1/2	9	53.60
42-1/2	45	7.23	9	--	6.80
45	47	52.08	<u>Interior Load Width (in.)</u>		
47	--	0.10	--	92	0.10
<u>Height (ft)</u>			92	93	21.60
--	12-1/2	0.51	93	94	75.42
12-1/2	13	13.67	94	95	2.91
13	13-1/2	64.30	95	--	--
14	--	--	<u>Width of Door Openings (in.)</u>		
<u>Height of Door Openings (in.)</u>			--	86	--
--	94	4.59	86	88	18.98
94	100	18.41	88	92	0.98
100	106	32.88	92	93	65.54
106	108	37.45	93	--	14.50
108	--	6.67			

Note: 1 ft = 0.3048 in.
1 in. = 0.0254 m.

Six central lessons have resulted from truckers' experiences to date with movement of nuclear materials in concentrated loads:

1. The structural analysis of the package and trailer should be done by considering the two in their joint configuration; separate analyses are not adequate.
2. The tie downs or other mechanisms used to secure the package may materially affect the structural properties of the package-trailer unit.
3. A broad load distribution will reduce structural fatigue and improve roadability.
4. Trailer design alterations made to accommodate higher loads have generally resulted in higher vehicle weight and in reduced payload capacity.

5. The center of gravity of the loaded trailer should be kept as low as possible to minimize the tendencies to overturn.
6. The specific design of a trailer's suspension system may either mitigate or worsen problems resulting from load concentration or high center of gravity.

If TRU waste packagings were designed to be small enough to permit a truck trailer to legally carry two or more packages, the problems resulting from load concentrations at a single point could be reduced. The use of structural features with packagings to spread the load over the trailer and to increase load securance would be beneficial.

4.1.6 Truck Weight, Dimension, and Configuration Limits

Regulations in each of the 50 states govern truck weight, dimension, and configuration limits. Regulations pertain to:

- gross vehicle weight
- weight on single axles
- weight on tandem and triple axles
- vehicle height
- vehicle width
- vehicle length
- vehicle configuration (e.g., single, double or triple trailers).

Traditionally, there has been substantial variation in the stringency of regulations among the 50 states. Most annoying to truckers are the relatively narrow weight and configuration restrictions of most states bordering the Mississippi River. These states generally have 33,200 kg (73,280 lb) gross weight limits and do not allow the use of double or triple trailers. Because of their location, these states effectively set legal weight and configuration limits for most transcontinental truck movements.

Table 4.3 describes current limits for total tractor-trailer length and gross weight in the 50 states. Most states now have gross weight limits of 36,300 kg (80,000 lb) or higher, which results in a minimum payload capacity of about 22,700 kg (50,000 lb). Many now permit double trailers and some permit triple trailers. Overall length limitations are generally 16.75 to

TABLE 4.3. Maximum Truck Weight and Dimension Limits^(a,b) as of July 1, 1980

State	Overall Length (ft)	Gross Weight (lb)	State	Overall Length (ft)	Gross Weight (lb)
Alabama	60	80,000	Missouri	65	73,280
Alaska	none	105,500	Montana	85	105,500
Arizona	65	80,000	Nebraska	65	95,000
Arkansas	65	73,651	Nevada	70	129,000
California	66	80,000	New Hampshire	60	80,000
Colorado	70	85,000	New Jersey	55	80,000
Connecticut	60	80,000	New Mexico	65	86,400
Delaware	85	80,000	New York	108	127,400
D.C.	55	73,280	North Carolina	55	79,800
Florida	110	138,271	North Dakota	75	105,500
Georgia	60	80,000	Ohio	108	127,400
Hawaii	65	80,800	Oklahoma	--	90,000
Idaho	75	105,500	Oregon	75	105,500
Illinois	65	73,280	Pennsylvania	70	100,000
Indiana	98	127,400	Rhode Island	55	99,000
Iowa	65	80,000	South Carolina	60	80,608
Kansas	105	130,000	South Dakota	70	95,000
Kentucky	65	82,000	Tennessee	55	80,000
Louisiana	65	88,000	Texas	65	105,500
Maine	60	80,000	Utah	65	80,000
Maryland	65	80,000	Vermont	60	80,000
Massachusetts	98	127,400	Virginia	56	79,800
Michigan	65	(c)	Washington	65	105,500
Minnesota	66	80,000	West Virginia	55	80,000
Mississippi	60	73,280 ^(d)	Wisconsin	65	80,000
			Wyoming	85	101,000

(a) All states have height restrictions of either 13 ft 6 in. or 14 ft, the width limit is generally 8 ft.

(b) In some states, size restrictions are more stringent on noninter-state highways.

(c) Vehicles are limited to 11 axles.

(d) To become 80,000 lbs on November 1, 1981.

NOTE: 1 ft = 0.3048 m

1 in. = 0.0254 m

SOURCE: American Trucking Association

33.5 m (55 to 110 ft). Height limits are 4.1 or 4.3 m (13.5 or 14 ft) in all states. The typical width restriction is 2.44 m (8 ft).

There is a trend for some states with higher weight limits to revert to lower weight limits in the future to decrease road damage and to reduce road maintenance costs, especially in light of declining road use tax revenues. Many

states with low weight limits have soil and climatological conditions that make their roads more susceptible to damage by high axle loadings. Many portions of the U.S. Interstate Highway system and other principal material highways are at or near the point when major repairs will be required. Thus, the present trend to the lower range of weight restrictions is expected to continue in the future.

Many states allow truck movements with loads and dimensions in excess of statutory limits via special permits. Some permits are issued on a blanket basis for an extended period of time, e.g., the transport of oversized construction equipment in non-winter months. However, the laws usually require that the load be indivisible before a permit is issued.

Where possible, TRU wastes should not be moved in oversized loads for a number of reasons. First, most TRU waste movements do not meet indivisibility criteria in the classic sense because loaded overpack weights can usually be lowered by reducing the quantity of TRU wastes carried. This reduction in payload weight may be greater for oversized packagings because of their heavier tare weight. Additionally, oversized loads of TRU wastes may bring negative reaction from the public by 1) providing a political battleground for approval of oversized loads, 2) antagonizing them because of their perception that oversized loads are more prone to accidents, and 3) making the waste shipments more conspicuous by the added placarding required for oversized loads.

4.2 REVIEW OF RAILROAD OPERATIONS RELATED TO TRU WASTE SHIPMENTS

TRU wastes are currently being moved in ATMX-500 and ATMX-600 rail cars. Rail carriers provided aid in the preparation of this report by defining their concerns, preferences, and requirements regarding TRU waste transportation through interviews and workshops. Like their trucking counterparts, railroad representatives felt that the pattern of TRU waste shipments by rail might more closely resemble spent fuel shipping patterns than those associated with LLW movements.

As a consequence of recent litigation (Court Decision 1980) it seems likely that TRU waste will be moved in conventional rather than special freight trains. The rail carriers feel that the cars moving TRU waste should be dedicated to that service and may have special safety features such as shelf couplers (used on the ATMX cars) designed to remain coupled in an accident.

Conventional freight car movements are slower than truck movements. It typically requires three to five times as long to complete a shipment cycle by rail as by truck.

In the rail carrier workshop held at Columbus, Ohio (1981), rail carriers consistently expressed greater concern about TRU waste shipments than did truckers. Their major concern is that a main rail line may be shut down for an extended time because of an accident involving TRU waste. For this reason, some rail carriers may impose operational restrictions such as slow train speeds (e.g., 56 km/hr or 35 mi/hr, or less) and may forbid the mixture of rail cars carrying TRU wastes in trains with cars carrying explosive or flammable chemicals.

In regards to canister or packaging design, the rail carriers' main concern is that the canister or packaging 1) have high structural integrity including the ability to withstand puncture forces that could occur during an accident, 2) be readily retrievable in the event of a mishap, and 3) maximize load capacity utilization so as to minimize the number of rail car loadings needed to move a specified amount of TRU wastes.

4.2.1 Dedication and Scheduling

Rail carriers would prefer to move TRU wastes in dedicated trains under some circumstances. The concentration of defense TRU wastes at a handful of sites and the limited number of repositories which will be destinations makes dedicated rail operations a potentially cost-effective means of transporting TRU wastes. However, high volume and continuous traffic flows are needed to achieve cost savings from dedicated rail service using rail rates for conventional freight service as a basis for comparison.

The outcome of recent litigation (U.S. Law Week 1980) suggests that rail carriers may not have the option of carrying TRU wastes by dedicated (special) trains. Accordingly, the remainder of this section will assume that TRU wastes will be moved in conventional freight train service. However, the rail carriers would still prefer not to carry flammable or explosive materials on trains that carry TRU wastes (DeSteele and Rhoads 1977).

Rail carriers prefer that TRU wastes moved by rail be moved by specially equipped, dedicated rail cars. They prefer that the cars have features such as shelf couplers and cushioned underframes that increase load safety. They suggest that such cars be carefully maintained to maximize their availability and minimize the likelihood of an equipment failure.

It is possible that tie-down arrangements for packagings placed on flat cars will be inspected infrequently by rail employees. Rail operators strongly prefer semipermanent attachment of packagings to rail flatcar beds by bolting to the use of cable or chain tie downs. (However, partial shearing of bolts might not be observed during inspections.) This bolting feature is proposed by the rail carriers to be a reasonable replacement for the surveillance of truck shipments by the ever present truck drivers. The use of fixed and sealed packagings similar to the ATMX rail cars provide an even better solution to these concerns by the rail carriers.

Because TRU wastes are expected to be moving in conventional rail service, scheduling of arrivals and departure times to minimize detention at the TRU waste terminals will not normally be possible. Delays are experienced in conventional rail service for reasons that are attributed to the myriad of cargo types and sources on a single train. These are not encountered in trucking operations with exclusive-use vehicles. Delays are common at classification yards, during car interchange between carriers and trains, and when motive power is in short supply.

It may be possible to negotiate contracts with rail carriers specifying an expected delivery period, e.g., the load will be tendered to the repository no later than five days following the shipment origination. Some shipment arrangements on a regular schedule are possible and desirable. For example, it would be useful to establish an arrangement such that loads were tendered at specific times each week. This could result in improved service quality and better equipment utilization, but might result in increased costs.

4.2.2 Rail Trip Cycles

Unlike truckers, rail carriers will generally not wait an extended amount of time for a rail car to be loaded. An engine dispatched to collect a car

at a waste terminal will expect the car to be available for immediate movement. Rail crews may help the shipper close a bulky car door or they may conduct a brief visual inspection of tie-down arrangements but this is the extent of the acceptable delay.

Rail carriers collect demurrage on cars not tendered for movement or use by the carrier within stated time limits. Because these charges are quite high, rail carriers have no objection to lengthy car detention times by shippers, except in periods of acute car shortage.

The above statements would not hold for movements of dedicated trains or dedicated fleets of trains for which negotiated costs were based on quick turn-around time. However, as noted earlier, dedicated rail movements are unlikely for TRU waste shipments because of the outcome of litigation between shippers and rail carriers regarding the assessment of special train freight rates (U.S. Law Week, 1980).

Rail car movements in conventional service can be summarized as follows:

- local service
 - empty rail cars moved from rail terminals to shippers
 - empty rail cars moved from receivers to rail terminals
 - loaded rail cars moved from rail terminals to receivers
 - loaded rail cars moved from shippers to rail terminals
- interchange service
 - empty and loaded cars interchanged among trains operated by the same or different rail carriers
- road service
 - empty and loaded cars moved in trains between rail terminals.

Economies are achieved in conventional rail service by minimizing empty car movements, maximizing locomotive utilization, maximizing loaded rail car capacity utilization, and balancing local service movements. With these considerations in mind, likely rail TRU waste trip cycle characteristics can be identified.

In a typical cycle:

- A switch engine is dispatched to take one or more empty rail cars suitable for carrying TRU wastes to the waste origin point situated on a spur line. The empty rail cars are detached and the loaded cars are hooked up. After the tie-down arrangements are inspected, the switching locomotive takes the loaded rail cars to a rail classification yard.
- At the classification yard the TRU waste cars are classified into a road train. After the train is classified it will wait for locomotives. Motive power will be provided 1) when the train is scheduled to leave, or 2) when a sufficient number of cars headed for a common destination have accumulated, or 3) when motive power becomes available in cases when locomotives are in short supply.
- While enroute to its destination, the TRU waste cars may be reclassified into other trains or interchanged with other carriers, depending on the routing. Each reclassification and interchange entails delay.
- Upon reaching the destination terminal, the TRU waste cars will be separated from the train. As switch engine capacity becomes available, the loaded TRU waste cars will be taken to the destination.
- Empty TRU waste rail cars available at the destination will be returned by the switch engine to the classification yard. The empty car will generally be moved in the reverse (alternate routing is possible) to the origin classification yard. The empty cars will be taken to the TRU waste origin point. The empty cars will be detached at the TRU waste origin point, loaded cars will be picked up, and the cycle repeated.

Many variations on this basic pattern are possible. For example, the empty cars may be returned to origin points at different times than when loaded cars are picked up. The same may be true at the destination. Various kinds of rail service may be used to accomplish the pickup or delivery of the rail cars.

The main characteristic of this operational pattern is that it is composed of a series of distinct local and distance movements. The movements are not usually tightly coordinated to a specific time schedule. They occur as trains, power, crews, and facilities become available.

4.2.3 Rail Transportation Resource Utilization

For conventional rail service, the pattern and level of transportation resource utilization is largely established as implied in the prior section. However, marginal efficiency and cost improvements are still possible.

The key to these improvements is the institution of a regular schedule of consistent waste volumes between origin and destination points. This permits rail carriers to plan the pickup/delivery of loaded/empty rail cars to minimize extra hauls and to expedite service. If guarantees of shipment volumes are provided to carriers, it may be possible to negotiate delivery time standards.

If a few more rail cars and TRU waste packagings are available than the minimum required, these could serve as buffers in the freight flow and should assist in achieving a reasonably smooth and continuous flow of TRU wastes from origin to destination. Higher traffic volumes will also result in more consistent and better utilization of local rail services.

Some rail carriers would like to see the trains carrying TRU wastes restricted to speeds as low as 56 km/hr (35 mi/hr). Because a train's kinetic energy is proportional to the square of its velocity, an accident involving a train moving at this speed would be less likely to cause leakage from a package than would a train moving at a higher speed, which is common on U.S. railways. If this speed restriction is employed, shipping costs will increase because of reduced train and track capacity utilization. Moreover, at reduced speeds, undesirable train harmonic vibrations may occur on rails jointed at 12.2 m (40 ft) spacings because rail car wheels are often spaced at the same or 2 times that distance.

A rail car in continuous turnaround dedicated service often moves 16,000 to 24,000 km (10,000 to 15,000 mi) per month, according to Jack Stouffer, Consolidated Rail Corporation. However, the average serviceable freight car in conventional service moved less than 2900 km (1,800 mi) per month in 1980 (AAR, 1981). The difference in output levels is largely accounted for by idle times at rail terminals, classification yards, and shipping/receiving points. Because TRU wastes are expected to be moved largely in conventional service, they will likely move at the slower rate.

4.2.4 Rail Carrier Equipment

The types of rail cars currently available that could be used for transporting defense TRU wastes include:

- ATMX rail cars, Series 500 and 600
- Conventional flatcars
- Other flatcars [e.g., depressed (low-boy), bulkhead]

The ATMX rail cars, which are special metal box cars that provide exterior packaging and rail cars in one integral unit, are described in Sections 5.1.2 and 5.3.2.

The other types of railcars can be used by carrying exterior packagings (e.g., the proposed TRUPACT) that contain the TRU wastes.

Special features that may be employed for nuclear waste transportation include shock-absorbing equipment couplers that do not uncouple in a derailment, and cushioned underframes.

4.2.5 Distributing the Load and Securing It to the Rail Car

In contrast to truckers who are quite concerned about the load distribution of packages on truck trailers, rail carriers express only limited concern in this regard. Rail cars are structurally stronger and a variety of heavily reinforced designs are available. Furthermore, vehicle gross weight restrictions are less severe for railroads than they are for truckers.

A frequently cited concern of rail carriers is the height of the loaded railcar's center of gravity. A high center of gravity can cause wheels to creep up rails on curves and on uneven tracks, causing derailments. One solution to this problem is the use of depressed center flatcars.

If the packaging is not bolted to the rail car or enclosed within the rail car body, tie downs are used to secure the load (Tri-State Motor Transit Company 1978). Tie downs of packagings should provide a static capacity of 5, 2, and 10 times the maximum weight of a loaded packaging in the transverse, vertical, and longitudinal directions, respectively. These tie-down specifications are the same as those used by truckers in nuclear transportation operations. Cable or chain tie downs can extend to the corners of the rail car, which increases

load securance. A combination of tie downs and bolting may also be employed. This would provide maximum securance and would reduce the chance of the packagings separating from the rail car in the event of an accident.

4.2.6 Rail Weight and Dimension Limits

Unlike trucks, rail cars have no legal weight and size restrictions which must be considered when planning shipment routes. Carriers and rail systems, however, have physical restrictions that must be considered. Examples of such restrictions include:

- bridge height clearances
- tunnel clearances
- clearances between rail tracks and buildings
- track curvatures
- track load bearing capacity.

These restrictions are less severe for rail carriers than for truckers in all dimensions - length, width, height, gross weight, axle weight. They can often be circumvented by rerouting the rail car, or in the case of weight restrictions, by occasionally violating the load restriction.

The railroad clearance office of Burlington Northern, Inc. has provided the following general guidelines and procedures for transportation of heavy loads by rail cars (National Railway Publication Company 1981):

- The maximum gross weight for a car with 4 axles is 122,000 kg (135 tons); gross weight for cars with 6 axles is about 181,000 kg (200 tons).
- Flatcars up to 27.4 m (90 ft) in length can be handled routinely on main lines.
- Depressed center flatcars are preferred for high density, large weight loads.
- The empty weight of a heavy-duty 4-axle flatcar is approximately 36,000 kg (40 tons); the empty weight of a 6-axle depressed center flatcar usually ranges between 34,000 and 45,000 kg (37 and 50 tons).
- Cars with gross weights exceeding 181,000 kg (200 tons) are subject to a maximum speed limit of 64 km/hr (40 mi/hr) on main line tracks if moved in normal train service.

- Cars carrying grain and coal are routinely loaded with 91,000 kg (100 tons) of cargo.

These guidelines represent generally accepted operating practices on well maintained, heavy-weight track.

Rail carriers generally specify rail car load limits in a linear relationship to the number of axles on a rail car, and on the ability of the track to sustain the load. Rail carriers are uncomfortable with the use of rail cars having more than 4 axles although they have moved cars with as many as 22 axles. These concerns are based on: 1) cars with more than 4 axles often have more difficulty negotiating a curve than 4-axle cars, and 2) rail carriers have limited experience in the use of rail cars with other than 4 axles. The possibility of moving TRU wastes by 6- or 8-axle rail cars may deserve further investigation if economies of higher payload can be achieved through their use.

If the TRU waste package/rail car combination complies with Association of American Railroad (AAR) Plate B envelope dimension limitations (American Railway Engineering Association 1970), the load unit will be able to engage in unrestricted interchange among rail carriers. A loaded rail car complying with Plate B restrictions is unlikely to encounter serious clearance problems enroute. Plate B specifications are shown in Figures 4.2 and 4.3. Note that a rail car width of 3.0 m (10.0 ft) meeting Plate B specifications would have a distance between truck centers of nearly 16 m (53 ft), a total length of about 18.3 m (60 ft).

On many routes it is possible to use cars with dimensions substantially greater than Plate B limits. This can result in cost savings if the load is limited in size by volume, rather than weight. However, a packaging designed with dimensions in excess of Plate B specifications could be restricted from moving TRU wastes between some points, and is not recommended by rail carriers.

4.3 INTERPRETATION OF TRANSPORTATION CARRIER REQUIREMENTS AND PREFERENCES AS APPLIED TO TRU WASTE FORMS AND CANISTERS

The potential impacts of carrier requirements and preferences as applied to TRU waste forms and canisters are primarily related to the external packagings and their effects on the total load of the vehicles. Thus, waste canisters

NOTE: The 2-1/2" above top of rail is absolute minimum under any and all conditions of lading, operation, and maintenance.

All new or rebuilt cars should be so designed that no part of car shall be less than 2-3/4" above the top of the running rail under all allowable wear and spring deflection conditions. Those roads using multiple wear wheels may find it necessary, in maintaining the 2-3/4" minimum clearance, to compensate for wheels worn close to the condemning limit by replacing wheel and axle sets, bearings or wedges.

SOURCE: ASSOCIATION OF AMERICAN RAILROADS,
MECHANICAL DIVISION

FIGURE 4.2. Plate B Specifications as of March 1, 1972 for Rail Cars for Unrestricted Interchange Service (American Railway Engineering Association 1970)

NOTE: 1 ft = 0.3048 m
1 in = 0.0254 m

MAX. WIDTH OF CAR

NOTE: (a) THE REDUCTION IN WIDTH IS PREDICTED ON THE BASE CAR, DEFINED ON PLATE B, AND ON A 13° CURVE.

BASE CAR { EXTREME WIDTH 10'-8"
TRUCK CENTERS 41'-3"

13° CURVE = 441'-8 3/8" RADIUS.

MAXIMUM SWINGOUT AT CENTER OF CAR WITH 41'-3" TRUCK CENTERS = 5 3/4".

(b) THE MAXIMUM WIDTHS SHOWN ARE BASED ON THE SWINGOUT AT CENTER OF CAR WHICH USUALLY GOVERNS. MAXIMUM ALLOWABLE WIDTH OF CAR, OTHER THAN AT CENTER OF CAR, IS SHOWN ON PLATE D. ON CARS WITH LONG OVERHANGS, THE SWINGOUT AT ENDS OF CAR MUST ALSO BE CHECKED.

FIGURE 4.3. Plate B Specifications as of March 1, 1972 for Rail Car Width vs. Distance Between Truck Centers

and forms should be compatible with carrier needs on external packagings. Only a few concerns relate directly to the waste canisters and essentially none were found that relate directly to the waste form.

Both truck and rail carriers have strong concerns to provide safe transport of TRU wastes. Truckers feel that existing safety precautions are generally adequate and they favor transporting TRU wastes. Rail carriers are concerned about a major accident that could cause extended shut down of a main line. They are inclined to want additional safety precautions (e.g., low speed limits such as 56 km/hr, or extra puncture protection by the external packagings) and they are somewhat unfavorable toward transporting TRU wastes. Trucking equipment is generally designed to be lighter and is structurally more flexible (to meet tighter highway weight restrictions) than the heavy and rigid rail cars. Thus, external packagings must be designed more with the vehicle in mind, and load weights and dimensions are more restricted for trucks than for rail cars.

A characteristic of the packagings and canisters that the carriers prefer for safety reasons is that they be nonflammable. Thus, wooden containers are less desirable than steel containers. No concern was expressed over the flammability of the waste form. Both truck and rail carriers strongly prefer external packagings that have dimensions and tie-down provisions the same as those for standard cargo containers.

Occasionally packagings and vehicles carrying radioactive materials are not properly loaded by shippers. As a result, canisters have migrated within the packaging or vehicle and have even fallen and ruptured. To minimize such problems, carriers prefer canisters that are designed to maximize stackability and stability. In this regard, modular rectangular (and even interlocking) designs are preferable to cylindrical ones because they maximize coterminous canister surface areas and minimize empty space into which canisters can migrate. Canisters that are sized to fill the external packagings as completely as possible would also minimize this problem. Designs with high ratios of width to height would display the greatest stability. Interlocking units might be desirable.

Carriers strongly prefer to transport loads with low center of gravity to improve the stability and safety of the shipments. Thus, they prefer to carry packages that are relatively dense and/or are not stacked high. This would generally imply the use of short canisters filled with dense wastes. The waste forms could be densified by mechanical compaction or by conversion to dense forms such as glasses.

To minimize radiation exposure to the carrier workers and to the public, it is currently the practice in the nuclear transportation industry to load the most radioactive ("warmest") canisters in the center of a vehicle load. Canisters with lower activities are packed around the warmer units to result in lower radiation levels along the perimeter of the vehicle. To pack radioactive materials this way, individual load units should be relatively small, e.g., 55-gallon drums. If large canisters are used, it will not be possible to distribute the load to achieve minimal radiation levels at the vehicle or packaging perimeter. In those cases, loading of wastes into the packages, canisters or intermediate packagings might effect some reductions of external radiation levels.

To minimize turnaround time, packages that can be loaded/unloaded with a variety of techniques and equipment are often preferred. This generally applies to smaller canisters such as 55-gallon drums, which can be handled by a variety of techniques. On the other hand, larger and fewer package units are preferred to save handling time if appropriate handling equipment is available. Another way that was suggested to minimize turnaround time is to have external packagings that could be loaded from the top and the sides.

Carriers, particularly railroads, prefer that external packagings be equipped with special handles or other appurtenances to facilitate retrieval in the event of severe accidents. Handles (preferably recessed) should be located so that crane hooks can easily be attached regardless of the packaging's position.

Truckers strongly prefer packagings that distribute their loads broadly over the length of the trailer. This would allow lighter trailers with greater payloads to be used; it would reduce structural fatigue resulting from load

concentrations; it would improve vehicle roadability and controllability; it would also increase driver comfort and lessen driver fatigue; and it would allow for securing more concentrated loads. Because of these load effects on truck transport, truck carriers recommend that structural analysis of vehicles and packagings be done taking into account both as one unit.

Load distribution could be accomplished by loading a vehicle with two or more smaller packagings rather than one large one. Alternatively, spanners or other structural features could be incorporated into the package design to distribute the load.

Rail carriers attach less importance to load distribution than truckers, primarily because of the higher strength of the rail cars.

Maximum legal truck weight limits among the various states vary from 33,200 kg (73,280 lb) to 62,600 kg (138,271 lb). However, because most states have load limits at the lower range, external packagings should be designed for trucks operating under one of two gross weight limits: 33,200 kg (73,200 lb) and 36,300 kg (80,000 lb). All states may eventually adopt an 36,300 kg or higher weight limit, but this is not certain. This weight typically results in a maximum load of packagings plus waste of about 22,700 kg (50,000 lb).

It would of course be possible to use packagings designed for states with 36,300 kg gross weight limits in states with lower weight limits by only partially loading the package. The heavy package would then reduce the amount of TRU waste which could be legally carried.

Overall truck length limitations are generally 16.75 to 33.5 m (55 to 110 ft). Height limits are 4.1 or 4.3 m (13.5 or 14 ft) in all states. Typical width restriction is 2.44 m (8 ft).

Overweight or oversized truck shipments can be made by obtaining special permits from the states. However, these permits usually require that a load can not be subdivided. In most cases with TRU wastes, less wastes could be placed in a load or smaller packagings could be designed, which implies that an overweight load is considered to be subdivisible. In addition, administrative requirements among the various states for overweight or oversized load permits would suggest that these should not be planned for on a routine basis.

Rail car weight and dimension limits are not legally constrained. But, they are operationally constrained by factors such as side and top clearance restrictions and track-load bearing capability.

If the rail car/TRU waste package unit is designed to meet AAR Plate B dimensional restrictions, clearance problems will be avoided on essentially all rail routes. Loaded rail cars conforming to Plate B specifications by the American Association of Railroads may engage in unrestricted interchange among carriers. Loaded rail cars in excess of these dimensions will move freight more economically only if volume capacity is the load-limiting factor.

Gross weight restrictions on rail car loads vary by rail line. As a general rule, heavy track, well maintained, is permitted to carry the normal 4-axle rail cars and their loads weighing up to 122,200 kg (135 tons) and special, 6-axle rail cars weighing up to 181,000 kg (200 tons). A typical gross load of 95,200 kg (105 tons) would allow a load of packagings plus waste of about 63,500 kg (70 tons). Exceptions can be made for rail car movements just as oversize shipments are permitted for trucks.

Both trucks and rail carriers generally prefer the use of dedicated vehicles (i.e., trailers and rail cars) that are modified specifically to carry the radioactive materials. These vehicles would preferably have additional features (such as special tie downs and suspensions) to improve the safety of transport. Use of such vehicles will be more costly if large volumes of TRU waste are not shipped routinely.

Truckers prefer regularly scheduled pick-up and delivery times (and short turnaround times at the destinations.) They are more effective when this is done. Rail carriers have similar interests but the nature of their normal operation provides less incentive for regular pickup/delivery schedules.

Rail carriers would likely transport TRU wastes within their normal operations, even if dedicated rail cars are used. That involves the normal making up of trains and connecting/disconnecting of pre-loaded or unloaded rail cars at more than one junction along the route. Rail carriers would also prefer to prohibit rail cars with explosive or flammable materials from being on trains carrying TRU wastes. Truckers will carry only TRU wastes in a single load and will typically transport the load directly to the destination without change of trailer, tractor or drivers, and with a minimum number of stops.

5.0 TRANSPORTATION HARDWARE REQUIREMENTS

Transportation hardware in this report includes external packaging, appurtenances for vehicles, and loading/unloading equipment. Requirements for these items are given in the following sections.

5.1 TRANSPORTATION (EXTERIOR) PACKAGING

External packaging requirements differ greatly for the various shipping categories under existing and proposed regulations. Packagings for LSA and Type A shipments usually consist of individual, good quality waste canisters and are disposable. Shipments in these categories typically contain multiple packages and could be shipped in conventional trucks, trailers and rail cars. LLS material under the proposed transportation rules would also be shipped in this manner.

Because of their relatively modest performance requirements, Type A packagings are not expected to significantly impact the waste canister design or present problems for transportation handling hardware. In cases where the waste canister is to serve as the Type A packaging, specific case analyses would be needed.

Because of their relatively high cost and high integrity needs, Type B packagings usually contain multiple waste canisters. These external packagings are usually reusable and are designed for a specific range of canister characteristics. Specifications for existing and proposed packagings to transport Type B and large quantities of TRU wastes are discussed in this section.

Three Type B shipping packagings (containers) exist for transporting TRU wastes or are being developed and are considered in this study: the Super Tiger® packagings, TRUPACT packagings and the ATMX packaging/rail car. Both the Super Tiger® and the ATMX have been used for the shipment of radioactive materials. TRUPACT containers are being developed by the Transportation Technology Center (TTC) at Sandia National Laboratories for the DOE. These packagings are intended to provide containment in the event of impact, puncture and fire accidents.

5.1.1 Super Tiger®

The Super Tiger® packaging has been used in the past for shipping Type B quantities of radioactive materials both by truck and by rail (U.S. Nuclear Regulatory Commission 1977a, U.S. Nuclear Regulatory Commission 1977b)^(a) These radioactive materials are typically contained in Type A drums or boxes. The Super Tiger® has the outside dimensions of one size of a standard cargo container, 2.4 m x 2.4 m x 6.1 m (8 ft x 8 ft x 20 ft), and can be handled, stored and shipped like any standard cargo container. Inner and outer steel shells separated by polyurethane foam were used for containment of radionuclides and for accident resistance respectively. A diagram of the Super Tiger® is given in Figure 5.1.

The outer shell is fabricated from ductile low-carbon-steel plate. This shell is designed to deform severely without rupture in the event of an impact accident. All edges or joints are overlapped and double-seam-welded and reinforced with a layer of steel plate. All external edges are protected with a diagonal gusset plate. One end of the shell is attached by bolts through a channel frame containing a weather-tight seal and is removable for access to the inner shell.

The steel inner shell is approximately 1.9 m x 1.9 m x 4.4 m (6.3 ft x 6.3 ft x 14.3 ft). All edges or joints are overlapped and double-seam-welded like those in the outer shell. A removable end plate provides access for cargo loading. It is attached by bolts and has a silicone rubber seal that serves as a primary containment barrier.

The two steel shells are separated by a 0.25-m-thick, specially-formulated, fire-retardant rigid polyurethane foam which provides thermal insulation and absorption of energy upon impact. The insulation is approximately 0.84 m thick on each end.

The Super Tiger® can accommodate forty-two loose 55-gallon drums, or six 6-pack (2-by-3 array) drum units, or six modular boxes, and has a maximum payload of 13.6 MT (30,000 lbs).

(a) The certificate of compliance for Super Tiger® packaging has lapsed and has not been reissued. This is because cracking of welds and loss of seal integrity has resulted from normal use.

FIGURE 5.1. Super Tiger®

5.1.2 ATMX

Both the Super Tiger® and the TRUPACT are packagings that are designed to be placed on ordinary flatbed trucks or rail cars. The ATMX rail car is different in that the packaging and the rail car are one integral unit (Griffin et al. 1974, Adcock and McCarthy 1978). The ATMX is currently being used to ship CH-TRU wastes from Rocky Flats and Mound Laboratories to Idaho Falls.

The DOE-owned ATMX rail cars have many safety devices, including roller-bearing wheels, shock-absorbing towing gear, interlocking couplers to prevent uncoupling in a derailment, and locking-type center pins to prevent the loss of the trucks (swiveling wheel carriages near each end of the rail car) under most circumstances. The underframe is a heavy one-piece steel casting that is reinforced by welded steel plates making a continuous floor. The sides of the superstructure are constructed of cross-braced steel armor plate that is designed not to buckle during a rollover. The rail cars have inner steel sheeting part-way up the sides. The ends of the car are heavily reinforced and designed with a slope that will tend to deflect missiles such as other cars over the roof of the car should an accident occur. The roof of the car has about 0.13 m (5 in.) of polyurethane foam insulation between its two steel skins. No insulation is in the side or end walls. A small personnel access door is in one end of the car.

There are two types of ATMX rail cars: the ATMX-500 and the ATMX-600. They are similar, except the ATMX-500 has an interior height of 1.91 m (6.25 ft) and the ATMX-600 is 2.79 m (9.17 ft) high. The ATMX-500 is separated into three compartments by fixed bracing with usable length and width for each compartment of 5.11 m (16.8 ft) and 2.82 m (9.29 ft). The ATMX-600 is separated into three variable-sized compartments with a total internal length of 15.24 m (50.0 ft) and a width of 2.84 m (9.33 ft). Both are loaded by removing the three roof sections that are sealed by a gasket during locking with ganged multiple latches. The floors and bay partitions are sheathed with fireproofed plywood. The maximum payload for the ATMX-500 is 40.8 MT (90,000 lbs) and for the ATMX-600 is 45.9 MT (101,300 lbs). Figure 5.2 shows an ATMX-600 rail car.

The ATMX rail cars operate under the provisions of DOE Exemption 5948 (Hazardous Materials Regulations Board 1972), which allows the shipment of

FIGURE 5.2. ATMX-600 Packaging/Rail Car

government CH-TRU wastes in ATMX rail cars provided they are packaged in Type A drums or plywood boxes coated with fiberglass-reinforced polyester that are intended to provide radionuclide containment for normal transport. For the ATMX-600, drums can be prepackaged in 2.4 m x 2.4 m x 6.1 m (8 ft x 8 ft x 20 ft) steel cargo containers. This reduces loading and handling time and provides adequate secureness for the drums; it also provides additional confinement for the cargo. The ATMX-600 rail car can carry 240 loose 55-gallon drums (when packaged in a triangular array with the base of the triangle along the sides of the car) or 140 drums when using cargo containers, 24 Rocky Flats boxes or 32 modular boxes. If 55-gallon drums are assembled into 2 x 3 arrays, the capacity of the ATMX-600 rail car is then reduced to 192 drums without cargo containers and to 96 with cargo containers. The ATMX-500 rail car can carry 228 loose 55-gallon drums (when packed the same as in the ATMX-600 car as described above), 180 when using 2 x 3 arrays, and 90 when using 15 modular boxes. It can carry 12 Rocky Flats boxes.

5.1.3 TRUPACT

Transuranic package transporter (TRUPACT) packagings are being developed at Sandia National Laboratories for both truck and rail Type B shipments (Eakes et al. 1980). As presently conceived, the TRUPACT will have steel inner and outer frameworks made of rectangular tubing. Steel sheets covering the inner and outer surfaces of the inner and outer frameworks are separated by about 0.36 m (14 in.) of rigid polyurethane foam in the rail TRUPACT and 0.3 m (12 in.) in the truck TRUPACT. The foam is about 0.9 m thick on each end. The inner liner is constructed of stainless steel sheets; the outer shell is carbon steel. In the wall between the inner and outer frameworks is a stainless steel plate designed to prevent puncture of the inner liner. Access to the inner cavity is through two hinged closures. The inner closure has one inflatable elastomeric seal and one that is not inflatable to provide a seal after loading. The outer hinged door is also sealed with elastomeric gaskets when bolted shut and acts as an impact limiter and provides puncture and fire protection. Because designs of the TRUPACTs are not complete, some features could change, including dimensions. Discussion in this report is obviously limited to current design concepts.

The larger TRUPACT for rail shipment (there is also a narrower concept is currently proposed to have outside dimensions of 3.0 m x 3.3 m x 7.1 m

FIGURE 5.3. TRUPACT Container Showing Railroad Configuration with Six-Packs

(10.0 ft x 10.9 ft x 23.2 ft), w x h x l (see Figure 5.3) and is designed to contain forty-eight 55-gallon drums or eight 6-packs, eight modular boxes measuring 1.9 m x 1.3 m x 0.94 m (50 in. x 37.5 in. x 75 in.), or eight Rocky Flats FRP boxes. Modular boxes can be used to overpack six 55-gallon drums. The rail TRUPACT is expected to have a maximum payload of 13.6 MT (30,000 lbs). Up to two rail TRUPACT containers can be shipped per flatcar.

The TRUPACT for truck shipments is currently proposed to have outside dimensions of 2.4 m x 2.7 m x 7.5 m (8.0 ft x 9 ft x 24.5 ft) w x h x l and inside dimensions of 1.8 m x 2.1 m x 5.6 m (6.0 ft x 7.0 ft x 18.5 ft) w x l x h. It has been designed to hold thirty-six 55-gallon drums or six 6-packs or six modular boxes and to have a maximum payload of 13 MT (28,000 lb). One TRUPACT can be transported on a truck trailer.

The TRUPACTs for both rail and truck shipment are still under development and are expected to become available for routine use during 1986. Dimensions and some structural details could change before design is completed.

5.2 REVIEW OF ANCILLARIES FOR CARRYING VEHICLES

The Super Tiger® and the TRUPACT packagings can be shipped by highway or by rail. Truck and tractor trailers provide support and have physical restraint devices for the packagings for highway transport. One packaging can be placed on a large truck bed or on a truck trailer. Open flatbed rail cars provide support and have physical restraint devices for rail transport. There are a number of different configurations of rail cars. These cars can carry one to four Super Tigers® or one to three TRUPACTS, depending on the specific car. The railroad will supply a car suitable to carry the load. Packagings can be placed directly on rail cars or conceivably on trucks that can be carried "piggyback" on rail cars.

Cargo containers are equipped with corner fittings as specified by the International Standards Organization (ISO). These fittings facilitate handling a cargo container and securing it to the vehicle on which it is to be transported. Figures 5.4 and 5.5 show these corner fittings and various handling mechanisms associated with them. The fittings also allow for stacking of the cargo containers and are used in cargo ships as shown in Figure 5.6.

A cargo container can be tied down with cables as shown in Figure 5.7A. The flatbed of the rail car or truck can be equipped with ISO connector fittings that mate with the holes in the bottom fittings of the container. These fittings are illustrated in detail in Figure 5.4 and their use is shown in Figure 5.7B. When these fittings are locked into place, the restraining force against load shifting is distributed over considerably more area than can be accomplished with cable tie downs.

The outside dimensions of the Super Tiger® conform to ANSI standards (American National Standards Institute 1971) for those of the most commonly used cargo container. The Super Tiger® corner fittings will thus mate with equipment designed to handle or transport such cargo containers. The proposed TRUPACT containers for both truck and rail use, on the other hand, have outside dimensions that do not meet the 1971 ANSI standards. They were designed to give interior space dimensions into which modular boxes, Rocky Flats boxes, or 2-by-3 arrays of 55-gallon drums could be conveniently placed with efficient use of the space. (Use of the Super Tiger® for these packages results in waste of space and small cargo volumes.) Because of its nonstandard size as presently

FIGURE 5.4. Examples of ANSI Standard Corner Fitting Engaging, Lifting, and Securing Devices (American National Standards Institute 1971)

FIGURE 5.5. Examples of Methods of Lifting Containers by ANSI Standard Corner Fittings (American National Standards Institute 1971)

VIEW "A"
HORIZONTAL RESTRAINT
PROVIDED BY SHIP'S CELL

VIEW "B"

STACKING FITTING

STACKING FITTING PROVIDES
HORIZONTAL AND VERTICAL RESTRAINT

EXAMPLE OF CONTAINER SHIP CROSS SECTION

VIEW "C"

EXAMPLE OF DECK SECURING FITTING WHICH
PROVIDES GATHERING PLUS BOTH HORIZONTAL
AND VERTICAL RESTRAINT

FIGURE 5.6. Examples of Use of ANSI Standard Corner Fittings on Ships (in Vertical Container Cell and on Deck)

A. Example of Use of Cable Tie Downs

B. Example of Use of Corner Fittings in Railway and Truck Applications

FIGURE 5.7. Examples of Tie Downs of Standard Cargo Containers

conceived, the corner fittings of a TRUPACT container will not mate with the usual track or rail equipment. Special equipment or adaptations of existing equipment will have to be used to handle and to secure the TRUPACT containers.

The ATMX rail car is a packaging and rail car in one integral unit. The description of the carrying vehicle and its ancillaries was given in Section 5.1.

5.3 REVIEW OF LOADING/UNLOADING EQUIPMENT AND PROCEDURES

This section gives a brief review of the equipment and procedures used for loading and unloading the waste packages onto and off of the transportation vehicles.

5.3.1 Loading/Unloading the Super Tiger®

The Super Tiger® is moved to a loading dock by flatbed trucks or trailers. In contrast to a standard cargo container, the internal shell of the Super Tiger® cannot carry the weight distribution of the usual forklift truck. Typically drums or crates are delivered to the open end of the Super Tiger® and moved to the closed end by hand, sometimes assisted by the use of rollers placed on the floor.

Drums can be loaded into the Super Tiger® in two layers. Six 55-gallon drums are moved to the closed end and placed three abreast, two deep. A 1.22-m (4 ft) wide sheet of 1.9-cm (3/4-in.) plywood is placed on top of them. The next six drums are moved to the end and hoisted to the top layer by means of a hand-operated jack or maneuvered up an inclined plane by hand and are oriented over the bottom layer of drums. This procedure is continued until the Super Tiger® is loaded with 42 drums.

When drums are assembled in a 2-by-3 array, the six-pack, the additional supports needed to form an integral unit cause the array to fit very snugly when placed three deep, and two layers high in the Super Tiger®. Hence, six of the six-packs can be placed in a Super Tiger®. The modular box that is being developed poses the same tight clearance problems, but six modular boxes can be placed in the Super Tiger® at one time.

As with the loading of any other cargo, material placed in the Super Tiger® must be secured against shifting in transit by means of wood blocking, inflatable separators, or other means.

5.3.2 Loading/Unloading the ATMX Rail Car

Loose drums, boxes and crates are loaded directly into the 500 series ATMX rail car (after removing the roof sections and lining the floor with fireproof plywood) using normal warehouse handling equipment such as crane hooks and rigging, with one or more workers in the car. They are secured into position using wood blocking or inflatable separators to keep them from shifting in transit. Heavy or unusually shaped items are secured by using chains or cables attached to fittings that are welded to the car frame. If two layers are to be loaded, the bottom layer is covered with 1.9-cm (3/4-in.) fireproof plywood to form a level loading platform for the upper layer. Each layer of drums is banded together with steel banding to form a single "floating load."

When the movable bulkheads of the ATMX-600 rail car are placed in the center of the car, the two bays thus formed can each receive a standard cargo container of outside dimensions 2.44 x 2.44 m x 6.10 m (8 ft x 8 ft x 20 ft). Standard ISO corner securing fittings are welded onto floor mounts in the ATMX-600 rail car and can be used to provide restraint for the load. Additional fore and aft restraint is provided by 5.08-by-10.16 cm (2-by-4 in.) steel studs that engage the container corner fittings, or by conventional blocking. The use of standard cargo containers reduces the useful shipping volume as given in Section 5.1.2 but can potentially reduce overall transportation costs by the increased rail car utilization as a result of rapid turnaround time.

DOT Special Permit 5948 (Hazardous Materials Regulations Board 1972) allows the loading of cargo directly into the ATMX-600 rail car after reinforcement modifications are made to the car. This is commonly done to ship Rocky Flats boxes but is not commonly done to ship drums because of the labor needed to load and block individual drums and the long turnaround time required. This method could be used under special circumstances, such as the unavailability of cargo containers or the need to ship specially-sized crates.

Flatbed trucks or trailers are used to move cargo containers to a dock for loading cargo and then to move the loaded cargo container to a rail siding.

Large forklift trucks exist that can move an empty or loaded cargo container, and small forklift trucks can be driven into the cargo container to facilitate loading or unloading the cargo. The loaded cargo containers are lifted by a spreader frame engaging the four top corner fittings of the cargo container. (See Figure 5.5.) When lifted by a crane, the spreader frame applies a vertical lift to each of the top corners of the cargo container.

Cargo is loaded into the cargo containers in accordance with Association of American Railroads (AAR) and National Cargo Bureau recommendations for securing the load and sealing the door on the end. As a further precaution against loss of contents during an accident, cargo containers are always loaded into the ATMX car with their door ends toward the center of the rail car.

5.3.3 Loading/Unloading the TRUPACT

The internal shell of the proposed TRUPACT, like that of the Super Tiger®, is not able to hold the concentrated weight of the usual forklift truck. However, as conceived, the TRUPACT will have its own built-in mechanism to convey packages to the end of the container. Individual drums may be loaded into a TRUPACT with the design option of a built-in pallet. Drums can be assembled into six-packs or placed into modular boxes to form integral units of six drums. These integral units may be loaded with the built-in pallets in the one design option or on a pair of retractable roller conveyors built into the TRUPACT floor in the other design option. Modular boxes used as the primary canister are also planned to be carried by the TRUPACT. Unusual shapes or sizes of canisters can be placed on and secured to a pallet for loading and transport. Restraint of packages within the TRUPACT is expected to be done by conventional blocking.

5.4 INTERPRETATION OF THE TRANSPORTATION HARDWARE REQUIREMENTS AS APPLIED TO TRU WASTE FORMS AND CANISTERS

The potential impacts of transportation hardware as applied to TRU waste forms and canisters are primarily related to the external packagings, to the density of the waste forms, and to the shape and size of the canisters. These possible impacts relate to the payload weight limit of the packagings, weight distribution within some packagings, the height of the packagings, the containment provided by some packagings, and capability to handle off-sized packages.

The payload weight limit could be exceeded if external packagings were loaded fully with canisters having waste forms of high specific gravity. The effects on any of the external packagings of not exceeding the payload weight limit may be the incomplete use of all the volume available in these packagings.

Table 5.1 lists some possible waste canisters and physical data known or calculated for these waste canisters. The specific gravity of the canisters' contents was chosen to represent a range of waste forms. The final column in Table 5.1 relates to weight limits for filled canisters to be handled manually without lifting.

Table 5.2 shows the maximum number of each type of canister or overpack described in Table 5.1 that can be carried in each of the existing or planned external packagings. The maximum numbers are determined for the payload weight limits and for available space limits. No allowance has been made for the weight of materials used to block and secure the loads. Numbers are underlined to highlight which canisters and waste forms are limited by weight rather than by space.

Generally, the most efficient use of internal space for all the external packagings is accomplished when they are loaded with individual drums or cylinders. This is almost the only existing method of filling the Super Tiger® because its restriction on concentrated floor loads does not permit the use of devices to handle large packages. Because of this limitation and because there are few mechanical devices that can be used to place smaller-sized cargo in the Super Tiger®, waste canisters are limited in weight to those that can be handled manually. According to Vern Apple, U.S. Ecology Incorporated, this weight is about 180 kg (400 lb) if the canisters are not to be lifted and about 45 kg (100 lb) if they are to be lifted. Because of the tailored dimensions of the TRUPACT to those of the modular box, the TRUPACT is relatively efficient in space utilization when loaded with modular boxes or six-packs.

Conveyor systems are planned to load six-packs of 55-gallon drums or modular boxes (within which the waste may be placed in smaller canisters) into the TRUPACT. It is assumed here that the weight of waste forms and canisters to be carried by the TRUPACT is taken into consideration in the design of the conveyor systems. The conveyor option for the TRUPACT is not planned to handle

TABLE 5.1. Characteristics of Potential Canisters

Name	Canister Dimensions (a) mm (in.)	90% of Net Volume L	Tare Weight kg (b)	Net weight of contents when 90% full at specific gravity given kg				Waste form sp. gr. at 180 kg total weight (c)
				0.5	1.2	1.8	3.0	
30-gal. drum	482.6d x 736.6 (19d x 29)	102	20	51.1	122.6	184	306.6	1.6
55-gal. drum	609.6d x 889.0 } Out (24d x 35) 571.5d x 844.6 } In (22.5d x 33.25)	187	31	93.5	224.4	336.6	561	0.8
83-gal. drum	660.4d x 1092.2 (26d x 43)	283	40	141.5	399.6	509.4	849	0.5
6-pack of 55-gal. drums	1876.6 x 1251 x 901.7 (73.9 x 49.25 x 35.5)	1122	276	561	1346	2020	3366	N.Ap.
Modular box with 6 55-gal. drums	1879.6 x 1270 x 952.5 (74 x 50 x 37.5) 1.9 (0.075) thick	1122	377	561	1346	2020	3366	N.Ap.
Modular box without drums	1879.6 x 1270 x 952.5 (74 x 50 x 37.5) 1.9 (0.075) thick	2028	191	1014	2434	3650	6084	N.Ap.
Rocky Flats Box	2133.6 x 121.9 x 132.0 } Out (84 x 48 x 52) 2095.5 x 118.1 x 120.6 } In (82.5 x 46.5 x 47.5)	2688	272	1344	3226	4838	8064	N.Ap.
Steel Cylinder	508d x 304.8 x 6.4 (20d x 12 x 0.25)	51	44	25.5	61.2	91.8	153	2.67
Steel Cylinder	1016d x 304.8 x 6.4 (40d x 12 x 0.25)	208	128	104	249.6	374.4	624	0.25
Steel Cylinder	1016d x 1524 x 12.7 (40 x 60 x 0.50)	1040	638	520	1248	1872	3120	N.Ap.
Steel Cylinder	304.8d x 1828.8 x 6.4 (12 x 72 x 0.25)	110	93	55	132	198	330	0.79
Steel Cylinder	609.6 x 1828.8 x 12.7 (24 x 72 x 0.50)	435	420	217.5	522	783	1305	N.Ap.

(a) d is the diameter of a cylindrical package, the second number is the height and, where given, the third number is the thickness. Where no d is given, the package is rectangular and the dimensions are for length x width x height.

(b) Tare weight for drums is the weight of the metal drum plus the weight of 2 polyethylene bags. The weight of a rigid plastic liner is not included.

Tare weight for six-pack is the weight of six 55-gallon drums as above plus the framing for the six-pack.

Tare weight for the modular box with six 55-gallon drums is the weight of six 55-gallon drums as above plus the weight of an empty modular box.

(c) 180 kg is the maximum weight that can be readily manhandled. N. Ap. = Not Applicable; the canister alone weighs more than 180 kg. These canisters could not be manhandled.

TABLE 5.2. Maximum Number of Canisters in External Packagings^(c)

Canister Name	(Super Tiger*)					(TRUPACT-Truck)					(TRUPACT-Rail)					(ATMX-500)					(ATMX-600)					(ATMX-600)				
	for payload weight of 13,600 kg at sp. gr. given				for space limits (a)	for payload weight of 13,000 kg at sp. gr. given				for space limits (a)	for payload weight of 13,600 kg at sp. gr. given				for space limits (a)	for payload weight of 40,824 kg at sp. gr. given				for space limits (a)	for payload weight of 41,656 kg ^(b) at sp. gr. given				for space limits (a)	for payload weight of 45,950 kg at sp. gr. given				for space limits (a)
	0.5	1.2	1.8	3.0		0.5	1.2	1.8	3.0		0.5	1.2	1.8	3.0		0.5	1.2	1.8	3.0		0.5	1.2	1.8	3.0		0.5	1.2	1.8	3.0	
30-gal. drum	191	95	66	41	68 ⁽²⁾	183	91	63	40	78 ⁽²⁾	191	95	66	41	100 ⁽²⁾	574	286	200	125	360 ⁽²⁾	586	292	204	127	348 ⁽³⁾	646	320	225	140	372 ⁽²⁾
55-gal. drum	109	53	37	23	42 ⁽²⁾	104	51	35	22	52 ⁽²⁾	109	53	37	23	64 ⁽²⁾	328	160	111	69	228 ⁽²⁾	335	163	113	70	144 ⁽²⁾	365	180	125	77	240 ⁽²⁾
83-gal. drum	75	31	24	15	18 ⁽¹⁾	72	29	23	14	24 ⁽¹⁾	75	31	24	15	48 ⁽²⁾	225	93	74	46	84 ⁽¹⁾	229	95	76	47	120 ⁽²⁾	253	104	83	51	184 ⁽²⁾
6-pack of 55-gal. drums	16	8	6	3	6 ⁽²⁾	15	8	5	3	6 ⁽²⁾	16	8	6	3	8 ⁽²⁾	48	25	17	11	30 ⁽²⁾	50	25	18	11	16 ⁽²⁾	55	28	20	12	32 ⁽²⁾
Modular box with 6 55-gal. drums	16	8	6	3	6 ⁽²⁾	15	8	5	3	6 ⁽²⁾	16	8	6	3	8 ⁽²⁾	48	25	17	11	15 ⁽¹⁾	44	24	17	11	16 ⁽²⁾	49	26	19	12	32 ⁽²⁾
Modular box without drums	11	5	3	2	6 ⁽²⁾	10	5	3	2	6 ⁽²⁾	11	5	3	2	8 ⁽²⁾	34	15	10	6	15 ⁽¹⁾	34	16	11	6	16 ⁽²⁾	38	17	12	7	32 ⁽²⁾
Rocky Flats Box	9	4	3	2	2 ⁽¹⁾	9	4	3	1	2 ⁽¹⁾	9	4	3	2	8 ⁽²⁾	28	13	9	5	12 ⁽¹⁾	28	13	9	5	8 ⁽¹⁾	31	14	10	6	24 ⁽²⁾
Steel Cylinder	195	129	100	69	150 ⁽⁵⁾	187	123	95	66	180 ⁽⁵⁾	195	129	100	69	288 ⁽⁶⁾	587	388	300	207	648 ⁽⁴⁾	600	396	307	211	660 ⁽⁶⁾	663	436	338	233	870 ⁽⁵⁾
Steel Cylinder	58	36	27	18	35 ⁽⁵⁾	56	34	26	17	40 ⁽⁵⁾	58	36	27	18	60 ⁽⁶⁾	176	108	81	54	144 ⁽⁴⁾	179	110	83	55	120 ⁽⁶⁾	196	121	91	61	210 ⁽⁵⁾
Steel Cylinder	11	7	5	3	7 ⁽¹⁾	11	7	5	3	8 ⁽¹⁾	11	7	5	3	10 ⁽¹⁾	35	21	16	11	36 ⁽¹⁾	36	22	16	11	20 ⁽¹⁾	39	24	18	12	42 ⁽¹⁾
Steel Cylinder	92	60	46	32	95 ⁽¹⁾	88	57	44	30	108 ⁽¹⁾	92	60	46	32	133 ⁽¹⁾	276	181	140	96	486 ⁽¹⁾	281	185	143	98	308 ⁽¹⁾	310	204	158	108	490 ⁽¹⁾
Steel Cylinder	21	14	11	8	21 ⁽¹⁾	20	14	11	7	26 ⁽¹⁾	21	14	11	8	32 ⁽¹⁾	64	43	34	23	114 ⁽¹⁾	65	44	34	24	72 ⁽¹⁾	72	48	38	26	120 ⁽¹⁾

(a) Number in parentheses indicates number of layers counted. Maximum numbers were calculated using rectangular, longitudinal triangular or transverse triangular pack, whichever gave the largest number.

(b) Tare weight of 4264 kg for two cargo containers subtracted from payload weight for ATMX-600.

(c) The load limitation is by volume except where underlined by dashes.

"small" canisters such as 55-gallon drums on an individual basis. These canisters are expected to be combined into six-packs before loading. The built-in pallet option would accommodate loading of individual drums.

The systems used for loading/unloading the canisters of wastes can have a significant effect on the radiation exposure to the workers during these operations. The time and manpower required for the operations and the nearness of the workers to the canisters will directly affect the occupational exposure. Thus, manual loading/unloading will likely cause higher exposures and may limit the maximum allowable surface radiation levels from the drums.

The maximum heights of canisters are limited by the internal height dimension of the external packagings. For the Super Tiger® the internal height is 1.9 m, for the planned TRUPACT for truck transportation 2.0 m, for the planned TRUPACT for rail transportation 2.3 m, for the ATMX-500 1.9 m, for the ATMX-600 with cargo containers 2.3 m, and for the ATMX-600 loaded directly 2.8 m. All of these values are less than the height of 3.0 to 4.6 m that is sometimes considered for a waste repository. Modular boxes or Rocky Flats boxes can be used to contain smaller canisters. Their internal height dimensions are 0.9 m and 1.4 m respectively. Taller canisters might be usable if they were stacked horizontally but this concept would have to be evaluated for each canister design.

The ATMX rail cars can have fittings welded to the car frame for attaching chains or cables for restraint of cargo. This makes the ATMX rail cars convenient for securing heavy or unusually shaped packages. The other external packagings can accommodate off-sized packages, but may be somewhat limited by their smaller cavities, by the lack of hardware for convenient use of cargo restraints, or, for the Super Tiger®, by the limitation on weight distribution. The Super Tiger® is no longer qualified as a Type B packaging, and the ATMX-500 and -600, have not been qualified to provide containment in the event of an accident. The packages placed in the ATMX cars are expected to provide containment for normal transport conditions. Cargo containers used in the ATMX-600 rail car do not provide this required containment in the event of an accident. Their only purpose is to facilitate handling.

None of the canisters listed in Table 5.1 provides a significant amount of shielding. Any waste that requires shielding for transportation purposes will

require that it be provided internal or external to the canister. Such shielding would tend to add weight and reduce usable volume for waste, and if it is reused, add extra handling and return shipping activities and costs.

6.0 SUMMARY AND POTENTIAL IMPACTS OF TRANSPORTATION REQUIREMENTS

This section summarizes the characteristics of the existing CH-TRU defense wastes and canisters, the regulations, carrier needs, and the transportation hardware as related to transportation of these wastes. It also summarizes the potential impacts of these transportation aspects on the potential forms and canisters for the CH-TRU defense wastes.

6.1 SUMMARY OF WASTES AND CANISTERS/CONTAINERS

Transuranic wastes consist of a myriad of conventional materials that are contaminated with transuranic radionuclides. Materials that comprise these wastes are metal and glass scrap, paper and rags, sludge and filters from filtration operations, solidified oils, concrete and asphalt, plastics and rubber, and many others to a lesser extent. The transuranic nuclides in the wastes are primarily plutonium isotopes and their decay products in wastes from processing of weapons materials. Smaller amounts of wastes arise from process of heat-source plutonium (with a high fraction of ^{238}Pu) and thorium-uranium-233 materials. A smaller amount of wastes contains ^{244}Cm from processing of curium heat-source material.

Wastes can be converted to more durable solid forms to immobilize the radionuclides during transportation and final storage/disposal. The major forms that are considered for incorporation of wastes are:

- glassy slag
- glasses
- ceramics
- sintered ashes or calcines
- waste particles within metal matrices
- asphalt and plastics
- cement
- salt cake.

The original waste can comprise 10 to 100 wt% of one of these final waste forms, with most in the range of 30 to 60% (see Table 2.4). The volume of the final waste form is typically 15 to 120% of the original waste volume. The average plutonium content in the waste currently stored is 6.7 g/m^3 but can vary by a factor of +8 to -1,000. The most common canisters to date for defense TRU wastes are plastic-lined 55-gallon steel drums and fiberglass-reinforced plywood boxes. The remaining 7 to 10% of the existing retrievable waste volume is stored in a myriad of other canisters. Canisters given the most consideration for wastes in the immobilized forms are steel drums and more rigid cylindrical steel vessels ranging from 30 to 102 cm (12 to 40 in.) in diameter and 90 to 305 cm (36 to 120 in.) long.

6.2 SUMMARY OF REGULATIONS, CARRIER REQUIREMENTS AND TRANSPORTATION HARDWARE

This section presents a summary of the pertinent regulations, carrier requirements, and transportation hardware requirements relating to transport of defense CH-TRU wastes. Implicit in the summary is that transportation of the wastes would be according to practices and regulations for commercial operations. It should be recognized that deviations from these factors could be authorized for handling defense wastes.

6.2.1 Regulations and Licensing Summary

Radioactive material packages in transportation are regulated by the U.S. Nuclear Regulatory Commission (NRC) and the U.S. Department of Transportation (DOT) to protect the safety of the public and the transportation worker. Rules by these agencies cover the design, manufacture, testing and operation of transportation packaging. Packaging requirements are dependent on the hazard and quantity of radioactive materials to be transported. Hazards are differentiated based on the radionuclides present and on the chemical and physical forms of the materials.

Current regulations allow for transportation of radioactive materials in five categories. These categories, in order of increasing package integrity needs are: Low Specific Activity (LSA), Type A, Type A Special Form, Type B, and Large Quantity. Table 6.1 summarizes requirements of these categories. LSA

TABLE 6.1. Package Performance Requirements for Transportation

Requirement for Package Category

Requirement	LSA	Type A	Type A Special Form	Type B	Large Quantity
Primary Requirement	Strong, tight container	Prevent loss of radioactive material in normal transport	Containment under accident conditions	Containment under accident conditions	Containment under accident conditions
Maximum TRU Contents	1E-7 Ci/g	0.001 Ci	20 Ci	20 Ci	No limit
Containment Needs	By outer package	Outer package meets tests below	Outer package meets Type A tests. Inner capsule or waste form meet tests below	Outer package meets tests below	Outer package meets tests below. For >20 Ci Pu, inner package also meets tests below.
Performance tests					
Heat	None	54°C	54°C	54°C	54°C
Cold	None	-40°C	-40°C	-40°C	-40°C
Vibration	None	Normal transport	Normal transport	Normal transport	Normal transport
Pressure	None	0.5 atm	0.5 atm	0.5 atm	0.5 atm
Compression	None	5 times package weight	None	None	None
Impact	None	1.2 m drop	9.1 m drop	9.1 m drop	9.1 m drop
Puncture	None	5.9 kg, 3.2 cm diam/rod dropped 1 m	1.4 kg, 2.5 cm diam/rod dropped 1 m	1 m pkg drop onto 15 cm dia. pin	1 m pkg drop onto 15 cm dia. pin
Fire	None	None	802°C in air for 10 min.	802°C fire for 30 min.	802°C fire for 30 min.
Water	None	Water spray	None	8-hr immersion under 1 m water	8-hr immersion under 1 m water

materials must be shipped in "strong, tight" packages. Type A packages must retain their contents under normal conditions of transport and must demonstrate this capability by passing specific performance tests. Additional and more stringent tests are required for Type A Special Form materials but credit may be taken for the waste form if it contributes to the integrity of the package. Type B and Large Quantity shipments must contain their contents under hypothetical transportation accident conditions. The regulations specify performance tests including impact, puncture, fire and water immersion in a specified sequence. In addition, fissile material shipments in excess of 350 g must be evaluated for prevention of nuclear criticality. Plutonium shipments in excess of 20 Ci must maintain two containment barriers following these tests.

Packages for Type B and Large Quantity shipment categories are the most complex and expensive denoted by the regulations. These packages must pass the most stringent criteria, and documentation is required on the design, manufacture and operation of each package.

General design criteria apply to all radioactive material packages. These include definition of requirements for lifting fixtures, vehicle tie downs, surface dose rates, heat generation rates, and surface contamination levels.

Extensive revisions to existing regulations are proposed by both the NRC and DOT. Proposed changes to the packaging regulations would revise the allowable package types and the radionuclide quantities per package; they would delete the Large Quantity category, divide Type B into two categories and add a new shipment category: Low Level Solids (LLS). The resulting six shipment categories under the new regulations in increasing order of integrity needs are: LSA, LLS, Type A, Type A Special Form, Type B (M) and Type B (U).

Package requirements for each category under the proposed regulations are shown in Table 6.2. In the LSA category, "strong, tight" packaging would be eliminated and replaced by the stronger Type A packaging. The LLS category is similar to the LSA category except higher radionuclide concentrations are allowed in exchange for restriction on solubility and dispersibility of the waste materials. Type A and Type A Special Form packaging are similar to existing concepts. The Type B (M) package would require licensing in all

TABLE 6.2. Proposed Packaging Requirements

Requirement	Requirements for Package Category					
	LSA	LLS	Type A	Type A Special Form	Type B (M)	Type B (U)
Primary Requirement	Prevent loss of radioactive material in normal transport	Prevent loss of radioactive material in normal transport	Prevent Loss radioactive material in normal transport	Containment under accident conditions	Containment under accident conditions	Containment under accident conditions
Maximum Contents ^(a)	$<1\text{E-}4\text{ A}_2/\text{g}$	$<2\text{E-}3\text{ A}_2/\text{g}$	A_2	A_1	No limit	No limit
Containment Needs	Dilute form, outer package	Monolithic form, outer package	Type A outer package	Outer package meets Type A Tests. Inner capsule or waste form meet tests for accident conditions	Outer package meets accident tests	Outer package meets accident tests
Test Standards	Type A ^(b,c)	Type A ^(b,c)	Type A ^(b)	Capsule or waste form meet SF tests, outer package	Type B ^(b,d)	Type B ^(b,e)

(a) "A" values depend on individual isotopes in the shipment.

(b) See Table 6.1 for requirements.

(c) Exempt from heat and cold requirements for Type A.

(d) Specific requirements are negotiable in this category.

(e) Double containment is required for TRU shipments in excess of 20 Ci.

countries of intended use. National licensing officials would be allowed to exchange a relaxation of design standards for as-yet undefined operational restrictions. Type B (U) package requirements are similar to those for existing Type B and would be allowed within most countries without additional approvals.

6.2.2 Carrier Requirements Summary

Both truck and rail carriers may transport TRU wastes but their methods of operation will probably differ greatly because of inherent differences in the transportation technologies and historical operating practices employed.

Both truck and rail carriers have strong concerns to provide safe transport of TRU wastes. Truckers feel that existing safety precautions are generally adequate and they are favorable toward transporting TRU wastes. Rail carriers are concerned that a major accident could release radioactive materials and shut down a main line. Thus, they are inclined to want additional safety precautions (e.g., low speed limits or extra puncture protection by the external packagings) and they are somewhat unfavorable toward transporting TRU wastes. Trucking equipment is generally designed to be lighter and is structurally more flexible (to meet tighter highway weight restrictions) than the heavy and rigid rail cars.

6.2.2.1 Trucking Operations

Truckers will carry only TRU wastes in a single load and will typically transport the load directly to the destination without change of trailer, tractor or drivers, and with a minimum number of stops.

Because significant quantities of TRU wastes have accumulated at a limited number of installations, it should be possible to use a dedicated fleet of trucks to move TRU wastes. This will permit these trucks to be specially equipped to accommodate TRU waste packages. Dedicated trucking operations can be as economical or even more economical than conventional trucking operations if quick turnaround times are achieved at terminals. On the average, a truck in tightly coordinated dedicated service will move 29,000 to 32,000 km (18,000 to 20,000 mi) in a month. Truck drivers moving TRU wastes will likely be specially trained in nuclear material transportation and will be with the vehicle load at all times during transport. There may be two drivers on a tractor-trailer unit.

For the external packaging configurations most frequently discussed, truckers will probably use a flatbed trailer to move the TRU waste packages. Trailers may be reinforced or specially designed for carrying concentrated loads or include special cushioning.

At the loading/unloading terminals, the drivers may drop off one trailer and pick up another for the return haul, or they may wait for the trailer they are pulling to be loaded/unloaded. Other operational variations are possible. In any case, it is important to the truckers for operating efficiency and cost to minimize turnaround times at the terminals. This involves having handling equipment at the terminals that is compatible with the loads.

Maximum legal truck weight limits vary among the states from 33,200 kg (73,280 lb) to 62,600 kg (138,271 lb). However, most states have load limits at the lower end of the range. The likely gross load limit that will permit relatively free truck movement is 33,200 kg (73,280 lb) to 36,300 kg (80,000 lb).

Overall truck length limitations are generally 16.75 to 33.5 m (55 to 110 ft). Height limits are 4.1 or 4.3 m (13.5 or 14 ft) in all states. Typical width restriction is 2.44 m (8 ft).

Overweight or oversized truck shipments can be made by obtaining special permits from the states. However, these permits usually require that a load cannot be subdivided. In most cases with TRU wastes, less waste can be carried in a packaging or smaller packagings could be designed, which implies that an overweight load is considered to be subdivisible. In addition, administrative requirements among the various states for overweight or oversized load permits would suggest that these should not be planned for on a routine basis.

6.2.2.2 Rail Operations

Rail carriers would likely transport TRU wastes within their normal operations, even if dedicated rail cars are used. That involves the normal making up and connecting/disconnecting of pre-loaded or unloaded rail cars at more than

one junction along the route with one or more days at each junction. Thus, rail carriers generally have only small concerns about short turnaround times at terminals. Conventional rail operations will generally result in less than 2,400 km (1,500 mi) of service per rail car per month. Conventional rail service results in individual rail cars receiving relatively little attention unless there is an obvious component failure. Accordingly, a rail car carrying TRU wastes will probably receive little more than occasional superficial inspection enroute. Because rail cars carrying TRU wastes will likely be on the same trains with those carrying other materials, rail carriers prefer to prohibit rail cars with explosive or flammable materials from being on trains carrying TRU wastes.

The rail cars used to carry TRU waste packages will probably be flatcars, or possibly specially equipped box-cars. Based on the precedent set by the ATMX rail car and other rail cars carrying hazardous materials, the TRU waste cars will probably be equipped with couplers that impede uncoupling in the event of an accident and cushioned underframes that absorb longitudinal stresses.

Rail car weight and dimension limits are not legally constrained, but they are operationally constrained by factors such as side and top clearance restrictions and track load bearing capability. If the rail car/TRU waste package unit is designed to meet AAR Plate B dimensional restrictions, clearance problems will be avoided on essentially all rail routes. Loaded rail cars conforming to Plate B specifications may engage in unrestricted interchange among carriers. Loaded rail cars in excess of these dimensions will move freight more economically only if volume capacity is the load-limiting factor.

Gross weight restrictions on rail car loads vary by rail line. As a general rule, heavy track, well maintained, is permitted to carry the normal 4-axle rail cars weighing up to 122,000 kg (135 tons) and special 6-axle rail cars weighing up to 181,000 kg (200 tons). Exceptions can be made for rail car movements just as oversize shipments are permitted for trucks.

Rail carriers may decide to impose some operating restrictions on trains carrying TRU wastes. Possible restrictions include: 1) speed limits of 56 km/hr (35 mi/hr) or less, 2) minimal separation distances between cars carrying TRU

wastes and cars carrying other hazardous materials, and 3) possibly, the total exclusion of cars carrying certain other hazardous material from trains carrying TRU wastes.

6.2.3 Transportation Hardware Summary

Transportation hardware includes external packaging, vehicle appurtenances, and loading/unloading equipment.

Packaging needs for LSA Category shipments can be met by modest quality waste canisters that are typically disposable. Packagings for Type A shipments (and the proposed LLS Category) require additional integrity, and can be met with good quality canisters with good sealing. Conventional trucks, trailers and railcars can be used for these shipments without overpacks.

Reusable external packagings are intended to provide protection and containment for waste canisters in the event of accidents for Type B category shipments, so that waste canisters can have less stringent design criteria. Two external packagings exist that have been used for shipping of CH-TRU wastes: the Super Tiger® and the ATMX packaging/rail car. A new external packaging, the TRUPACT, is being designed and is expected to be available for use about 1986.

The Super Tiger® can be carried by conventional truck-trailers or rail cars. Two of these packagings can be carried on some large trailers and up to four can be carried on some rail cars. The Super Tiger® has steel inner and outer walls with thermal insulation between. It has been certified in the past to provide containment in the event of impact/fire accidents, although its license with this certification has expired and has not been renewed. The outside dimensions of Super Tiger® (2.4 m x 2.4 m x 5.1 m long, or 8 ft x 8 ft x 20 ft) are the same as a standard-sized cargo container and includes fittings for use with standard hold-down devices on rail cars and trucks. It is loaded through a door with air-tight seals on one end. The floor of the Super Tiger® cannot withstand concentrated loads, which precludes the use of fork lift trucks and most loading devices. Thus, it is normally loaded by hand. Canister sizes and weights are restricted to those that can be handled manually (e.g., 55-gallon drums).

The loading/unloading system used will affect the occupational radiation dose, based on the proximity of the workers to the waste canisters and the time

required for handling the wastes. Systems that require manual handling will result in more occupational radiation exposure and could limit the allowable dose rate from the canisters.

The DOE-owned ATMX rail car is an external packaging that is integral with a heavy-duty rail car. The ATMX is an enclosed steel car that has a partial inner wall and some thermal insulation in the roof. The ATMX has not been certified to provide containment in the event of accidents, but is being used to transport wastes (in which containment must be provided by or within the canister in normal transport) under a DOT special permit. The ATMX-500 has outside dimensions of 3.1 m x 2.1 m high x 18.3 m long (10.3 ft x 7 ft x 60 ft), and the taller ATMX-600 is 3.05 m high (10 ft). The taller ATMX-600 can accept two standard cargo containers. Each is loaded using hoists or cranes through large openings after removal of the three roof sections. The ATMX-500 has three fixed compartments about 5.11 m long (16.8 ft); the ATMX-600 can have three compartments or two larger ones by manipulating the movable separating walls. When there is no rail track at the waste loading station, the waste packages are loaded onto a truck and shuttled onsite to a rail loading station where the packages can be transferred into the ATMX rail car.

The proposed TRUPACT packaging is planned to have steel inner and outer walls separated by insulation. The inner wall is planned to provide single containment in the event of an accident. The TRUPACT proposed for use on trucks has outside dimensions of 2.4 m x 2.7 m x 7.5 m (8.0 ft x 9 ft x 24.5 ft), w x h x l. The larger-sized proposed rail TRUPACT has outside dimensions 3.0 m x 3.3 m x 7.1 m (10.0 ft x 10.9 ft x 23.2 ft), w x h x l. One TRUPACT can be carried on a truck trailer and up to two can be carried on rail cars. The proposed TRUPACTs do not have dimensions coinciding with those of standard cargo containers, so a different system for packaging hold-down will be required. The TRUPACT is planned to be loaded through the double-sealed door on one end by using a self-contained conveyor system or a built-in movable pallet. The loading system is being designed to handle individual canisters when the pallet option is incorporated. It is planned to handle bulk waste containers or six

55-gallon drums within a proposed new modular steel box (which should also provide Type A containment) or six 55-gallon drums bound together in a six-pack using either the pallet or conveyor system. The proposed TRUPACT will not be able to accommodate concentrated weight loads such as are incurred when using a conventional fork lift.

6.3 IMPACTS OF TRANSPORTATION REQUIREMENTS ON DEFENSE CH-TRU WASTE FORMS AND CANISTERS

The regulations, carrier requirements and transportation hardware all can affect the TRU waste forms and canisters in some ways. The waste canisters must be compatible with transportation hardware and must provide containment under normal transport conditions. The summary of specific impacts is given in this section.

6.3.1 Regulations and Licensing Impacts

Transportation regulations impact the design of TRU waste canisters and waste forms if their characteristics are used to meet transportation requirements. In general, the more stringent the requirement for the waste canister in transportation, the less additional packaging must be provided. Thus, it is advantageous, if acceptable to licensing authorities, to take credit for waste characteristics and to modify designs for waste canisters to optimize packaging for transportation and disposal.

Available information on TRU wastes was used to determine which transportation categories may be applicable to specific waste canisters and to untreated and treated or repackaged wastes. Results of this analysis are summarized in Table 6.3. Shipments of TRU wastes in the LSA and Type A Normal Form categories would not be allowed under existing regulations. Currently-used waste canisters (e.g., 55-gallon drums) are believed to meet applicable shipping requirements but the TRU contents in the wastes exceed radionuclide limits for these categories.

Type A Special Form requirements will require two waste packages. The inner container must pass accident-related tests similar to those for Type B packages. The outer package must meet Type A normal form requirements. This means untreated wastes could require up to two additional packages over

TABLE 6.3. TRU Waste-Canister Compliance with Existing Regulatory Classifications

	Compliance of TRU Wastes with Shipping Category Criteria				
	LSA	Type A	Type A Special Form	Type B	Large Quantity
Untreated Wastes Canisters Meet Requirements	Yes	Yes	No	No	No
Contents Below Limits	No	No	Yes	Yes	Yes
Treated Wastes Canisters Meet Requirements	Possible	Possible	Possible	Possible	Possible
Contents Below Limits	No	Small Packages Only	Yes	Yes	Yes

existing canisters. Canisters for treated wastes could be designed to take the place of high integrity inner packaging. It is believed that this category would generally not be advantageous over Type B packages for untreated wastes. For treated wastes, specific-case analyses are required to determine the feasibility of this shipment category.

Type B packages for TRU wastes could be disposable or reusable. Depending on the design of the external packagings, the canisters may be required to provide the second level of containment if required. For untreated wastes, little if any credit could be taken for waste form characteristics. For treated wastes of uniform and good quality, some credit may be taken for the structural characteristics of the waste form, and could result in reduced overpack needs. Disposable Type B and Large Quantity packagings may be cost-effective for concentrated and uniform waste forms. Untreated waste forms are usually not sufficiently uniform or concentrated to be considered for this application.

Current trends in transportation packaging regulations could significantly impact TRU waste canisters. In addition, interpretation of existing regulations in the areas of brittle fracture toughness and acceptable leak rates could impact accepted design standards and materials used for waste packaging.

The impact of the currently proposed transportation regulations to TRU wastes is partly dependent on interpreting their application to mixtures of radionuclides found in these wastes. Three possible interpretation bases for determining the allowable amount of TRU radionuclides in the various waste categories are identified in this study: 1) weighting of the radionuclides by mass fraction (most restrictive), 2) application of the unity rule (the

sum of the fractions of each radionuclide to its allowable amount must not exceed unity, and 3) weighting of the radionuclides by activity fraction (least restrictive). Table 6.4 summarizes the application of these interpretations and packaging requirements described in Table 6.2 to TRU wastes.

TABLE 6.4. Possible Applicability of Proposed Shipping Categories for TRU Content in Wastes

Interpretation Basis for TRU Content Per Regulations	Shipment of TRU Wastes in Categories Given Is:					
	LSA	LLS	Type A	Type A Special Form	Type B (M)	Type B (U)
Mass Weighting	Prohibited	May be allowed for treated wastes	NA ^(a)	NA	NA	NA
Unity Rule	Allowed for some untreated wastes	May be allowed for treated wastes	(b)	(b)	NA	NA
Activity Weighting	Allowed for treated and some untreated wastes	May be allowed for treated wastes	NA	NA	NA	NA
No Interpretation Required	--	--	Allowed for some untreated Wastes ^(b)	Allowed for treated or encapsulated wastes ^(b)	Allowed for treated and untreated wastes	Allowed for treated and untreated wastes

(a) Not applicable.

(b) Unity rule is applicable in all cases.

For LSA and LLS classifications, the proposed rules are more liberal than existing rules. Some untreated TRU wastes may qualify for transportation in the LSA classification and some treated wastes may qualify in LSA or LLS categories in Type A packagings, provided the contents and canister integrity can be verified. The applicability of these proposed transport categories would require evaluation of specific cases.

Proposed Type A package limits would allow the transport of current canister types containing small quantities of TRU radionuclides. The amount of wastes that could qualify in this classification are expected to be quite small.

Radionuclide content limits for the Type A Special Form category in the proposed regulations are more strict than are existing rules. However, feasible package sizes may still be allowed, but encapsulation or treatment of wastes would still be required. Shipping of TRU wastes in this category appears to offer few advantages over Type B packaging.

Type B shipments would still be required under the proposed regulations. Because defense TRU wastes will only be transported domestically, it appears advantageous to use Type B (M) shipping category unless future operational restrictions become sufficiently limiting to preclude its practical use for TRU wastes. Packages meeting the more restrictive Type B (U) requirements could always be used. These requirements are similar to those for the existing Type B category, and waste form and canister impacts would be identical to those discussed above for existing regulations.

In summary, existing regulations provide little incentive for modifying current canister designs and waste forms for TRU wastes. Possible exceptions are disposable Type B canisters for treated wastes, and inner containers for reusable Type B packages to provide double containment of plutonium. Study of specific designs is required to determine the utility of these options. Adoption of the currently proposed regulations would allow a larger range of options for shipping categories. Transportation packaging could be simplified if credit could be taken for the integrity of waste canisters and waste characteristics.

6.3.2 Carrier Impacts

The potential impacts of carrier requirements and preferences as applied to TRU waste forms and canisters are primarily related to the external packagings and their effects on the total load of the vehicles. Thus, waste canisters and forms should be compatible with carrier needs for external packagings. Only a few concerns relate directly to the waste canisters and essentially none were found that relate directly to the waste forms.

A characteristic of the packagings and canisters that the carriers prefer is that they be nonflammable. Thus, wooden containers are less desirable than steel containers. No concern was expressed over the flammability of the waste form. Carriers prefer external packagings that have the same dimensions and tie-down provisions as those of standard cargo containers.

To minimize concerns about canisters that can shift and fall within their external packagings, carriers prefer canisters that are designed to maximize stackability and stability. In this regard modular rectangular (and even

interlocking) designs are preferable to cylindrical units because they maximize coterminous canister surface areas and minimize empty space into which canisters can migrate. Canisters that are sized to fill the external packagings as completely as possible would also minimize this problem. Designs with high ratios of width to height would display the greatest stability.

Carriers strongly prefer to transport loads with low centers of gravity to improve the stability and safety of the shipments. Thus, it is preferred to carry packages that are relatively dense and/or are not stacked high. This would generally imply the use of short canisters filled with dense wastes.

To minimize radiation exposure to the carrier workers and to the public, canisters with lower activities are commonly packed around the units with higher activity to result in lower radiation levels along the perimeter of the vehicle. To pack radioactive materials this way, individual load units should be relatively small, e.g., 55-gallon drums. Large canisters would render it impossible to distribute the load to reduce external radiation levels. In those cases, loading of wastes into the canisters or intermediate packagings might be done to effect some reductions of external radiation levels.

To minimize turnaround time, packages that can be loaded/unloaded with a variety of techniques and equipment are often preferred. This generally applies to smaller canisters such as 55-gallon drums, which can be handled by a variety of techniques. On the other hand, larger and fewer package units are preferred to save time if appropriate handling equipment is available. Another way that was suggested to minimize turnaround time is to have external packagings that could be loaded from the top and the sides.

Rail carriers prefer that external packagings be equipped with special handles or other appurtenances to facilitate retrieval in the event of severe accidents. Handles (preferably recessed) should be located so that crane hooks can easily be attached regardless of the packagings position.

External packagings for trucks must be designed more with the vehicle in mind, because load weights and dimensions are more restricted than for rail cars. An important consequence of this is that truckers strongly prefer packagings that distribute their loads broadly over the length of the trailer. This

would allow lighter trailers with greater payloads to be used; it would reduce structural fatigue resulting from load concentration; it would improve vehicle roadability and controllability; it would also increase driver comfort and lessen driver fatigue; and it would allow for easier securing of more concentrated loads.

Load distribution could be accomplished by loading a vehicle with two or more smaller packagings rather than one large one. Alternatively, spanners or other structural features could be incorporated into the package design to distribute the load.

Rail carriers attach less importance to load distribution than truckers, primarily because of the higher strength of the rail cars.

Load limits for transport vehicles indicate that maximum payloads of packagings plus wastes are approximately 22,700 kg (50,000 lb) for trucks and 63,000 kg (140,000 lb) for conventionally-sized rail cars for routine transportation. Designs of canisters and external packagings should take those limits into account.

6.3.3 Transportation Hardware Impacts

Shipments in LSA, Type A and in the proposed LLS Category require no special transportation overpacks, they require only good or Type A containers and can be made in conventional freight vehicles.

Shipments in Type B Category require external packagings that provide containment in the event of an accident. The impacts on waste forms and canisters by the Type B packagings relate to the payload weight limit of the packagings, weight distribution within some packagings, the height of packagings, the containment provided by some packagings, and the capability to handle specially sized packages.

The payload weight limit could be exceeded if external packagings were loaded fully with canisters having waste forms of high specific gravity. The effects on any of the external packagings of staying within the payload limit

would be the incomplete use of all the volume available in these packagings. Specific limitations for some postulated canister sizes were given in Table 5.2.

The most efficient use of internal space for all the external packagings is accomplished when they are loaded with individual drums or other appropriately sized canisters. This is almost the only existing method of filling the Super Tiger® because its restriction on concentrated floor loads does not permit the use of conventional devices to handle large packages. Because of this limitation, waste canisters shipped in the Super Tiger® are limited in weight to those that can be handled manually.

Conveyor or built-in pallet systems are planned to load six-packs of 55-gallon drums or modular boxes (within which the waste may be placed in smaller canisters) into the TRUPACT. The pallet system for the TRUPACT is planned to handle "small" canisters such as 55-gallon drums on an individual basis. In most cases, canisters are expected to be combined before loading, and these can be handled using the conveyor system mounted on the TRUPACT floor in place of a pallet.

The loading/unloading system used will affect the occupational radiation dose to the workers. Systems that require manual handling will result in more occupational radiation exposure and could limit the dose rate from the canisters.

The maximum heights of canisters are limited by the internal height dimension of the external packagings. For the Super Tiger® the internal height is 1.9 m, for the planned TRUPACT for truck and rail transportation 2.0 m and 2.3 m respectively, for the ATMX-500 1.9 m, for the ATMX-600 with cargo containers 2.3 m, and for the ATMX-600 loaded directly 2.8 m. All of these values are less than the height of 3.05 m that is sometimes considered for a waste repository. Rocky Flats boxes or proposed modular steel boxes can be used to contain smaller canisters. Their internal height dimensions are 1.2 m and 0.9 m respectively. Taller canisters might be usable if they were carried horizontally but this concept would have to be evaluated.

The ATMX rail cars can have fittings welded to the car frame for attaching restraining hardware for cargo. This makes the ATMX rail cars convenient for

securing heavy or unusually shaped packages. The other external packagings can accommodate specially-sized packages, but may be somewhat limited by their smaller cavities, by the lack of hardware for convenient use of cargo restraints, or for the Super Tiger® and TRUPACT, the limitation on floor weight distribution.

The Super Tiger® is no longer licensed as a Type B packaging. The ATMX rail cars are currently operating under an exemption to Type B requirements. They provide containment under normal transport conditions. The packages placed in these external packagings are expected to provide the containment. Cargo containers, frequently used in the ATMX-600 rail car to facilitate handling, do not provide this required containment.

Any waste that requires shielding for transportation purposes must have that provided internal or external to the canister. Such shielding would tend to add weight and reduce usable volume for waste, and if it is reused, add extra handling and return shipping activities and costs.

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GLOSSARY

SOURCE^(a)

DEFINITION

IAEA-Wm

Canister

A rigid container for radioactive waste that is in direct contact with the waste or with disposable bags that may hold the waste. The canister may be lined with other materials such as plastic or cement. The canister provides physical containment but not shielding. A canister can have many shapes and can be made from a variety of materials.

Cargo Container

(See Freight Container)

IAEA-m

Carrier

Any organization or private individual undertaking the conveyance of radioactive materials by any means of transport. The term includes both carriers for hire or reward (known as common or contract carriers), carriers on own account (known as private carriers), and freight forwarders.

TWSOm

Contact-Handled TRU Waste

Transuranic waste that does not require shielding other than that provided by its container. Solid or solidified materials that contain plutonium or other long-lived alpha emitters in known or suspected concentrations greater than 10nCi/g, but have sufficiently low external radiation levels after packaging (less than 200 mR/hr) that the containers can be handled directly.

Dictionary-m

Container

A receptacle for transporting material. A container can be the only enclosure or it can be any of one or more enclosures that may be inside or outside of another.

IAEA-W

Containment

The retention of radioactive material in such a way that it is effectively prevented from becoming dispersed into the environment.

(a) See legend at end of glossary for definition of these symbols.

SOURCEDEFINITION

IAEA

Containment System

The components of the packaging specified by the designer as intended to retain the radioactive material during transport.

IAEAam

Freight (or Cargo) Container

A container designed to facilitate the handling, transfer and carriage of goods by one or more modes of transport without intermediate removal and reloading of its contents. These containers are commonly designed to specified standards.

IAEAa

Low-Level Solid (LLS) Radioactive Material

Any of the following:

- (a) Solids (e.g., consolidated wastes, activated materials) in which:
 - 1) the activity under normal transport conditions is, and remains, distributed throughout a solid or a collection of solid objects, or is, and remains, uniformly distributed in a solid compact binding agent (such as concrete, bitumen, ceramic), and
 - 2) the activity is, and remains, insoluble so that, even under loss of packaging, the loss of radioactive material per package resulting from the effects of wind, rain, etc., and from total immersion in water is limited to less than 0.1 the maximum activity of the material (A_2) in a period of one week, and
 - 3) the estimated activity averaged throughout the radioactive material does not exceed 2×10^{-3} the maximum activity divided by the grams of material (A_2/g).
- (b) Objects of nonradioactive material contaminated with radioactive material, provided that the radioactive contamination is in a nonreadily dispersible form and the level of contamination averaged over 1 m^2 (or the area of the surface if this is less than 1 m^2) does not exceed
 - $20 \text{ } \mu\text{Ci}/\text{cm}^2$ for beta and gamma emitters and low toxicity alpha emitters;
 - $2 \text{ } \mu\text{Ci}/\text{cm}^2$ for other alpha emitters.

Low-Specific Activity (LSA) Material

Any of the following:

- a) Uranium or thorium ores and physical or chemical concentrates of those ores.
- b) Unirradiated natural or depleted uranium or unirradiated natural thorium.
- c) Tritium oxide in aqueous solutions, provided the concentration does not exceed 10 Ci/litre.
- d) Materials in which the activity, under normal transport conditions, is, and remains, uniformly distributed and in which the average estimated specific activity does not exceed 10^{-4} the maximum activity divided by the grams of material (A_2/g).
- e) Materials in which the activity is uniformly distributed and which, if reduced to the minimum volume under conditions likely to be encountered in transport, such as dissolution in water with subsequent recrystallization, precipitation, evaporation, combustion, abrasion, etc., would have an average estimated specific activity of no more than $10^{-4} A_2/g$.
- f) Objects of nonradioactive material contaminated with radioactive material, provided the nonfixed surface contamination does not exceed ten times the values given in IAEA Safety Series Report No. 6(1979), and the contaminated object or the contamination on the object, if reduced to the minimum volume under conditions likely to be encountered in transport, such as dissolution in water with subsequent recrystallization, precipitation, evaporation, combustion, abrasion, etc., would have an average estimated specific activity of no more than $10^{-4} A_2/g$.
- g) Objects of nonradioactive material contaminated with radioactive material, provided that the radioactive contamination is in a nonreadily dispersible form and the level of contamination averaged over 1 m^2 (or the area of the surface if this is less than 1 m^2) does not exceed:
 - $1 \text{ } \mu\text{Ci}/\text{cm}^2$ for beta and gamma emitters and the low toxicity alpha emitters;
 - $0.1 \text{ } \mu\text{Ci}/\text{cm}^2$ for other alpha emitters.

SOURCE

DEFINITION

49 CFR 171m

Overpack

An enclosure that is used by a single consignor that can be used to consolidate two or more packages for convenience in handling (also Freight Container), or to provide protection of packages and/or containment of package contents in event of nonstandard conditions such as an accident.

10 CFR 71.4,
IAEA-W

Package

The packaging and its radioactive contents. It includes the waste form, including any container(s) and other engineered barriers (e.g., absorber materials), as it is prepared for handling, transport, storage and/or disposal. A container may be a permanent part of the waste or may be reusable (e.g., shielding cask, shock absorbers, etc.) for any waste management step.

10 CFR 71.4m

Packaging

One or more receptacles and wrappers including absorbent material, spacing structures, thermal insulation, radiation shielding, devices for cooling and for absorbing mechanical shock, external fittings, neutron moderators, nonfissile neutron absorbers, and other supplementary equipment.

IAEA-Wm, IAEA-m

Radioactive Material

A material of which one or more constituents exhibit radioactivity. For purposes of regulation, this term is restricted to radioactive material with a radioactivity level or specific activity greater than a specified value. For transportation purposes, it is any material having a specific activity greater than 0.002 $\mu\text{Ci/g}$.

IAEA-Wm

Radioactive Waste

Any material containing or contaminated with radionuclides at concentrations or radioactivity levels greater than exempt quantities established by the regulatory authorities and for which there is no foreseen use.

SOURCEDEFINITION

TWSOm

Remotely-Handled TRU Waste

Transuranic waste that requires shielding in addition to that provided by its container in order to protect people nearby. Solid or solidified materials (other than high-level wastes) that contain long-lived alpha emitters at concentrations greater than 10nCi/g, and have fission-product gamma-radiations levels (greater than 200 mR/hr) that require biological shielding and remote-handling techniques even after packaging.

IAEA, 10 CFR 71m

Special Form Material

An indispersible solid radioactive material or a sealed capsule containing radioactive material. The sealed capsule shall be so constructed that it can be opened only by destroying the capsule.

Special form material has any of the following physical forms of licensed material of any transport group:

- a) The material is in solid form having no dimension less than 0.5 millimeter or at least one dimension greater than five millimeters; does not melt, sublime, or ignite in air at a temperature of 1,000°F.; will not shatter or crumble if subjected to the percussion test described in 10 CFR 71, Appendix D; and is not dissolved or converted into dispersible form to the extent of more than 0.005 percent by weight by immersion for 1 week in water at 68°F or in air at 86°F.; or
- b) The material is securely contained in a capsule having no dimension less than 0.5 millimeter or at least one dimension greater than five millimeters, which will retain its contents if subjected to the tests prescribed in 10 CFR 71, Appendix D; and which is constructed of materials which do not melt, sublime, or ignite in air at 1,475°F, and do not dissolve or convert into dispersible form to the extent of more than 0.005 percent by weight by immersion for 1 week in water at 68°F or in air at 86°F.

10 CFR 71

Transport Group

Any one of seven groups into which radionuclides in normal form are classified, according to their toxicity and their relative potential hazard in transport, in Appendix C of 10 CFR 71.

SOURCEDEFINITION

Transuranic nuclides are in Group I.

a) Any radionuclide not specifically listed in one of the groups in Appendix C shall be assigned to one of the Groups in accordance with the following table:

Radionuclide	Radioactive half-life		
	0 to 1000 days	1000 days to 10 ⁶ years	Over 10 ⁶ years
Atomic number 1-81	Group III.....	Group II.....	Group III.
Atomic number 82 and over.	Group I.....	Group I.....	Group III.

IAEA-Wm

Transuranic Wastes

Wastes containing quantities of transuranic radionuclides above agreed limits. The current value in the U.S.A. is 10 nCi/g of waste.

IAEA-Wm

Transuranium Nuclides

Nuclides having an atomic number greater than that of uranium (i.e., greater than 92). The principal transuranium radionuclides of concern in radioactive waste management are tabulated below with their half-lives and decay modes.

Nuclide	Half-Life (Years)	Principal Decay Modes
Neptunium-237	2,140,000	alpha
Plutonium-238	86	alpha, spontaneous fission
Plutonium-239	24,390	alpha, spontaneous fission
Plutonium-240	6,580	alpha, spontaneous fission
Plutonium-242	379,000	alpha
Americium-241	458	alpha
Americium-243	7,950	alpha
Curium-245	9,300	alpha
Curium-246	5,500	alpha, spontaneous fission

For waste management purposes in the U.S.A., Uranium-233 (alpha decay, half-life 160,000 years) and its decay daughter products are considered as transuranium nuclides.

IAEAa

Type A Packaging

Packaging that is designed to withstand the normal conditions of transport as demonstrated by the retention of the integrity of containment and shielding.

IAEAa

Type B Packaging

Packaging that is designed to withstand the damaging effects of a transport accident as demonstrated by the retention of the integrity of containment and shielding, to the extent required by the regulations, after the tests specified in the regulations.

10 CFR 71m

Type A Quantity, and Type B Quantity and Large Quantity

A quantity of radioactive material the aggregate radioactivity of which does not exceed that specified in the following table:

Transport Groups	Type A Quantity (in curies)	Type B Quantity (in curies)	Large Quantity (in curies)
I.....	0.001	20	Quantity in Excess of Type B
II.....	0.05	20	
III.....	3	200	
IV.....	20	200	
V.....	20	5,000	
VI and VII.....	1,000 ^(a)	50,000	
Special Form.....	20 ^(a)	5,000	

^(a)Except that for californium-252, the limit is 2 Ci.

IAEA

Vehicle

A road vehicle (including an articulated vehicle, i.e. a tractor and semi-trailer combination) or railroad car or railway wagon. A trailer shall be considered as a separate vehicle.

Legend

Dictionary - from Webster's Dictionary
 IAEA - from IAEA Safety Series No. 6, 1979
 IAEA-W - from IAEA Waste Management Glossary
 10 CFR 71 - from 10 CFR 71
 49 CFR 171 - from 49 CFR 171
 TWSO - from Report DOE/AL/TRU 8002
 a - abbreviated from that in the source
 m - modified from that in the source

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