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**ANALYSIS OF THE NEUTRON
SHIPPING CONTAINER, MODEL 4T**

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ANALYSIS OF THE NEUTRON SHIPPING CONTAINER, MODEL 4T

1. SCOPE

This analysis has been submitted to AEC/DOT to certify that the Lawrence Livermore Laboratory shielded shipping cask system can safely transport all isotopes of americium, curium, berkelium, californium, einsteinium, and fermium in solid form. The following maximum limitations will be maintained on shipments in this container:

- a) a combined maximum total heat load of 200 W from radioactive decay heating,
- b) a total neutron emission from any combination of the above elements of 1.5×10^9 n/sec (fission spectrum),
- c) a total net mass of 250 g of any combination of the above isotopes except for limitations listed in d and e below,
- d) a total net mass of 15 g of any combination of the following isotopes (potential criticality hazards):
 ^{242}Am , ^{245}Cm , ^{247}Cm , ^{249}Cf , ^{251}Cf ,
- e) a total net mass of 3 g of ^{251}Cf ,
- f) a total integrated radiation dose of 200 mrem/hr at the external surface of the shielding container,
- g) a total integrated radiation dose of 10 mrem/hr three ft from the external surface of the shielding container.

Appendix A is a general discussion on the way these limitations apply to specific isotopes.

The shipping container (Fig. 1) consists basically of two separate shields: an outer neutron shield filled with gypsum-spodumene and an inner stainless steel gamma shield filled with depleted uranium metal. For maximum shielding, the smaller gamma shield is inserted into the larger neutron shielding jacket to provide both gamma and neutron shielding.

We designed the shipping container so that the outer neutron shielding jacket can be used with or without the inner gamma shield; therefore, this shipping container can be used to transport either one or several special form containment vessels. In the former case, one special form capsule is placed inside the gamma shield and the shield is placed inside the shipping cask. In the latter case, the gamma shield is removed from the cask and a special rack is substituted. This rack has room for several separate special form containment vessels. In the first case (one special form capsule), provision is made for the inner cask to be held at room temperature by use of a cooling coil cast into the uranium cask. This is merely a convenience for certain experiments where it is preferable that the contents be kept at room temperature. Loss of cooling will

Fig. 1. Fully assembled model 4T shipping container.

Fig. 2. Special form Conoseal capsule with gasket detail.

not result in higher temperatures than those presented in the calculations, nor will it affect the containment capabilities of the cask system. For this reason, the cooling provisions of this cask system have been ignored in our calculations. Figure 2 shows the gasket detail of the special form capsule.

The shipping container is designed to meet the requirements of AEC Manual, Chapter 0529 (Appendix B).

2. DESCRIPTION

In maximum shielding configurations, the shipping container is cylindrical, 3 ft 5 in. in diameter, 4 ft tall, and is mounted on a steel pallet base 4 ft 6 in. square. The cover is cylindrical and it is held in place by 12 studs with nuts. The inner cavity of the container is a cylinder 16 in. in diameter by 23-1/2 in. deep. The inner cavity can accommodate several special form containment vessels or one gamma shield. The gamma shield is an independent vessel, and is used when the gamma shielding of the outer container alone is inadequate for the shipment. The gamma shield is cylindrical, 14 in. in diameter by 20 in. tall, and has a cylindrical cover held in place by 6 studs with nuts. The inner cavity of the gamma shield is a cylinder 2.50 in. in diameter and can accommodate one special form containment vessel. Two alternate covers are available providing cavity depths of 5.12 in. or 8.43 in.

The shipping container weighs 7000 lb with the gamma shield, and 5100 lb without the shield. Different containment vessels are used with each cask configuration. (See items 3, 5, and 10 below.)

3. CONSTRUCTION MATERIALS

The shipping container is cylindrical and composite. The materials we used in the cask are listed in sequence starting from the outside of the container and moving in:

- a) Hot-rolled carbon steel plate, 0.250 in. thick, exterior painted with white enamel.
- b) Gypsum-spodumene composite 12-in. thick, cast in place. Mix ratio (by weight) is one part plaster of paris, one part spodumene, and one part water. Cured weight is approximately 120 lb/ft³.
- c) Hot-rolled carbon steel plate, 0.250 in. thick, interior painted with white enamel.
- d) Type 304 stainless steel, 0.250 in. thick (exterior wall of inner vessel).
- e) Depleted uranium cylinder, 4.37 in. thick.
- f) Cylindrical lead wall, 1.23 in. thick. The lead is used to encapsulate a cooling coil formed from stainless steel tubing 0.250 in. o.d. x 0.022 in. thick.
- g) Type 304 stainless steel plate, 0.125 in. thick. This material forms a well for the containment vessel.
- h) Containment vessel, type 347 stainless steel.

Items d through g are a part of the gamma shield, and are not present if the gamma shield is not used.

All ferrous metals are fabricated with full penetration welds. Continuous inspection is used during fabrication to assure void-free shielding.

4. MATERIALS USED AS NEUTRON ABSORBERS OR MODERATORS

The 1.23-in.-thick lead cylinder and the 4.37-in.-thick depleted uranium cylinder serve as gamma shields and also as elastic scatterers for degrading neutrons with energies greater than 1 MeV. The lithium-6 in the spodumene aggregate absorbs epi-thermal neutrons (about 200 keV energy) and the hydrogen content of the gypsum is used for neutron moderation.

5. MEANS OF CONTAINMENT

All of the heavy element oxides will be in "special form," as defined by AEC Manual, Chapter 0529, Paragraph I.A.15, and will be initially packaged in a screw top metal capsule. This capsule, which is not gas tight, will be contained in a special stainless steel type 347 pressure vessel with a Conoseal Joint (made by Marman Corporation^{*}). This vessel is suitable for use at temperatures from -450° to 1500°F, and pressures of 2,600 psig (at room temperature), and 150 psig at 1500°F. The container will be prechecked for leakage under vacuum with a helium mass spectrometer. The acceptable leak rate of the vessel is less than 1×10^{-9} standard cubic centimeters of helium per second at above rated temperature and pressure. This vessel is designed to contain all radioactive material during decay heating, fire, or any accident that might occur in transit. Though tests have been performed on a particular vessel (Marman capsule #MJN 68462), shipments are not limited to this container. Any vessel conforming to the "special form" requirements may be used in this shipping cask.

The outer cover of the neutron jacket is sealed by a flat rubber gasket, and the gamma shield cover is sealed by a rubber O-ring. These seals are not required by either AEC or DOT regulations, and serve only to keep the container clean.

6. HEAT DISSIPATION

The largest heat source carried by the cask generates 683 Btu/hr (200 W) from isotopic decay heating. A cooling loop is available, and may be used to maintain ambient temperatures within the container. However, since accidents can nullify this cooling unit, the container is designed to safely dispose of radioactive decay heat by thermal radiation, conduction and convection. The containment vessel, which contains the radioactive source, may be heated to 1500°F for extended periods, and it will radiate heat to the inner lead shield at a rate of

^{*}Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Atomic Energy Commission to the exclusion of others that may be suitable.

2400 Btu/hr. In the heat transfer calculation (Appendix C) the temperature of the lead was limited to 500°F. This heat transfer capability is in excess of the 683 Btu/hr generated by the radioactive heat source.

The heat in the gamma shield will be transferred primarily by radiation to the outer container, and through the outer container to the outer walls. Convective cooling will transfer heat from the outer container to the surrounding air. If the shipping container is exposed to bright sunshine and still air at 130°F for an extended period of time, with a 200 W heat source inside, the temperature of the lead portion of the inner vessel will reach 356°F.

The shipping container is required to withstand a 30-min, 1475°F fire (Appendix B); in fact, it is capable of operating at a significantly higher temperature (see sections 5 and 10).

7. PRESSURE RELIEF SYSTEM

The outer neutron shield vessel containing the gypsum-spodumene mixture is outfitted with three 70-psig rupture discs. One rupture disc is located in the top cover plug and two in the lower container body. Each of the two rupture discs in the container body has been connected to a vent channel running the full length of the container body. The vent channels are 1/2 in. X 1/2 in. X 1/8 in. steel angles tack-welded to the inside of the outer wall and are completely open to the rupture disc fitting.

8. LIFTING SYSTEM FOR CASK

The shipping container is provided with four lifting lugs. One lug will safely carry more than three times the weight of the container. The rectangular base of the container forms a pallet so that the container may be raised with a fork lift.

9. IDENTIFICATION OF CONTAINER

The shipping container is identified by a stainless steel plate welded to the outer vertical steel surface. The identification plate states the following information:

RADIOACTIVE MATERIAL
DOT SP # 6478 TYPE "B"
NEUTRON SHIPPING CASK MODEL 4T
WEIGHT 7000 LBS. W/GAMMA SHIELD
WEIGHT 5100 LBS. W/O GAMMA SHIELD
LRL DRAWING NUMBER AAA-60-144963
RETURN TO:
LAWRENCE RADIATION LABORATORY
BLDG 251 LIVERMORE, CALIFORNIA

10. CONTAINER CONTENTS

This container is designed to safely contain and adequately shield 50 g of curium 244 or the equivalent radiation from other actinide elements.

Using the partial half-life for fission of ^{244}Cm as 1.346×10^7 yr, and the half-life for alpha decay at 18.11 yr, the total alpha emission is 8.985×10^{15} disintegrations per minute, and the spontaneous fission rate is 2.014×10^8 /sec for the 50 g of curium 244. This corresponds to a generation of 0.4825 cc of helium gas per day in the containment vessel, and an emission of 142 W of thermal heat from both the alpha and fission decay. The increase in pressure from generation of fission gases is negligible compared to the growth of helium gas.

The 50 g of curium 244 will be sealed in a Conoseal container #MJN-68462-1, with an internal volume of 70 cc. Using a metal container 1-1/4 in. o.d. by 2-7/8 in. long to hold the curium oxide powder, the void volume remaining in the Conoseal container is 45.1 cc. The 50 g of curium will produce 0.4825 cc per day of helium which will produce 14.7 psig container pressure at room temperature after 104 days of storage.

If the Conoseal container were heated to its maximum operating temperature of 1500°F the pressure in the container would be 94.3 psig after 104 days of curium storage. This is within the pressure and temperature rating of the Conoseal container.

The chemical form of the radioactive material to be shipped will always be dry ignited oxide. This oxide powder will be contained in a metal tube which will be closed with a screw type seal with provision made to gradually bleed off any pressure into the containment vessel. The metal primary container will be inserted into the type 347, all stainless steel, "Conoseal" sealed pressure vessel which is the final containment vessel. This container will allow the radioactive material to conform to the "special form" transport category as defined by AEC regulations.

Since the materials to be transported will be limited in quantity and packaged dry in a "special form" container, the contents are not a potential nuclear criticality hazard.

11. DESIGN COMPLIANCE WITH AEC CRITERIA

This section discusses point by point the compliance of the shipping cask design with the criteria listed in Section II and Annexes 1, 2, and 4 of AEC Manual, Chapter 0529 (Appendix B).*

Section II Paragraphs

- A.1. Compliance—Radioactive material will be in a dry powder form carried in a metal screw top cylinder. This cylinder is for convenience in handling only, and is not considered a means of containment.

*Section I and Annex 3 have been deleted because they are not germane to this paper.

The special form capsule, which will contain one metal cylinder, is fabricated from type 347 stainless steel and sealed with a stainless steel Conoseal gasket.

The cavity and the external surface of the gamma shield are fabricated from stainless steel. The neutron shield cavity is painted carbon steel.

- A.2. The neutron shield cover is secured by twelve studs with nuts. The gamma shield cover is secured by eight studs with nuts. The special form capsule cover is secured by six socket head cap screws.
- A.3.a. Compliance—Four lugs. Even if one lug lifts the entire weight, it will not generate tensile stress in excess of one-third of the yield stress of the material. (Refer to calculations in Appendix C.)
- A.3.b. Compliance—The lifting lug on the lid can support the entire weight of the loaded container without generating stress in excess of one-third of the yield stress of the material. (Refer to calculations in Appendix C.)
- A.3.c. Not applicable—All lugs comply with A.3.a.
- A.3.d. Compliance—Neutron shielding material is steel-reinforced gypsum-spodumene composite which will remain in place even if the vessel is ruptured.
- A.4.a. Compliance—An I-beam base and tiedown lug system is provided which is sufficient to meet these requirements. (Refer to calculations in Appendix C.)
- A.4.b. Not applicable—Lifting lugs are an integral part of the tiedown lugs and meet the requirements of A.3.a.
- A.4.c. Compliance—Lugs are not a structural part of the container assembly. (See A.3.d.)
- B.1. Compliance—The outer shell can support a load in excess of five times the weight of the cask. Gypsum-spodumene fill provides added stability against buckling. (Refer to calculations in Appendix C.)
- B.2. Compliance—The container can withstand more than 25 psi external pressure. (Refer to calculations in Appendix C.)
- C.1. Compliance—The container is used to transport isotopes of Am, Cm, Bk, Cf, Es, and Fm, in dry form. Of these, ^{242}Am , ^{245}Cm , ^{247}Cm , ^{249}Cf , and ^{251}Cf have the largest fission cross section, and the total quantities of all five of these isotopes is limited to 15 g per shipment; ^{251}Cf specifically is limited to 3 g. Quantities of all other isotopes (all of which have small fission cross sections) are limited to 250 g. The

quantities of isotopes per shipment are limited, and the contents are packaged dry in a special form container so that the system will be subcritical even if both inner (gamma), and outer (neutron) shields are filled with water.

- C.2,3. Not applicable since liquids will not be transported in this carrier.
- D.1.a. Compliance—See E.1, through 3.
- D.1.b. Compliance—See F.1,2.
- D.2,3. At this date, we do not know of any control exercised by the shipper that would affect the design of the shipping containers.
- E. The standards for normal conditions of transport are based on conditions listed in Annex 1.

ANNEX I PARAGRAPHS

1. Heat—Heat calculations (Appendix C) show that the container may be stored in the sunlight (130° temperature) for indefinite periods of time without detrimental effect.
2. Cold—All materials are adequate for -40°F as evidenced by laboratory tests (see Appendix D).
3. Pressure—The container will withstand several atmospheres of external pressure (see Appendix C calculations).
4. Vibration—The container is a steel-lined vessel filled with solid aggregate which is suitable for normal-transport vibration.
5. Water Spray—The inner vessel containing the radioactive source is a special form capsule and has been tested for normal transport and hypothetical accident conditions. The uranium shield is encased with a type 304 stainless steel welded enclosure. The gypsum-spodumene aggregate is protected by a 1/4-in. steel liner.
- 6.7. Free and Corner Drop—The pallet, which is welded to the container, may be damaged by the fall but the container will not be damaged.
8. Penetration—Tests have been conducted which indicate that a 1-1/4-in.-diam bar weighing 13 lb dropped 40 in. will slightly dent the 1/4-in.-outer steel plate of the container but will not cause failure.

9. Compression—Calculations (Appendix C) indicate that the container will safely support five times its own weight.
- E.1.a,b,c. Compliance—Radioactive material will be packaged in a dry form in a metal cylinder. The cylinder will be placed into a type 347 stainless steel capsule equipped with a Conoseal metal gasket. The working pressure of this vessel is 2600 psi at room temperature, and 150 psi at 1500°F. The vessel will be fully leak tested with a helium mass spectrometer before use.
- E.1.d,e. Not applicable—Secondary coolant is available but it is not required since the containment vessel has adequate high-temperature capability, and the shipping container has sufficient heat-transfer capacity.
- E.2.a,b. Compliance—The contents of the container are administratively limited and packaged dry in a special form capsule so that insufficient mass is present to form a critical assembly under conditions of maximum neutron moderation and/or severe geometric deformation of the package.
- E.2.c. Compliance—See Paragraph E.1.a,b,c. Type 347 stainless steel containment vessel is adequate to prevent entry of water.
- E.3. Compliance—The Conoseal joint satisfies requirements. (See E.1.a,b,c.)
- F. The container was evaluated for the following hypothetical accident conditions listed in Annex 2:

ANNEX 2 PARAGRAPHS

1. Free Drop—Calculations (Appendix C) indicate that the outer shield will be deformed by the 30-ft drop resulting in a 3-in. decrease of effective gypsum-spodumene shielding. Drop tests were conducted on the studs holding the outer plug to the container body. Two tests indicated that the stud-mounting system will absorb without failure the sum of the impact energy of the lid plug plus the inner gamma shield. (See Appendix C.)
2. Puncture—Previous puncture tests at Oak Ridge National Laboratory indicate that the container will survive this test. (See Appendix C.)
3. Thermal—Dehydration of some of the gypsum composite will occur. The loss of water does not change the mechanical structure appreciably. Rupture discs are provided to release the excessive pressure buildup.

The basic gamma shield is primarily uranium metal (melting point 2071°F) encased in a type 304 stainless steel liner which is protected from the direct fire by the outer 12-in. gypsum-spodumene shield.

The inner special form vessel is constructed from type 347 stainless steel and is designed for a working pressure of 150 psig at an operating temperature of 1500°F.

4. Water Immersion—The inner special form vessel is helium leak tight.

F.1.a. Several computer calculations using the ANISN* shielding code were made at ORNL by E. D. Arnold in which he assumed that there was: (1) a 3-in. loss and, (2) a 9-in. loss of effective neutron shielding. The following was extracted from Mr. Arnold's letter dated December 21, 1970:

"In the results for the 4T cask you will find three cases covered: (1) the standard cask design using the spodumene-gypsum mix of standard density, (2) the squashed cases using a mix having a density of 1.25 times normal but a thickness of only three-fourths that of the basic design, and (3) the pinched cases where the density is normal but the thickness is only 25% of design.

"The attached table illustrates these results for a few points in the spodumene-gypsum zones. You will note that the dose rate at a 34-cm radius in the pinched case is only 12% higher than that of the standard case. Thus it would be reasonable to determine dose rates for any amount of thickness reduction by simply using the dose rate at the corresponding thickness in the standard case and applying any necessary geometric and cladding correction factors. The results indicate that even with a loss of 75% of the spodumene-gypsum shield the neutron + secondary gamma dose rate will increase only 32 fold. A 25% loss of shielding will increase the neutron + secondary gamma dose rate approximately 3 fold. The fission product gamma dose rate is affected to a much lesser degree."

*Oak Ridge National Laboratory shielding code.

Neutron + Secondary Gamma Dose Rates for Three
Conditions Involving the LRL 4T Cask*

Dist. from $\bar{C}$ of cask (cm)	$4\pi r^2$ Dose (rad/hr/neut)		
	Std [†]	Squashed**	Pinched ^{††}
27	5.836E-5	5.934E-5	6.373E-5
30	2.858E-5	2.294E-5	3.116E-5
31	2.297E-5	1.480E-5	2.499E-5
32	1.847E-5	1.197E-5	2.019E-5
33	1.496E-5	9.740E-6	1.645E-5
34	1.214E-5	6.549E-6	1.361E-5
36	8.134E-6	4.509E-6	
39	4.645E-6	2.301E-6	
42	2.795E-6	1.286E-6	
45	1.771E-6	7.686E-7	
48	1.174E-6	4.684E-7	
51	8.049E-7		
54	5.585E-7		
57	4.313E-7		

* Extracted from E. D. Arnold's letter (ORNL) dated December 21, 1970.

[†] = Normal 12 inch thickness of spodumene-gypsum composite.

** = 75% of 12 inch shield compacted to 1.25X normal density.

^{††} = 25% of 12 inch shield at original density.

Since mechanical calculations (Appendix C) indicate that only a 3-in. decrease in effective shielding will result from the 30-ft drop test, it is evident from the above shielding calculations that the radiation dose rate will not reach the 100 fold level (1000 mrem/hr) permitted by the regulations.

F.1.b. Compliance—The containment vessel is fabricated from type 347 stainless steel and the gasket used therein is of type 321 stainless steel. Since both materials have the same coefficient of thermal expansion ($11.1 \times 10^{-6} \text{ } ^\circ\text{F}^{-1}$, 32°F to 1500°F), differential expansion is not a problem. The containment vessel has a working pressure of 150 psi at 1500°F .

F.2.a,b,c. The radioactive material is packaged in a dry condition and the total mass is administratively limited so that when the cask is subjected to the hypothetical accident (free drop, puncture,

thermal, and water immersion) it will remain subcritical. See E.2,a b.

- G.1. The contents of the package are limited to exclude the possibility of critical chain reactions before or after the hypothetical accident.
- G.2. See Section II.C.
- H.1,2. The contents of the package have been so limited that any number of packages would be subcritical in any arrangement, even after the package is subjected to the hypothetical accident conditions of free drop, thermal exposure, and water immersion, in that sequence.
- I,J. Not applicable.

ANNEX 4 PARAGRAPHS

Tests were conducted on the Marman capsule MJN 68462 to verify that it would meet the following special form requirements:

1. Free Drop—One helium-filled special form vessel was dropped twice from a height of 30 ft onto a rigidly supported half-inch steel plate. In each test the head of the bolts securing the sealing cover to the vessel body struck the steel plate. A helium mass spectrometer leak test showed no leakage after each drop test.
2. Percussion—The special form vessel is designed for use at pressures of up to 2,600 psig at room temperatures and is of sufficient strength to survive the percussion test.
3. Heating—Four helium filled vessels were heated to 1500°F and then cooled to room temperature. Helium mass spectrometer leak tests conducted continuously during heating and cooling showed no leakage.
4. Immersion—The thermal test above is a more severe test and demonstrates that the container will not leak when immersed in water.

Appendix A.

Limitations on Radioactive Materials

This appendix demonstrates how the limitations listed in Paragraph 1 apply to specific shipments of alpha emitting particles and also to spontaneously fissioning materials. For example, assume that we ship reactor-produced curium 244 made by long term irradiation of plutonium. Let's also assume that the basic fission products have been removed from the material, and only the curium fraction and several related impurities remain. A typical analysis of such material might show the curium fraction to contain 80% ^{244}Cm , 2% ^{242}Cm , 1/2% ^{245}Cm , 10% ^{246}Cm , 1/2% ^{247}Cm , 5% ^{241}Am , and 2% ^{243}Am .

Because of the varied composition of the material, we have to determine which of the seven limitations is going to govern the amount of material that can be transported at one time. To do this, we must determine:

- a) which isotopes have significantly short partial half-lives for spontaneous fission and therefore emit neutrons in significant amounts,
- b) which isotopes have short alpha half-lives, and therefore have a high heat generation rate (from alpha decay),
- c) which isotopes present (if any) have high thermal fission cross-sections, and therefore could be potential criticality hazards. [These isotopes are specifically covered under lines (d) and (e) of Paragraph 1.]

Line (c) of Paragraph 1 shows that the shipment must not exceed 250 g. Therefore, the maximum mass of each specific isotope can be readily determined from the previous chemical analysis, and conformance is then determined by calculating the decay heat, neutron emission, and mass of each isotope present. Table A-1 shows these calculations for a 250 g curium fraction of the isotopic composition described above:

Table A-1. Decay heat and neutron activity in reactor produced curium.^a

	Mass (g)	Heat evolved (W)	Neutrons emitted (sec)
^{244}Cm	200	~570	$\sim 28 \times 10^8$
^{242}Cm	5	~625	$\sim 1.3 \times 10^8$
^{245}Cm	1.3	<<1.0	negligible
^{246}Cm	25	<1.0	$\sim 2.8 \times 10^8$
^{247}Cm	1.3	<1.0	negligible
^{241}Am	12.5	~1.45	negligible
^{243}Am	5	<1.0	negligible
Total:	250	~1196	$\sim 3.2 \times 10^9$

^aWe made the above calculations using published values for alpha and spontaneous fission half-lives and the energy of the alpha particles emitted. We used a value of 3.5 neutrons liberated per fission for neutron emission estimates.

Table A-1 shows that to meet the 200 W restriction on heat load [line (a)], we must eliminate 5/6 of the amount assumed in trial calculations. That is, we can only ship 1/6 of 250 g (41.7 g) of the curium fraction per container.

Adjusting the values, we obtain the following for the contents of the projected shipment

33.3 g of ^{244}Cm
0.83 g of ^{242}Cm
0.21 g of ^{245}Cm
4.1 g of ^{246}Cm
0.21 g of ^{247}Cm
2.1 g of ^{241}Am
0.83 g of ^{243}Am

These values conform to the limitations placed on the container as stated in lines (a) through (e); lines (f) and (g) must be confirmed by actual measurement after loading the shipping container.

As all of the above listed isotopes emit primarily "soft" (less than 100 keV energy) gamma rays, it is evident that there will be no difficulty in meeting lines (f) and (g). It should be noted that the shielding in this shipping container is intended primarily to attenuate neutrons emitted from spontaneous fission of the species being transported. In all cases, it is expected that if the contents emit less than 1.5×10^9 n/sec, the shielding on the container will be more than sufficient to attenuate the soft gamma rays that are predominantly emitted by the actinide elements. Lines (f) and (g) then, are merely back-up limitations to satisfy AEC restrictions on all radioactive shipments of this type.

Appendix B.

U.S. ATOMIC ENERGY COMMISSION AEC MANUAL

SELECTIONS FROM CHAPTER 0529

Safety Standards for the Packaging of Radioactive and Fissile Materials

II. PACKAGE STANDARDS

A. General Standards for All Packaging

1. Packaging shall be of such materials and construction that there will be no significant chemical, galvanic, or other reaction among the packaging components, or between the packaging components and the package contents.

2. Packaging shall be equipped with a positive closure which will prevent inadvertent opening.

3. Lifting Devices

- a. If there is a system of lifting devices which is a structural part of the package, the system shall be capable of supporting 3 times the weight of the loaded package without generating stress in any material of the packaging in excess of its yield strength.

- b. If there is a system of lifting devices which is a structural part only of the lid, the system shall be capable of supporting 3 times the weight of the lid and any attachments without generating stress in any material of the lid in excess of its yield strength.

- c. If there is a structural part of the package which could be employed to lift the package and which does not comply with a., above, the part shall be securely covered or locked during transport in such a manner as to prevent its use for that purpose.

- d. Each lifting device which is a structural part of the package shall be so designed that failure of the device under excessive load would not impair the containment or shielding properties of the package.

4. Tie-down Devices

- a. If there is a system of tie-down devices which is a structural part of the package, the system shall be capable of withstanding, without generating stress in any material of the package in excess of its yield strength, a static force applied to the center of gravity of the package having a vertical component of 2 times the weight of the package with its contents, a horizontal com-

ponent along the direction in which the vehicle travels of 10 times the weight of the package with its contents, and a horizontal component in the transverse direction of 5 times the weight of the package with its contents.

- b. If there is a structural part of the package which could be employed to tie the package down and which does not comply with a., above, the part shall be securely covered or locked during transport in such a manner as to prevent its use for that purpose.

- c. Each tie-down device which is a structural part of the package shall be so designed that failure of the device under excessive load would not impair the ability of the package to meet other requirements of this section A.

B. Structural Standards for Large Quantity Packaging

Packaging used to ship a large quantity of radioactive material, as defined in I, A.6., above, shall be designed and constructed in compliance with the structural standards of this section. Standards different from those specified in this section may be approved by the manager or other designated official if the controls proposed to be exercised by the shipper are demonstrated to be adequate to assure the safety of the shipment.

1. Load Resistance. Regarded as a simple beam supported at its ends along any major axis, packaging shall be capable of withstanding a static load, normal to and uniformly distributed along its length, equal to 5 times its fully loaded weight, without generating stress in any material of the packaging in excess of its yield strength.

2. External Pressure. Packaging shall be adequate to assure that the containment vessel will suffer no loss of contents if subjected to an external pressure of 25 pounds per square inch gauge.

C. Criticality Standards for Fissile Material Packages

1. A package used for the transport of fissile material shall be so designed and constructed and its contents so limited that it would be

subcritical if it is assumed that water leaks into the containment vessel, and:

- a. water moderation of the contents occurs to the most reactive credible extent consistent with the chemical and physical form of the contents; and
 - b. the containment vessel is fully reflected on all sides by water.
2. A package used for the transport of fissile material shall be so designed and constructed and its contents so limited that it would be subcritical if it is assumed that any contents of the package which are liquid during normal transport leak out of the containment vessel, and that the fissile material is then:
- a. in the most reactive credible configuration consistent with the chemical and physical form of the material;
 - b. moderated by water outside of the containment vessel to the most reactive credible extent; and
 - c. fully reflected on all sides by water.
3. The manager or other designated official may approve exceptions to the requirements of this section where the containment vessel incorporates special design features which would preclude leakage of liquids in spite of any single packaging error and appropriate measures are taken before each shipment to verify the leak tightness of each containment vessel.

D. Evaluation of a Single Package

1. The effect of the transport environment on the safety of any single package of radioactive material shall be evaluated as follows:
 - a. The ability of a package to withstand conditions likely to occur in normal transport shall be assessed by subjecting a sample package or scale model, by test or other assessment, to the normal conditions of transport as specified in E., below, and
 - b. The effect on a package of conditions likely to occur in an accident shall be assessed by subjecting a sample package or scale model, by test or other assessment, to the hypothetical accident conditions as specified in F., below.
2. Taking into account controls to be exercised by the shipper, the manager or other designated official may permit the shipment to be evaluated together with or without the transporting vehicle, for the purpose of one or more tests.

3. Normal conditions of transport and hypothetical accident conditions different from those specified in E. and F., below, may be approved by the manager or other designated official if the controls proposed to be exercised by the shipper are demonstrated to be adequate to assure the safety of the shipment.

E. Standards for Normal Conditions of Transport for a Single Package

1. A package used for the shipment of fissile material or a large quantity of radioactive material, as defined in I. A.6., above, shall be so designed and constructed and its contents so limited that under the normal conditions of transport specified in annex I, below:
 - a. there will be no release of radioactive materials from the containment vessel;
 - b. the effectiveness of the packaging will not be substantially reduced;
 - c. there will be no mixture of gases or vapors in the package which could, through any credible increase of pressure or an explosion, significantly reduce the effectiveness of the package;
 - d. radioactive contamination of the liquid or gaseous primary coolant will not exceed 10^{-7} curies of activity of Group I radionuclides per milliliter; 5×10^{-6} curies of activity of Group II radionuclides per milliliter; 3×10^{-4} curies of activity of Group III and Group IV radionuclides per milliliter; and
 - e. there will be no loss of coolant or loss of operation of any mechanical cooling device.
2. A package used for the shipment of fissile material shall be so designed and constructed and its contents so limited that under normal conditions of transport, specified in annex I, below, considered individually:
 - a. the package will be subcritical;
 - b. the geometric form of the package contents would not be substantially altered;
 - c. there will be no leakage of water into the containment vessel. This requirement need not be met if, in the evaluation of undamaged packages under H.1., I.1.a., or J.1., below, it has been assumed that moderation is present to such an extent as to cause maximum reactivity consistent with the chemical and physical form of the material; and

d. there will be no substantial reduction in the effectiveness of the packaging, including:

- (1) reduction by more than 5 percent in the total effective volume of the packaging on which nuclear safety is assessed;
- (2) reduction by more than 5 percent in the effective spacing on which nuclear safety is assessed, between the center of the containment vessel and the outer surface of the packaging; or
- (3) occurrence of any aperture in the outer surface of the packaging large enough to permit the entry of a 4-inch cube.

3. A package used for the shipment of a large quantity of radioactive material as defined in I, A. 6., above, shall be so designed and constructed and its contents so limited that under the normal conditions of transport specified in annex 1, below, considered individually, the containment vessel would not be vented directly to the atmosphere.

F. Standards for Hypothetical Accident Conditions for a Single Package

1. A package used for the shipment of a large quantity of radioactive material, as defined in I, A. 6., above, or the shipment of fissile material when the package will contain more than .001 curie of Group I radionuclides, .05 curie of Group II radionuclides, 3 curies of Group III radionuclides, 20 curies of Group IV or Group V radionuclides, or radionuclides in special form, or 1000 curies of Group VI or Group VII radionuclides shall be so designed and constructed and its contents so limited that if subjected to the hypothetical accident conditions specified in annex 2, below, as the Free Drop, Puncture, Thermal, and Water Immersion conditions, in the sequence listed in annex 2, it will meet the following conditions:

- a. The reduction of shielding would not be sufficient to increase the external radiation dose rate to more than 1000 millirems per hour at 3 feet from the external surface of the package.
- b. No radioactive material would be released from the package except for gases and contaminated coolant containing total radioactivity exceeding neither:
 - (1) 0.1 percent of the total radioactivity of the package contents; nor
 - (2) 0.01 curie of Group I radionuclides, 0.5 curie of Group

II radionuclides, 10 curies of Group III radionuclides, 10 curies of Group IV radionuclides, and 1000 curies of inert gases irrespective of transport group.

A package need not satisfy the requirements of this paragraph if it contains only low specific activity materials, as defined in I, A. 7., above, and is transported on a motor vehicle, railroad car, aircraft, inland water craft, or hold or deck of a seagoing vessel assigned for the sole use of the shipper.

2. A package used for the shipment of fissile material shall be so designed and constructed and its contents so limited that if subjected to the hypothetical accident conditions specified in annex 2, below, as the Free Drop, Puncture, Thermal, and Water Immersion conditions, in the sequence listed in annex 2, the package would be subcritical. In determining whether this standard is satisfied, it shall be assumed that:

- a. 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;
- b. 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; and
- c. there is reflection by water on all sides and as close as is consistent with the damaged condition of the package.

G. Evaluation of an Array of Packages of Fissile Material

1. The effect of the transport environment on the nuclear criticality safety of an array of packages of fissile material shall be evaluated by subjecting a sample package or a scale model, by test or other assessment, to the hypothetical accident conditions specified in H., I., or J., below, for the proposed fissile class, and by assuming that each package in the array is damaged to the same extent as the sample package or scale model. In the case of a Fissile Class III shipment, the manager or other designated official may, taking into account controls to be exercised by the shipper, permit the shipment to be evaluated as a whole rather than as individual packages, and either with or without the transporting vehicle, for the purpose of one or more tests.
2. In determining whether the standards of H.2., I.1.b., and J.2., below,

are satisfied, it shall be assumed that:

- a. the fissile material is in the most reactive credible configuration consistent with the damaged condition of the package, the chemical and physical form of the contents, and controls exercised over the number of packages to be transported together; and
- b. 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.

H. Specific Standards for a Fissile Class I Package

A Fissile Class I package shall be so designed and constructed and its contents so limited that:

1. any number of such undamaged packages would be subcritical in any arrangement, and with optimum interspersed hydrogenous moderation unless there is a greater amount of interspersed moderation in the packaging, in which case that greater amount may be considered; and
2. two hundred and fifty such packages would be subcritical in any arrangement, if each package were subjected to the hypothetical accident conditions specified in annex 2, below, as the Free Drop, Thermal, and Water Immersion conditions, in the sequence listed in annex 2, with close reflection by water on all sides of the array and with optimum interspersed moderation unless there is a greater amount of interspersed moderation in packaging, in which case that greater amount may be considered. The condition of the package shall be assumed to be as described in G., above.

I. Specific Standards for a Fissile Class II Package

1. A Fissile Class II package shall be so designed and constructed and its contents so limited, and the number of such packages which may be transported together so limited, that:
 - a. five times that number of such undamaged packages would be subcritical in any arrangement if closely reflected by water; and

- b. twice that number of such packages would be subcritical in any arrangement if each package were subjected to the hypothetical accident conditions specified in annex 2, below, as the Free Drop, Thermal, and Water Immersion conditions, in the sequence listed in annex 2, with close reflection by water on all sides of the array and with optimum interspersed hydrogenous moderation unless there is a greater amount of interspersed moderation in the packaging, in which case that greater amount may be considered. The condition of the package shall be assumed to be as described in G., above.

2. The transport index for each Fissile Class II package is calculated by dividing the number 50 by the number of such Fissile Class II packages which may be transported together as determined under the limitations of I., above. The calculated number shall be rounded up to the first decimal place.

J. Specific Standards for a Fissile-Class III Shipment

A package for Fissile Class III shipment shall be so designed and constructed and its contents so limited, and the number of packages in a Fissile Class III shipment shall be so limited that:

1. the undamaged shipment would be subcritical with an identical shipment in contact with it and with the two shipments closely reflected on all sides by water; and
2. the shipment would be subcritical if each package were subjected to the hypothetical accident conditions specified in annex 2, below, as the Free Drop, Thermal, and Water Immersion conditions, in the sequence listed in annex 2, with close reflection by water on all sides of the array and with the packages in the most reactive arrangement and with the most reactive degree of interspersed hydrogenous moderation which would be credible considering the controls to be exercised over the shipment. The condition of the package shall be assumed to be as described in G., above. Hypothetical accident conditions different from those specified in this subparagraph may be approved by the manager or other designated official if the controls proposed to be exercised by the shipper are demonstrated to be adequate to assure the safety of the shipment.

ANNEX 1

NORMAL CONDITIONS OF TRANSPORT

1. **Heat** - Direct sunlight at an ambient temperature of 130° F in still air.
2. **Cold** - An ambient temperature of -40° F in still air and shade.
3. **Pressure** - Atmospheric pressure of 0.5 times standard atmospheric pressure.
4. **Vibration** - Vibration normally incident to transport.
5. **Water Spray** - A water spray sufficiently heavy to keep the entire exposed surface of the package except the bottom continuously wet during a period of 30 minutes.
6. **Free Drop** - Between 1 1/2 and 2 1/2 hours after the conclusion of the water spray test, a free drop through the distance specified below onto a flat essentially unyielding horizontal surface, striking the surface in a position for which maximum damage is expected.
7. **Corner Drop** - A free drop onto each corner of the package in succession or in the case of a cylindrical package, onto each quarter of each rim, from a height of 1 foot onto a flat essentially unyielding horizontal surface. This test applies only to packages which are constructed primarily of wood or fiberboard, and do not exceed 110 pounds gross weight, and to all Fissile Class II packagings.
8. **Penetration** - Impact of the hemispherical end of a vertical steel cylinder 1 1/4 inches in diameter and weighing 12 pounds, dropped from a height of 40 inches onto the exposed surface of the package which is expected to be most vulnerable to puncture.
9. **Compression** - For packages not exceeding 10,000 pounds in weight, a compressive load equal to either 5 times the weight of the package or 2 pounds per square inch 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.

Free Fall Distance	
Package Weight (pounds)	Distance (feet)
Less than 10,000	4
10,000 to 20,000	3
20,000 to 30,000	2
More than 30,000	1

ANNEX 2

HYPOTHETICAL ACCIDENT CONDITIONS

1. **Free Drop** - A free drop through a distance of 30 feet onto a flat essentially unyielding horizontal surface, striking the surface in a position for which maximum damage is expected.
2. **Puncture** - A free drop through a distance of 40 inches striking, in a position maximum damage is expected, the top end of a vertical cylindrical mild steel bar mounted on an essentially unyielding horizontal surface. The bar shall be 6 inches in diameter, with the top horizontal and its edge rounded to a radius of not more than one-quarter inch, and of such a length as to cause maximum damage to the package, but not less than 6 inches long. The long axis of the bar shall be perpendicular to the unyielding horizontal surface.
3. **Thermal** - Exposure to a thermal test in which the heat input to the package is not less than that which would result from exposure of the whole package to a radiation environment of 1475° F for 30 minutes with an emissivity coefficient of 0.9, assuming the surfaces of the package have an absorption coefficient of 0.8. The package shall not be cooled artificially until 3 hours after the test period unless it can be shown that the temperature on the inside of the package has begun to fall in less than 3 hours.
4. **Water Immersion (fissile material packages only)** - Immersion in water to the extent that all portions of the package to be tested are under at least 3 feet of water for a period of not less than 8 hours.

ANNEX 4

TESTS FOR SPECIAL FORM MATERIAL

1. **Free Drop** - A free drop through a distance of 30 feet into 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 1-inch diameter steel rod weighing 3 pounds, dropped through a distance of 40 inches. The capsule or material shall be placed on a sheet of lead, of hardness number 3.5 to 4.5 on the Vickers scale, and not more than 1-inch thick, supported by a smooth essentially unyielding surface.
3. **Heating** - Heating in air to a temperature of 1475° 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 - pH 8, with a maximum conductivity of 10 micromhos per centimeter.

Appendix C. Supporting Calculations for Neutron Shipping Container, Model 4T

LIFTING DEVICES

AEC and DOT regulations require that a cask lifting device be able to support three times the weight of the loaded package without generating yield stress in any cask material. This section examines cask conformity to that requirement.

Figure C-1 shows the cask lid lug that is used to lift the entire cask. The lug is fabricated from a 3/4 in.-thick A-36 steel plate which has a tensile yield stress (S_{yp}) of 36,000 psi and a shear yield stress ($1/2 S_{yp}$) of 18,000 psi. We determine the actual yield stress of the lifting lug by

$$L = FW/N$$

where

L = load/lug-lb

W = cask weight = 7000 lb

N = number of lugs = 1

F = safety factor = 3.

Substituting,

$$L = \frac{3 \times 7000}{1} = 21,000 \text{ lb.}$$

Fig. C-1. Cask lifting lug: Center plug.

Bearing Stress at Section AA

$$S = \frac{L}{A},$$

where

$$A = \text{area} = 1.5 \times 0.75 = 1.125 \text{ in.}^2$$

$$S = \frac{21,000}{1.125} = 18,650 \text{ psi (<36,000 psi).}$$

Tensile Stress at Section AA

$$S = \frac{L}{A},$$

where

$$A = (3.00 - 1.50) \times 0.75 = 1.125 \text{ in.}^2$$

$$S = \frac{21,000}{1.125} = 18,650 \text{ psi (<36,000 psi).}$$

Shear Stress at Section BB

$$S_s = \frac{L}{A},$$

where

$$A = 2 \times 1.5 \times 0.75 = 2.25 \text{ in.}^2$$

$$S_s = \frac{21,000}{2.25} = 9,320 \text{ psi } (< 18,000 \text{ psi}).$$

Figure C-2 shows the flat plate of the lid with a load (L) applied to the lifting lug. Find maximum stress (occurs at 15-in. diameter).^{C-1}

$$S = \frac{3L}{2\pi t^2} \left[\frac{2a^2 (m+1) \log \frac{a}{b} + a^2 (m-1) - b^2 (m-1)}{a^2 (m+1) + b^2 (m-1)} \right],$$

where

S = stress-psi,

L = applied load-lb = 3

× 7000 = 21,000 lb

t = plate thickness-in. = 1 in.

m = reciprocal of Poisson's

ratio = $\frac{1}{0.26} = 3.84$

a = outer radius-in. = 14.37 in.

b = inner radius-in. = 7.5 in.

Therefore,

Fig. C-2. Top plate of center plug.

$$S = \frac{3 \times 21,000}{2 \times \pi \times (1)^2} \left[\frac{2(14.37)^2 (3.84 + 1) \log \frac{14.37}{7.5} + (14.37)^2 (3.84 - 1) - (7.5)^2 (3.84 - 1)}{(14.37)^2 (3.84 + 1) + (7.5)^2 (3.84 - 1)} \right]$$

$$= \frac{63,000}{6.28} \left[\frac{1300 + 587 - 160}{1000 + 160} \right] = \frac{63,000 \times 1727}{6.28 \times 1160}$$

$$= 14,928 \text{ psi } (< 36,000 \text{ psi}).$$

Fig. C-3. Container lifting lug.

The container body shown in Fig. 1 has four lifting lugs, but only two lugs will be used to lift the cask during testing. The lugs are fabricated from 3/4-in.-thick A-36 steel plate which has a tensile yield stress (S_{yp}) of 36,000 psi and a shear yield stress ($1/2 S_{yp}$) of 18,000 psi (Fig. C-3). We determine the actual yield stress of the lifting lugs by

$$L = FW/N,$$

where

F = safety factor = 3

W = cask weight = 7000 lb

N = number of lugs = 2.

Substituting,

$$L = \frac{3 \times 7000}{2} = 10,500 \text{ lb.}$$

Bearing Stress at Section AA

$$S = \frac{L}{A} = \frac{10,500}{1.25 \times 0.75} = 11,200 \text{ psi } (< 36,000 \text{ psi}).$$

Tensile Stress at Section AA

$$S = \frac{L}{A} = \frac{10,500}{(3.00 - 1.25) \times 0.75} = 8000 \text{ psi } (< 36,000 \text{ psi}).$$

Weld Shear Stress Near Section BB

Assume all of the load is taken by the 1/2-in.-thick plate and that the weld is loaded in shear.

$$S_s = \frac{L}{A \times E},$$

where

A = area of weld in shear

$$= 2 \times 0.5 \times 4.5 = 4.5 \text{ in.}^2$$

E = weld efficiency = 0.7 for weld joints attained by double welding. ^{C-2}

$$S_s = \frac{10,500}{4.50 \times 0.7} = 3333 \text{ psi } (< 18,000 \text{ psi}).$$

TIEDOWN DEVICES

Figure C-4 shows the cask tied to a vehicle. The tiedown system consists of four lugs connected to the vehicle bed by steel cables. The base of the cask is also secured to the vehicle bed.

The tiedown lugs are 3/4-in.-thick A-36 steel plate and the I-beams at the container base are 4 in. standard 9.5 lb/ft, A-36 steel. A-36 steel has a yield point stress of 36,000 psi and a shear stress of 18,000 psi. For a cask weighing 7000 lb, the tiedown devices are required to withstand the following forces, applied at the center of gravity, without exceeding the yield stress of the material:

$$P_h = \text{horizontal component} = 10 \times \text{wt} = 10 \times 7000 = 70,000 \text{ lb}$$

$$P_t = \text{transverse component} = 5 \times 7000 = 35,000 \text{ lb}$$

$$P_v = \text{vertical component} = 2 \times \text{wt} = 2 \times 7000 = 14,000 \text{ lb.}$$

1. Find the maximum tensile load, L_{max} , that could be applied to the ends of the I-beams to produce a yield stress in the welds (Fig. C-5). Assume that the beam is rigid and not over stressed.

Fig. C-4. Drawing of cask secured to vehicle. See Fig. C-8 for side view.

Fig. C-5. I-beams welded to container.

$$L_{\max} = \frac{AS_{yp}E}{N}$$

where

A = area of weld per beam = $7 \times 2 \times 1/4 \times 0.707 = 2.47 \text{ in.}^2$

E = weld efficiency = 0.5 weld not spot examined

S_{yp} = yield stress = 36,000 psi

N = number of beam ends = 2.

$$L_{\max} = \frac{2.47 \times 36,000 \times 0.5}{2} = 22,250 \text{ lb/beam end.}$$

2. Find maximum load permissible ($L_{\max}$ /beam end) on 4-in. I-beam.

Figure C-6 shows a cantilevered beam, where the tensile stress at Section AA is

$$L_{\max} = \frac{S_{yp}Z}{l}$$

where

S_{yp} = yield stress = 36,000 psi

l = length-in. = 15 in.

Z = section modulus-in.³ = 3.3 in.³

Substituting,

$$L_{\max} = \frac{36,000 \times 3.3}{15} = 7900 \text{ lb.}$$

These calculations show that the beams on the base are limited to a cantilevered load of 7900 lb at the ends of each beam.

Fig. C-6. Cantilevered I-beam.

3. Find $L_{\max}$ at Section CC at a maximum yield stress of 36,000 psi (Fig. C-3).

$$L_{\max} = S_{yp} \times A$$

where

S_{yp} = 36,000 psi

A = area = $(4.00 - 1.50) \times 0.75 = 1.88 \text{ in.}^2$

$$L_{\max} = 36,000 \times 1.88 = 67,800 \text{ lb.}$$

4. Find $L_{\max}$ at the 1.50-in.-diam hole where the bearing stress (S_{yp}) is 36,000 psi.

$$L_{\max} = S_{yp}A = 36,000 \times 1.50 \times 0.75 = 40,500 \text{ lb.}$$

5. Find $L_{\max}$ at weld in Section BB.

$$L_{\max} = S_s A E,$$

where

$$S_s = \text{shear stress at yield} = 18,000 \text{ psi}$$

$$A = \text{weld area} = 2 \times 4.5 \times 0.5 = 4.5 \text{ in.}^2$$

$$E = \text{weld efficiency} = 0.7$$

$$L_{\max} = 18,000 \times 4.5 \times 0.7 = 56,700 \text{ lb.}$$

These calculations show that the bearing stress limits the force applied to the tiedown lug to 40,600 lb/lug.

6. Find the maximum force that can be applied to the steel rope used to secure the cask to the vehicle bed.

A 3/4-in. diameter 6 X 19 steel cable with a breaking strength of 51,200 lb ties down the cask. The wire rope fittings are drop forged steel and are rated equal to or better than the load capacity of the wire rope. Wire rope is normally plow steel, SAE 1045. The yield stress of wire rope is calculated by

$$S_{\text{ultimate}} = 115,000 \text{ psi}$$

$$S_{yp} = 80,000 \text{ psi}$$

$$A = \frac{P}{S},$$

where

$$A = \text{effective cross sectional area-in.}^2$$

$$P = \text{load applied-lb}$$

$$S = \text{unit stress-psi.}$$

$$A = \frac{P \text{ (at breaking strength)}}{S_{\text{ultimate}}} = \frac{51,200}{115,000} = 0.446 \text{ in.}^2$$

$$P = S_{yp} \times A = 80,000 \times 0.446 = 35,600 \text{ lb}$$

Therefore, 3/4-in.-diam steel cable will reach its yield stress at 35,600 lb.

ANALYSIS OF THE TIEDOWN SYSTEM

The 4-in. I-beams will be secured to the vehicle bed. From previous calculations, this force ($L_{\max}$) is limited to 7900 lb for each end of the I-beam.

1. Find the maximum force, P_b , which may be exerted on the end of each 4-in. I-beam after the vertical component P_v has been absorbed by the I-beams (Fig. C-7). This may be calculated by

$$nP_b = nL_{\text{max/beam}} - P_v + W.$$

where

P_b = load-lb that may be applied to each I-beam end

n = number of I-beam ends = 6

$L_{\text{max/beam}}$ = load to produce yield stress in beam = 7900 lb

P_v = vertical component force = $2W = 14,000$ lb

W = cask weight = 7000 lb

Thus,

$$P_b = \frac{6 \times 7,900 - 14,000 + 7,000}{6} = 6,740 \text{ lb.}$$

Fig. C-7. Vertical forces acting on container.

2. Find the load on the tiedown lug and wire rope (P_c) to counteract the P_h (10 W) force only (Fig. C-8).

Moments were taken about point x and an assumption was made that only the wire ropes, 3 and 4, and the end of beams 8, 9 and 10 are effective in securing the cask to the vehicle. To simplify the calculations it was also assumed that each beam would take one-half of its maximum permissible load in the P_v direction and the other half in the P_t direction.

$$\cos 45^\circ \times n_c \times P_c \times ma + \frac{nP_b \times ma}{2} - P_h \times ma = 0,$$

where

n_c = number of wire ropes

ma = moment arm

P_c = force in wire ropes

P_b = load permitted on end of beams after deducting P_v and W loads = 6740 lb

$P_h = 10W = 10 \times 7,000 = 70,000$ lb

n = number of I-beam ends = 3.

Fig. C-8. Cask secured to vehicle. See Fig. C-4 for plan view.

$$\cos 45^\circ \times 2 \times P_c \times 64 + \frac{3 \times 6740 \times 54}{2} - 70,000 \times 28 = 0,$$

using algebra

$$P_c = \frac{1,960,000 - 545,000}{\cos 45^\circ \times 2 \times 64} = 15,620 \text{ lb (due to } P_h \text{ force only).}$$

3. Find the load on the tiedown lug and the wire rope (P_c) induced by the tangential force (P_t) only.

Moments were taken about point y and an assumption was made that only the wire ropes 1 and 4, and the end of beams 5 and 10 were effective in securing the cask to the vehicle bed in the P_t direction. It was also assumed that one-half of the P_b force was used to react to the P_t force.

$$\sin 45^\circ \times n_c \times P_c \times ma + \frac{n \times P_b \times ma}{2} - P_t \times ma = 0$$

where

n_c = number of wire ropes = 2

P_c = force in wire rope-lb

ma = moment arm-in.

P_b = 6740 lb

P_t = tangential force = 5 W = 35,000 lb

n = number of I-beam ends = 2.

Substituting,

$$\sin 45^\circ \times 2 \times P_c \times 64 + \frac{2 \times 6740 \times 44}{2} - 35,000 \times 28 = 0.$$

Solving for P_c ,

$$P_c = \frac{980,000 - 296,000}{0.707 \times 2 \times 64} = 7,560 \text{ lb (due to } P_t \text{ load only).}$$

Therefore, the maximum total load on each wire rope will be the sum of P_c loads that resulted from the horizontal and transverse forces P_h and P_t . Or,

$$P_{c \text{ total}} = 15,620 + 7,560 = 23,180 \text{ lb (<35,600 lb).}$$

Previous calculations indicate that the tiedown lugs may be subjected to loads of up to 40,600 lb/lug and that each wire rope may be subjected to forces of up to 35,600 lb before reaching the yield stress of the materials. Therefore, this tiedown system is satisfactory.

STRUCTURAL STANDARDS FOR LARGE QUANTITY PACKAGING

If the cask were uniformly loaded as a simple beam with a total force of five times its weight, the stress must not exceed the yield stress of the material. The outer shell is 1/4-in. A-7 steel plate and has a yield stress of 33,000 psi (Fig. C-9).

1. Find section modulus of 41-in. diameter tube.

$$Z = 0.098 \frac{D^4 - d^4}{D}$$

where

D = outer diameter = 41.0 in.

d = inner radius = 40.5 in.

Substituting,

$$Z = 0.098 \frac{41^4 - 40.5^4}{41} = 310 \text{ in.}^3$$

2. Find the beam bending stress.

$$S = \frac{W\ell}{8Z}$$

where

S = tensile stress-psi

W = total load applied-lb = $5 \times 7000 = 35,000$ lb

ℓ = length of beam-in. = 48.5 in.

Z = section modulus = 310 in.³

Solving for S ,

$$S = \frac{35,000 \times 48.5}{8 \times 310} = 685 \text{ psi } (< 33,000 \text{ psi}).$$

3. Find the maximum allowable pressure in the shipping container.

Material: SA-7 Carbon Steel

$$S_{yp} = 33,000 \text{ psi (Ref. C-2, Sec. 8)}$$

- a. Check outer wall for internal or external pressure:

Allowable tensile stress (S) = 12,650 psi (Ref. C-2, Ch. UCS-23)

Weld efficiency (E) = 0.6 (Ref. C-2, Ch. UCS-23)

Wall thickness (t) = 0.25 in.

Wall radius (R) = 20.25 in.

Allowable pressure:

$$\begin{aligned} P &= (SEt)/(R + 0.5t) = [(12,650)(0.6)(0.25)]/[20.25 + 0.6(0.25)] \\ &= 93 \text{ psig } (> 70 \text{ psig, rupture disc internal pressure;} \\ &\quad > 25 \text{ psig external pressure per regulations).} \end{aligned}$$

Fig. C-9. Cask uniformly loaded as a simple beam.

- b. Check upper inner shell for external pressure: (Ref. C-2, Ch. UG-28 and Fig. UCS-28.2)

Outside diam (D) = 25.5 in.

Thickness (t) = 0.25 in.

Length (L) = 17.25 in.

$$D/t = 25.5/0.25 = 102$$

$$L/D = 17.25/25.5 = 0.678$$

Therefore: B = 15,500.

Allowable pressure:

$$P = 15,500/102 = 152 \text{ psig } (>70 \text{ psig rupture disc}).$$

- c. Check lower inner shell for external pressure:

D = 16 in.

t = 0.25 in.

L = 23.5 in.

$$D/t = 16/0.25 = 64$$

$$L/D = 23.5/16 = 1.47$$

B = 14,200

Allowable pressure:

$$P = 14,200/64 = 222 \text{ psig } (>70 \text{ psig rupture disc}).$$

THERMAL ANALYSIS

AEC regulations require that the 200 W generated by nuclear decay be dissipated by the shipping cask. To determine whether the cask satisfied AEC requirements, we calculated the temperatures both inside and at the surface of the cask assuming both normal transportation and hypothetical accident conditions.

Cask Surface Temperature

The surface temperature may be calculated by assuming that the heat input to the container surface from solar radiation and source decay is equal to the heat loss to the air.^{C-3}

Solar Heat

$$Q_s = A e I, \text{ (Ref. C-3, Ch. 4)}$$

where

A = projected area of vessel = 13.6 ft²

e = surface absorptivity for solar radiation = 0.25 (white enamel)

I = incident solar radiation on a normal surface (av 10 a.m. to 2 p.m.) on a clear day = 250 Btu/hr-ft²

$$Q_s = (13.6)(0.25)(250) = 850 \text{ Btu/hr.}$$

Nuclear Heat (Source Decay)

$$Q_n = 683 \text{ Btu/hr (200 W)}$$

Total heat input:

$$850 + 683 = 1533 \text{ Btu/hr}$$

Heat loss to air:

$$Q_c = CRa^{1/3}(T_s - T_a)^{4/3}A, \text{ (Ref. C-3, Ch. 7)}$$

where

C = convection coefficient = 0.12

R = thermal conductivity of air = 0.0177 Btu/hr-ft°F

a = thermal property of air = $0.68 \times 10^6/\text{ft}^3\text{°F}$

T_s = surface temperature of container

T_a = air temperature = 130°F

A = vertical surface area of container = 42.7 ft².

Thus,

$$\begin{aligned} \text{Heat loss to air} &= (0.12)(0.0177)(0.68 \times 10^6)^{1/3}(T_s - 130)^{4/3}(42.7) \\ &= 1533 \text{ Btu/hr} \end{aligned}$$

Solving for $T_s = 180^\circ\text{F}$.

Temperatures Inside the Cask

Temperature of inner wall of spodumene-gypsum container:

The spodumene-gypsum container is a short thick-walled cylinder that may be assumed to be a sphere for purposes of heat transfer.

Heat Transfer Rate

$$Q = [2\pi R(T_2 - T_0)] / (D_2^{-1} - D_0^{-1}),$$

where

R = thermal conductivity of spodumene-gypsum = 0.28 Btu/hr-ft-°F,

T_2 = inside temperature,

T_0 = outside temperature = 180°F,

D_2 = inside diameter = 1.92 ft,

D_0 = outside diameter = 4.16 ft.

But,

$$Q = 683 \text{ Btu/hr (200 W)},$$

$$683 = [2\pi(0.28)(T_2 - 180)] / [(1.92)^{-1} - (4.16)^{-1}],$$

$$T_2 = 289^\circ\text{F}.$$

Temperature of the Gamma Shield

Since the gamma shield is constructed from depleted uranium and lead (good thermal conductors), the temperature throughout should be essentially uniform. The rate of heat transfer across the gap separating the inner and outer vessel is

$$Q = S F_a F_e A (T_1^4 - T_2^4),$$

where

S = Boltzmann Constant = 0.173×10^{-8} Btu/hr-ft²-°F⁴,

F_a = configuration factor = 1.0,

A = surface area of inner vessel = 7.5 ft²,

T_1 = temperature of inner vessel,

T_2 = temperature of outer vessel = 289°F (749°R),

Q = heat transfer rate = 683 Btu/hr,

F_e = emissivity factor = $(1/e_1 + 1/e_2 - 1)^{-1}$,

where

e_1 = emissivity of inner vessel = 0.43 (stainless steel),

e_2 = emissivity of outer vessel = 0.92 (gray paint).

Solving for F_e ,

$$F_e = (1/0.43 + 1/0.92 - 1)^{-1} = 0.413.$$

Therefore the heat transfer rate is

$$Q = (0.173 \times 10^{-8}) (1.0) (0.413) (7.5) [T_1^4 - (749)^4] = 683 \text{ Btu/hr},$$
$$T_1 = 816^\circ\text{R} = 356^\circ\text{F}.$$

Thermal Analysis of a Hypothetical Fire

EURATOM has conducted tests where several lead shielded shipping casks with gypsum outer layers were subjected to a furnace test after being dropped 30 ft.^{C-4} One cask, weighing over 1400 lb and designed with a 1-in. outer layer of wet plaster gypsum was placed in a furnace whose temperature toward the end of the test averaged 1400°F. It was removed from the furnace while internal temperatures continued to be monitored. The cavity temperature increased from 60°F, 15 min after the start of the fire, to a 220°F maximum temperature approximately 90 min after the start of the fire.

As a result of this and other tests, the EURATOM report concludes that "...plaster (gypsum) provides especially good insulation against fire, (and) while under normal conditions of transport (it) maintains a reasonably high thermal conductivity."

The Neutron Shipping Cask, Model 4T has 12 in. of moist gypsum-spodumene composite and provides considerably greater fire protection than the 1-in. layer of gypsum used in the EURATOM tests.

PRESSURE BUILDUP IN SPECIAL FORM CAPSULE

The following calculations determine pressure buildup in the special form capsule. The pressure buildup is caused by helium formed by radioactive decay.

Metal container: outside: 1.25 in. diam $\times$ 2.875 in. long.

inside: 1.125 in. diam $\times$ 2.500 in. long.

Metal volume = $1.04 \text{ in.}^3 = 17.05 \text{ cc}$

Crystal density = 8 g/cc (curium oxide)

Mass = 50 g

Volume = 6.25 cc

Total displacement = $17.05 + 6.25 = 23.30 \text{ cc}$

Container volume = 69.4 cc

Clearance volume = $69.4 - 23.3 = 46.1 \text{ cc}$

Gas generation = 0.4825 cc/day (STP)

Gas generation in 104 days = $104 (0.4825) = 46.1 \text{ cc}$

Pressure of vessel in 104 days at 68°F

$$P = 14.7 [(46.1 + 46.1)/(46.1)] - 14.7 = 14.7 \text{ psig}$$

Pressure of vessel in 104 days at 1500°F

$$P = (14.7 + 14.7) [(1500 + 460)/(68 + 460)] - 14.7 = 94.3 \text{ psig} (<150 \text{ psig})$$

FREE DROP ANALYSIS—HYPOTHETICAL ACCIDENT

Twelve stainless steel studs and stud mounting sleeves are used to absorb the kinetic energy of the center plug mass in the 30-ft drop test (Fig. C-10). The worst condition possible would be if the cask fell upside down on an open manhole. In this condition the special studs and sleeves must absorb all of the kinetic energy of the moving mass in the center cavity.

Fig. C-10. Energy absorption by special stud mounts—30-ft drop.

The energy absorption capability of the stud mounting system was tested by dropping two separate test units from a 30-ft height. Figure C-11 depicts a 211-lb weight $[(2538 \text{ lb})/(12 \text{ studs}) = 211 \text{ lb/stud}]$ suspended from a stud mounting unit. Each assembly was mounted into an outer housing and then dropped from a 30-ft height onto a heavy steel plate. All

Fig. C-11. Stud mounting detail.

compute the force required to produce this stress level in the stud by

$$L = S_{\text{ultimate}} A,$$

where

$$L = \text{force-lb}$$

$$S_{\text{ultimate}} = \text{stress in bolt} = 96,000 \text{ psi}$$

$$A = \text{area of stud} = \frac{\pi d^2}{4} = \frac{3.14 \times (0.812)^2}{4} = 0.518 \text{ in.}^2$$

Substituting,

$$L = 96,000 \times 0.518 = 49,700 \text{ lb.}$$

Next, we compute the stress in the weld that connects the sleeve to the container body is a 49,700 lb force is applied to the stud.

$$S_s = \frac{L}{A},$$

where

$$S_s = \text{shear stress in weld}$$

$$L = \text{force applied} = 49,700 \text{ lb}$$

$$A = \text{area of weld} = \pi \times 2.00 \times 0.5 = 3.14 \text{ in.}^2$$

of the kinetic energy from the moving 211-lb weight was absorbed by the stud mounting sleeve and the stud.

In both cases the stud mounting sleeve was deformed into a bellows shape in the thin wall section, and the length of the sleeve was thereby shortened approximately 2 in. The length of each stud was increased by 7%. Graphic integration of the stress-strain curve for type 304 stainless steel indicates that at 7% elongation, the area under the curve is 3600 psi and at the ultimate strength (55%) the area is 44,700 psi (Fig. C-12). This comparison shows that theoretically, 12 times the energy that was absorbed in the 30-ft drop test is required to produce failure in the stud ($44,700/3,600$).

1. Find the shear stress in the weld of the stud sleeve, when the stud is stressed to its ultimate strength.

Figure -12 shows that stress at ultimate strength (σ_{ult}) is 96,000 psi. We com-

Fig. C-12. Stress-strain curve: Type 304 stainless steel.

Substituting,

$$S_s = \frac{49,700}{3.14} = 15,820 \text{ psi.}$$

2. Find the maximum shear stress permissible assuming weld material to be A-36 steel. C-5

$$S_s = 0.577 S_{\text{ultimate}}$$

where

S_s = ultimate shear stress

S_{ultimate} = ultimate tensile stress
= 58,000 psi.

$$S_s \text{ ultimate} = 0.577 \times 58,000 = 33,500 \text{ psi} (> 15,820 \text{ psi})$$

SHIELDING LOSS FROM 30-FT DROP TEST (Fig. C-13)

Horizontal Axis Impact^{C-6}

The nomograph on Page 61 of the *Cask Designers Guide* lists nondimensional quantities as

$$\frac{WH}{R t_s L \sigma_s} \text{ and } \frac{R \sigma_{pb}}{t_s \sigma_s} \text{ and } \frac{2R t_e}{L t_s},$$

where

W = cask weight = 7000 lb

H = drop height-inches = $30 \times 12 = 360$ in.

R = outer radius-inches = 20.5 in.

t_s = outer shell thickness-inches = 0.25 in.

t_e = thickness of steel end plate-inches = 0.50 in.

L = length of shell-inches = 48.5 in.

σ_s = dynamic flow stress in steel-psi = 33,000 psi.

σ_{pb} = dynamic flow stress in lead-psi.

The numerical value 400 psi is used for the gypsum-spodumene mixture since it is substituted in place of lead. Substituting,

$$\frac{WH}{R t_s L \sigma_s} = \frac{7000 \times 360}{20.5 \times 0.25 \times 48.5 \times 33,000} = 0.307.$$

$$\frac{R \sigma_{pb}}{t_s \sigma_s} + \frac{2R t_e}{L t_s} = \frac{20.5 \times 400}{0.25 \times 33,000} + \frac{2 \times 20.5 \times 0.50}{48.5 \times 0.25} = 0.995 + 1.69 = 2.685.$$

Fig. C-13. Shielding loss.

Fig. C-14. Corner drop test.

$$\theta = 31^\circ \quad (\text{Ref. C-6, Fig. 2.21})$$

$$d = R (1 - \cos \theta) = 20.5 (1 - \cos 31^\circ)$$

$$d = 2.93 \text{ in. (shielding loss).}$$

Corner Drop

A Lawrence Livermore Laboratory computer code, "DRIVE" (COMD 176-67) was used to calculate the deformation of a 41-in.-diam sphere dropped 30 ft (Fig. C-14). Assuming a 0.25-in.-thick steel wall and a 6500-lb force acting on the sphere, we found that the sphere was deformed 7.50 in.

Figure C-14 shows a 7.50-in. deformation on the corner of the model 4T cask. To produce a 7.50-in. deformation in this cask requires bending three concentric 0.25-in.-thick steel shells plus a total of 1.50-in.-thick flat steel plates at the end. Since the bending stress of a steel plate is proportional to the reciprocal of the square of the plate thickness, i.e.,

$$S = \frac{F(s)}{t^2}, \text{ then the ratio in stress between a 0.25-in. plate and a 1.50-in.}$$

plate is

$$\frac{S_{0.25}}{S_{1.50}} = \frac{\frac{F_s}{(0.25)^2}}{\frac{F_s}{(1.50)^2}} = 36$$

Therefore, the 1.50-in. plate will carry 36 times more force than a 0.25-in. plate at the same stress level.

It is therefore concluded that the DRIVE code calculation for the sphere was conservative when related to the actual cylindrical cask and that it is very unlikely that a 30-ft corner drop of the actual cask would produce an effective loss of shielding greater than 2.75 in.

Vertical Axis—End Drop

The DRIVE code was also used to calculate the deformation of the end of a 41-in. diameter right cylinder dropped 30 ft. The calculations were based on a vessel constructed entirely from 0.25-in. steel plate and weighing 7000 lb. The calculations indicate that the theoretical center of the cask would move 3 in. vertically but that the effectiveness of the shield would not change.

Puncture Analysis—30 ft Drop Test^{C-7}

Tests by Oak Ridge indicate that the 0.25-in.-thick A-7 steel outer jacket is adequate to survive the puncture test.

REFERENCES

- C-1. R. J. Roark, Formulas for Stress and Strain (McGraw-Hill, New York, 1954), p. 201.
- C-2. ASME Boiler and Pressure Code, Section VIII (American Society of Mechanical Engineers, New York, 1971).
- C-3. A. I. Brown, Introduction to Heat Transfer (McGraw-Hill, New York, 1958).
- C-4. Examination of the International Atomic Energy Agency's Regulations for Safe Transport of Radioactive Materials, Transnucleaire, Paris, Rept. EUR 3485-e, f (1968).
- C-5. F. B. Seeley and J. O. Smith, Advanced Mechanics of Materials (Wiley and Sons, New York, 1952).
- C-6. L. B. Shappert, Cask Designers Guide, Oak Ridge National Laboratory, Tenn., Rept. ORNL-NSIC-68 (1970).
- C-7. J. H. Evans, H. A. Nelms, and W. C. Stoddart, "Experimental and Analytical Development at ORNL for Demonstrating Shipping Cask Compliance with Federal Regulations," in Proc. Second Int. Symp. on Packaging and Transportation of Radioactive Materials (Union Carbide Corp. and the U.S. Atomic Energy Commission, Gatlinburg, Tennessee, 1968), p. 253.

Appendix D.

Properties of Gypsum-Spodumene Composite

The gypsum-spodumene composite is produced by combining equal parts by volume of casting gypsum ($\text{CaSO}_4 \cdot 1/2 \text{H}_2\text{O}$), spodumene ($\text{Li}_2\text{AlSi}_2\text{O}_6$) and water. The ingredients are mixed for 5 to 10 min in a plaster mixer and then poured. The resulting chemical reaction ($\text{CaSO}_4 \cdot 1/2 \text{H}_2\text{O} + 1-1/2 \text{H}_2\text{O} \rightarrow \text{CaSO}_4 \cdot 2 \text{H}_2\text{O}$) is exothermic and the setting time is from 10 to 30 min depending on the size of the pour. Excess water is trapped by the setting mixture into a homogeneous composite. The resulting solid strongly resembles gypsum wall plaster. Spodumene, which acts as an aggregate in the composite, is a water insoluble mineral of 20 to 140 mesh particle size, much like sand in texture and appearance.

Tests of the gypsum-spodumene composite were conducted at the Lawrence Livermore Laboratory, and yielded the following properties:

Density: 120 lb/ft³.

Ultimate compressive strength: 458 psi.

This was a test of four 1.0 in. diam by 3.5 in. long specimens conducted on a 10-ton compression test machine with a 1000-lb load test cell.

Modulus of Elasticity: 1.3×10^6 psi.

This was a confined compression test of two 1.25 in. diameter by 0.50-in.-long specimens conducted on a 60-ton compression test machine. Individual values were 1.2×10^6 psi and 1.4×10^6 psi.

Scratch Hardness: 82.6 S.

This was a test of five specimens as determined by a scratch hardness tester.

The ability of the gypsum-spodumene composite to withstand freezing was demonstrated by twice chilling a specimen to -320.4°F with liquid nitrogen and warming it to room temperature. No cracking, crumbling or other damage was evident.

No thermal properties tests were conducted on the composite. Since this material is similar to gypsum wall plaster (the sand in the plaster is replaced by spodumene in the composite), a value of 0.25 Btu-ft/hr-ft²(°F) was used for thermal conductivity in calculations. This is a commonly published value for gypsum wall plaster.

As the excess water in the composite is not chemically bound, it will boil at 212°F. At 262°F, the gypsum will dehydrate, reverting to the original hemi-hydrate ($\text{CaSO}_4 \cdot 1/2 \text{H}_2\text{O}$).

Appendix E. DOT Special Permit No. 6478

DEPARTMENT OF TRANSPORTATION
HAZARDOUS MATERIALS REGULATIONS BOARD
WASHINGTON, D. C. 20590

SPECIAL PERMIT NO. 6478

This special permit is issued pursuant to 46 CFR 146.02-25 of the U.S. Coast Guard (USCG) Dangerous Cargo Regulations and 49 CFR 170.15 of the Department of Transportation (DOT) Hazardous Materials Regulations, as amended, and on the basis of the June 24, 1969, petition by Lawrence Radiation Laboratory, Livermore, California; as supplemented by submittals to the U.S. Atomic Energy Commission, Division of Materials Licensing on January 28, 1970 and January 20, 1971.

1. Shipments of large quantities of fissile radioactive materials, special form, are hereby authorized in the packaging as described in this special permit and as further provided for herein. This packaging, when constructed and assembled as prescribed herein, with the contents as authorized herein meets the standards prescribed in the DOT Regulations, Sections 173.394(c)(2), 173.396(c)(3), and 173.398(c).
2. Each shipper, under this permit, other than the petitioner named above, shall register his identity with this Board prior to his first shipment, and shall have a copy of this permit in his possession before making any shipment.
3. The packaging authorized by this permit consists of an upright, double-walled, steel cask weldment, 3.5' diameter by 4' high, mounted on a structural steel base, with a bolted top plug closure. The cask shell encloses a spodumene-gypsum cement neutron shield aggregate. A separate inner gamma shield is used, when required, consisting of concentric cylinders of lead and depleted uranium. Contents are loaded in innermost sealed metal containers which are, in turn, loaded into "special form" capsules, or (when contents exceed 5000 curies), specifically within the Marman type capsule #MJN 68462. Either capsule is then placed within an internal capsule holder, or directly into the internal cavity of the gamma shield. The package is identified as the Model 4T neutron shipping cask and is described on Lawrence Radiation Laboratory Drawings Nos.: AAA 414964-OE, AAA 60-414965-OB, AAA 60-414963-OF, AAA 70-100076-OA, and Aeroquip Drawing No. MJN 88462 (Marman Capsule).

The total weight of the package is 7000 lbs. or 5100 lbs. (without gamma shield).

Contents must be limited such that the dose rate with or without the gamma shield at 3 feet from the surface of the bare capsule or bare gamma shield containing the capsule, would not exceed 1000 mrem/hr.

Spacers must be provided in the shipping cask cavity to prevent damage to contents due to internal movement.

4. The contents of each package authorized by this permit consists of large quantities of special form radioactive material, including fissile radioactive material. The maximum thermal decay energy of the contents must not exceed 200 watts, with the contents further limited to the dry, solid forms of the following:

- a. Not more than 250 grams of any combination of the isotopes of americium, curium, berkelium, californium, einsteinium, and fermium provided that:
 - (i) the total mass of any combination of americium-242, curium-245, curium-247, and/or californium-249 does not exceed 15 grams; and

(ii) the total mass of californium-251 does not exceed 3 grams; or

b. Combinations of the isotopes listed in paragraph (a) above, limited such that the sum, for all isotopes present, of the ratio between the total weight for each isotope, or combination as appropriate, to the permissible weight of that isotope (or combination), does not exceed unity.

5. The packaging authorized by this permit meets the requirements for shipment as Fissile Class III, with not more than one package per transport vehicle or stowage area.

6. The outside of each package must be plainly and durably marked "DOT SP 6478" and "TYPE B", in connection with and in addition to the other markings and labels prescribed by the DOT regulations. Each shipping paper issued in connection with shipments made under this permit must bear the notation "DOT SPECIAL PERMIT NO. 6478", in connection with the commodity description thereon.

7. Each package must have its gross weight plainly and durably marked on the outside of the package.

8. This permit authorizes shipments only by vessel, motor vehicle and rail.

9. For shipments by water:

a. A copy of this permit must be carried aboard any vessel transporting radioactive material under these terms.

b. The shipper or agent shall notify the USCG Captain of the Port in the port area through which the shipment is to be made, of the name of the vessel on which the shipment is to be made, and of the time, date, and place of loading or unloading. When the initial notification is given in a port area, it must be accompanied by a copy of this permit, addressed to the attention of that Captain of the Port.

c. Packages shall not be overstowed with any other cargo. If stowed below decks, the hold or compartment in which stowed must be ventilated.

10. Prior to each shipment authorized by this permit, the shipper shall notify the consignee of the dates of shipment and expected arrival.

11. Any incident involving loss of contents of the package must be reported to this Board at the earliest feasible moment.

12. The permit does not relieve the shipper or carrier from compliance with any requirement of the DOT Regulations, including 46 CFR Parts 146 to 149 of the USCG Regulations, except as specifically provided for herein.

13. This permit expires on May 31, 1973.

Issued at Washington, D.C.:

R. G. Schwing, Capt.
For the Commandant
U.S. Coast Guard

14 June 1971
(DATE)

W.R. Fiste
For the Administrator
Federal Highway Administration

16 June 1971
(DATE)

Mac E. Rogers
For the Administrator
Federal Railroad Administration

21 June 1971
(DATE)

Address all inquiries to: Secretary, Hazardous Materials Regulations Board, U.S.
Department of Transportation, Washington, D.C. 20590. Attention: Special Permits.

Dist: a, b, d, e, h, i

DEPARTMENT OF TRANSPORTATION
HAZARDOUS MATERIALS REGULATIONS BOARD
WASHINGTON, D.C. 20590

SPECIAL PERMIT NO. 6478
FIRST REVISION

Pursuant to 46 CFR 148.02-25 of the U.S. Coast Guard (USCG) Dangerous Cargo Regulations and 49 CFR 170.15 of the Department of Transportation (DOT) Hazardous Materials Regulations, as amended, and on the basis of the July 8, 1971, petition by the University of California, Lawrence Radiation Laboratory, Livermore, California:

Special Permit No. 6478 is hereby amended by revising paragraph (8) to read as follows:

"8. This permit authorizes shipments only by vessel, cargo-only aircraft, motor vehicle and rail. For shipments by aircraft, the provisions of §173.396(g)(1) apply; and a copy of this permit, kept current, must be carried aboard any aircraft transporting radioactive material under these terms.

All other terms of this permit, as revised, remain unchanged. The complete permit currently in effect consists of the original issue and the First Revision.

Issued at Washington, D.C.:

R. G. Schwing, Capt.
For the Commandant
U. S. Coast Guard

22 July 1971
(DATE)

W. R. Fiste
For the Administrator
Federal Highway Administration

27 July 1971
(DATE)

Mac E. Rogers
For the Administrator
Federal Railroad Administration

29 July 1971
(DATE)

Ellis C. Langford
For the Administrator
Federal Aviation Administration

2 August 1971
(DATE)