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SHIELDED NEUTRON SHIPPING CASK

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July 6, 1970

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This paper was prepared for presentation at
the 18th Conference on Remote System Technology, November 17 - 19, 1970
at Washington, D. C.

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ABSTRACT

A shielded neutron shipping cask was designed to transport three-gram quantities of californium 252. The cask weighs 25 tons and may be shipped by common carrier anywhere in the United States. Neutron sources will be packaged in all-metal pressure vessels suitable for use at 1500°F. Three source vessels, each three inches in diameter by twelve inches long, may be stored in a rotating magazine at the center of the cask. An eight-foot-long plug with grapple fingers locks the magazine during transport and is also used to remotely load or unload the neutron-source vessels. A Boral plate is used to absorb slow neutrons and a steel billet provides primary-gamma shielding near the center of the cask. The neutron shield consists of borated limonite concrete and borated gypsum cast into the cavities formed by two concentric steel shells.

INTRODUCTION

The increasing availability and use of neutron-emitting isotopes has made the design of a large capacity neutron shipping cask desirable (Figure 1).

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* This work was performed under the auspices of the United States Atomic Energy Commission.

Large scale isotope production at the Oak Ridge National Laboratory and the AEC's Savannah River Plant will make gram quantities of ^{252}Cf available within a relatively short time. This cask was designed to transport by road or railway, anywhere in the United States, sources with a neutron intensity of up to 9×10^{12} fission neutrons per second. Three grams of californium 252 or 400 grams of curium 244 are typical shipments that can be made in this cask. Several shielding calculations were made to optimize the weight and size of cask versus the integrated external radiation dose rate. The capture-gamma dose rate was reduced dramatically when a close-in Boral slow-neutron absorber and a steel primary-gamma shield was substituted for a stainless-steel-clad lead shield of a similar thickness. By changing the shielding materials and the bulk density of the concrete, the neutron shielding capacity of the cask was increased by a factor of six over the first design utilizing the stainless-steel-clad lead gamma shield and lesser density concrete.

The cask will safely dissipate 1,000 watts of decay heat from the radioactive source without the use of an external cooling system. A special bolted-closure special-form vessel was designed to contain the radioactive material. This vessel utilizes a stainless steel to stainless steel gasketing system and is suitable for internal pressures up to 150 psig at 1500°F. The vessel is reusable and may be assembled remotely using master-slave manipulators.

The cask may be dry loaded from either the top or bottom, or may be loaded underwater in a pool facility. At the Livermore neutron shielded chemistry cells[1] the cask will be bottom unloaded into an intercell underground transfer system. The cask was designed to meet the packaging standards for radioactive materials as listed in Chapter 0529 of the AEC Manual.

CASK CONSTRUCTION

The cask is almost spherical, (86 inches in diameter by 108 inches high) and weighs 25 tons. Two steel concentric shells (the external is one-inch thick and the inner is five-eighths-inch thick) form cavities into which the shielding mixtures are cast. The outer cavity is 11-3/8 inches thick and is filled with borated gypsum; the inner cavity is 21 inches thick and is filled with limonite concrete. A removable center section penetrates the concentric shells and houses a 2-5/8-inch thick steel shield with a 3/8-inch thick Boral (50% B_4C) inner liner. This center section, 17 inches in diameter by 9 feet long, also houses a rotating magazine and shutter mechanism. The rotating magazine has three wells, each three inches in diameter by twelve inches tall, for holding radioactive sources. A three-inch-diameter by eight-foot-long vertical plug locks the magazine and shutter in place during transport. This plug is equipped with grapple fingers on the lower end which are remotely operated by a choke-wire cable. To unload the primary vessel the grapple plug is raised to clear the rotating magazine; the magazine and shutter are then indexed, and the grapple plug is lowered and coupled to the primary vessel. The grapple fingers are locked in place by an over-center linkage and a positive 5/8-inch travel of the choke wire is required to open the fingers and thereby release the primary vessel. After rotating the shutter back to its normal transport position, and opening the cover plate at the bottom of the cask, the primary vessel is lowered from the cask to the hot cell transfer system by use of the vertical three-inch-diameter plug.

SOURCE TRANSFER

At Livermore, transfers of neutron emitters into or out of the shipping cask will be accomplished by bottom-type transfers (Figure 2). The cask will be moved over the center port of the underground intercell transfer system by a pneumatic-powered rail car. The lower support portion of the cask will be filled with water to provide neutron shielding as the neutron source passes out of (or into) the cask. The grapple plug is used to lower the primary vessels to the underground fork truck, or to pick up the source for loading into the magazine. Four feet of concrete shielding has been provided above the intercell transfer system to permit operator access to the cask area during transfers.

In order to permit loading of the cask underwater in a pool facility when direct bottom loading is not feasible, the outer exposed parts of the cask are fabricated from stainless steel or painted mild steel.

NEUTRON SHIELDING MATERIALS

The shielding materials that were selected for maximum neutron and gamma ray attenuation are shown as Case 7 at the top of Figure 3. In choosing the neutron-moderating materials, attention was given to obtaining mixes with a relatively high hydrogen content yet maintaining desirable mechanical and thermal properties. The borated limonite concrete (12% H_2O) and the borated gypsum (20% H_2O) will be poured and sealed in an as-cast state to preserve the initial water content of the mixture. The cask is fitted with rupture discs to prevent vessel rupture by pressurization that would be caused by a fire. The borated gypsum is a mixture consisting of 10 pounds casting-type gypsum, 1.2 pounds boron frits containing 16.4 percent elemental boron, and approximately five pounds of water. The bulk density of this mixture is 100 lbs/cu. ft. after curing. The borated limonite concrete is a mixture of portland cement, Blackburn limonite aggregate (3/8 inch size and smaller), 11 lbs of boron frits per cubic foot of mixture, and water which after curing weighs approximately 180 lbs/cu. ft. The Boral plate is a 3/8-inch thick aluminum-metalclad boron carbide-aluminum core containing 50 percent B_4C by weight.

Seven cases of different shielding materials and configurations were investigated using the ANISN[2] shielding code. The calculations were done in one-dimensional spherical geometry using elemental compositions. The neutron and gamma dose rates were calculated in the $S_{16}P_3$ mode using 27 energy groups for neutrons and 20 for gammas. The greatest reduction in dose rate resulted when the 3/8-inch-thick Boral plate was added near the neutron source and boron frits were included in the concrete mixture as "1/V" neutron absorbers. Optimization in shielding effectiveness resulted from using steel in lieu of lead for primary-gamma shielding, and increasing the bulk density of the concrete in the middle zone (limonite concrete) from 140 lbs/cu. ft. to 180 lbs/cu. ft.

A plot of the capture gamma dose rate for Case 1 and Case 7 (Figure 4) indicate a large absorption of slow neutrons in the center area by the Boral plate and a greater attentuation of capture-gamma rays by the denser limonite concrete. Comparing Case 7 to Case 1, the capture-gamma dose rate was reduced by a factor of 11, the primary-gamma dose by a factor of 22 and the neutron dose by a factor of 1.6. Since the primary-gamma and neutron dose rates in

Case 1 were only a small portion of the total dose rate (4% and 9%) the largest change was effected by reduction of the capture-gamma dose rate. The total dose rate at the surface of the cask for Case 7 is 5 x 10^{-12} mrem per hour per source neutron, which is sufficient shielding for shipments of up to three grams of californium 252. In Case 5, the materials used were identical with Case 7 except that a 30 mil cadmium sheet was used in place of the Boral plate. The shielding capability of Case 5 was nearly the same as Case 7 but was not used because of the low melting point of the cadmium metal.

INTERSTATE TRANSPORT

A semitrailer (Figure 5) will be provided to transport the cask on any first class road throughout the United States by common carrier. The cask will be bolted to the trailer frame at its base and braced with six one-inch-diameter plow-steel cables attached to the top section.

Because the cask is large and the shielding materials are good thermal insulators, a large temperature differential (500°F maximum) is required to dispose of the thermal output of the source to the atmosphere. An optional liquid cooling system has been provided for maintaining ambient temperature in the primary vessel. Since this cooling system may be lost in an accident, the neutron sources will be packaged in a pressure vessel suitable for continuous storage at 1500°F and the source intensity will be limited to a decay-heat output of 1000 watts.

CASK SURVIVAL IN AN ACCIDENT

It is mandatory that the cask remain intact and that the shielding not be impaired from an accident during transport. It is conceivable that the cask could be involved in a highway accident at high speed and the cask might ram the end of a steel girder. The spilled fuel from the tractor could ignite and engulf the cask in flames. It is essential that the source remain intact in the cask under these conditions and the loss of shielding be minimized. To simulate the above accident conditions, the cask was designed to survive a 30 foot drop, puncture, and 30 minute fire at 1475°F.

The outside steel plate (one-inch thick) and adjacent 11-3/8 inch-thick layer of borated gypsum provides excellent thermal insulation, puncture resistance, and energy absorption capability. The gypsum is an outstanding fire-resistant material and has been found to be an excellent thermal insulator for shipping casks[3].

The deformation of the cask wall caused by a 30 foot drop was analytically investigated using a dynamic, large-inelastic-deformation computer code[4]. It was assumed that the cask was an 86 inch diameter sphere with a one-inch-thick steel shell filled completely with gypsum. This is a conservative assumption because the cask is constructed with two concentric shells. The internal weight (40,000 lbs.) was distributed on the hemispherical half of the structure nearest the impacting surface. The gypsum was treated as a compressible medium with a bulk modulus of 119,000 psi. The calculations show that the largest permanent deformation will be six inches. This amount of deformation does not appreciably affect the shielding capability of the cask.

When subjected to severe impact loads the gypsum will compress, but not shatter, as is the case with concrete. Since cracks in shielding produce radiation hot spots and should be avoided, the gypsum is an ideal neutron shield which will absorb the impact energy but remain intact.

The adequacy of the outer shell to withstand the puncture accident was related to previous tests[5] at the Oak Ridge National Laboratory. These tests indicated that a one-inch-thick steel liner is adequate for a lead-filled cask weighing 25 tons. Gypsum has an advantage over lead in that it will not melt during a fire and run out the puncture hole. Steam may be generated but the basic configuration of the gypsum will not change.

CONCLUSION

This shipping cask has sufficient neutron and gamma shielding to ship multigram quantities of californium 252 and all of the other transplutonium isotopes. The size and weight of the cask has been optimized to permit transport on a semitrailer without exceeding local highway regulations. The cask may be loaded or unloaded in a non-shielded area with a minimal radiation exposure to the operator. The mechanical assemblies are simple but positive in action to assure full operator control. The center section of the cask is completely removable permitting revisions or additions if program requirements change.

REFERENCES

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2. Ward W. Engle, Jr., "Users Manual for ANISN, K-1693", Union Carbide Nuclear Division, March 30, 1967.

3. "Examination of the International Atomic Energy Safe Transport of Radioactive Materials", EUR 348 5-EF Volume IV Report, Chap. VII, Thermal Protection Methods.

4. DRIVE - Computer Code Described in Lawrence Radiation Laboratory Internal Report.

5. J. H. Evans, H. A. Helms, and W. C. Stoddard, "Experimental and Analytical Developments at Oak Ridge National Laboratory for Demonstrating Shipping Cask Compliance with Federal Regulations", 2nd International Symposium on Packaging and Transportation of Radioactive Materials, p. 253-267 (1968).

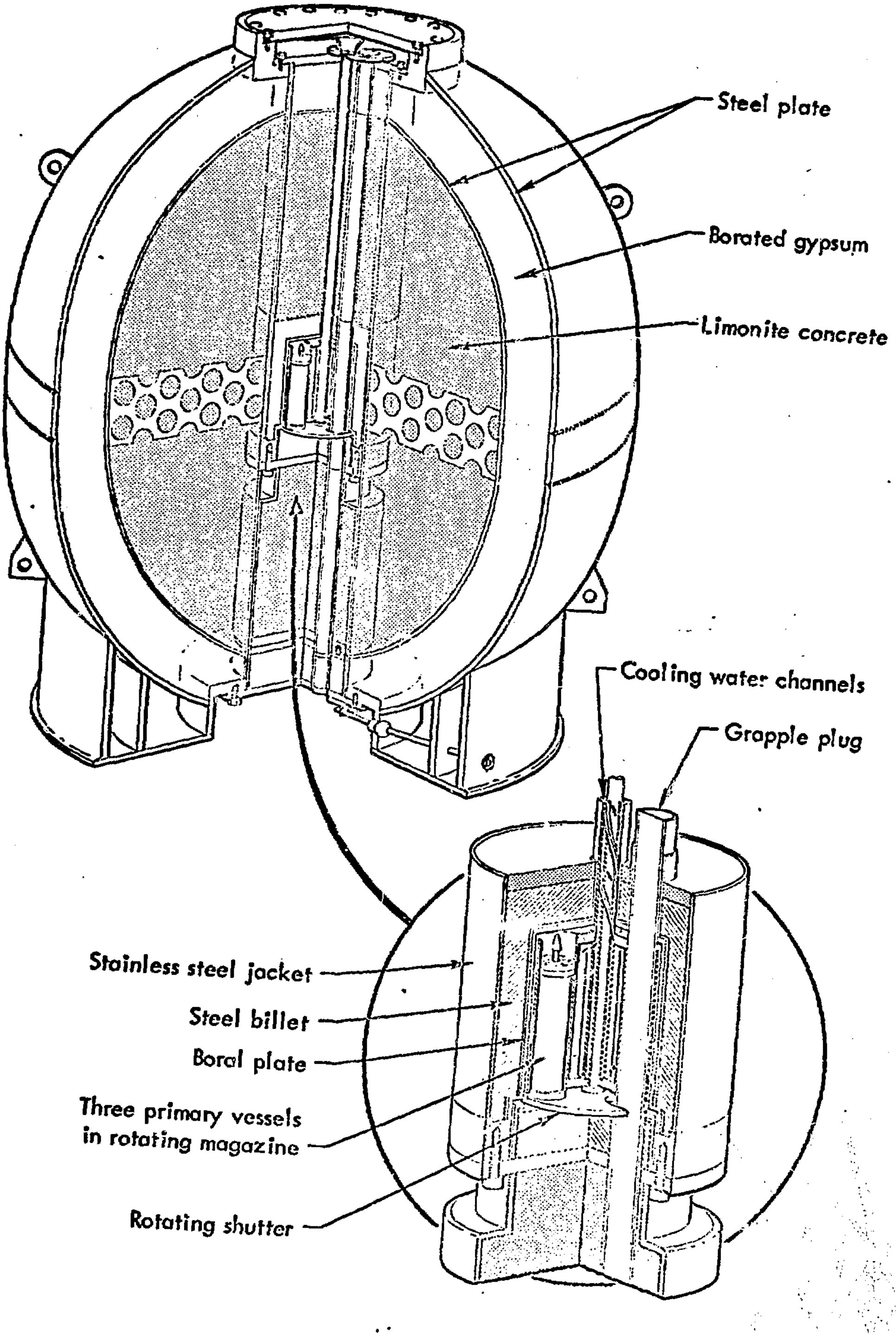

FIG. 1 SHIELDED NEUTRON SHIPPING CASK

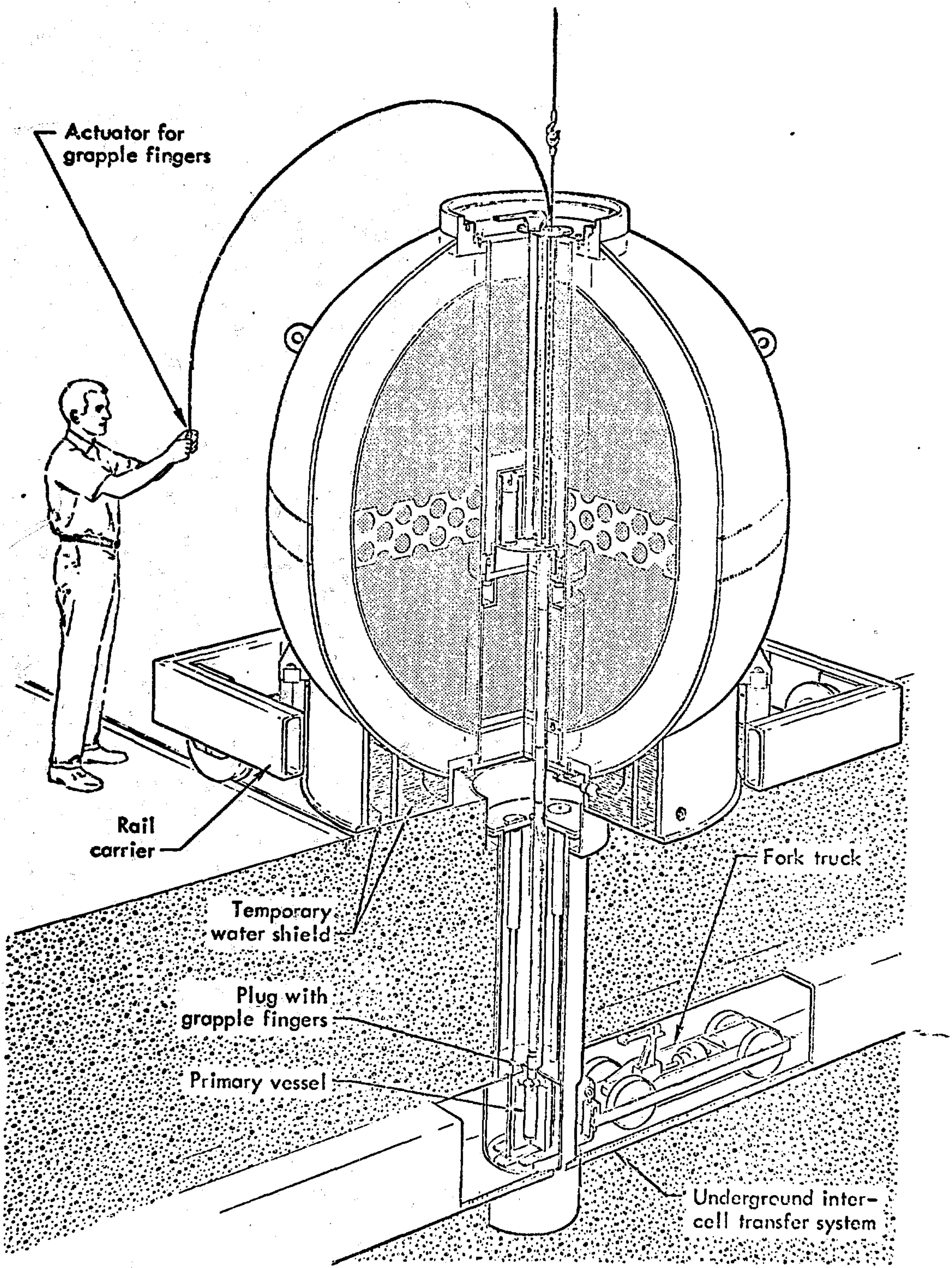

FIG. 2 BOTTOM LOADING OF CASK

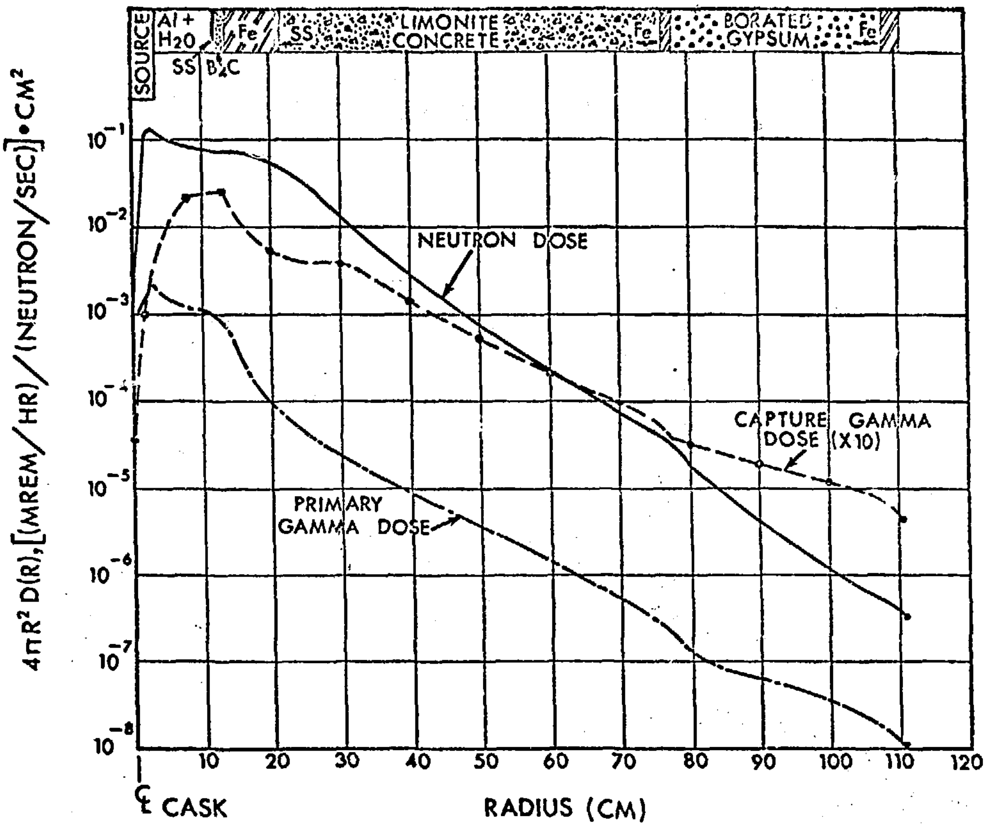

FIG. 3 RADIATION DOSE RATE CASE 7

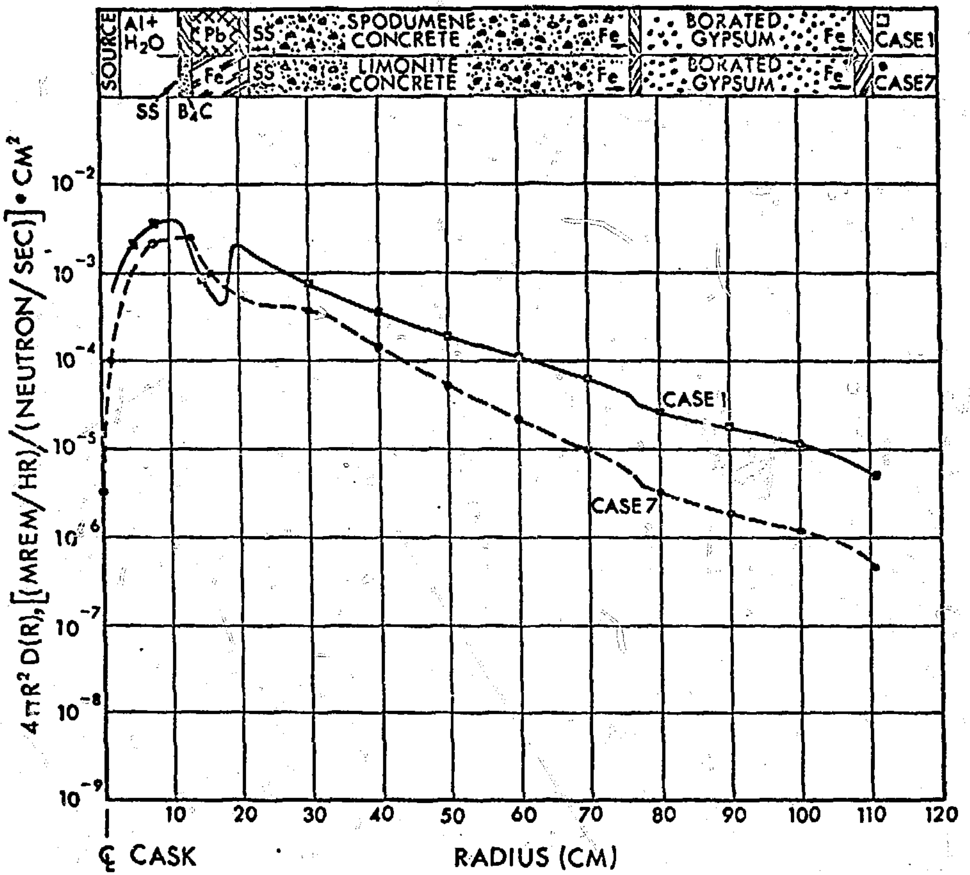

FIG. 4 CAPTURE-GAMMA DOSE RATE

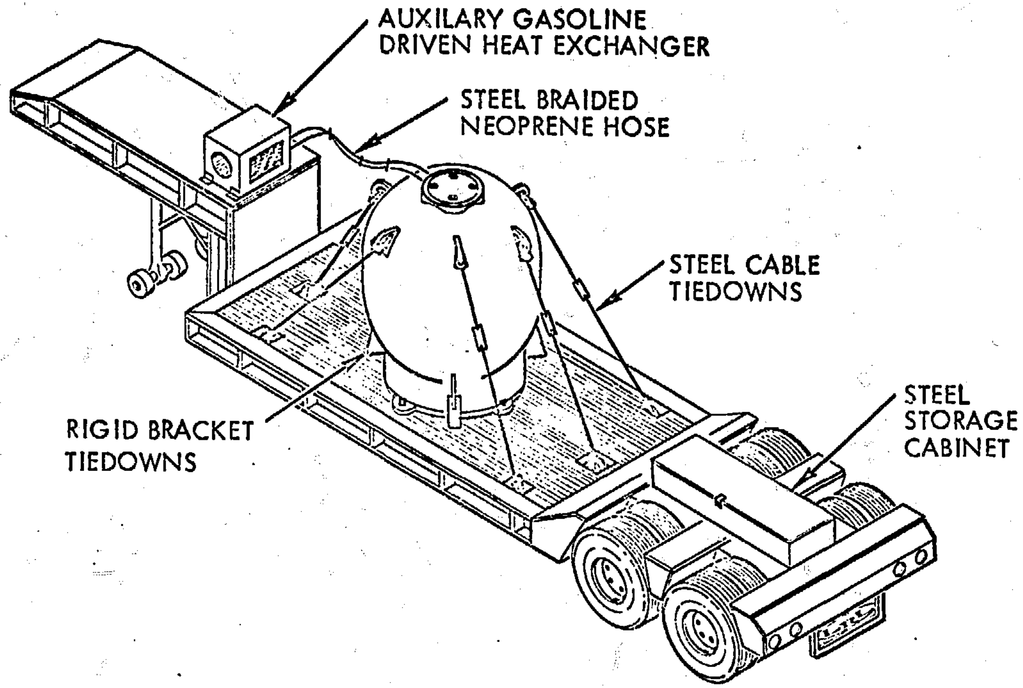

FIG. 5 SHIPPING CASK AND TRANSPORT TRAILER

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SUMMARY

A shipping cask (see Fig. 1) has been designed to transport high-specific-activity neutron-emitting isotopes. The unit has a radiation attenuation factor and heat capacity sufficient to allow the transport of three grams of ^{252}Cf (9×10^{12} fission neutrons/sec) or the equivalent dose from other elements. The permissible heat load has been limited to 1000 watts from radioactive decay. A liquid cooling loop has been included to maintain temperature-sensitive sources at a controlled value during normal transport conditions. In the event of an accident that negates the liquid cooling system, the primary shield will safely dissipate 1000 watts of heat and maintain its structural integrity. The cask, which weighs 25 tons, is 86 inches in diameter and is nearly spherical in shape. A special semi-trailer will be provided to allow transport of the cask over first class highway without the necessity of special permits.

The cask construction includes a removable center plug which contains a rotating magazine with three storage positions 3 inches in diameter and 12 inches tall. A bolted-closure special-form vessel has been designed and proof tested to contain the radioactive materials. The vessel utilizes a stainless steel to stainless steel gasketing system and is suitable for internal pressures of 150 psig at an operating temperature of 1500°F.

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* This work was performed under the auspices of the United States Atomic Energy Commission.

Although intended as a bottom-loading cask, the unit may be loaded from either top or bottom in a deep pool facility. The source containers are loaded by utilization of a three-inch-diameter by eight-foot-long plug which is equipped with grapple fingers on the lower end. This plug is stored in the cask during actual transport and physically locks the rotating magazine in place.

In order to obtain the best radiation attenuation factors in the smallest and lightest configuration, several different approaches to this cask were considered. The ANISN[1] shielding code was used to investigate neutron and gamma attenuation of several types of shielding materials and configurations, assuming a spherical geometry for the overall shield. Final selection of the shielding materials used was based on the ability of the materials to withstand thermal and mechanical damage that might be encountered during an accident as well as the radiation shielding characteristics. The major shielding materials selected for the cask were (from the outside inward): steel plate, gypsum and boron frit aggregate, borated limonite concrete, and a solid steel billet lined with a Boral sheath which was encased in a stainless steel liner.

Possible damage to the exterior of the cask by a 30 foot free fall was investigated by using the computer code DRIVE[2]; this code has been written to evaluate the effects of a dynamic, large-inelastic deformation on bulk objects. The use of conservative values and assumptions in the computer calculations indicated a final permanent deformation of six inches in the external shell. This reduction of shielding is within the allowable limits of increased surface dose after a major accident. Any structural effects that occur will not be detrimental to the containment capabilities of the cask.

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1. Ward W. Engle, Jr., "Users Manual for ANISN, K-1693", Union Carbide Nuclear Division, March 30, 1967.

2. DRIVE - Computer Code Described in Lawrence Radiation Laboratory Internal Report.

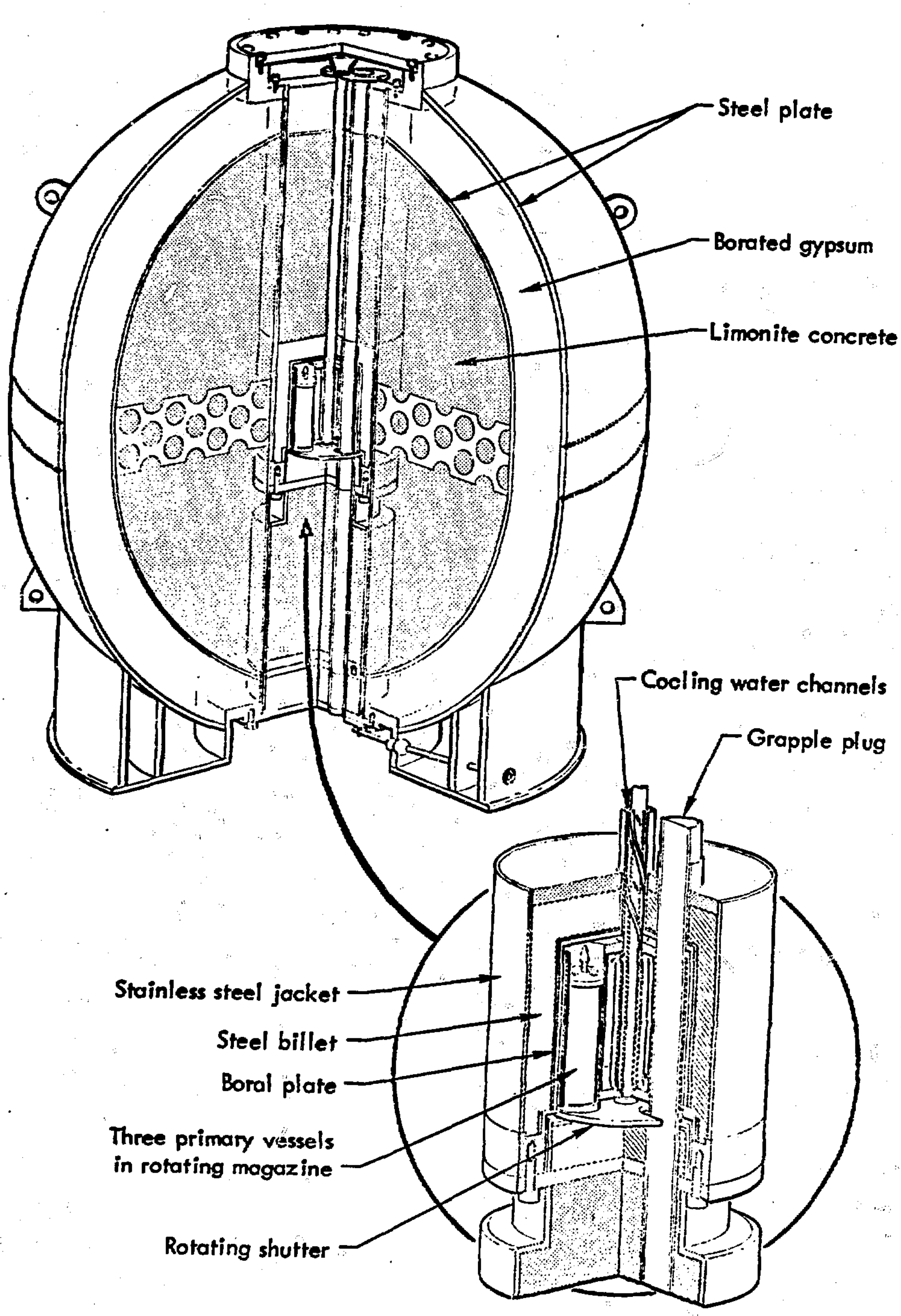

FIG. 1 SHIELDED NEUTRON SHIPPING CASK