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MASTER

K-1714

PROTECTIVE SHIPPING PACKAGES
FOR 8- AND 12-INCH DIAMETER
UF₆ CYLINDERS

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Engineering Division

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Abstract

This report concerns the design and development of protective shipping packages for 8- and 12-in.-diam uranium hexafluoride cylinders. A reinforced high-temperature phenolic foam plastic developed at the Oak Ridge Gaseous Diffusion Plant is used as a structural support and fire-resistant insulation lining. The packages, which are also considered applicable for shipment of other fissionable material containers, have received both AEC and ICC approval for Class II shipment of these cylinders.

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Protective Shipping Packages for 8- and 12-Inch Diameter UF₆ Cylinders

PART I - SUMMARY
PART II - TEST DATA
PART III - NUCLEAR SAFETY ANALYSIS
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PART I

Summary

Protective shipping enclosures for 8- and 12-in.-diam uranium hexafluoride cylinders¹ which are also applicable for the shipment of other containers of fissionable materials have been developed at the Oak Ridge Gaseous Diffusion Plant. The reinforced, high-temperature phenolic foam plastic,^{2,3} also developed at this facility, is used as a structural support and fire-resistant insulation lining.

Prototype packages containing the 8- and 12-in. cylinders, at normal fill weight, have met the test requirements outlined in AEC Manual Chapter 0529.⁴ The final designs included in this report incorporate all improvements which, based on prototype test data and engineering evaluations, were considered desirable for improved structural integrity, fire protection, and shipping convenience. Packages so designed have received both AEC and ICC approval for Class II shipment of specific UF₆ cylinders.

CONTAINER HOUSING

Except for capacity, the outer shell design is similar to that of the standard 18-gauge steel drum described in ICC specifications for 17H containers. Closing rings with 5/8-in.-diam bolts, positioned at distances of about 16 and 22 in. from the top ends of the 12- and 8-in. cylinder packages, respectively, are used to secure deep, high-temperature foam-filled container housings.

Each design¹ provides for a cylindrical inner housing of 16-gauge steel with a bolted, neoprene gasketed cover of the same material. A 3/4-in.-thick sponge rubber pad underneath the top cover and a 3/4-in. neoprene pad at the base of the inner housing limit and cushion cylinder movement. Two sets of four wooden blocks positioned at 90° angles around the inner housing near the top and cross-lapped end timbers at the base separate the two housings and provide structural support. In prototypes of the 8-in. cylinder package, an additional set of the blocks was positioned near the base; however, engineering evaluation of test results has indicated that the units are not needed as structural support members. The wood blocks are fastened by screws to support frames welded to the inner liner and by lag screws through the external shell; these lag screws are coated with a metal bonding material to provide a watertight seal.

High-temperature insulation and structural support are provided by a minimum of 5 in. of the reinforced plastic foamed between the housings. Vent holes of 3/16 in. in diameter are located in the side and bottom of the external housing for release of gas pressures which may be generated by plastic decomposition in a fire. The vent holes are drilled prior to foam filling. Before the package is painted, these plastic-filled openings are additionally sealed against weathering by two coats of an epoxy that does not react with the plastic.

The 12-in.-diam cylinders normally have a cylindrical, screw-type protective cap on the valve end and on the opposite end where a screw-plug fitting is installed; they extend beyond the cylinder protective steel skirts positioned at each end. The cylinder used in the tests was modified by replacing the base cap with a threaded, flat steel plate of a height equal to the extended length of the base skirt. This provided a flat support for the cylinder when positioned in the inner housing; no design change was required for the 8-in. cylinder.

NUCLEAR EVALUATION

A nuclear safety evaluation of the shipping packages for the 8- and 12-in.-diam UF_6 cylinders has indicated that all requirements for fissile Class II packages have been satisfactorily met. A total of 133 packages, each containing an 8-in. cylinder of UF_6 at enrichments to 12.5%, may be transported together. The transport unit is 0.3. As many as 44 packages, each containing a 12-in.-diam cylinder of UF_6 at enrichments to 5.0%, may be transported together. The transport unit is 0.9.

PART II

Test Data

Accident Test Conditions of Transport

NORMAL

The protective packages, containing cylinders filled with simulated UF_6 (ferrous sulfide and lead pieces) at the normal fill weights of 250 lb for the 8-in.-diam cylinder and 450 lb for the 12-in.-diam cylinder, were not subjected to the normal test requirements of AEC Manual Chapter 0529. Earlier prototype packages of essentially the same configuration and strength specifications had previously completed this series of tests with negligible damage. Moreover, it was considered that successful completion of the hypothetical tests under similar conditions but of greater severity would ensure satisfactory compliance with normal testing.

HYPOTHETICAL

Drop Test

A free fall through a distance of 30 ft onto a flat, essentially unyielding horizontal surface, striking the surface in such a position as to suffer maximum damage.

Result

Both 8- and 12-in.-diam cylinder packages were dropped 30 ft, first in a horizontal position, then at a 45° angle, bottom end downward. Areas at points of impact of both units were crushed without fracture. Beyond this, the only significant damage was the slight opening of the 8-in. unit cover at the closing ring. This in all probability resulted because the original design for the 8-in. package included a standard cover with the closing ring at the top of the drum. The volume change by either impact test does not exceed 5%; the separation distances between containers would be decreased slightly. As a result of this test, the design was revised and is now similar to the 12-in. design which positions the closing ring away from the end and provides a deep protective cap for the package.

A small tear in the heat-affected zone of the base lug weld on the 8-in. cylinder package was also observed following the horizontal drop. This rupture occurred when the lug bent as it struck the pad. Weld size, limited by the concave

configuration of the shell and lug width at this point, was insufficient to properly support the lug. Lug width has since been increased to provide greater strength.

The pad used in the drop tests is constructed of reinforced concrete. Embedded steel cross beams support a flush surface slab of 4-in.-thick steel armor plate.

Puncture Test

A free drop through a distance of 40 in. striking, in such a position as to suffer maximum damage, the top end of a vertical cylindrical mild steel bar mounted on an essentially unyielding horizontal surface. The bar shall be 6 in. in diameter, with the top horizontal and its edge rounded to a radius of not more than 1/4 in., and of such a length as to cause maximum damage to the package, but not less than 8 in. long. The long axis of the bar shall be normal to the package surface.

Result

Both packages were indented about 1-1/4 in. without rupture of the walls.

Thermal Test

Exposure for 30 min within a source of radiant heat having a temperature of 1475°F and an emissivity coefficient of 0.9, or equivalent. For calculational purposes, it shall be assumed that the package has an absorption coefficient of 0.8. The package shall not be cooled artificially until after the 30-min test period has expired and the temperature at the center of the package has begun to drop.

Result

The packages containing the 8- and 12-in. cylinders were positioned upright on railroad rails used as supports on the diesel oil tanks of the fire-testing system and tested simultaneously. Micromax temperature readings were obtained from thermocouples clamped to the top and sides of the drums.

Temperatures varied from top to bottom of the units; readings indicated 1100 to 1500°F at the top, 1900 to 2200°F at the center, and 1600 to 1800°F near the base. Following this exposure for a period of 45 min, the packages had a 4-hr cooling period before water immersion.

Internal temperatures were measured by positioning Temp-Plate pellet temperature indicators on the walls of the inner housings and at several places along the

lengths of the cylinders as shown in photographs 824, 827, and 828. The temperature range of these devices is 120 to 450°F, ~ 50° increments. Inspection of these indicators after dismantling of the packages disclosed that the temperature had not reached 200°F at any point. This includes the area where the opening of the package cover had occurred during the drop test of the 8-in. cylinder, although only 1/2 in. thickness of uncharred plastic insulation remained at that location. The fill limit of each cylinder is based on the weight of liquid UF₆ at 300°F which would just fill the cylinder.¹

Water-Immersion Test

Immersion in water for 24 hr to a depth of at least 3 ft.

Result

Following immersion as described, the 12-in. inner housing remained dry; that of the 8-in. cylinder contained 7 in. of water. Leakage into the inner housing was attributed at the time to a small amount of plastic insulation which had not been removed from the flange of the inner shell after the foaming operation, thus making the gasket ineffective. Later investigation revealed one bolt had not been completely tightened due to foam resistance underneath the flange. Hence, the bolts which hold the mold to the flange of the inner housing during the foam-filling operation are now longer than the regular flange bolts, resulting in cavities in the plastic in the molding operation. These cavities permit proper closure on installation of the inner housing cover.

Although double containment is part of the design criteria, the leakage to the inner housing described above is not considered significant, since the cylinder itself did not leak. A heavier flange, as shown on the drawing, should also prove effective in preventing inleakage. Normal inspection and checking procedures established for production conditions should preclude fabrication omissions.

As shown by the test of the 12-in. unit, properly gasketed containers with sealed vent holes will provide a high degree of protection from weather or immersion, as will the well-fitted lid and body plastic sections, coated with epoxy or similar sealant.

SPECIAL TESTS

Vent Hole Omission in Fabrication

The test was made to determine the effect of excluding vent holes in the upper section of the drum. The unit suffered a ruptured top end section when a small

explosion occurred after 5 min, but the fire test was continued for a total of 35 min. Three-fourths of the outer shell cover perimeter was forced out of the lock ring by the explosion, exposing the lid plastic to the flames. Later examination revealed that the foamed plug retainer under the package cover had been moved from its normal position by the explosion, thus providing a larger opening for heat entry at the tongue and groove joint. Charring of the rubber gasket occurred, which permitted leakage of about 3 in. of water into the inner housing in the ensuing water-immersion test. The plug movement apparently had little effect on the cylinder temperature, however, since it did not reach 200°F at any point.

Multipurpose Use Test

In a second experiment, the multipurpose potential of the packages under development was demonstrated effectively by a fire test of a polyethylene bottle within an 8-in. shipping package. The plastic bottle, with a melting temperature of approximately 150 to 160°F, is one normally used for uranium solution handling.

The bottle was 90% filled with water and installed in the 8-in. package inner housing. Vermiculite, which was readily available, was used to fill the free space between the bottle and housing wall. Normally a plastic sleeve, light in weight and water impermeable, with a melting point of about 300°F, would be utilized at this position.

After a 40-min exposure to the flames, and the normal cooling period, the Temp-Plate temperature indicator readings at the inner housing cover were found on inspection to be between 150 and 180°F. Temperature indicators on the plastic bottle near the top and close to the metal cover, and near the bottom, registered less than 120°F, the first indicating position.

Foam Plastic Impermeability Test

Earlier conclusions based on small quantity testing regarding the water impermeability of the plastic lining⁴ prior to fire damage have since been invalidated. In a flotation test of a full-sized 12-in. cylinder package with unsealed vent holes and containing a filled cylinder, the unit initially floated with 3 to 4 in. of the top exposed. After 48 hr, the package was 3 ft beneath the surface, suspended by the recovery rope. In this test, no inleakage of water occurred into the inner housing. The conclusion that the plastic will eventually absorb water was confirmed in further container testing, in both sanitary and treated plant water, using 5-gal containers of the foam with unsealed vent holes. Complete water penetration occurred in this case.

The plastic contains about 3% boron by weight, which is a neutron absorber. Laboratory tests indicate that as much as 30% of the boron can be dissolved from the plastic by prolonged immersion in water.

Sealed Vent Hole Tests

In the first test, a 4-gal container, in which several vent holes were drilled in the side and base prior to foaming, was filled with the plastic foam. The foam-filled openings were then sealed with two coats of an epoxy, and since the lid gasket was of foam rubber and a possible source of leakage, the edge of the closed lid was similarly treated.

The container was left outdoors in all types of winter weather, including abnormally warm periods, from October 29, 1966, to March 6, 1967. For half of this period the unit was positioned with the top down, the balance of the time it was in a horizontal position. A weight check at the end of the test period revealed no change.

The second test involved a drum shipping package with a neoprene gasketed cover, sealed vent holes, and a filled 8-in. cylinder. The package was floated in a pond for one week. A weight check after removal and drying showed no change. The unit, which is nearly 6 ft tall, was then positioned vertically in an 8-ft-deep tank, and the tank was filled with water. On removal, after a 24-hr immersion, water leakage from under the closing ring was observed; the measured weight gain was 112 lb. Inleakage appeared to be where the closing ring and the gasket rim were damaged in the removal of the drum from the pond; this damaged side was the one immersed in water in the flotation test. No water was found inside the inner housing. All vent hole seals appeared to be in good condition. It is considered that adequate sealing of vent holes and proper fitting of sections will prevent water inleakage and absorption by the plastic in normal operational usage.

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PART III

Nuclear Safety Analysis

BASIC DATA

The pertinent physical properties of UF_6 and the nominal dimensions of the UF_6 cylinders under consideration are given in Table 1. All UF_6 fuel supplied the nuclear industry must meet rigid requirements set forth in the Federal Register⁵ including a purity specification of 99.5% by weight UF_6 . The maximum possible hydrogen moderation of the UF_6 is determined by making the conservative assumption that all impurity is hydrogen fluoride. At the specified ^{235}U enrichments, the $\text{H}/^{235}\text{U}$ atomic ratio and the quantity of fissile isotope are established from an H/U atomic ratio of 0.088 and the cylinder fill limits, respectively. The uranium density, 3.2 g/cc, is that of the solid UF_6 at 68°F.¹

TABLE 1
Properties of 8- and 12-Inch-Diameter UF_6 Cylinders

Nominal Dimensions	8 in. diam x 51 in. long	12 in. diam x 40 in. long
^{235}U Enrichment Limit	12.5%	5.0%
Max. $\text{H}/^{235}\text{U}$ Atomic Ratio	0.7	1.7
UF_6 Fill Limit	250 lb	450 lb
Contained ^{235}U	9.6 kg	6.9 kg

GENERAL CRITICALITY CONSIDERATIONS

In evaluating the proposed shipping packages, it is first noted that the amount of the fissile ^{235}U isotope contained in each cylinder, as essentially unmoderated UF_6 , may be considered as an individually safe amount for full water reflection (see applicable data^{6,7} of Fig. 1 and properties of UF_6 cylinders listed in Table 1). Also, a minimum design spacing of at least 1-ft edge-to-edge separation of the fissile material is provided by the protective structural packages.

In addition, from the data of Fig. 1 and from core density considerations,⁸ it is apparent that a very large number of 8-in. cylinders would be required for criticality in air-spaced arrays, while similar arrays of the 12-in.-diam cylinders, per se, could not be made critical. These conclusions are supported by transport theory calculations, made with the ANISN Code,⁹ which indicate a

Figure 1
 ^{235}U CRITICAL MASS OF UF_6

k_{∞} of 1.20 for an array of the 8-in.-diam $U(12.5)F_6$ cylinders of infinite length, and similarly, a k_{∞} of only 0.85 for an array of the 12-in.-diam $U(5.0)F_6$ cylinders. See Figs. 2 and 3. These k_{∞} values are even lower if the effect of the cylinder wall on the thermal neutron distribution between fuel and moderator is included.* A modified Hansen-Roach cross section set and the white boundary option were used in the Code.⁷ The white boundary condition assumes all neutrons are reflected isotropically at the cell boundary, this corresponding to the outer edge of the water moderator.

The calculations shown in Figs. 2 and 3 do indicate, however, that criticality is possible for water-moderated lattices of both the 8-in. and the 12-in. cylinders. Thus the effect of interspersed hydrogenous moderators in an array of the shipping packages is a principal nuclear safety consideration. Since the phenolic foam plastic used as an insulation material in the protective shipping packages contains both carbon and hydrogen, the plastic is assumed to provide moderation equivalent to the optimum found for hydrogenous materials. However, it should be noted that no credit is taken for the boron of the packaging material which is an efficient $1/v$ absorber. Again referring to Figs. 2 and 3, it is seen that the k_{∞} is greater than unity only at water-moderator thicknesses from about zero to 2 in., with the optimum reactivity occurring at a water-moderator thickness of 0.5 in. This thickness is slightly less than the 1-in. moderator thickness that had been assumed to be optimum in a previous study.⁷

It is evident from the data given that the critical region is comparatively small for such latticed arrays and that the minimum 1-ft design spacing of the fissile material, which was maintained throughout all prescribed safety tests, is more than an adequate separation for water flooding. It should be noted that, in the following array determinations, no credit is taken for the effect of the container wall itself: this has been shown to provide more than adequate allowance for any possible effects of partial flooding, where the average water density might be less than 1 g/cc, i.e., snow, ice, etc.⁷ It should also be noted that latticing does not appear to increase the k_{∞} of highly enriched UF_6 but only those low-enrichment systems where the ^{238}U resonance escape probability is enhanced by the presence of external moderators. See Figs. 4 and 5.

*Although nickel and Monel are the basic materials of construction for the UF_6 cylinders under consideration, the effect of the cylinder wall was approximated by using an equivalent thickness of steel in the transport theory calculations.

DWG. NO. G-66-582

Figure 2

K_{∞} OF 8-INCH DIAMETER U(12.5)F₆ CYLINDERS

DWG. NO. G-66-683

Figure 3

K_{∞} OF 12-INCH DIAMETER U(5.0)F₆ CYLINDERS

Figure 4
 K_{∞} OF 8-INCH DIAMETER UF_6 CYLINDERS

Figure 5
 K_{∞} OF 8-INCH DIAMETER UF_6 CYLINDERS

UNREFLECTED ARRAYS

Table 2 shows the results of interaction potential calculations¹⁰ which were made for unreflected, air-spaced cubic arrays in which the array unit is a sphere containing either 250 or 450 lb of UF_6 according to the respective fill limits of the 8- and 12-in.-diam cylinders. Each array unit was surrounded by a water-moderator jacket varying in thickness between zero and 1 in. The neutron penetration thermal buildup factors (ab), used for interunit moderation, were derived by Henry, et al.¹¹ from activation measurements with cadmium covered indium foils, taken at the Tower Shielding Reactor of the Oak Ridge National Laboratory. Values of the k_{eff} and leakage probabilities were determined from ANISN Code calculations. Lattice volumes of the array units correspond to the effective volumes of the protective structural shipping packages.

TABLE 2

Unreflected Arrays of 14.1- and 17.2-Inch-Diam UF_6 Spheres ^a					
Array Unit (k_{eff})	Water Jacket (in.)	Leakage Probability (1 - U)	Penetration-Buildup (ab)	Interaction Probability ($\sum_{qj} \Omega_{ij}$)	Number of Units (N)
Array Criticality Factor, C = 0.90					
0.1968	0.0	0.8598	1.000	0.908	12,100
0.2523	0.5	0.8189	1.400	0.625	3,900
0.3480	1.0	0.7548	1.112	0.730	6,100
Array Unit: U(12.5) F_6 , H/U = 0.088; 14.1-in.-diam sphere; edge spacing between UF_6 spheres, 19.4 in.; lattice volume, 21.7 ft ³					
0.1703	0.0	0.8379	1.000	0.942	3,600
0.2188	0.5	0.7983	1.408	0.673	1,300
0.3190	1.0	0.7354	1.112	0.802	2,200
Array Unit: U(5.0) F_6 , H/U = 0.088; 17.2-in.-diam sphere; edge spacing between UF_6 spheres, 15.4 in.; lattice volume, 20.0 ft ³					
^a Cubic arrays.					

The results given in Table 2 include the number of array units required for a criticality factor, C = 0.90, which is well within the assigned accuracy of the method. The interaction probabilities of the 14.1-in.-diam and 17.2-in.-diam UF_6 spheres are about the same at the specified lattice volumes. However, a smaller number of the larger spheres is required for an array criticality factor, C = 0.90. Since the calculated arrays of spherical units are considered more

Figure 6
MAXIMUM SUBCRITICAL NUMBER OF
14.1-INCH DIAMETER $U(12.5)F_6$ SPHERES

Figure 7
MAXIMUM SUBCRITICAL NUMBER OF
17.2-INCH DIAMETER $U(5.0)F_6$ SPHERES

reactive than the non-uniform cylinder arrays that would be obtained by actually stacking the shipping packages, the numbers $N = 3,900$ and $N = 1,300$ appear to be conservative estimates of the maximum number of shipping packages of the 8- and 12-in. cylinders, respectively, that may be placed in subcritical unreflected arrays. See also Figs. 6 and 7.

REFLECTED ARRAYS

In considering the effects of array reflection, a reduction factor of 6, previously derived⁸ for $U(93)F_6$, is thought to be conservative when applied to the $U(12.5)F_6$ and $U(5.0)F_6$ arrays. Such reduction factors are based on the limiting ratios found for critical masses of bare and water-reflected spheres, and may be applied directly to the low-density interacting arrays of interest. Since the calculational model assumes a water-moderator jacket surrounding each sphere, and this jacket provides both interunit moderation as well as some array reflection, no additional allowance was made for interunit moderation of the array.

Thus, applying the above reduction factor to the maximum subcritical values found for unreflected arrays, the maximum subcritical numbers of shipping packages of the 8- and 12-in. cylinders in arrays subject to both external reflection and interunit moderation with hydrogenous materials are 650 and 216, respectively.

THE ALLOWABLE TRANSPORT UNIT

For purposes of criticality control, the number of transport units assigned each package is 40 divided by the allowable number of packages per vehicle.⁴ The allowable number is determined by the following criteria:

1. Five times the allowable number of undamaged packages would be subcritical in any arrangement surrounded by complete water reflection, and
2. Twice the allowable number of damaged packages should be subcritical in any arrangement with moderation consistent with accident test results.

The proposed shipping packages, when subjected to rigorous tests, suffered only negligible damage which did not significantly alter the design spacing of the fissile material. Hence, since the foam plastic packaging material is equivalent to the optimum moderation found for hydrogenous materials, it is considered that Criterion 1 is more applicable to the present analysis. Thus, in the case of the

8-in. cylinder, $650/5 = 130$, and the calculated transport unit is $40/130 = 0.307$. As indicated in AEC Manual Chapter 0529,⁴ the calculated number shall be rounded to the first decimal place. The transport unit is therefore 0.3, and the allowable number of packages is 133. Similarly, in the case of the 12-in. cylinder, $216/5 \sim 43$, and the calculated transport unit is $40/43 = 0.93$. The transport unit is therefore 0.9 and the allowable number of packages is 44.

A further requirement is that any radiation measured in mr/hr at a distance of one meter from the package be less than the assigned transport unit. This criterion is also met, since measurements indicate that such radiation emanating from the packages containing these cylinders is less than 0.10 mr/hr at the specified distance.

CONCLUSION

It appears that the proposed shipping packages for the 8- and 12-in.-diam UF_6 cylinders have met all the criticality requirements for a fissile Class II package.

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PART IV

Photographs

Photo Number

PH-66-814	Shipping Packages for 12- and 8-Inch Cylinders
PH-66-1270	Shipping Package for 12-Inch-Diameter Cylinder
PH-66-817	View of 30-Foot Drop Test
PH-66-808 PH-66-815	Effects of End and Piston Drops on 12-Inch Package
PH-66-810 PH-66-812	Effects of Horizontal and End Drops on 8-Inch Package
PH-66-827 PH-66-828 PH-66-824	Both Cylinders and Typical Package Interior After Fire Tests
PH-66-1169	Fire Test of 8-Inch Package Containing Polyethylene Bottle

PHOTO NO. PH-66-814

PHOTO NO. PH-66-803

PHOTO NO. FH-66-815

PHOTO NO. PH-66-812

PHOTO NO. PH-66-827

PHOTO NO. PH-66-828

PART V

Drawings

AVERAGE WEIGHTS

SHIPPING CONTAINER WEIGHT-----	280 LBS.
FILLED 8" CYLINDER	<u>380 LBS.</u>
TOTAL WEIGHT	660 LBS.

PROTECTIVE PACKAGE FOR 8-INCH DIAMETER UF₆ CYLINDER

PROTECTIVE PACKAGE FOR 12-INCH DIAMETER UF_6 CYLINDER

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