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AEC RESEARCH AND DEVELOPMENT REPORT

K-1716

MASTER

PROTECTIVE SHIPPING PACKAGE
FOR 5-INCH-DIAMETER
UF₆ CYLINDER

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UNION CARBIDE CORPORATION
NUCLEAR DIVISION

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Engineering Division

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Oak Ridge Gaseous Diffusion Plant
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Abstract

This report concerns the design of a protective shipping package for the 5-in.-diam x 30-in. UF_6 cylinder. A reinforced high-temperature phenolic foam plastic is used as a structural support and fire-resistant insulation lining. The package, which can be readily modified for shipment of other fissile materials, has received both AEC and Bureau of Explosives approval for Class II shipment of the 5-in. UF_6 cylinder at any ^{235}U enrichment.

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Protective Shipping Package for 5-Inch-Diameter UF₆ Cylinder

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PART II - TEST DATA

PART III - NUCLEAR SAFETY ANALYSIS

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PART I

Summary

A protective package for the 5-in.-diam x 30-in. cylinder containing uranium hexafluoride at any ^{235}U enrichment has been developed at the Oak Ridge Gaseous Diffusion Plant.¹ The design incorporates the use of a recently developed high-²temperature phenolic foam plastic as a structural and fire-resistant component. The unit may be readily modified by the use of inserts in the inner housing for the shipment of other fissile compounds and solutions.

A package of this design has successfully passed the accident test requirements outlined in the AEC Manual Chapter 0529 and 10CFR 71. The use of such packages has been approved by the Atomic Energy Commission and the Bureau of Explosives for Class II shipment of 5-in.-diam UF_6 cylinders at any enrichment.

CONTAINER HOUSING

The shipping package is of the double-containment type. The 18-gage outer container, as shown in drawing on page 30, can be procured as a single drum of suitable diameter and the required length of 47.5 in. It can also be fabricated by welding sections of two standard 55-gal drums which conform to ICC Specification 17H. A standard closing ring with a 5/8-in. bolt is used.

The 16-gage inner housing in which the UF_6 cylinder or other package fissile materials may be contained consists of a 6-in. pipe with an 11-gage steel disc base and a flared 10.5-in.-diam upper section to provide handling access during cylinder installation and removal. The housing is flanged at the top and sealed by a neoprene gasketed 1/4-in. steel plate positioned by lock bolts with Teflon inserts.

The support base plate for the inner liner extends to within 4 in. of the outer shell and is attached to load-bearing wood supports securely fastened to the bottom section of the outer shell. Holes in the base plate prevent air pockets by allowing the foam plastic to fully enclose the lower part of the inner liner. A sponge rubber pad underneath the top plate and a neoprene pad in the base of the inner housing are used to cushion and retard cylinder movement.

The fire-resistant phenolic resin foam plastic, which contains approximately 3% by wt of boron and a fiber glass additive, is foamed between the inner and outer housings, providing a tough-skinned liner with a minimum thickness of 5-in. The plastic provides sufficient structural strength so that bracing between the housing shells is not required. Vent holes of 3/16 in. diam are located at intervals in the side and in the bottom of the external housing for release of gas pressures which may be generated by the decomposition of the plastic in the event of fire. The vent holes are drilled before foam-filling. Prior to painting the package, these plastic-filled openings and the molded plastic surfaces are additionally sealed against weathering by the application of two coats of an epoxy that does not react with the plastic.

NUCLEAR EVALUATION

The nuclear safety evaluation of the shipping container for the standard 5-in.-diam UF_6 cylinder containing UF_6 at any enrichment indicates that all requirements for a fissile Class II package have been met satisfactorily. A total of 400 such containers, each container being assigned a transport unit of 0.1, may be transported together. The analysis was based on the results of three independent methods for determining criticality in unreflected arrays, and includes an overall reduction factor of 75 applied to the maximum subcritical number of shipping packages for an air-spaced, bare cubic configuration.

PART II

Test Data

Accident Test Conditions of Transport

The provisions of the test requirements of AEC Manual Chapter 0529³ for packaging of fissionable materials and the test results obtained with the 5-in.-diam UF₆ cylinder package are given below:

NORMAL

Drop Test

A free fall, weights less than 10,000 lb, of 4 ft, onto a flat, essentially unyielding horizontal surface, striking the surface in such a position as to suffer maximum damage relative to nuclear safety.

Result

The shipping drum, containing a filled 5-in.-diam cylinder, was dropped on the base rim at a 45° angle. The rim section, which extends beyond the base of the drum, folded inward. No other damage to the drum was noted. The test cylinder, filled with ferrous sulfide crystals to the specified UF₆ fill weight of 55 lb, weighed 117 lb. The total weight of the shipping container, including the cylinder, was 288 lb.

The test pad used during the drop tests is constructed of concrete reinforced with steel rods. Imbedded steel cross beams are used to support a flush surface slab of 4-in.-thick armor steel plate.

Impact Test

The impact of the flat circular end of a steel cylinder, 1-1/4 in. in diameter and weighing 13 lb, dropped from a height of 4 ft normal to the exposed surface of the package which is not vulnerable to puncture.

Result

The steel cylinder was dropped on the drum lid and the side wall. The result was only a very slight dent at each location.

Water Spray Test

A water spray directing not less than 4 gpm spread over the entire exposure surface of the package except the bottom during a period of 30 min, with the bottom of the package not immersed in water.

Result

This test was not made. The external housing was sealed and gasketed, and the inner housing was also sealed with a gasketed flange. Since water immersion tests of small sections of plastic had previously revealed no penetration, it was considered unlikely that the spray test would induce leakage or affect the drop test.

Compression Test

A compressive load equal to either five times the weight of the package or 2 lb/in.² multiplied by the maximum horizontal cross section of the upright package, whichever is greater. The load shall be applied during a period of 24 hr, uniformly across the top and bottom of the package in the position in which the package would normally be transported.

Result

A total weight of 1500 lb was applied to the drum top for a 24-hr period, with the drum positioned on a reinforced concrete floor. Measurements taken at quadrant locations revealed no change in section heights.

HYPOTHETICAL ACCIDENT CONDITIONS

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

The shipping container was dropped 30 ft at a 45° angle with the loading end down, striking on the lid rim in close proximity to the lid bolt. The area at the point of impact was crushed inward about 1.5 in. The foam plastic, which has a density of about 5.6 lb/ft³, provided excellent structural support, and the

damage was not considered severe. There were no visible cracks in the metal. On conclusion of the tests, visual examination of the drum components revealed planar cracks in the plastic, apparently caused by slight lateral movement as the plastic compressed and then returned to position. Separation of about 1/8 in. and less was evident for a short depth between the plastic and the top section of the inner container, but good binding of plastic to metal was observed on the remainder of the housing. This minor damage to the plastic apparently had no effect on its fire-protection qualities.

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

The container was indented a maximum of 3/4 in., but no rupture of the wall was observed.

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 fall.

Result

The drum package containing the ferrous sulfide-filled UF₆ cylinder was positioned horizontally across two railroad rails at the central section of two concentric tanks 8.5 and 10.5 ft in diameter and 29 in. deep. Diesel oil was used as a fuel, with the oil level in the inner tank adjusted to 10 in. below the drum by water filling; that in the outer tank was at a higher level to provide better flame coverage in event of wind. Micromax temperature information for the drum was obtained from thermocouples that were clamped to the top and side and flame temperature measurements were obtained by thermocouples on a SS

ladder positioned adjacent to the drum. Readings were obtained using a high-speed Micromax. Temp-Plate pellet temperature indicators, with a temperature range from 120 to 500°F, were positioned on the inner components.

The test package received thermal exposure for a total of 100 min, this occurring in two separate fire tests of 55 and 45 min. In the first exposure, the wind increased in velocity to about 10 to 12 mph and the top section of the package did not receive the full effect of the fire. The second fire test was conducted two days later, at which time the wind velocity was 2 to 5 mph with gusts to 8 mph. The unit position was reversed 180° for this test so that the previous top side was downward.

The surface temperature readings from the drum-positioned thermocouples in the first test averaged 1500°F for the side thermocouple and considerably lower for the top unit due to the wind preventing good flame contact. Fire temperatures measured at heights of 1 and 2 ft above the oil level ranged from 1400 to 1750°F. Again, wind effect was noticeable. As the test progressed, lower temperatures were noted. This was later determined to be caused by lack of proper contact of the clamped-on thermocouples due to equipment expansion. Temperature measurements were not taken in the second position of the test; it being assumed, based on previous test data and wind conditions, that temperatures obtained would be in excess of requirement.

There were no thermocouple temperature measurements made within the plastic on the inner housing. The normal tendency for insulation temperatures to increase for a short period after heat removal was assumed in this case, and a 1-hr cooling period was allowed prior to the water immersion test.

Examination of the dismantled unit after the immersion test revealed the plastic was uniformly charred on all sides of the drum to a depth of about 2 in. The pellet temperature indicators positioned on the inner housing and the cylinder gave the following results:

- a. At the top of the steel flange of the inner housing - 150°F.
- b. On the inside wall of the inner housing - 120°F.
- c. On the top of the cylinder valve cap - 120°F.
- d. On the side of the cylinder, near the top and the bottom - 120°F.

It was observed that a crack in the plastic near the area of the 30-ft-drop impact, indicated in one of the photographs by a pencil insert, extended to the

wall of the inner housing at a point near the wall temperature indicator. However, as indicated above, this did not result in excessive temperatures at that area.

Water-Immersion Test

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

Result

After a 1-hr cooling period, during which the test package was transported approximately 3 miles to a plant area for the immersion test, it was immersed under 3 ft of water for 24 hr. Although heavy weights on the lid were required to keep the drum submerged, height measurements following removal from the water again showed no change.

Examination on removal revealed that water had penetrated the plastic insulation to within 1 in. of the inner housing. Since the shell of the drum contained small holes for venting of gases formed by decomposition of the plastic, in-leakage of water into the charred area was expected; it was not expected in the remaining plastic. However, no water was found in the inner housing, and the gasket of the flanged cover appeared to be in its original condition.

Although the foam plastic is 80-90% open pore construction, early small-scale tests, which included immersion of plastic sections under 4 ft of water for 72 hours and dye tests, did not show water penetration.¹ Subsequent larger scale tests proved the foam plastic, uncharred, to be water-absorbing; however, in additional tests, a properly sealed 8-in.-diam cylinder package was floated in a pond for a period of 1 week and no weight gain was registered after removal and drying.⁴

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PART III

Nuclear Safety Analysis of Shipping Container for 5-Inch-Diameter UF₆ Cylinder

The nuclear safety analysis was based on the results of three independent methods for determining criticality in unreflected arrays,⁵⁻⁷ and includes an overall reduction factor of 75 applied to the maximum subcritical number of shipping packages for an air-spaced, bare cubic configuration. A factor of 15 for interspersed moderation and external reflection with hydrogenous material, and a safety factor of 5 in accordance with AEC Manual Chapter 0529, Section II.J.1, are included in the above reduction factor.

BASIC DATA

All UF₆ fuel supplied to the nuclear industry must meet rigid requirements set forth in the Federal Register,⁸ including a purity specification of 99.5% by weight UF₆. The maximum possible hydrogen moderation is conservatively determined by assuming that all impurity is hydrogen fluoride, this corresponding to an H/U atomic ratio of 0.088. The amount of the fissile ²³⁵U isotope is established from the UF₆ fill limit of 55 lb for the standard 5-in.-diam cylinder and the ²³⁵U enrichment. The uranium density is that found for solid UF₆ at 68°F.⁹

The following maxima were assigned the UF₆ contained in the 5-in.-diam cylinder:

a. ²³⁵ U enrichment	100%
b. H/U atomic ratio	0.088
c. Contained ²³⁵ U	16.8 kg
d. U density	3.2 g/cc

CRITICALITY OF UNREFLECTED ARRAYS

The Interaction Potential Method

According to the interaction potential method,⁵ the criticality factor, C, of unreflected arrays is given by the relation,

Figure 1
 NEUTRON INTERACTION PROBABILITY
 CUBIC ARRAYS OF SPHERES

$$C = \frac{k_{\text{eff}}}{n \left(1 - \sum_{i=1}^n q_i \bar{\Omega}_i (1 - U) \right)} \quad (1)$$

where k_{eff} is the multiplication factor of an array unit, $(1 - U)$ is the neutron leakage probability of that unit, and

$$\sum_{i=1}^n q_i \bar{\Omega}_i$$

is the flux weighted neutron interaction probability of the array. The intensive properties, k_{eff} and $(1 - U)$ may be determined by ANISN,¹⁰ a one-dimensional transport theory code, using the Hansen-Roach cross section set.¹¹ For specific arrays of interest, the number of units, N , was determined from the interaction probability graph, Figure 1, which was prepared using a solid angle code.¹² The total fractional solid angle is that subtended on the central unit by all other units in the array not directly shielded by intermediate units. Partially shielded units are treated as though no shielding were present, tending to overestimate the actual solid angle.

Results of the interaction potential calculations are displayed in Table 1 for unreflected, air-spaced cubic arrays of identical spheres. An 8.5-in. sphere containing the same mass of UF_6 as the standard 5-in.-diam cylinder was used as an array unit.

TABLE 1
Criticality Factors of Unreflected Arrays of $\text{U}(100)\text{F}_6$ Spheres^a
Interaction Potential

Sphere Diameter ^b (in.)	k_{eff}	Leakage Probability (1 - U)	Number of Units (N)	Array Criticality Factor (C)
8.5	0.347	0.838	37,500	1.00
			30,000	0.90
9.0 ^c	0.366	0.828	35,000	1.00
			28,000	0.90

^aCubic arrays. Hydrogen moderation of the UF_6 is an H/U atomic ratio of 0.088. Lattice volume is 10.75 ft³.

^bEach UF_6 sphere contains 16.8 kg ²³⁵U.

^cIncludes 1/4-in. wall thickness Monel.

Since the results given in Table 1 include the number of units required for an array criticality factor, $C = 0.90$, which is well below the assigned accuracy of the method,⁵ such numbers may be considered as maximum subcritical values. Table 1 also indicates the effect of a 1/4-in. Monel wall, which is that of the 5-in.-diam UF_6 cylinder, on both the k_{eff} and the leakage probability of the array unit. This results in somewhat lower values than arrays of bare spheres.* The number, $N = 28,000$, corresponding to $C = 0.90$ for the 1/4-in. Monel wall UF_6 spheres, is thus considered as the maximum number of shipping containers that may be placed in a subcritical, unreflected cubic array.

The Density-Analog Method

An estimate of the number of units in critical air-spaced unreflected arrays may also be obtained from density-analog calculations. In this treatment, the basic criticality relation is given by:

$$\frac{m_c}{m_{s0}} = \left(\frac{\bar{\rho}}{\rho_0} \right)^{-s} \quad (2)$$

where m_c is the total critical mass of the array; m_{s0} is the critical mass of a bare unit of density ρ_0 ; $\left(\frac{\bar{\rho}}{\rho_0} \right)$ is the fraction of the total array volume occupied by the UF_6 ; and s is the density exponent. The density exponent is determined by the formula:

$$s = 2(1 - f) \quad (3)$$

where f is the "fraction critical" which has been defined as the ratio of the mass of an array unit m_a to the bare critical mass m_{s0} of a unit of similar shape.

The results of the density-analog treatment are displayed in Table 2, both for unreflected UF_6 spheres containing 16.8 kg ^{235}U and for 19.4 kg ^{235}U spheres which are considered nuclearly equivalent to the 16.8 kg ^{235}U spheres with a 1/4-in. Monel reflector. The intensive properties were obtained using ANISN and the Hansen-Roach cross section set.^{10,11}

*In some cases, where the container wall serves as an effective thermal neutron shield, the number of units required for system criticality may increase. This may be inferred from interaction experiments with moderated and unmoderated arrays of cadmium-wrapped containers of $\text{U}(93.2)\text{O}_2\text{F}_2$ solution.¹³

TABLE 2

Unreflected Arrays of Air-Spaced U(100)F₆ Spheres^a
Density-Analog

m_{so} (kg ²³⁵ U)	m_a (kg ²³⁵ U)	f	$\left(\frac{\bar{\rho}}{\rho_o}\right)$	s	Number of Units (N)
260.3	16.8	0.064	0.0174	1.87	30,060
260.3	19.4 ^b	0.074	0.0201	1.85	18,510

^aCubic arrays. Hydrogen moderation of the UF₆ is an H/U atomic ratio of 0.088. Lattice volume is 10.75 ft³.

^b²³⁵U mass nuclearly equivalent to the UF₆ sphere containing 16.8 kg ²³⁵U with 1/4-in. Monel reflector, i.e., $k_{eff} = 0.366$.

The KENO Code

A promising new Monte Carlo code, identified as KENO,⁷ has been developed recently to assist in the analysis of nuclear criticality safety problems. This code also uses the Hansen-Roach cross section set.¹⁰ Calculations were thus also made for the unreflected U(100)F₆ arrays utilizing KENO and the results listed in Table 3. The data indicate that much larger arrays would probably be required for system criticality than predicted by either the interaction potential or the density-analog methods.

TABLE 3

Criticality Factors of Unreflected Arrays of U(100)F₆ Spheres^a
KENO

Sphere Diameter ^b (in.)	k_{eff}	Leakage Probability (1 - U)	Number of Units (N)	Array Criticality Factor (C)
8.5	0.351	0.836	91,125 64,000	0.984 ± .014 ^d 0.900 ± .024 ^d
9.0 ^c	0.366	0.828	68,921	0.980 ± .033 ^d

^aCubic arrays. Hydrogen moderation of the UF₆ is an H/U atomic ratio of 0.088. Lattice volume is 10.75 ft³.

^bEach sphere contains 16.8 kg ²³⁵U.

^cIncludes 1/4-in. wall thickness Monel.

^d95% confidence level.

Discussion

Inherent in all of the above methods of determination are several factors of conservatism that should be noted. For example, a lattice volume of 10.75 ft^3 , corresponding to the volume of the proposed shipping container, was used in the calculations rather than the actual lattice array volume of 12.95 ft^3 , and the calculated UF_6 arrays of uniform spacing are considered to be more reactive than the nonuniform arrays which would normally be obtained by stacking the shipping containers. It may also be noted that both nickel and Monel are the basic materials of construction for the UF_6 cylinder under consideration, and that the effect of the cylinder wall was approximated by using an equivalent thickness steel in the transport theory calculations.

Of the methods employed in this evaluation, KENO is perhaps basically more rigorous. However, in view of the large number of units indicated by both KENO and the interaction potential method as being required for array criticality, it appears that the results of the inherently conservative interaction potential method are more appropriately used at this time. The maximum subcritical number of shipping containers in unreflected array is thus taken as 28,000.

REFLECTED ARRAYS

It has been found that a limiting ratio, R , exists for the critical masses of bare and water-reflected spheres, and that this ratio may be applied directly to the low-density arrays of general interest.⁶ In the case of $\text{U}(100)\text{F}_6$, the ratio R assumes a value of 6.0.* If the array were subject to both reflection and inter-unit moderation, as the results of the water-immersion test indicate might be possible, then an additional factor of 2.5 is used. Since it has been shown that as many as 28,000 shipping containers would be subcritical in an unreflected cubic array, then the maximum number of containers in a subcritical array subject to moderation and reflection with hydrogenous material is simply $28,000/15 = 1866$.

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.

*It is not recommended that this reflection factor be applied to the KENO calculations. Reflection factors determined by similar Monte Carlo codes,¹⁴ give appreciably higher values than those found in report LA-3366,⁶ and therefore, such factors should be generally used with the methods for which they were derived.

In addition to this obvious factor of conservatism, it may be noted that no credit is taken for the boron of the packaging material, which is an efficient $1/v$ neutron absorber.

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.³

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 would be subcritical in any arrangement with water moderation consistent with accident test results.

In view of the fact that, when subjected to rigorous accident test conditions, the proposed shipping container suffered only negligible damage which did not significantly alter the design spacing of the fissile $U(100)F_6$, it is apparent that Criterion 1 will determine the allowable number of packages. This number, therefore, is simply $1866/5 = 373$; and the transport unit assigned each package is $40/373 = 0.107$.

A further requirement is that any radiation measured in mr/hr at a distance of 1 meter from the center of the container be less than the assigned transport unit. This criterion is also met since measurements indicate that such radiation emanating from the package, containing a 5-in.-diam cylinder of $U(93)F_6$, is less than 0.1 mr/hr at the specified distance. This measurement is also considered applicable to $U(100)F_6$.

CONCLUSION

It appears that the proposed shipping container for the standard 5-in.-diam UF_6 cylinder has met all the criticality requirements for a fissile Class II package. With the transport unit rounded off to the first decimal, the allowable number becomes 400.

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PART IV

Photographs

Photo Number

PH-66-987	Disassembled Shipping Package and 5-in. Cylinder
PH-66-320 PH-66-317	Effects of 30-ft Drops and Puncture Test on Protective Shipping Package
PH-66-986 PH-66-985 PH-66-984	Top Views of Shipping Package and 5-in. Cylinder
PH-66-324 PH-66-322 PH-66-326	Top Views of Shipping Package and 5-in. Cylinder After Drop and Fire Tests
PH-66-323 PH-65-1140	Cutaway of Protective Shipping Package After Drop and Fire Tests

PHOTO NO. PH-66-317

PHOTO NO. PH-66-986

PHOTO NO. PH-66-985

PHOTO NO. PH-66-984

PHOTO NO. PH-66-324

PHOTO NO. PH-66-322

PHOTO NO. PH-66-326

PHOTO NO. PH-65-1140

PART V

Drawings

PROTECTIVE PACKAGE FOR 5-INCH DIAMETER UF_6 CYLINDER

Acknowledgments

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