H.C. \$ 3.00; MN 65

Date of Issue: April, 13, 1967

Report Number: K-1686

Subject Category: CRITICALITY STUDIES

RELEASED FOR ANNOUNCEMENT

IN NUCLEAR SCIENCE ABSTRACTS

PROTECTIVE SHIPPING PACKAGES
FOR 30-INCH-DIAMETER
UF₆ CYLINDERS

A. J. Mallett
C. E. Newlon

Engineering Division

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

UNION CARBIDE CORPORATION
NUCLEAR DIVISION
Oak Ridge Gaseous Diffusion Plant
Oak Ridge, Tennessee

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Abstract

Two designs which appeared suitable as standard protective packages for Class II shipment of 30-in.-diam x 81-in. cylinders containing moderation controlled uranium hexafluoride were developed at the Oak Ridge Gaseous Diffusion Plant. One is a horizontal loading unit comprising symmetrical separative top and bottom sections; the other is a cylindrical, end loading unit. A phenolic high-temperature foam plastic with fiber glass additive is used as a structural and fire-resistant material between the inner and outer casings of each unit. Both of the protective package designs have received AEC and ICC approval for Class II shipments of UF_6 enrichments to 4.5%. Based on the nuclear evaluation, ten of the filled packages may be transported together.

Protective Shipping Packages for 30-Inch-Diameter UF₆ Cylinders

PART I - SUMMARY

PART II - ACCIDENT TEST CONDITIONS OF TRANSPORT

PART III - NUCLEAR SAFETY ANALYSIS

PART IV - PHOTOGRAPHS

PART V - DRAWINGS

PART I

Summary

Two designs which appeared suitable as standard protective packages for Class II shipment of 30-in.-diam x 81-in. cylinders,^{1,2} containing moderation controlled uranium hexafluoride enriched to 4.5% ²³⁵U, were developed at the Oak Ridge Gaseous Diffusion Plant. One is a horizontal loading unit comprising symmetrical separative top and bottom sections; the other is a cylindrical, end loading unit.

A phenolic high-temperature foam plastic with fiber glass additive, fabricated in accordance with UCND job specifications, JS-31536-1 (AEC material specification SP-9)³ is used as a structural and fire-resistant material between the inner and outer casings of each unit.

Prototypes of each design have successfully passed the accident test conditions specified in AEC Manual Chapter 0529. The final designs shown incorporate all improvements which, based on prototype test data and engineering evaluations, were considered desirable with respect to improved structural integrity, fire protection, and shipping convenience. Units fabricated largely in accordance with the final designs, but with foam filled end sections in the horizontal loading package, successfully passed two consecutive 30-ft drop tests in a series of three such tests. Based on damage noted, these units would have passed the fire test after the second drop. Later substitution of wood end sections for the foam in the horizontal units reduced the overall length such that truck shipment can readily be made with the cylinders positioned at right angles to the longitudinal axis of the truck.

Final designs of both units have been approved by the Atomic Energy Commission and the Interstate Commerce Commission for shipment of UF₆ in the 30-in.-diam cylinder in either package, at ²³⁵U enrichments to not more than 4.5%, with not more than 4800 lb of UF₆ per container. Ten such packages may be transported together, each package being assigned a transport unit of 4.0.

1. Horizontal Loading Shipping Package

This protective container, UCND Drawing E-S-31536 J, Rev. 6, consists of two symmetrical sections of a cylindrical double shell, divided longitudinally to make top and bottom halves of the package. Inner and outer structural steel casings of 16- and 14-gage steel, respectively, are

supported along the length by eight 6 x 6 x 9-in. maple wood blocks and by approximately 6 in. of the high-temperature phenolic foam. The foam serves both as insulation and a structural support. The casings are separated at the ends by 4-in.-thick, laminated hemidisks made from 1-in.-thick maple. All maple used was select grade or better with a moisture content of 20% or less.

A rolled 2 x 2 x 3/16-in. angle, used as a tie bar, forms the internal framework of the outer shell of each half section. External framing includes three 3 x 2 x 1/4-in. angle iron circumferential ribs on the upper section, two of which have lifting holes for lid removal. A circumferential steel band 3 in. wide and 1/4 in. thick at each end and a similar adjacent band on the longitudinal shell section, tack welded to each other and to the outer shell, reinforce the end edges. A cradle assembly of two 3-1/2 x 3-1/2 x 3/8-in. and one 3 x 2 x 1/4-in. angle iron ribs is welded to the bottom section and is supported by footplates with bolt holes for tie down; 3/4-in. bolts are used for this purpose. Four 3/4-in. shackles through 15/16-in. holes in the bottom ribs, two on each side, permit unit lifting; the shackle pin is welded to prevent turning. Two vertical 3 x 2 x 1/4-in. angles are at each end of the enclosure and are welded to the shell and to the circumferential end band. Five 3/4-in. bolts at each side and two at each end through latches welded to the rib and angle sections securely hold the assembled unit.

Maple wood frames 2-5/8 in. thick and 6 in. wide, with a mating joint stepped 3/4 in. make up the joining members of the bottom and cover sections. The inner and outer edges of the mating housing are sealed with sponge rubber gaskets,* and the wood framework is covered with an intumescent paint which, on heating, expands to serve as an additional heat shield at the joint section. Protection of the frame and paint on removal of the lid is provided by short legs welded externally at the housing corners. Four 6 x 9-in. rubber pads cemented to the inner casing of each section above the wood block supports help prevent cylinder movement. Since the housing is designed to accommodate variations in cylinder lengths, plywood discs between the cylinder ends and the inner housing are used as filler pieces to further reduce cylinder movement.

Strategically spaced vent holes of 3/16 in. diam in the outer shell are predrilled prior to foaming. After foaming, the openings are covered with an epoxy for weather sealing and the metal casing is then painted. These openings prevent package rupture by allowing the nontoxic decomposition gases from the plastic to escape in event of fire.

*Sponge rubber, as used in this report, refers to cellular (closed pore) rubber.

2. End Loading Shipping Package

The second enclosure design for shipment of the 30-in.-diam cylinder, UCND Drawings E-S-31536 K, Rev. 4 and E-S-31536 L, Rev. 3, is an end loading unit of cylindrical configuration with inner and outer casings of 16- and 14-gage steel, respectively. The inner casing is flanged at the loading end, gasketed with 1/4-in.-thick sponge rubber, and closed by a circular 1/2-in.-thick steel plate bolted to the flange; the outer cover is a 3/16-in.-thick x 10-3/8-in. deep steel cap, filled with high-temperature foamed plastic to a depth of 5-3/8 in. The cover is fastened to the shell by four 3/4-in. bolts through yokes and plates which are welded to both units and designed to prevent bolt loss on accident. Four 4 x 6-in. oak stringers in the space between casings are positioned 90° apart and extend the length of the unit. Four 2 x 6 x 16-in. long blocks under the exterior steel framing at the loading end serve as shock blocks. Alignment lugs, 3/16 in. at 60° spacing, welded to the bottom container section, provide additional structural stiffness to prevent displacement of the steel cap. High-temperature foam plastic fills the remaining space except at the closed end where 4-in.-thick laminated hardwood provides support and insulation. Neoprene pads, 1/2 in. thick, are used on the inner shell base and in the head section to cushion the cylinder during loading and shipment.

The package is supported and protected externally by a rectangular framework of 2-in. schedule 40 pipe, positioned at the top and bottom.

PART II

Accident Test Conditions of Transport

The provisions of the test requirements of AEC Manual Chapter 0529 and 10-CFR-71 for packaging for fissionable materials,⁴ and the test results obtained with the 30-in.-diam UF₆ cylinder packages 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

1. Prototype Horizontal Loading Package. A prototype horizontal loading package containing a simulated UF₆ filled 30-in.-diam cylinder was dropped in a horizontal position. Damage was negligible. The test cylinder, filled with ferrous sulfide crystals and lead weights to the specified UF₆ fill limit of 4800 lb, weighed 6400 lb. The total weight of the shipping package was 8025 lb.
2. End Loading Package. The end loading package, total weight 8650 lb, was similarly tested. Damage was negligible.

The test pad used in the drop tests is constructed of reinforced concrete. Imbedded steel cross beams 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 most vulnerable to puncture.

Result

1. Prototype Horizontal Loading Package. The steel cylinder was dropped on the end and side wall of each container. A barely discernible dent resulted in each case.
2. End Loading Package. (Same as Prototype Horizontal Loading Package).

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

1. Prototype Horizontal Loading Package. This test was not made. The vent holes in each unit are sealed with an epoxy, and additionally sealed by the prime and finish coats of paint applied to the unit to prevent rainwater, moisture, etc., from seeping in during normal handling and use of the shipping enclosure. In event of a fire, the epoxy melts and opens the vent holes. Based on the design closures and the above sealing, water inleakage appeared highly unlikely.
2. End Loading Package. (Same as Prototype Horizontal Loading Package).

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

1. Prototype Horizontal Loading Package. This test was not made. Based on the 40,000 - 43,000-lb load requirement, and difficulty of conducting the test, a structural engineering assessment was accepted. This indicated the units would adequately meet the requirement.
2. End Loading Package. (Same as Prototype Horizontal Loading Package).

HYPOTHETICAL ACCIDENT TESTS

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

1. Horizontal Loading Package. As the container package development work progressed, improved lid tie-down methods were developed, additional reinforcing members were added to both top and bottom sections, and the design of the wooden joint bracing was improved. Thus the packages which underwent the following drop tests were considerably improved from the prototype designs used in early drop and fire test work.

A unit containing a filled cylinder was positioned on a scaled-down truck bed and the assembly dropped 30 ft, end down, to test the designed tie-down arrangement. Since the test proved successful, minor damage to the top end section only occurred when the truck bed rebounded and hit on the opposite end, the package was removed from the truck bed, dismantled for inspection, and reassembled without further modifications. It was then subjected, without the truck bed but containing the loaded cylinder, to the series of 30-ft drop tests mentioned earlier. The following results were obtained:

In the first test, the package was dropped at a 40° angle onto the base section of one end. All holding bolts remained intact and cover movement, with respect to the lower section, was negligible. The section receiving the initial blow was dented to a depth of about 3 in. and, probably resulting from the wrinkling of adjacent metal, a 1-1/2-in.-long tear was noted.

The next drop, made in a horizontal position with the base support side downward, caused the support plates to collapse completely, yet without fracture. The impact, perpendicular to the enclosure joint, caused a spread in the circumferential angle iron bands and resulted in fractures at the bolt bracket welds. This in turn permitted the joint to open about 1 in. wide for a distance of 12 in. on both sides of the package. Longitudinal braces at the end section were pressed into the outer shell about 2 in. All fasteners, though bent in varying degrees, again remained intact.

Turned 90° from the previous test position, the package was dropped 30 ft on the joint line. On the impact side, the joint opened to a maximum width of 1-1/4 in. for the full length of the package. After three successive tests in as many positions, all fasteners still held although cleavage was noted at some locations. The fasteners on the side drop had been driven about 2-1/2 in. into the framing.

After disassembly, the wooden joint framing was seen to be damaged extensively, particularly the end beam on the impact end. Fracture of this member had allowed a bend of 2-1/4 in. in the metal lining, coincident with the rim of the cylinder's concave end; however, no breaks were evident here or at any other place in the top and bottom sections. Although previous drop and fire tests had resulted in a hairline crack about 5 in. long in the rim of one end of the cylinder, no additional damage occurred in any of these tests as determined by air pressuring the cylinder above atmosphere.

2. End Loading Package. The 30-in. cylinder was removed from the horizontal package, installed in the end loading package, and this unit was also given a series of 30-ft drops. The package used had previously undergone a 30-ft drop test of the tie-downs when mounted on the scaled-down truck bed. Damage in this case was very slight and modifications were minor. Cover fasteners were changed and bolt supports modified to prevent impact shock from causing bolts to snap out of place and enable easier opening.

The first test was a 40° angle drop on the bottom end. Damage from this drop was minor. The tack welds holding the external protective base plate to the end leg support band broke, allowing the plate to spring open from 1/4 to 1-1/2 in. and exposing the outer casing of the package. The casing was not broken although the striking area was dented inward about 1-1/2 in.

In the second test the unit was dropped in a horizontal position onto the external pipe frame assembly of the base section. The outer frame was bent, particularly where the legs joined the circumferential bands at the ends of the enclosure. Most of the welds on the bottom plate were fractured.

The third drop was made at a 40° angle on the head section. The bolt brackets opposite to the corner first making contact bent inward and allowed two cover bolts to withdraw from their yokes. This in turn permitted the cover to open considerably, tearing the plastic insulation. In both end drop tests, the uniform cushioning effect by the foam plastic lining and surrounding casing was clearly evidenced in that the unit did not rebound but remained standing at the angle at which it was dropped.

Examination of the interior following dismantling and removal of the inner liner disclosed that one of the four longitudinal oak beams had

been split along its length by inward pressure from the external steel bar located on the same radial line as the wood beam. A few cracks were noted in the plastic, otherwise it was in good condition.

The UF₆ cylinder was found, on an air pressure test, to have developed some additional hairline rim cracks and a small leak at the threads where the valve was screwed into the cylinder head. Considering that this cylinder had been through many drop tests from 10 to 30 ft, both in and out of protective packages, plus two fire tests, this finally incurred minor damage was not unexpected. It is considered quite unlikely to occur in a vacuum tested, UF₆ filled cylinder in a single accident in which both drop and fire hazards may occur.

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

1. Prototype Horizontal Loading Package. A prototype horizontal loading unit with latch lid fasteners was used for this test. It was dropped on the lid section, striking the piston approximately 10 in. from the nearest outer rib. Indentation was about 3 in. and 2 openings, one of 1/2 in. and the other 5 in. long, occurred as the casing split at the rib tack welds. The cover had been slightly dislocated from three previous drops of 4, 8, and 10 ft in tests of cover tie downs; the piston test increased the misalignment near one end to about 3/4 in.

Latch lid fasteners proved unsatisfactory due to pin breakage and were replaced in later models with the strong bolt tie-down system, discussed on page 2, which retains lid position. However, piston damage will vary from essentially the same condition noted above to a direct hole without casing splits.

2. End Loading Package. A prototype end loading unit with latch lid fasteners was dropped such that the impact point was about 3 in. from one of the longitudinal wooden stringers. The casing was sheared and

a circular puncture resulted, exposing the plastic, to a depth of nearly 4 in. Later examination revealed that the inner liner had also been forced inward sufficiently to cause a small dent in the cylinder, but no breakage of this liner was noted.

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

1. Prototype Horizontal Loading Package. Following the piston test, the horizontal loading package was moved to the fire test facility, positioned on railroad rails laid across the oil tanks, and fire tested for 1 hr. Wind velocity during the test was less than 4 miles per hour. Micromax temperature recordings from thermocouples at two positions on the top, and one on the side of the unit, indicated temperatures between 1700-2150°F for the first 15-20 min. At this point, the support rails bowed out and the housing base supports softened and bent, allowing the unit to drop to the edges of the two central oil tanks. Following this position change, temperatures ranging from 1550-1700°F were recorded for the remaining 45 min. Since the unit was fire tested over an interval twice that of the required time and at temperatures exceeding the specified limit, it appeared desirable to learn the extent of the damage as quickly as possible. The flames were therefore extinguished.

Enlargement of the test facility had been necessary to accommodate the large packages for the 30-in.-diam cylinders. Installation of another tank provided an arrangement of three concentric units, 16.0, 10.5, and 8.5 ft in diameter and 29 in. deep. Diesel oil fuel height was adjusted by water filling. The oil level was 10, 8, and 6 in. below the base of the test unit, starting at the central tank. The varied depth in each tank had been proved on other tests to provide better flame coverage.

Removal of the enclosure cover after the cooling period revealed a continued smoldering and charring of sections of the wooden frame at the closure joint. On cutting open sections of the housing, some of the

wooden support blocks burst into flames. All wood used in this prototype was fir. The neoprene flat outer gasket of the joint framework had burned completely; the inner "O" ring cord gasket was intact at both ends and one side but had burned on the side where the cover overlapped the bottom section as a result of the various drop tests.

Removal of additional sections of the steel outer housing and measurement of the foam charring depth gave the following data: in the lower section - 2 to 4 in., at the ends - 2-1/2 to 3 in.; the plastic in the top section was almost completely charred. The foam rubber pads in the upper half and the neoprene pads in the lower half of the housing were undamaged and remained adhered to the walls as originally installed.

Temperatures of the inner metal liners and of the cylinder were recorded by Tem-Plate indicators. The temperatures obtained and locations are shown in Fig. 1. Cylinder temperatures were less than 200°F with the exception of one small area near the housing joint where drop damage had resulted in greater misalignment of the top section and hence, increased chance of heat entry. Although the temperature at this location exceeded 450°F, other cylinder temperatures in close proximity were less than 200°F.

The number of low temperatures indicates a gradient such that cylinder rupture was unlikely. The mass of steel (cylinder walls are 0.4 in. thick) plus the material within the cylinder, rapidly dissipated the heat away from any hot spot. The effect could be similar if the cylinder content were UF_6 , and if the heating period were short.

Engineering assessment of the drop test and fire damage to the horizontal loading unit resulted in several improvements which were incorporated in the final design (discussed in Part I). Although an actual fire test of this specific design was not made, based on the drop tests conducted, it is considered that any unit so fabricated will provide considerably greater protection against fire hazards than the prototype tested.

2. End Loading Package. Following both a horizontal 10-ft drop and the piston test, a fire test of a prototype end loading unit was conducted for a period of 45 min, with recorded temperatures ranging from 1800-2100°F. Wind velocity was less than 2 miles per hour. The highest internal housing temperature noted on dismantling the package was less than 250°F and this was at the top inside liner. Cylinder temperatures at various side, top, and end positions are shown in Fig. 2. Charring

of the plastic was about 2 to 2-1/2 in. deep. The 2 in. of compressed plastic resulting from the piston drop was charred less than 1 in. The unit was considered to have successfully passed the test.

Evaluation of the structural damage to the end loading unit used in the series of 30-ft drop tests indicates that it would have passed the fire test after the second drop. The difference between the final design and the fire-tested unit is the improved lid tie-downs, utilizing bolts and yokes instead of latch-type closures.

Water Immersion Test

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

Result

1. This test was not performed with either prototype package following the fire test. However, as a result of air pressure test, a short hair-line crack was found in the rim of an end section of the cylinder removed from the horizontal loading unit. The cylinder was weighed to the nearest half pound on available scales and immersed under 6 ft of water for 15 hr. After removal, drying, and reweighing, no change in weight was noted. Further, the cylinder was at atmospheric pressure and observations during the immersion period revealed no bubbles as a result of air displacement due to inleakage.
2. Water leakage into the cylinder section of the horizontal unit on flooding is a possibility, although slight, even without accident damage; it is quite unlikely into the end loading unit unless severe accident damage has occurred which creates openings in the inner liner. In either case, leakage into or from any UF_6 cylinder is unlikely. The cylinders are structurally sound and periodically, or if valve damage occurs, undergo examination and tests by a specific group authorized to conduct such investigations. They are vacuum tested prior to each filling of liquid UF_6 and visually checked for valve leakage during the cooling transition to solid UF_6 .

SHIPPING PACKAGE
30-INCH CYLINDER

Figure 1

SHIPPING PACKAGE
30-INCH CYLINDER -
VERTICAL LOADING

Figure 2

PART III

Nuclear Safety Analysis of Protective Structural Shipping Package for 30-Inch Diameter UF₆ Cylinder

A nuclear safety evaluation of a shipping package for the standard 30-in.-diam x 81-1/2-in.-long UF₆ cylinder at ²³⁵U enrichments to 4.5% has indicated that all requirements for fissile Class II packages have been met satisfactorily. Ten such packages may be transported together, each package being assigned a transport unit of 4.0. The analysis includes an overall reduction factor of 30 applied to a computed maximum subcritical number of shipping packages in bare array. A factor of 6 was used for external reflection and interunit moderation with hydrogenous materials, plus a safety factor of 5 in accordance with AEC Manual Chapter 0529, Section II. J. 1.⁴

In addition to the criticality calculations that were made for the nuclear safety analysis, neutron multiplication tests were also performed at the Oak Ridge National Laboratory in support of this determination. In these experiments it was found that seven of the 30-in.-diam cylinders, each containing 4700 lb of U(4.2)F₆, were subcritical when arranged in close-packed hexagonal arrays and submerged in water.⁵

PROPERTIES OF UF₆

All UF₆ fuel supplied to the nuclear industry must meet rigid requirements set forth in the Federal Register,⁶ including a purity specification of 99.5% by weight UF₆. The maximum possible hydrogen moderation is determined by making the conservative assumption that all impurity is hydrogen fluoride.

At the specified ²³⁵U enrichment, the H/²³⁵U atomic ratio and the quantity of fissile ²³⁵U isotope are established from an H/U ratio of 0.088 and the cylinder fill limit of 4800 lb UF₆, respectively. The uranium density is that of the solid UF₆ at 68°F.⁷ The following maxima were thus assigned the 30-in.-diam UF₆ cylinder under consideration.

²³⁵ U enrichment	4.5%
H/ ²³⁵ U ratio	1.9
Contained ²³⁵ U	66.3 kg
U density	3.2 g/cc

GENERAL CRITICALITY CONSIDERATIONS

In evaluating the proposed shipping package, it is first noted that nuclear safety has been established through the use of moderation control, which is defined as a method of assuring the nuclear safety of a system of fissionable material such that the $k_{\infty} < 1$ and the H/ ^{235}U atomic ratio of the hydrogen moderator and fissile material is maintained below a specified safe value. The method has been widely used for the large-scale shipment of low-enrichment UF_6 .⁸

It is further noted that transport theory calculations indicate a k_{∞} of only 0.80 for the moderation controlled, H/ ^{235}U of 1.9, 30-in.-diam $\text{U}(4.5)\text{F}_6$ cylinder with 0.4-in. steel wall (see Fig. 3). Since the infinite medium multiplication factor, k_{∞} , must be greater than unity for criticality, a value of 0.80 is considered adequate, in establishing nuclear safety, for possible calculational uncertainties including the assumed optimum water reflector thickness. In these calculations, which were made using the ANISN Code,⁹ the cylinders were considered to be of infinite length with a 1-in. water jacket around the outer edge of the cylinder wall. A modified Hansen-Roach cross section set and the white boundary option were used in the Code. The white boundary condition assumes all neutrons are reflected isotropically at the cell boundary, this corresponding to the outer edge of the reflector water jacket.

ORNL Neutron Multiplication Tests

In support of the above calculations, a short series of neutron multiplication tests was conducted at the Oak Ridge Critical Experiments Facility of the Oak Ridge National Laboratory. A description of the contents of the cylinders used is given in Table 1. Since these cylinders are normally filled in the horizontal position at the production sites, the test cylinders were first heated at 220°F to liquefy the UF_6 , which was then permitted to cool and resolidify with the cylinders standing in the vertical position. This procedure assured that the UF_6 would be in a compact and thus more favorable geometry for the tests.

A large steel tank 9 ft in diameter and 9-1/2 ft high served as a container for the reflector water in these tests (see Figs. 4 and 5). All measurements were made with the cylinders in the vertical position. With seven of these 30-in.-diam cylinders completely submerged in water, no significant multiplication of source neutrons was observed either with the cylinders in contact or when separated 1 in. edge to edge.

k_{∞} OF 30-INCH DIAMETER UF_6 CYLINDER

Figure 3

SEVEN 30-INCH DIAMETER $U(4.2)F_6$ CYLINDERS IN
CONTACT IN REFLECTOR WATER TANK

Figure 4

PHOTO NO. ORNL 73530

SEVEN 30-INCH DIAMETER $U(4.2)F_6$ CYLINDERS AT
1-INCH SEPARATION IN REFLECTOR WATER TANK

Figure 5

TABLE 1
 UF_6 Used in ORNL Neutron Multiplication Tests

Cylinder No.	Net Weight (lb)	Uranium ^a (wt %)	^{235}U (wt %)	^{235}U (wt %)	Moderation ^b (H/ ^{235}U)
1	4722	67.48	4.2668	61.798	0.78
2	4686	67.55	4.2053	60.506	0.37
3	4731	67.49	4.2296	61.384	0.74
4	4708	67.39	4.2122	60.746	1.36
5	4736	67.38	4.2652	61.866	1.41
6	4719	67.50	4.1874	60.628	0.68
7	4721	67.57	4.1737	60.518	0.25

^aThe theoretical U content in UF_6 is 67.61 wt % at 4.2% ^{235}U enrichment.

^bThe actual moderation ratio may be smaller since all impurity was assumed to be hydrogen fluoride.

CRITICALITY OF ARRAYS

On the basis of the preceding calculations, which do not appear to be negated by the experimental results obtained, it is somewhat doubtful if criticality could ever be achieved in any array of the 30-in.-diam UF_6 cylinders at the 4.5% ^{235}U enrichment level. Nevertheless, a conservative estimate of the maximum subcritical number of such units can be made if no credit is taken for the effect of the steel cylinder wall and the units are moderated externally, as for example by a 1-in. water jacket. In this case, which obviously has no real physical relation to the actual cylinders under consideration, the infinite medium multiplication factor, k_∞ , would be slightly greater than unity and criticality might be possible for very large arrays of these fictitious units (see Fig. 3).

Unreflected Arrays

Table 2 shows the results of calculations which were made for unreflected cubic arrays of 38-in.-diam spheres, each surrounded by a 1-in. water jacket, each occupying a lattice volume of 147.9 ft³ corresponding to the effective volume of the shipping package,* and each containing 4800 lb of UF_6 . The assumed moderation of the UF_6 , an H/ ^{235}U = 10, is higher than the specified value of 1.9, thus

*The effective volume is applicable to both horizontal and end loading package designs.

introducing an additional factor of conservatism in the calculations. The calculations were made using the interaction potential method.¹⁰

TABLE 2
Unreflected Arrays of 38-in. -diam U(4.5)F₆ Spheres^a

k_{eff}	Leakage Probability (1 - U)	No. of Units, N	Interaction Probability ($\sum q_i \Omega_i$)	Array Criticality Factor, C
0.722	0.374	840	0.742	1.00
		380	0.535	0.90

^aCubic arrays. Edge spacing of units: 25.5 in. Hydrogen moderation of UF₆: H/²³⁵U = 10. Each sphere surrounded by a 1-in. water jacket.

The results given in Table 2 include the number of units, N, required for an array criticality factor, C = 0.90, which is well within the assigned accuracy of the method. Since the calculated arrays of spherical units are considered to be more reactive than the arrays which could be obtained by stacking the actual shipping packages, the number N = 380 is thus considered a conservative estimate of the maximum number of shipping packages that may be placed in a subcritical, unreflected cubic array.

Reflected Arrays

In considering the effects of array reflection, it should be noted that the 1-in. water jacket in the calculational model provides both interunit moderation of the U(4.5)F₆ spheres as well as some array reflection. A reduction factor of 6 for complete array reflection, as previously derived for U(93)F₆,¹¹ is therefore thought to be somewhat generous when applied to this low-enrichment system. Such reduction factors are based on the limiting ratios that have been found to exist for the critical masses of bare and water-reflected spheres, and which may be applied directly to the low-density interacting arrays of interest. However, since the interunit moderation already present in the calculational model is assumed to be optimum, no additional allowance was made for interunit moderation of the array.

Since it has been shown that as many as 380 of the shipping packages would be subcritical in an unreflected cubic array, the maximum number of packages in a similar array subject to both reflection and interunit moderation is simply $380/6 \sim 63$. In addition to the obvious factors of conservatism used in this determination, it may be further noted that no credit is taken for the boron of the packaging material which is an efficient $1/v$ 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.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.
2. Twice the allowable number of damaged packages would be subcritical in any arrangement with moderation consistent with accident test results.

In view of the fact that, when subject to rigorous test conditions, the proposed shipping package suffered only negligible damage which did not significantly alter the design spacing of the fissile material, it is apparent that criterion 1 will determine the allowable number of packages. This number, therefore is simply $63/5 \sim 12$, and the transport unit is $40/12 = 3.3$. Rounding off, the transport unit is 4.0 and the allowable number of packages is 10.*

A further requirement is that any radiation measured in mr/hr at a distance of 1 meter from the center of the package be less than the assigned transport unit. This criterion is also met since measurements indicate that such radiation emanating from the package, containing a 30-in.-diam $U(4.5)F_6$ cylinder, is less than 0.1 mr/hr at the specified distance.

CONCLUSION

It appears that the proposed shipping package for the standard 30-in.-diam UF_6 cylinder has met all the criticality requirements for a fissile Class II package.

*Changes in regulations made after the original nuclear safety evaluation allow the calculated radiation unit to be rounded off to the first decimal place.

PART IV

Photographs

Horizontal-Loading Package for 30-Inch-Diameter UF₆ Cylinder

Photo No.

PH-66-656	Tie-Down Development Test
PH-66-655	30-foot Drop Test of Tie-Down
PH-66-499	After Piston Drop
PH-66-791	After 30-foot End Drop at 40° Angle
PH-66-788	Closeup After End Drop
PH-66-790	Joint Section After 30-foot Drop on Support Base
PH-66-799	After Three 30-foot Drops; End, Base, and Joint
PH-66-798	Base Section After Drop Tests
PH-66-796	Cover Section After Drop Tests

End-Loading Package for 30-Inch-Diameter UF₆ Cylinder

Photo No.

PH-66-588	Bolted Inner Housing After Foaming Operation
PH-66-658	Ready for Thermal Test After Piston Drop and 30-foot Drop with Scaled Down Truck Bed
PH-66-781	Ready for Free-Fall Test
PH-66-775	After 30-foot Base Drop at 40° Angle
PH-66-772	In Position for 30-foot Horizontal Drop
PH-66-783	Cover After Horizontal Drop
PH-66-773	After Three 30-foot Drops; Base, Cover, and Support

Fire Test Facility

Photo No.

PH-66-651	Fire Test of 30-inch-diameter Cylinder Package
-----------	--

PHOTO NO. PH-66-656

TIE-DOWN DEVELOPMENT TEST

PHOTO NO. PH-66-655

30-FOOT DROP TEST OF TIE-DOWN

PHOTO NO. PH-66-499

PHOTO NO. PH-66-791

PHOTO NO. PH-66-790

PHOTO NO. PH-66-788

PHOTO NO. PH-66-798

PHOTO NO. PH-66-796

PHOTO NO. PH-66-588

PHOTO NO. PH-66-658

PHOTO NO. PH-66-781

PHOTO NO. PH-66-775

PHOTO NO. PH-66-772

PHOTO NO. PH-66-783

FIRE TEST OF 30-IN. DIAMETER CYLINDER PACKAGE

PART V

Drawings

1. Horizontal Loading Shipping Container for 2-1/2 Ton Cylinder
E-S-31536 J Rev. 6.
2. End Loading Shipping Container for 2-1/2 Ton Cylinder
E-S-31536 K Rev. 4 and E-S-31536 L Rev. 3.

FIRE AND SHOCK RESISTANT OUTER CONTAINER
HORIZONTAL LOADING UNIT

Figure 6

FIRE AND SHOCK RESISTANT OUTER CONTAINER
END LOADING UNIT

Figure 7

Acknowledgments

The authors wish to acknowledge the contributions and assistance of the various craft groups involved in the container development program. Our thanks especially to the following Engineering personnel: Messrs. F. W. Stout and J. W. Gregory for their respective horizontal and end loading protective package designs and the related test evaluations; D. S. Pesce for technical advice; W. R. Wells for his assistance in all phases of test work and container fabrication; and T. Denton for valued aid in report preparation. Our thanks also to Mr. C. R. Barlow of the Technical Division who was responsible for the foam plastic insulation and related test work, and Messrs. R. R. Tippy, W. J. Moore, and J. W. Edwards of the Finance and Materials Division for graphic art and photographic aid.

Special mention should be made of the work performed by personnel of the Oak Ridge Critical Experiments Facility, Dr. A. D. Callihan, Director, for the rapid series of criticality experiments conducted with the 30-in. cylinders in order to provide reference data.

Bibliography

1. A. J. Mallett and S. J. Wheatley, Fissile-Material Container and Packaging Development and Testing Program, Union Carbide Corporation, Nuclear Division, Oak Ridge Gaseous Diffusion Plant, K-1661 (April 1, 1966).
2. H. F. Henry, Compiler and Editor, Guide to Shipment of U-235 Enriched Uranium Materials, Oak Ridge Operations Office, USAEC, June 1959 (TID-7019).
3. Fire Resistant Phenolic Foam, AEC Material and Equipment Specification SP-9, available through the Clearing House for Federal Scientific and Technical Information, National Bureau of Standards, U. S. Department of Commerce, Springfield, Virginia.
4. U.S. Atomic Energy Commission Manual Chapter 0529 - Safety Standards for the Preparation of Radioactive and Fissile Material for Transportation, August 22, 1966.
5. A. D. Callihan, Oak Ridge National Laboratory, personal communication to C. E. Newlon, Oak Ridge Gaseous Diffusion Plant, July 1966.
6. U.S. Atomic Energy Commission, Specifications and Packaging, Federal Register, 30: 14821, November 30, 1965.
7. E. L. Keller, Compiler and Editor, Uranium Hexafluoride Handling Procedures and Container Criteria, Oak Ridge Operations Office, USAEC, 1966 (ORO-651).
8. C. E. Newlon and A. J. Mallett, Hydrogen Moderation - A Primary Nuclear Safety Control for Handling and Transporting Low-Enrichment UF₆, Union Carbide Corporation, Nuclear Division, Oak Ridge Gaseous Diffusion Plant, K-1663 (May 31, 1966).
9. W. W. Engle, Jr., A Users Manual for ANISN, Union Carbide Corporation, Nuclear Division, Oak Ridge Gaseous Diffusion Plant, K-1693 (March, 1967).
10. C. E. Newlon, The Elements of Neutron Interacting Arrays - Part I, Union Carbide Corporation, Nuclear Division, Oak Ridge Gaseous Diffusion Plant, K-1619 (October 13, 1964).
11. H. C. Paxton, Criticality Control in Operations with Fissile Materials, Los Alamos Scientific Laboratory, LA-3366 (January 15, 1966).