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RADIOISOTOPE SHIPPING CONTAINER DEVELOPMENT*

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The results of a series of structural and fire tests on the fire and impact shield designed for the Oak Ridge National Laboratory radioisotope shipping containers are presented here. This work is being conducted by the Isotopes Development Center at ORNL as a part of its program to continually improve its shipping procedures and packaging. Since 1946, the beginning of the radioisotope program, more than 180,000 shipments containing ~2.2 million curies have been made without a single accident in which a significant release of radioactivity was involved. However, with the trend in radioactive material shipments to larger curie content per package, the need of greater safety in package design has become essential.

For radioisotope shipping carriers weighing up to ~1.25 tons and which are ~20 in. in dia., a low-cost fire and impact shield was designed and tested which will meet the packaging requirements given in the new federal regulation 10 CFR 72, notably the fire requirement and the 30 foot free fall requirement. The shield is constructed of 3-5/8-in.-thick maple (finished 4 in. lumber) (Figure 1) with mitered corners of nailed construction. A mild steel frame holds the shield intact under impact conditions. The frame is made of 1-in. steel straps and 1.5-in. steel angle iron for the small shields and up to 2.5-in. straps and 3-in. angle iron for the largest shields. The top is hinged for removal of the container.

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The smallest shield tested weighs 120 lb.; it measures 14 x 14 x 17-3/8 in. and holds a 60-lb. lead-shielded steel shelled container that has 1.5-in. shielding. The largest shield weighs 570 lb.; it measures 28-3/8 x 28-3/8 x 36-1/4 in. and holds a 2600-lb. container with 8-in.-thick lead shielding.

The design of the fire and impact shield as shown in Figure 1 has evolved from a series of tests performed on several different types of shields and kinds of wood. In the first series of tests, the resistance to fire of various kinds of wood was evaluated. The tests are designed to duplicate to some degree the time-temperature conditions of a standard 1-hr. fire test as defined by the National Fire Protection Association (NFPA Bulletin No. 251) and ASTM-E119-61.

Maple, pine, and hickory were exposed for 1 hr. to the flame of a pressurized kerosene burner. The outside temperature was maintained at 900 ± 50°C to duplicate the maximum temperature of the standard 1-hr. fire test. Maple showed only a 2-in. penetration vs 2.5 to 3 in. for pine. Considering the strength, availability, insulating properties, and cost, maple was the best wood to use. Maple, however, was not as good an insulator as pine, since the maximum temperature inside the pine shield rose only 30°C, and inside the maple shield it rose 60°C during the 1 hr. test. Hickory was not available in the thicknesses and widths needed and is no less expensive than maple. As a result of these tests, maple was selected as the material for use as a shield.

Each shield was instrumented with two thermocouples -- one on the outside surface and one in the interior cavity -- which were connected to a 10-point Brown recorder. The fire shield was placed in a sheet metal enclosure and heated with a pressurized kerosene burner. The burner was manually moved toward the shield at a rate that caused the rate of temperature increase indicated by the exterior thermocouple to conform to the standard 1-hr. fire test specifications.

Three wooden shields were fire tested in this manner. The first shield (external dimensions 24 x 24 x 24 in., thickness 4 in.) was constructed of 2- by 4-in. pine stacked vertically around the cask cavity and was bolted together with 1/2-in. bolts spaced 4 in. apart. The pine shield withstood the 1-hr. fire test successfully. Exterior temperatures were ~1000°C, and the maximum interior temperature at the end of the test was 140°C. At the completion of the test, the wood was charred to a depth of ~3 in. in the area of direct flame impingement, and other areas were charred to a depth of ~1-1/2 to 2 in. The fire in this shield was not completely extinguished at the end of the test, and ~3 hr. later the entire shield was completely burned.

It was observed during the test that the wood burned much more rapidly when the flame impingement was parallel to the grain than when perpendicular (Figure 2). All future wooden fire shields were designed to minimize the area of flame impingement parallel to the grain of the wood.

A second shield, used in routine radioisotope shipments and constructed of 3/4-in. aluminum-clad plywood reinforced with aluminum angle on the corners, was tested. The isotope shipping cask was removed from the wooden box for this test. The aluminum cladding began to buckle after 30 sec. exposure to the flame and was completely melted after 45 sec. exposure (melting point of Al = 659.7°C). Temperature at the outside surface of the shield was held at 900°C ± 50°C. The maximum interior temperature was 40°C for 20 min., at which time the shield burned through. The glue between laminations of the plywood caused the layers to crack and split when burned through, thus reducing the layer of insulating charcoal on the outside. For this reason, this particular plywood is not considered a good fire shield material.

In the second series of tests an attempt was made to differentiate between the practicality of using a fabricated wooden shield with a steel angle iron frame for support and a solid wood block with space drilled out to hold the radioisotope shipping cask. In this series of tests, two wooden fire and impact shields were built. The first type was built of 4- by 16-in.-thick white pine with outside dimensions of 19 x 19 x 19 in. and a finished wall thickness of 3-5/8 in. The side corners were mitered and nailed together and were protected with a 1-1/2-in.-wide angle iron frame. The top and bottom were purposely attached with the end grain of the wood exposed to determine the difference in burning rate of end grain and perpendicular grain. Two of these shields were built and each shield was instrumented with a thermocouple on the inside surface of the wood wall and another thermocouple on the outside surface of the wood wall.

Each of the shields was exposed to the flame of a pressurized kerosene burner. The temperature on the outside was held at 900°C ± 50°C for 1 hr. by manually adjusting the position of the burner. Inside both shields, the temperature remained at 15°C for the first 50 min. of the fire test. In the remaining 10 min. of the test, the temperature rose to 25°C in one shield and to 30°C in the other. Charring occurred to a depth of ~2-5/8 in. on the side of each shield where the direction of flame impingement was perpendicular to the grain of the wood and to a depth of ~3 in. on the top and bottom edges where the flame was parallel to the grain. The flame did not penetrate the shield during the test.

The second type of fire and impact shield tested was built of a solid piece of 14 x 14 x 14 in. douglas fir with a 6-in.-dia. hole drilled in the center to hold a small cask. The top was constructed of 14 x 14 x 4 in. douglas fir and was attached to the main body with four counterbored lag screws. Three shields of this type were dropped from a height of 15 ft. onto a solid concrete floor. Shield No. 1, when dropped onto a top corner at an angle of ~20°, split in half, and the small lead container on the inside of the shield fell out (Figure 3). Shield No. 2 was dropped onto one of its vertical side corners. A strip, 2 by 5 in., was broken off one corner (opposite the point of impact) and a lag screw was exposed. Another split, ~1/2 in. deep, occurred on another corner opposite the corner of impact. Shield No. 3 was dropped on its bottom, and a strip ~2 by 1 in. split off the top corner upon impact. Two other cracks, one ~2 in. deep and the other ~1-1/2 in. deep, appeared on the sides of the shield.

Shields No. 2 and 3 were submitted to a 1-hr. fire test with instrumentation and test conditions the same as described previously. The inside wall temperature increased from 0 to 15°C for shield No. 3 and from 0 to 30°C for Shield No. 2 in 1 hr. No damage to the small lead cask inside the shield occurred. In the area of the cracks, the shields were charred nearly through the entire depth, but the lead casks were not damaged.

The shields for the third series of tests were designed using the knowledge gained from the first two series but using maple. (This was the shield shown in the first figure.)

Two wooden fire and impact shields fabricated of 3-5/8-in. thick maple with mitered corners, nailed construction, and a mild steel frame to hold the entire shield intact, were tested. The shield weighed ~120 lb. and was loaded with four lead bricks weighing ~28 lb. each, for a total weight of 234 lb. The first shield was dropped from a height of 15 ft. onto a 6-in.-dia. piston, fastened to a pad consisting of a 12- by 12-ft. piece of steel armor plate 4.5-in. thick, backed up by a 5-ft.-thick slab of reinforced concrete. Below the pad was a 3-ft. dia. reinforced concrete column reaching down ~7 ft. to bedrock and extending 3 ft. into the bedrock. The pad was considered to be unyielding. There were no broken welds or cracking or splintering of the wood. The hinges on the top of the box were sprung but not broken, and the steel bracing on the bottom of the shield was slightly bent. The shield was then dropped from 30 ft. onto a 6-in.-dia. piston. The damage to the impact area of the shield was only slight; the steel frame was bent inward ~1/2 in., and one weld was broken. The hinges on the top of the shield straightened ~1/2 in., but there was no cracking or splintering of the wood (Figure 4).

The second shield in the third series was dropped from 30 ft. onto one of its bottom corners at an angle of ~45°. As is seen in Figure 5, this shield suffered only negligible damage. The corner of impact was slightly bent and the bottom brace was bent outward ~1/4 in. However, there were no broken welds or cracking and splintering of the wood.

The two fire shields were subjected to a 1-hr. fire test after the impact tests. Each shield was instrumented with two thermocouples -- one on the outside surface and one in the interior cavity. The shields were placed in a sheet metal enclosure and heated with a pressurized kerosene burner, which was manually positioned to maintain a constant outside temperature of 900 ± 50°C.

A 1/8-in.-thick perforated steel plate was placed on the bottom of one shield to test the value of this device as a flame deflector which would distribute the heat while allowing the volatile constituents contained in the wood to escape and be burned in the air. One corner joint on this shield was assembled with epoxy cement rather than nails to evaluate this type of construction.

Due to operational difficulties with the burners prior to the test, more kerosene was consumed than had been expected and the fuel was exhausted after 45 min. of testing. Both shields were allowed to burn in air for 30 min. while more fuel was obtained. During this 30-min. shutdown, the temperature inside the shield behind the flame deflector rose from 30 to 55°C. The temperature inside this shield at the completion of the test (1 hr. total kerosene burner operation) was 90°C. The temperature inside the other shield at the completion of the test was 60°C.

At the completion of the test, the fire was extinguished with a water spray and the shields were inspected. The use of the flame deflector did not appear to be effective since the fire penetrated the wood to a depth of ~2 in. in both shields; however, the screened area did burn more evenly. The glued corner joint failed and separated during the test (Figure 6), but the nailed joints remained intact. There was no damage to the lead bricks contained inside both shields.

The fourth and final series of tests was conducted on a shield similar to but larger than the ones discussed previously. The largest size proposed for use at ORNL was tested. Maple was selected as the wood because it is easily obtainable in the southeastern section of the United States. This shield weighing 570 lb. was designed to carry a cask with 8 in. of lead shielding weighing ~2600 lb. For the tests 2600 lb. of lead bricks were placed inside to simulate the weight of the cask.

In the first test, the shield was dropped from 30 ft. onto an edge. The damage was minimal.

This shield was then sent to Underwriters' Laboratories for fire testing in their safe-testing furnace. The shield was subjected to the standard

1-hr. fire test as outlined in ASTM-E119-61. During the test approximately one-half of the wood burned away and the maximum temperature reached in the lead inside the shield was 200°F. Complete details of this fire test were published by Mr. L. Horn (1) of Underwriters' Laboratories.

Literature Cited

1. L. Horn, Underwriters' Laboratories, COO-277, March, 1964.