Proceedings of the 15th International Symposium on the
Packaging and Transportation of Radioactive Materials
PATRAM 2007
October 21-26, 2007, Miami, Florida, USA

MULTIPURPOSE FRESH FUEL PACKAGE

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ABSTRACT

A multipurpose fresh fuel package was developed to handle both transportation requirements as well as plant storage requirements. The system was designed so a simple outer package protected an inner container that was used to store the fuel. The inner container was unique in that it had to protect the fuel during a facility fire event. The need for fire protection of the inner container required the movement of the fire protection functions of the outer container to the inner container. The outer package, or overpack, provided the primary drop and puncture protection. The design was simplified to allow complete interchangeability of the inner container with the overpacks as well as interchangeability of the fuel support system within the package with any other package. The need for interchangeability was driven by the need for only a few overpacks and several hundred inner packages. The system was developed by testing an engineering prototype. The lessons learned from the extensive testing of the prototype allowed fabrication of full scale certification test units that underwent operational and regulatory testing. Both full scale drop tests and fire testing were performed.

INTRODUCTION

The package has been designed to transport and store low void reactivity fuel CANFLEX® (LVRF) for use in CANDU® reactors. The fissile material consists of uranium oxide enriched to a maximum of 1.33%. The package can transport up to 36 LVRF bundles. Except for the uranium enrichment, and the presence of a single burnable absorber element in each bundle, the LVRF bundles are essentially the same as conventional CANDU® reactor fuel. Since the A_2 value for low-enriched uranium is unlimited and radiation is negligible, the only safety function performed by the package is criticality control. This function is achieved, in the case of a transportation accident, by confining the fuel elements within the package and by preventing excessive reconfiguration of the fuel elements and neutron absorber elements. Two separate, full-scale prototype models were used to perform a number of performance tests, including normal conditions of transport (NCT) free drops, accident conditions of transport (ACT) free drops and punctures, and an ACT fire test.

The package is designed as a Type AF packaging. The packaging is rectangular in shape and is designed to be handled by forklift and transported by highway truck. The maximum gross weight of the loaded package is 3,800 lbs. The packaging includes an outer container, designated the overpack assembly and an inner container, designated as the cargo assembly, which also may be used to store the contents at each facility. Inside the cargo assembly are the fuel support trays. The components of the packaging are shown in Figure 1 and described in more detail in the sections which follow. The package is primarily constructed of Type 304 stainless steel. Components are typically joined with full-thickness fillet welds, i.e., fillet welds whose leg size is nominally equal to the lesser thickness of the parts joined.

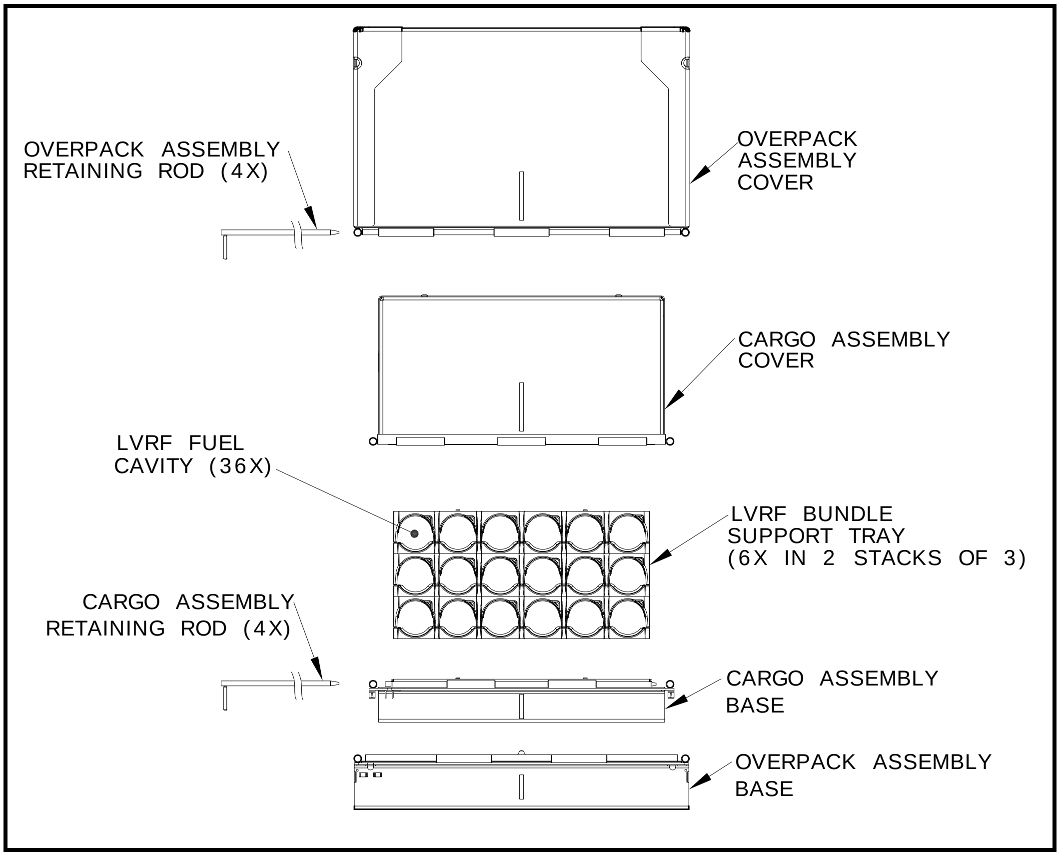

Figure 1 - Package Components

The inner container or cargo assembly is designed to protect the fuel during storage. The main hazard to the fuel during storage, in addition to normal handling events, is a fire. Hence the cargo assembly, consisting of the steel shell with alumina silica insulation and the fiber reinforced polymer fuel trays, protects the fuel while allowing easy access to the fuel for regulatory verification and inspection.

PACKAGE REQUIREMENTS

The package has been designed to meet all the applicable structural requirements of the International Atomic Energy Agency (IAEA) TS-R-1 regulations. The design objectives for the package with regard to transportation requirements are twofold:

1. Demonstrate that, under NCT, the package maintains confinement of the LVRF bundles within the package, and the package experiences no significant reduction in its effectiveness to withstand ACT; and

2. Demonstrate that, under ACT, the package maintains the LVRF bundles in a subcritical configuration. This is accomplished by:
   a. Continuing to maintain confinement of the LVRF bundles;
   b. Ensuring that the LVRF bundles and support trays experience no reconfiguration which exceeds the bounds assumed in the criticality analysis;
   c. Ensuring that the cargo assembly and overpack assembly experience no damage or deformation which exceeds the bounds assumed in the criticality analysis.

Consequently, the design criteria for NCT are that the LVRF package exhibit only minor damage subsequent to the NCT conditions and tests, including no damage that would prevent the package from meeting the acceptance criteria for any subsequent ACT test. For ACT, the design criteria are: a) that the overpack cover remain attached to the overpack base, thus ensuring confinement of the LVRF bundles, b) that observed and measured fuel bundle and support tray post-test configurations are bounded by the assumptions made in the criticality analysis, and c) that measured post-test deformations of the cargo assembly and overpack assembly are bounded by the assumptions made in the criticality analysis.

Due to the in plant handling requirements the various components of the package must be fully interchangeable. . Since the cargo assemblies are stored separately, they are required to be interchangeable with any overpack that is used for transportation. Likewise, since the fuel trays can be moved from one cargo assembly to another during loading, they must also be interchangeable with the cargo assemblies.

The cargo assembly must be easily handled and opened to allow for annual inspections to verify the fuel. The lids must come off with minimum tooling and the trays be compatible with probes used by IAEA inspectors.

PAYLOAD

Contents are CANFLEX® low void reactivity fuel (LVRF) bundles. Each bundle is made from 42 fuel elements which are slightly enriched (up to 1.33% U-235) and one element containing natural uranium oxide mixed with dysprosium oxide, which acts as a burnable poison. The maximum possible mass of uranium, as UO_2, is 18.886 kg per bundle. The minimum possible mass of dysprosium, as Dy_2O_3, is 61.1g per bundle. The maximum overall weight of a bundle, including all non-fuel components, is 23.701 kg. The nominal length of the bundle is 495.3 mm, and nominal active length of fuel in the elements is 482.1 mm. Fuel elements are arranged in three concentric rings with the natural uranium/dysprosium element in the center position. The natural uranium/dysprosium element and the inner ring of elements have a larger diameter than elements in the outer two rings.

PACKAGE DESIGN

The overpack assembly is the outermost container of the package, and its function is to provide protection for the cargo assembly under NCT and ACT. The overpack assembly has the shape of a flat-sided box, with a length of 52.0 inches, a width of 41.6 inches, and a height of 31.6 inches.

The overpack assembly consists of the overpack base and the overpack cover. The overpack base is made from a ¼-inch thick stainless steel plate, supported by formed sheet steel 0.14 inches thick which creates a raised structure for use with a fork lift truck. To locate the cargo assembly within the overpack assembly, two 1-1/2-inch diameter tapered pins are welded to the ¼-inch thick base plate. To aid in locating both the overpack cover and the seal, a 1×1×1/8 inch angle is located just inside the periphery of the overpack base plate. To effect the attachment of the overpack cover, 1-inch outer diameter by 0.12-inch wall thickness tubes are welded along the four edges of the overpack base plate, two on each side. When the overpack cover is installed, these tubes mate with similar tubes on the cover such that a 5/8-inch diameter solid rod can be inserted through both sets of tubes, in effect "stitching" the two sides of the joint together. One rod is used on each side of the packaging (a total of four), providing a strong yet compliant joint which is capable of sustaining local damage without loss of integrity. The gap between the cover and base is closed with a dust seal made from ¼-inch inner diameter braided ceramic sleeving material which is attached to the base plate using adhesive.

The overpack cover is made in a sandwich construction with a 0.13-inch thick outer steel sheet, a 0.08-inch thick inner steel sheet, and a 2.3-inch thick layer of nominally 10 lb/ft^3 polyurethane foam in between. The foam cavity is nominally sealed shut against moisture. The four vertical edges and top corners are reinforced with doubler sheets made from 0.13-inch thick steel sheet. At each top corner (four total), sheets are formed and assembled to create an internal lifting pocket for the purpose of lifting the cover only. The shape of the pocket is trapezoidal, and lies fully within the outer flat faces of the overpack cover. The external opening of each pocket is a slot which is designed to mate with a cable and swaged end fitting. Each pocket features a drain hole to allow rain water to drain out. At the lower end of the overpack cover is located a framework of 1.25×1.25×3/16-inch angle steel. Attached to this framework are the 1-inch outer diameter by 0.12-inch wall thickness tubes which mate with those of the overpack base. There are three tubes on each side of the cover that mate, in an alternating pattern, with the two tubes on each side of the base.

The overpack assembly retaining rods are tapered at one end and approximately equal in length to the side of the packaging to which they connect. Each rod has a short handle at one end, affixed at a right angle to the rod and which is used to operate the rod. The handle also serves to secure the rod in position once installed. Once the rod is fully inserted, the handle may be rotated into a secured position in a "parking slot" in the base and secured with a hairpin cotter pin. The pin cannot be extracted without rotating the handle out of the "parking slot", and the handle cannot be rotated without removing the cotter pin, thus ensuring that the retaining rods stay in place and the overpack cover remains securely attached to the overpack base. During transport, a self-adhesive shock recording device may be attached to the outside surface of the overpack assembly.

The cargo assembly is the innermost container of the package, and its function, with support from the overpack assembly, is to confine the LVRF bundles during transport. An added function is to provide protection for the fuel while stored onsite. The cargo assembly has the shape of a flat-sided box, with a length of 48.1 inches, a width of 37.7 inches, and a height of 22.7 inches. The cargo assembly consists of the cargo base and the cargo cover. All six sides of the cargo assembly feature refractory thermal insulation.

The cargo base is made from a ¼-inch thick steel plate, supported by formed sheet steel 0.13 inches thick which creates a raised structure for use with a fork lift truck. This support structure contains two, 1-1/2-inch diameter holes which mate with the pins on the overpack base, and which serve to locate the cargo assembly within the overpack assembly. The central region of the cargo base is covered with a 1-inch thick layer of ceramic insulating board, enclosed within a shell of 0.13-inch thick steel sheet which is welded to the cargo base. In a manner essentially identical to that of the overpack assembly, the cargo cover is attached to the cargo base by means of 5/8-inch diameter retaining rods which pass through 1-inch outer diameter by 0.12-inch wall thickness tubes attached alternately to the cover and base. Two tubes are attached to each side of the base, and three tubes are attached to each side of the cover. The manner of securing the retaining rods in place is identical to that described above for the overpack assembly. The gap between the cover and base is closed with a dust seal made from ¼-inch inner diameter braided ceramic sleeving material which is attached to the base plate using adhesive.

The cargo cover is made in a sandwich construction with a 0.13-inch thick outer steel sheet, a 0.08-inch thick inner steel sheet, and a 1.0-inch thick layer of ceramic insulating board in between. The insulating board cavity is nominally sealed shut against moisture. On the inside of the cargo cover is located a center wall which divides the cargo cavity into two equal volumes. The wall, which has a cross sectional thickness of 1.5 inches, is constructed of 0.08-inch thick steel sheets separated by U-shaped reinforcements. The lower edge of the center wall is reinforced by a 1-inch outer diameter by 0.12-inch wall thickness tube. At the middle of each long top edge, a pocket (total of two per cover) is formed using sheet material for the purpose of lifting the cargo cover only. These pockets are located within the thickness of the center wall. As was the case for the overpack cover lifting pockets, these pockets are sealed against water entry into the cargo assembly and fitted with a drain hole. They have a slotted opening designed to mate with a cable and the same swaged end fitting as used for the overpack cover.

The fuel support trays form two stacks within the cargo assembly, one in each of the two cavities formed by the cargo cover’s center wall. Each support tray unit consists of a lower and an upper portion. The lower portion is approximately 1.4 inches tall and the upper portion approximately 3.9 inches tall. The two portions are indexed together by means of integral dowel pins. When assembled, the trays form horizontal cylindrical cavities which accept the LVRF bundles. Each tray unit can accommodate six LVRF bundles. The tray units are stacked three-high in each cavity for a total of six units, accommodating up to 36 bundles in total. Each tray unit is located to the adjacent unit by means of integral dowel pins. The stack is located on the bottom by integral dowels which protrude from the cargo base, and stabilized at the top by steel tabs which protrude down from the inside surface of the inner shell of the cargo cover, and which interface with the top tray of each stack. The surfaces of the trays which contact the fuel are covered with a layer of adhesive-backed elastic polyurethane foam. The trays are molded from a fiberglass-reinforced polyester resin having a nominal thickness of 3/16-inches. A dense pattern of nominally 3/16-inch thick reinforcing webs is used on the back side of each tray portion to impart strength and stiffness.

TESTING

The testing performed on both certification test unit 1 (CTU 1) and CTU 2 each consisted of NCT 4 ft free drops, ACT 30 ft free drops, and puncture drop tests. Prototypic fuel bundles, steel pipe bundles, and loose steel bars were used to simulate the payload. The ends of the loose bars were marked with colors to easily observe any migration of the bars following the drop tests.

The testing demonstrated that the package prevents loss or dispersal of the payload when subjected to the NCT and ACT tests. Since the magnitude of damage to CTU 2 was greater than that to CTU 1, CTU 2 was subjected to the ACT thermal test. None of the damage inflicted as a result of the testing posed any serious challenge to the package or closure integrity. None of the retention rods suffered any damage that inhibited their function.

Following the drop test series, CTU 1 was disassembled upside-down in order to better facilitate an assessment of fuel element migration. The bottom row of loose bar bundles had some minor migration (as evidenced by the colored ends of the bars). However, none of the dysprosium elements had migrated from their original tray compartment. The prototypic fuel bundles were deformed into an oval shape, but there were no additional failed welds or failures in the cladding. The fiberglass trays exhibited the most damage on the impact side. The trays were cracked and small pieces had sheared off. However, the trays were generally in good condition and still capable of containing both the pipe bundles and the bar bundle payloads. The inside of the cargo assembly of CTU 1 displayed signs of minor deformation, especially on the impact side; however, there were no failed welds or tears in the skin and no large gaps in the closure area. No dispersal of material was detected from CTU 1.

Figure 2 - Edge Drop Test

Following the drop tests and fire test, CTU 2 was disassembled upside-down in order to better facilitate an assessment of bar migration. The contents were covered with soot and tar like deposits. The bottom row of loose bar bundles had some minor migration. However, the quantity of migrated bars was very small. None of the simulated dysprosium elements had migrated from their original tray compartment.

Figure 3 - Burn Test

The fiberglass trays exhibited the most damage near the top corner impact location with a large piece breaking off from the top tray. The other trays were cracked and small pieces had sheared off. The trays were however generally in good condition and still capable of containing both the pipe bundles and the bar bundle payloads. The fiberglass trays of CTU 2 were fitted with temperature indicating labels. None of the labels were found to have recorded a temperature, indicating that the temperature did not exceed 331ºF in the area of the temperature strips. Small portions of the foam cushion on most of the trays were damaged by the heat. Other than the soot and the damage to the foam cushion, there appeared to be no thermal damage to the fiberglass trays.

The inside of cargo assembly of CTU 2 displayed some deformation, especially on the impact area of the top corner drop; however, there were no failed welds or tears in the skin and no large gaps in the closure area. The estimated size of the top corner deformation was 4¼ inches. No dispersal of material was detected from CTU 2.

Figure 4 – Payload Condition, Post Drop and Burn Test

CONCLUSIONS

To meet the changing requirements for transporting and storing CANDU® fuel, a new package capable of shipping LVRF has been successfully developed. Its relatively simple design and closure with interchangeable parts allows the complete package to be used for transport while the inner package with composite fuel trays can be used for storage. At this time the design has not been approved for use by the regulators.

REFERENCES

1. Title 10, Code of Federal Regulations, Part 71 (10 CFR 71), *Energy — Packaging and Transportation of Radioactive Material*.
2. International Atomic Energy Agency (IAEA), *Regulations for the Safe Transport of Radioactive Material*, Safety Series No. TS-R-1 (ST-1, Revised), 1996 Edition (Revised).