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

Development of a Type B PWR Fresh Fuel Package

Charles J. Temus
AREVA Federal Services
(Packaging Technology Inc.)

Richard Montgomery
AREVA NP Inc

ABSTRACT

A Type B fresh fuel package has been developed to ship two PWR fuel assemblies. The package maximizes the number of fuel assemblies that can be transported by truck (by road weight limits) while providing protection for both the fuel and the neutron moderator during regulatory postulated drop and thermal events and meets the 1996 IAEA regulations as adopted by the US Nuclear Regulatory Commission. The package uses a combination of energy absorbing material and an internal fuel restraint system to ensure that the fuel remains intact during these postulated events. Criticality control was enhanced by use of a higher temperature resistant hydrogenated material that allowed the package weight to be minimized. Full scale drop and burn tests were performed to demonstrate regulatory requirements.

Additionally, the package is designed to minimize normal transport and handling loads being transmitted to the fuel without the use of a separate shock isolation system. Road and handling tests were performed to demonstrate that vibration and shock loads from transport did not compromise the fuel. The package has an adjustable fuel cavity to allow a variety of fuel assembly designs to be shipped, including variations in bundle length, width, spacer grid locations, and upper and lower end fitting configurations. As mentioned previously, the package is designed as a Type B packaging and will be used to transport assemblies containing Blended Low Enriched Uranium (BLEU).

INTRODUCTION

The need to develop a new package was two fold. The first driver was the change in regulations that made many of the existing packages become obsolete as of October 1, 2008. Commercially, AREVA needed a new packaging that could handle the newer generation fuels and provide not only accident protection for the fuel, but also day-to-day handling protection. The day-to-day fuel handling operations have become more and more important as utilities move to just-in-time fuel deliveries to minimize storage and handling of the fuel while continuing to minimize refueling times. Thus the need to streamline handling, combined with the increasing value of the fuel, provides a tremendous incentive for all parties involved to minimize any potential for unacceptable loading of the fuel.

Since the package would need to be able to transport many different types of fuel for the present generation of reactors as well as the new generation of reactors, the package was developed to be as versatile as possible. Three variations of the design are provided to cover AREVA's fuel assembly family: a short version MAP-12 for 12-foot fuel designs, an intermediate version MAP-13 for fuel designs between 12-foot and 13-foot, and a long version MAP-14 for EPR fuel.

DESIGN CRITERIA

The first basic design criterion for the packaging is that it had to accommodate various cross-sections of fuel with widely varying bundle lengths. Second, the packaging had to be capable of shipping Blended Low Enriched Uranium (BLEU) fuel. The BLEU project used previously higher enriched fuel material to manufacture commercial reactor fuel. Due to the history of the feed stock for this material it had the potential of containing some isotopic quantities that require a Type B package.

Also, the package obviously was required to meet the regulatory criteria for radioactive materials shipments. For a fresh fuel package the primary regulatory design criteria revolves around criticality control. For a package like the MAP package, which must ship many different fuel configurations with varying cross sections, lengths, fissile material masses, and enrichment levels, criticality control under all conditions requires strict geometry control and protection of the neutron absorber and moderator materials.

Since the package also required qualification as a Type B package, due to the type of fuel being transported, containment also was a major consideration. The containment boundary for the package was designated as the fuel cladding. Experience had shown that the fuel cladding can take some bending without rupturing; however, any sharp bends increased the probability of rod breakage and potential leaking. Previous testing of fresh fuel package designs showed that sharp bends that lead to leaking came from buckling of the fuel at the ends between the grids and/or end fittings; thus, the MAP includes significant protection against these failure modes.

In addition to the regulatory design requirements the package has a number of design requirements associated with its economic life and day to day handling. These include the ability to transport 12 fuel assemblies on a legal weight truck in the United States. The limit for most states is 80,000 lbs for the complete truck. With the development of lighter weight tractors and trailers this weight restriction leaves the maximum payload weight in the 48,000 to 50,000 lb range. With 1,700 lbs per assembly or 3,400 lbs as the maximum loaded payload weight complies with this requirement. The package also had to be compatible with the over the road environment including vibration and shock loads from road hazards. In the design process these had to be quantified and later verified by road tests.

The package must also be handled at all the existing PWR reactor sites. The overall length of the package was set by current handling facilities. Both door openings and overhead crane height had to be considered. In addition to the basic fuel assemblies the package was also designed to accommodate control component assemblies that are now being requested to be shipped assembled within their respective fuel assemblies.

Since the streamlined package does not utilize a separate shock isolation system, the package had to include design features that would protect the fuel from road induced vibration and excessive shock loads during transport. The packaging also must preserve the straightness of the fuel, while providing up-righting capability and the ability to unload from the side with accessibility to the top end for the fuel handling grapples, easy adjustment between fuel sizes, minimum loose parts, durability over a 30 year life, and verifiable positioning for each of the required fuel assembly envelopes.

The criteria of low maintenance and long life influenced the selection of materials. Due to a need for the package well before the original planned date of replacing existing packages, the material selections were further limited to well known and previously used materials. The shortened schedule also precluded the original plan for an engineering test unit for development purposes.

DESIGN

The design of the package was done partially by calculation and partially by test. The design by calculation was basically limited to criticality control and some of the normal condition of transport conditions. The structural design and hypothetical accident thermal conditions were done by test. All of the normal day-to-day handling evaluations were first done by calculation and than verified by test.

Criticality control was addressed by geometric control and the use of a neutron absorber and moderator. The geometric control was maintained by designing the base of the package as a load carrying member that was also used for up-righting the fuel for loading and unloading. Additionally, to address potential vibration issues, the base was stiffened with transverse ribs that made the package into to a stiff frame. The fuel is transported in a diamond configuration taking advantage of the stiffer configuration of the fuel matrix and providing greater support on two sides rather than just one. The fuel is held in place by the use of adjustable doors. The adjustment in the latch and door hinges allows the cavity to be adjusted for various fuel envelopes. The height of the door can be controlled by varying shim heights under the hinge and door blocks, thus giving positive indication of correct adjustment for each fuel type.

Surrounding the fuel cavity is a borated neutron absorber. Adjacent to that is the moderator. Although slightly lower in hydrogen atom density, a thermoplastic was selected for the moderator material. The thermoplastic has a much higher melting temperature than polyethylene providing a larger margin of safety against the hypothetical accident thermal event. The thermoplastic selected had a melting temperature in the excess of 490 F as compared to a melting temperature of approximately 180 F for most polyethylene.

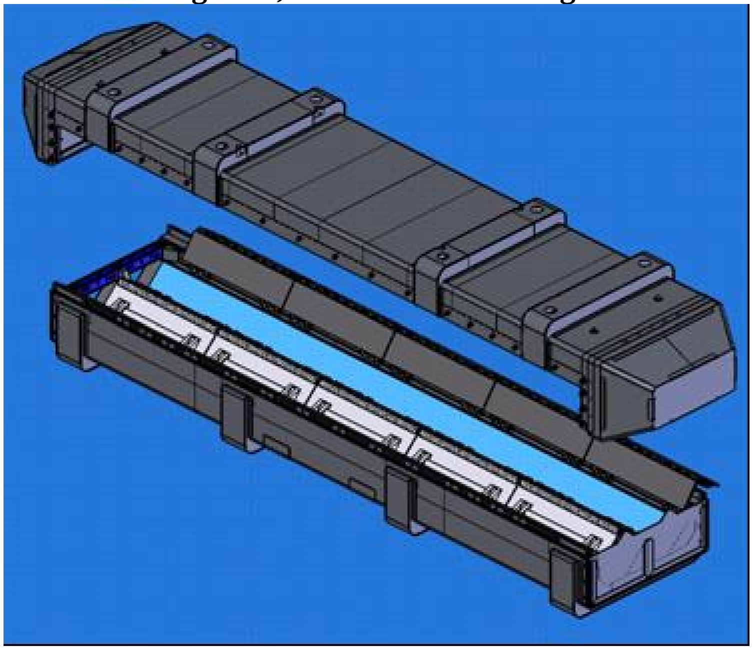
Thermal protection for the package was accomplished by using polyurethane foam sandwiched between the outer stainless steel shell and the inner fuel cavity. The polyurethane foam selected has a proven record of providing thermal protection for radioactive material packages. Bench tests were performed as documented in a separate paper presented at this conference. These bench tests were designed to determine the minimum thickness and density of foam that could be used and still provide adequate thermal protection for the thermoplastic moderator. The combination that was selected was the use of 6 pound/cubic foot foam with a double layer of ceramic refractory paper between the outer shell and the foam. This combination allowed a temperature drop between the outer shell and the foam. The added protection reduced the char rate of the foam during the fire event allowing it to adequately protect the thermoplastic moderator. Additional thermal protection to reduce conductive heat transfer in through the closure area of the package to the fuel cavity was provided by adding fiber-reinforced polyester structural material between the outer shell and the inner cavity.

The structural protection of the containment boundary (the cladding) was accomplished in two different ways. The main concern was the buckling of the fuel due to the end hypothetical accident condition 9 meter drop, which had been observed with other fresh fuel packages. Bending of the fuel had been seen due to both bending of the fuel rods due to buckling and also due to the interaction of the fuel rods with the debris filters on the fuel nozzles which had deformed under the loading of the fuel. The actual buckling of the fuel was addressed in two ways. First the end load was minimized by adding a tapered impact limiter to the end of the package. This impact limiter size was limited by the overall allowable length of the package. The impact limiter was filled with 10 pound/cubic foot foam which acted to absorb energy and minimize the loading to the fuel. The doors within the fuel cavity which held the fuel in place were designed with sufficient strength to resist the horizontal loading from the fuel rods preventing the rods from bowing outward and buckling.

To minimize time for opening and closing and also minimizing the number of parts to be handled the end impact limiters were designed to be integral with the lid allowing them to lifted off as the lid is lifted from the base. The closure consists of an interlocking channel on each side of the base that fits within a “U” shaped cavity in the lid that is cross pinned with ball lock pins. Besides providing for a very stiff, redundant, strong edge connection providing structure integrity to the closure it also minimizes ingress of the flame during the fire event. The ends are closed off by having interlocking angles that slide together as the lid with impact limiter is slid over the body. The interlocking angles combined with the ball lock pins provide a moment resisting connection that prevents the separation of the lid and base in all accident conditions. The ball lock pins can be attached to the lid to prevent loss.

The fuel is restrained axially within the cavity by an axial restraint bar that fits across both fuel cavities. The door latches are over center type latches that allow for some preload on the doors yet are locked in place and prevent from coming unlatched by the close fitting lid. All doors may be opened and swung out of the way except for one during unloading which would act as retainer for the fuel as the base is up righted.

Figure 1, Schematic of Package



TESTING

Three certification test units (CTUs) were fabricated of the intermediate length design. The long version was not tested since the final decision for the EPR fuel package has not been made. The test packages were made from the same materials and added weight would generate the worst cases for the tests. CTU 1 was first road tested to determine its response in over the road conditions. A simulated fuel bundle was fabricated for each unit being identical to a real fuel bundle in all ways except for the pellets being tungsten. The other fuel cavity for each package contained a ballast assembly with weight distributed the same as fuel assembly. This consisted of an assembly of steel plates and rods. The testing was performed for each unit in accordance with Table 1.

Table 1, Certification Tests

CTU #	Penetration	Puncture	4' NCT	30' HAC
1	Lid impact	20^o Oblique puncture through CG on lid CG over base side closure joint puncture	10^o slap-down on base	30^o slap-down on base
2	n/a	n/a	n/a	Vertical bottom end
3	n/a	20^o Oblique puncture through CG on lid	Horizontal lid down	Horizontal lid down

For a long slim package like the MAP normally the most severe damage comes from the slap down event which was demonstrated on CTU 1. The slap down attacks the closure and tends to open the closure up. The results from this test showed that the package bent slightly due to the slap down and approximately five ball lock pins failed on each side of the container. The redundant nature of the closure along with the interlocking angles allowed the closure to remain tightly closed.

Figure 2, Slap Down

The vertical bottom impact directly challenged the containment of the fuel by trying to buckle it. The combination of reducing the impact load and the doors restricting the horizontal movement of the fuel rods allowed the fuel assembly to survive the drop with basically no damage.

Figure 3, End Drop

CTU 3 was tested with a flat drop on the top. The purpose of this test was to crush the thermal protecting foam the most to minimize the foam protection. The container was also dropped on the puncture pin in this orientation as well. The puncture pin penetrated the outer shell but did not damage the inner shell above the fuel. The lid was chosen because it had the minimum amount of thermal protection of any part of the container.

CTU 3 was burned in a full engulfing hydrocarbon fire for 38 minutes exceeding the 30 minute minimum requirement. The polyurethane foam charred over sealing up the puncture hole and protected the thermoplastic moderator. Only small amount of the moderator melted on an edge of the block in a single location. The remaining moderator and neutron absorber material was not damaged.

Figure 4, Fire Test

Figure 5, Post Fire Test

Figure 6, Fuel Post Fire Test

The testing program demonstrated that the package could adequately protect two PWR fuel assemblies in all regulatory accident conditions while maintaining both containment and criticality control.

CONCLUSIONS

The MAP package can ship a wide variety of PWR fuel with varying basic dimensions while fully complying with the current packaging regulations. It also has the ability to move this fuel economically by shipping up to 12 assemblies on a legal weight truck. The package is easy to use with few components. It also addresses many of the current fuel quality considerations ensuring that the fuel arrives at the utilities undamaged and fully useable.