Critical Design Challenges of the MOX Fresh Fuel Package (MFFP)

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Abstract

A Report on preliminary design of the Mixed Uranium-Plutonium Oxide (MOX) Fresh Fuel Package (MFFP). Packaging Technology, Inc. (PacTec) is designing the MFFP as part of the Duke, COGEMA, Stone and Webster (DCS) consortium. DCS is tasked with providing the Department of Energy (DOE) with domestic MOX fuel fabrication and reactor irradiation services for the purpose of disposing of surplus weapons usable plutonium. Currently there are no Type B(U)F-85 packages certified for transport of fresh MOX fuel in the Unites States.

This paper presents many of the significant design challenges and the resulting solutions found during the preliminary design of the MFFP. The design is constrained by both regulatory and operational issues. Because of the plutonium content, the design must be a Type BF, which among other things requires a full level of containment. Both economics (desire for maximized payload) and operational (conveyance mode restricts size and weight) constraints lead to a highly optimized design. Several interesting solutions have been found and are presented, including puncture resistant impact limiter and a weight efficient closure. Discussion of both analytical and engineering test results are presented with discussion of how the results provide an optimal design which balances licensing risk with operational ease. The paper will conclude with a summary of how the program will proceed based on regulator input, engineering test results, and analytical conclusions.

Introduction

The MFFP has been designed to transport fresh Pressurized Water Reactor (PWR) MOX Fuel Assemblies (FA's) in accordance with the requirements of 10 CFR 71[i] and 49 CFR 173[ii]. There are many design challenges associated with the design of this package which are due only in small part to regulatory requirements for a Type B(U)F-85 packages. The most significant challenge is the weight limitation of 15,000 lbs, which includes the MFFP cask, impact limiters, payload, and transportation skid. Around this weight limitation a cask is designed which must perform to two main criteria: 1) remain leak tight and maintain criticality control for the worst case series of regulatory load conditions and, 2) provide protection of the relatively fragile fuel during normal transportation operations while meeting an ALARA exposure during loading and unloading operations. Some of the solutions to the design challenges presented during this

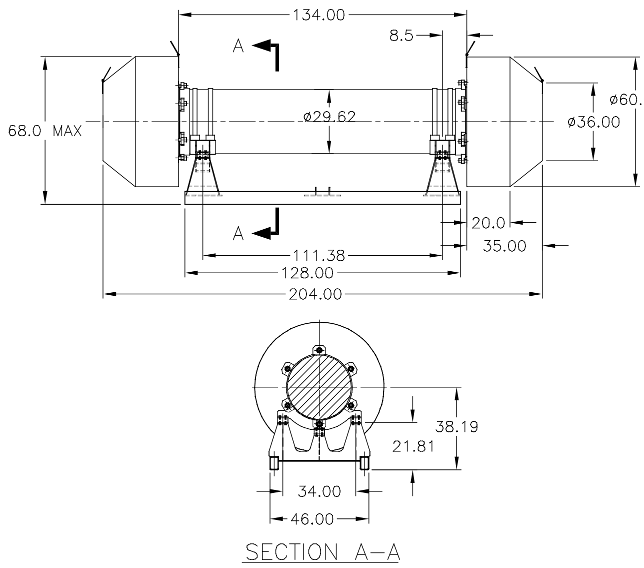

Figure 1 - MFFP System Envelope

project have been straight forward and rather obvious, others have required ‘out of the box’ thinking.

Description of the MFFP Design

As designed the maximum gross shipping weight of the MFFP is 14,240 pounds including payload, cask body, strongback, and impact limiters. The MFFP may be shipped with one to three MOX FAs. The maximum width of the MFFP is the impact limiter diameter of 60-inches; the maximum length is 204-inches. The maximum height as configured for transportation is 68-inches. The outer envelope dimensions of the package and shipping skid are shown in Figure 1. There are no active devices utilized on the MFFP for the transfer or dissipation of heat. The package maximum internal thermal load is 240 watts (80 watts per fuel assembly). The fresh fuel payload is not a large source of radiation. As a result, adequate biological shielding is provided by the cask shell, end closures, and impact limiters.

MFFP Cask

The cask serves as the containment boundary for the payload of fresh MOX FAs. The cask components that form the containment boundary are the cylindrical shell, the inner bottom plate, the seal flange, the inner plate and seal ring of the closure lid, the vent port plug and elastomeric seal, the fill port plug and elastomeric seal, and the closure lid containment elastomeric O-ring. The cylindrical cavity formed by these components is 28½-inches in diameter and 165¼-inches in length.

The 9⁄16-inch thick cask shell is made from Nitronic 50 austenitic stainless steel. A circumferentially continuous doubler plate is used near each end of the shell to interface between the six impact limiter attachment lugs and the shell. The doubler plate also serves to provide an interface with the transportation skid for longitudinal restraint. The lid end of the cask is locally thicker than the cask shell to accommodate the closure lid sealing area and the closure bolt threaded holes.

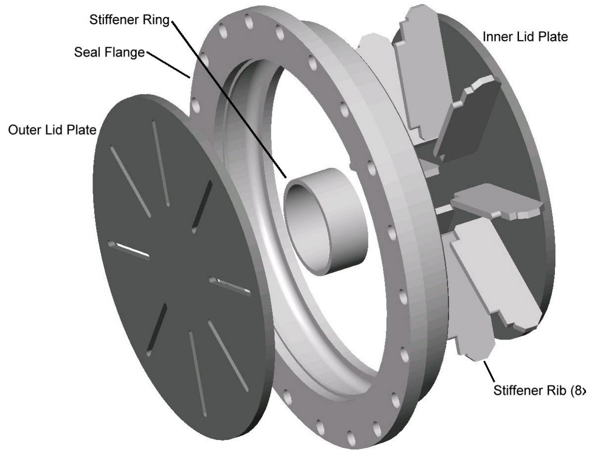

Figure 2 – Closure Lid

The lid is designed to be lightweight while offering resistance to deformation under all regulatory conditions, having a ¾-inch thick outer plate and ⅝-inch thick inner plate, stiffened with ½-inch thick radial webs. It also is made from Nitronic 50 austenitic stainless steel. The seal ring of the lid has a minimum thickness of one inch, and provides locations for the containment O-ring seal and two adjacent O-rings used for leak testing, as well as providing a location for the vent, fill, and test ports. The lid is attached to the cask using 24, ¾-inch Grade 8 bolts. An exploded view of the closure lid, showing the internal reinforcements, is shown in Figure 2.

The bottom end closure construction is a simple 1½-inch thick flat plate made from Nitronic 50 austenitic stainless steel. There are no containment penetrations located at the bottom end of the cask.

MFFP Impact Limiters

As shown in Figure 1, impact limiters are installed at each end of the MFFP for thermal and impact protection during transport. The impact limiters are comprised of cylindrical and conical sections. The cylindrical sections correspond to the cask-to-impact limiter interface length of 20-inches, and have an outer diameter of 60-inches. The adjacent conical section is 15-inches long with a minimum diameter of 35-inches. The bottom hole is designed to reduce end drop impacts, and has a diameter of 20-inches and a depth of eight inches. The impact limiter shells are constructed of Type 304 stainless steel. The lid end impact limiter has ¼-inch thick shells (5⁄16-thick for the end-hole plate) to resist perforation in the Hypothetical Accident Conditions (HAC) puncture event, and to protect the lid and sealing area from puncture and HAC fire damage. The bottom impact limiter has 11-gauge (0.12-inch thick) shells. Within the impact limiter shells is closed cell, rigid polyurethane foam. The polyurethane foam provides the majority of the energy absorption during the HAC drop events, and thermal protection of the seal during the HAC fire event. Each impact limiter is attached using six, relatively long 1-inch bolts, with most of the shank length reduced to a diameter of 0.805-inches. The bolts are designed to absorb impact energy without fracture.

MFFP Strongback

The strongback assembly, shown in Figure 3, is Type 304 stainless steel. The strongback longitudinal weldment is ¼-inch thick plate and provides support for the neutron absorbing material and for the MOX FAs. Eight support disk assemblies are attached to the strongback longitudinal weldment at each fuel assembly grid location. Each support disk assembly is composed of three clamp arm assemblies. The clamp arm assemblies are hinged to allow loading of the fuel assemblies, as depicted in Figure 4. The clamp arms are designed with

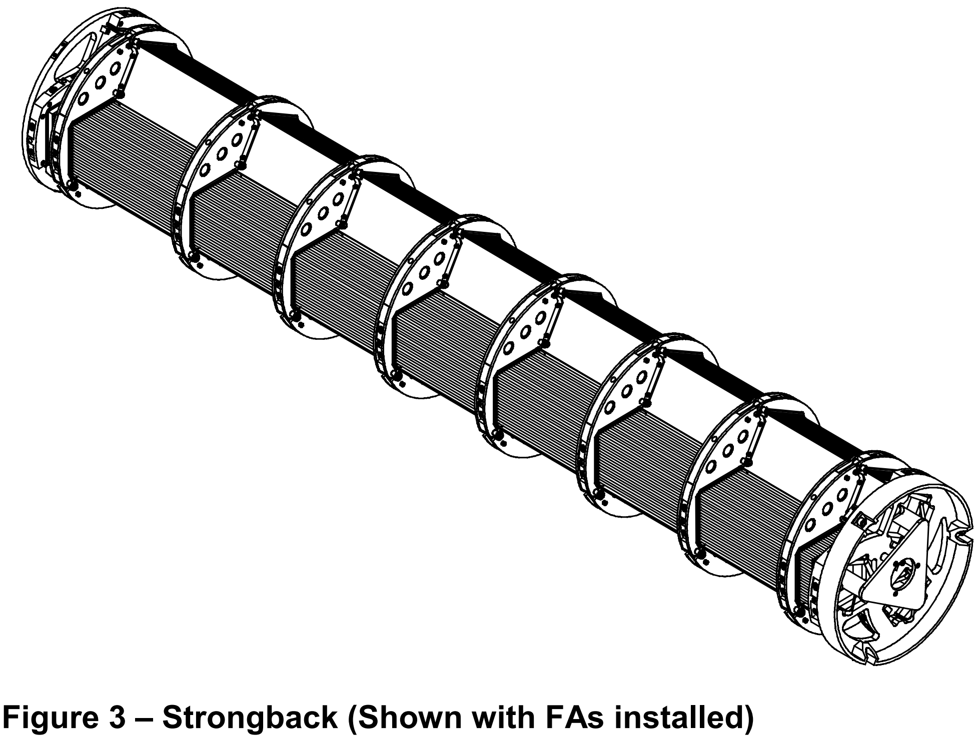

Figure 3 – Strongback (Shown with FAs installed)

clamping mechanisms to securely clamp the fuel assemblies into the strongback. Each clamp arm is constructed of two ⅜-inch thick plates, separated by the fuel clamping mechanism and stiffened to provide in-plane stability. The lid and bottom end disks clamp the top and bottom fuel assembly nozzles in the same way that the grids are clamped, and provide axial restraint to the fuel assembly. The loaded strongback is slid into and out of the cask horizontally, aided by anti-friction plastic pads located in the top and bottom end disks. Lid and bottom end disks support the strongback such that the smaller support disks have no contact with the cask shell.

Criticality control is provided in the MFFP package by the geometric spacing of the fuel assemblies and by borated neutron absorbing material contained on the strongback assembly. The strongback weldment and clamp arm assemblies maintain the geometric spacing. The borated neutron absorber plates are secured to the strongback weldment by cover pads at ten locations corresponding to the fuel assembly clamping locations.

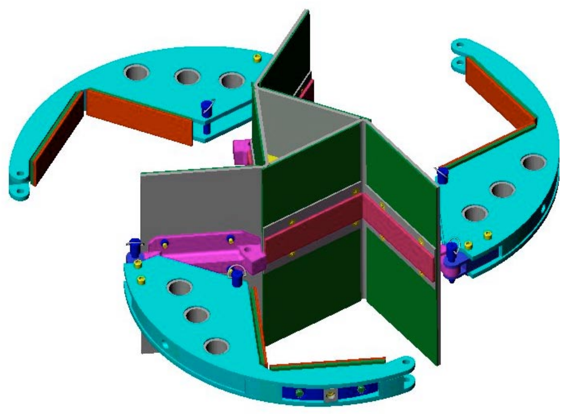

Figure 4 – Strongback Section View (Clamp Arms shown partially open)

Design for Regulatory Requirements

The primary regulatory requirements for a Type B(U)F-85 package are: 1) provide containment, 2) provide shielding, and 3) provide criticality control. Because the feed stock for the MOX fuel payload is polished of high source term anticides, shielding specific design features are not required. Thus, containment and criticality control are the primary drivers for the design against regulatory requirements. Certification will be ‘by test’.

The containment requirements for the MFFP are to be leak-tight for any individual Normal Conditions of Transport (NCT) followed by the worst case Hypothetical Accident Conditions. Because of the weight (as well as outer dimension envelop) restrictions, the structures affect containment must be optimized. This leads to the use of Nitronic 50 (a.k.a. XM-19), which is a high strength austenitic stainless steel. Nitronic 50 offers a 67% increase in strength compared to Type 304 stainless steel and retains the overall ductility and low temperature toughness that would be lost by using an alloy steel.

The decision to use Nitronic 50 was driven by the long, slender profile of the cask. While this profile minimized weight, it reduces the section modulus and increases the slapdown acceleration response during an oblique drop. The strongback, which supports the fuel during normal operations is highly optimized for weight and offers little support relative to the acceleration levels experienced during the HAC drops. To develop confidence in the design, non-linear analytical techniques have been employed. A moderately conservative Finite Element Model (FEA) model was constructed of the MFFP cask and a pure horizontal drop was simulated with increasing acceleration loads applied incrementally to well beyond the levels expected from an actual event. From the results of the FEA, a load-displacement curve is produced. The collapse load limit method as described in the ASME Code (see Figure 5) was used to determine that the cask would remain stable (i.e., not buckle) and that the cask diameter and wall thickness was minimized.

Knowing the cask diameter and wall thickness, as well as the weight of the three fuel assemblies that would be transported, the weight budget for the remaining components could then be more easily understood. The remaining weight did not allow the design to include an effectively monolithic closure system. Accordingly, a light weight lid design was developed with bore seals. Figure 3 show the construction of the built-up section lid, which is constructed of Nitronic 50. The cask is thick enough to resist puncture directly onto the body of the cask but will deform. To protect the closure from puncture damage, a puncture resistant impact limiter is used at the lid end of the cask. While the bottom end impact limiter has ⅛-inch thick skins, the closure end has ¼-inch thick skins. The choice of ¼-inch material was based largely on past experience. Half-scale engineering tests were used to prove both the stability of the cask during a 30-foot pure horizontal drop and that the closure impact limiter would resist puncture.

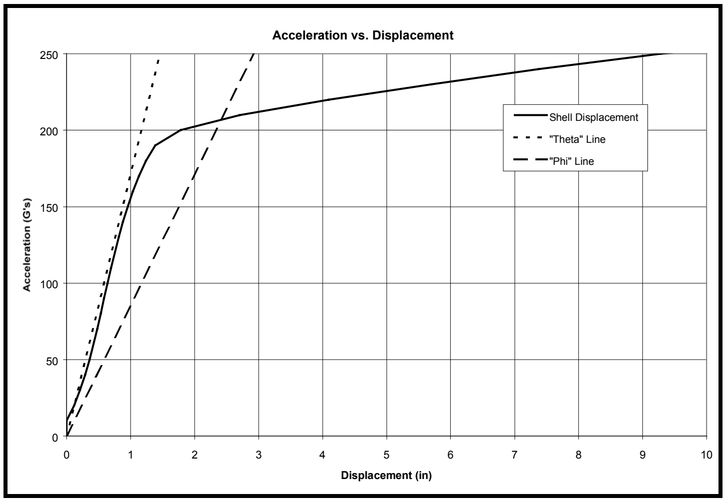

Figure 5 –Collapse Load Curves (NB-3213.25)

Engineering Test Results

The engineering test unit was built in half-scale, and incorporated only those features considered necessary for the evaluation of the planned tests. The primary purpose of the tests was to evaluate the puncture resistance of the package. The engineering test described herein addressed the following package design issues:

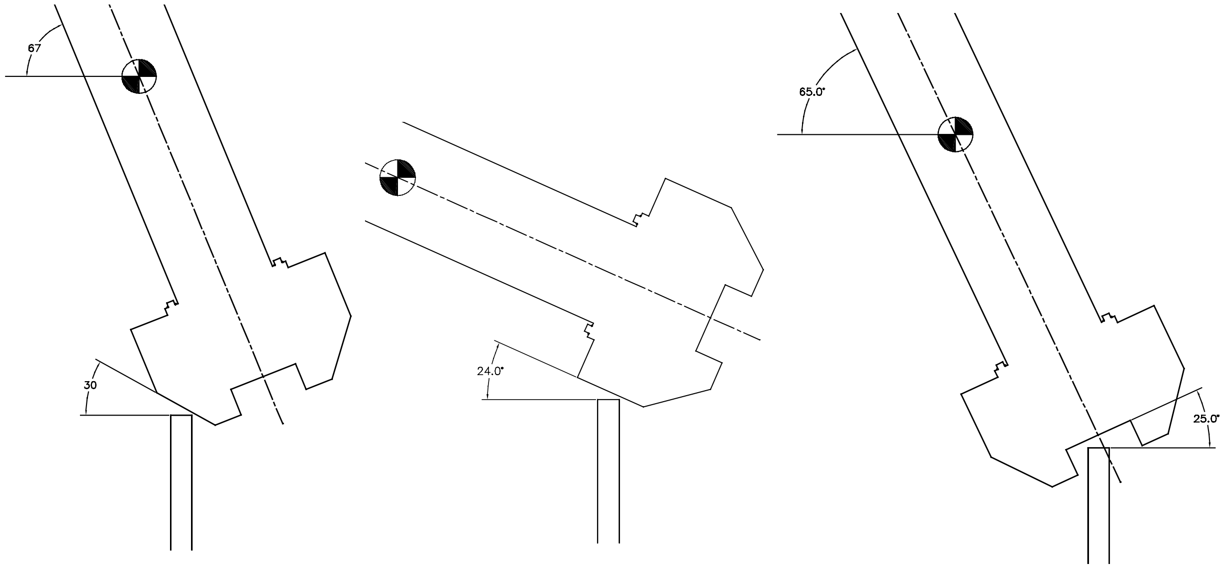

Figure 6 – Puncture Test Orientations

- *Resistance to puncture*. While puncture on the body (including oblique, or "French Puncture") is not expected to present any difficulty, punctures on or near the containment seal are of concern. The design of the lid-end impact limiter includes extra thickness skin to prevent perforation, thus completely protecting the seal area from puncture bar attack. Two different (half-scale) thicknesses were present on the engineering test unit: ⅛ (¼) and 5⁄32 (5⁄16) inches thick. The lesser thickness was tested first. If it had allowed perforation, the greater thickness would have been tested. Had the thicker skin allowed perforation, the impact limiter skins would not have been able to function as proposed since thicker sections are precluded by weight limits. In that case, the seal area itself would have been designed for increased strength.
- *Shell Stability*. Although non-linear FEA analyses show that the cask shell will not buckle during any of the NAC or HAC events, the engineering test unit was fabricated using a prototypic shell geometry.

Following the engineering tests, the test article was taken to the shop for final inspection of the seal region. No appreciable change of the seal region dimensions was noted. Based on the success of the ⅛-inch thick impact limiter shells in resisting perforation, the final design of the lid end impact limiter has ¼-inch thick stainless steel shells (full scale), and consequently, puncture bar impact on the seal region, and exposure of the seal region to HAC fire temperatures, is precluded. The engineering test also demonstrated the ability of the closure lid to resist puncture loads and remain leaktight, although due to the perforation resistance of the impact limiter shells, this feature is not expected to be necessary. Because the end hole plate did tear slightly, it has been thickened slightly. Since no puncture resistance at the bottom end of the package is necessary (since there are no penetrations or elastomer seals located there), to save weight, the shells of the bottom end impact limiter have a full scale thickness of ⅛-inch stainless steel.

Figure 7 – Puncture Test Results

Design for Normal Operations

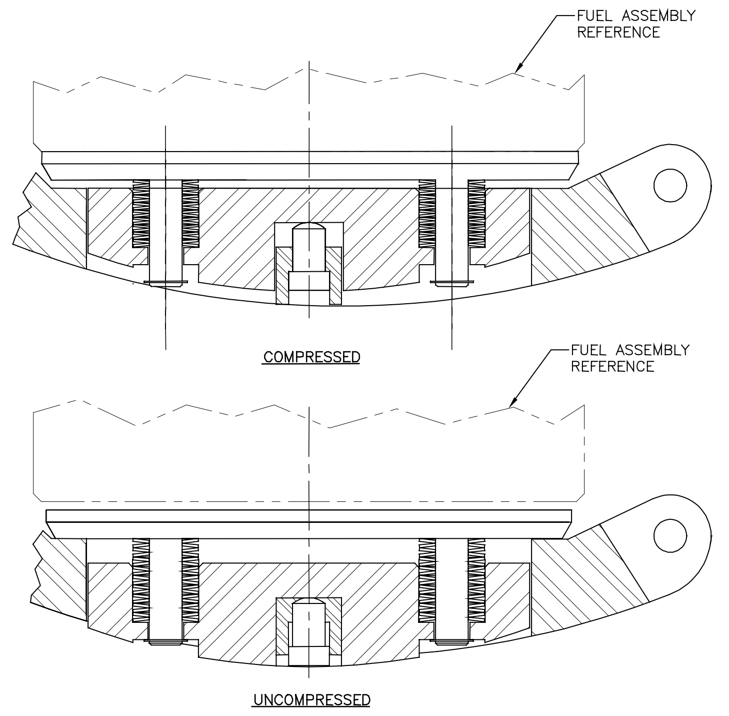

Figure 8 – Puncture Test Results (Worst Result)

The primary concern for normal loading and unloading operations involving the strongback is dose to the operators. Although the source term of the MOX FA's is low enough such that shielding for the package is not required, the dose during installation of the FA's is of concern because of the close proximity required. The primary operation which requires very close handling of the loaded strongback is opening and closing of the clamp arms, including application of the 100 to 600 lbs. clamping load to the FA's. To decrease the time required for such operations, two fairly simple design features have been added. To speed the opening and closing of the clamp arms, three Bal-Lok pins per clamp arm are used rather than the conventional multiple bolt operations used on other fresh fuel packages. Although two of the pins are in very close proximity to the fuel, the time to insert or remove the pins is extremely short, thus reducing the overall dose. The second design feature which speed operations near the fuel is clamp pad which incorporates beville springs. Once set properly, the clamp pad will easily and reliably provide a clamp force which is within the specified 100 to 600 lbs. range. The simple arrangement requires only that the clamp bolt is turned until tight against the 'nut' and does not require monitoring of torque or number of turns. This process can be performed well away from the fuel via a long reach tool, greatly reducing operator exposure.

Current Status

Barring changes dictated by forthcoming certification testing, the design of the MFFP is complete. A request for quotation to fabricate a certification test unit has been issued, bids received and successful bidder determined. Certification testing will occur next summer, circa June 2002. If all goes as expected, the requisite Safety Analysis Report for Packaging (SARP) will be submitted to the NRC in early 2003. The package may be licensed about twelve months thereafter.

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[i] Title 10, Code of Federal Regulations, Part 71 (10 CFR 71), *Packaging and Transportation of Radioactive Material*, United States Regulatory Commission (USNRC), 1999

[ii] Title 49, Code of Federal Regulations, Part 173 (49 CFR 173), *Shippers-General Requirements for Shipments and Packaging*, United States Department of Transportation (USDOT), 1999