CONCEPTUAL DESIGN OF A MOX FRESH FUEL SHIPPING PACKAGE

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ABSTRACT

Packaging Technology, Inc. (PacTec) is a participant in the Duke, Cogema, Stone and Webster (DCS) consortium tasked with providing the Department of Energy (DOE) with domestic mixed oxide (MOX) fuel fabrication and reactor irradiation services for the purpose of disposing of surplus weapons usable plutonium. PacTec is responsible for development and licensing of a new MOX fresh fuel shipping package (MFFP). Currently, no such package is licensed for use within the United States. A previous package, the MO-1 (C of C 9069/B( )F) package, is no longer certified for MOX fresh fuel and is not adaptable. Current program needs are such that a modern and, preferably, higher capacity package design is required.

This paper presents the conceptual design of the new MOX fresh fuel package. An overview of design and licensing constraints and associated issues is provided. The majority of light water reactor fresh fuel packages in the U.S. transport uranium-based fuel that is designated Type AF for transportation. MOX fresh fuel, because of the plutonium content, is designated Type BF and requires the package provide a full level of containment. In addition, reactor facility constraints are such that loading and unloading options are somewhat restricted and certain handling features are preferred. This results in trade-offs between a more readily licensed, end loading package, and a more easily operated, “clamshell” closure design. This paper addresses key design trade-offs such as this.

Because of a desire to minimize the number of MOX shipments, a certain degree of design optimization is also required. For example, it is a contractual requirement to ship the maximum number of assemblies possible, given the size and weight constraints associated with prescribed transport vehicles. To ensure that this requirement is met, various engineering development test programs are required. These test programs focus on aspects such as closure design configurations and features and the inherent need to minimize outer packaging shell thickness, while still adequately protecting the package from the hypothetical accident condition. This paper presents and discusses those programs.

The paper concludes with an overview of remaining steps required to finalize the design and successfully license the package with the Nuclear Regulatory Commission (NRC). This specifically includes identification of remaining design and licensing challenges and the approaches, such as full scale testing, being used to address them.

INTRODUCTION

The U.S. Department of Energy (DOE) has contracted with a consortium of companies to provide their specialized expertise to design, construct and operate facilities and associated equipment needed to manufacture, transport and irradiate mixed oxide (MOX) fuel. This MOX fuel is to be used in commercial light water reactors in the United States. The purpose of this project is to dispose of surplus, weapons-grade plutonium. Packaging Technology, Inc. (PacTec) is a participant in this consortium consisting of Duke, Cogema and Stone and Webster (DCS). PacTec is responsible for the development and licensing of a new MOX Fresh Fuel Package (MFFP) for the shipment of the MOX fresh fuel assemblies from a MOX Fuel Fabrication Facility (MFFF) to existing commercial reactors where the MOX fuel irradiation will occur.

Currently, there are no packages licensed for MOX fresh fuel use within the United States. A previously certified MOX fresh fuel package, the MO-1 (C of C 9069/B( )F), is no longer licensed for shipments of MOX fuel. Although the MO-1 may be suitable for shipment of lead assemblies (two), a modern package is considered necessary for transport of production assemblies. Current key/governing design criteria for the new MFFP are as follows:

- Package shall be designed to receive a Type B(U)F-85 Certificate of Compliance (C of C) from the Nuclear Regulatory Commission (NRC).
- Package shall carry as many fuel assemblies as possible while still meeting the transportation requirements of the carrier (DOE Transportation Safeguards Division).
- Package shall meet the fresh fuel handling requirements of the MOX fuel fabricator to ensure transport of MOX fuel assemblies from the MFFF to the reactor site preserves the operational capability of the fuel.
- Package shall operationally be able to be unloaded, and if need be loaded, at each of three different reactor fuel handling facilities (preferably without facility modifications).

Based on imposed program constraints and regulatory requirements, the MFFP is designed to meet three handling and shipping conditions:

- Normal Operating Conditions – The package shall restrain and protect the MOX fuel assemblies against shock, vibration, and deflection requirements defined by the MOX fuel fabricator. In addition the package shall meet size, weight, thermal, radiation, handling and tiedown requirements consistent with the carrier.
- Normal Conditions of Transport (NCT) – These are the regulatory requirements for obtaining a C of C as defined in 10CFR71, Subpart F, Section 71.71 (1), and refer to package performance under normal transportation, or event-free, conditions. The NCT requirements include a 3 foot drop.
- Hypothetical Accident Conditions (HAC) – These are the regulatory requirements for obtaining a C of C as defined in 10CFR71, Subpart F, Section 71.73 (1) and include a series of hypothetical accident events (impact, puncture and fire, and immersion).

The MFFP concept design consists of four main components as follows:

- A containment shell with lid,
- Energy absorbing impact limiters on each end of the package,
- A strongback for mounting the fuel assemblies, and
- A removable shipping skid.

Key details associated with the PacTec developed conceptual design, which meets the regulatory agencies requirements and the users and handlers needs, are presented in the rest of this paper.

CONCEPTUAL DESIGN DEVELOPMENT

The process used for conceptual design development started with a data gathering step, which led directly to development of a Design Interface Specification (DIS). In parallel with, and subsequent to development of the DIS, a variety of trade-off studies were performed. With study results in place, a general configuration, which appeared to best satisfy all imposed constraints, was selected for more detailed development. That concept design development effort is scheduled for completion during the first quarter of 2000. Each of the steps in the process and the resulting concept design are discussed below.

Data Gathering

The starting basis for the MFFP conceptual design was a DOE Oak Ridge National Laboratories document relating to a new MOX Fresh Fuel Transport Package. (2) That document provided an initial summary of criteria which could be used for design and certification of a MFFP. In addition, the document provided two concept package configurations as a potential starting point for new package design. The two concepts were: 1) a cylindrical package with an end closure that loads and unloads either horizontally or vertically, and 2) a cylindrical package with a “clamshell” closure (i.e., splitting in half, lengthwise) that loads and unloads horizontally. In both cases, the packaging was to provide a level of containment due to the plutonium content of the fuel. An inner “strongback” structure which supports the fuel assemblies along their length, and which can be tilted to a vertical position to allow for ease of fuel loading and unloading, was also integral to both concepts.

With insights gained from the above background document, meetings and site visits were then held with the fuel fabricators, the reactor site operators and DOE’s Transportation Safeguards Division (TSD). This allowed all critical interface definitions to be established and or refined. Physical inspections of facilities, facility equipment and transport trailers and detailed reviews and discussions of associated operating practices continued to enhance PacTec’s understanding of all requirements which would ultimately govern transportation package and ancillary equipment designs.

Although no longer licensed for transport of MOX fuel, the MO-1 package was also studied for possible adoption of some of its design features. Similarly, MOX packages used in Europe were overviewed for additional design insights. The designs of current low enriched uranium (LEU) fresh fuel packages were also studied for their applicability, especially relative to provisions for securing and supporting the fuel assemblies.

Design Interface Specification

Due to the large number of organizations and interfaces involved, a Design Interface Specification (DIS) was developed. All packaging interfaces, including those associated with the fuel assemblies, transport trailers and facilities (reactor and fuel fabricator site) were included in the DIS. This document was then issued for formal acceptance by DOE and all parties of the consortium and is the governing basis of the MFFP design. The interfaces having the greatest impact on the new MFFP design are as follows:

- Size and weight limitations associated with use of DOE provided trailers

- Facility space and crane (capacity and hook height) limitations
- Fuel assembly structural support requirements
- Type BF certification tests

TRADE-OFF STUDIES AND SELECTION OF GENERAL PACKAGE CONFIGURATIION

Several trade-off studies were performed to help guide selection of the preferred concept. The most significant was a study of three generic package configurations, 1) end loading, 2) clamshell and 3) individually contained fuel assemblies in a single overpack. See Figure 1.

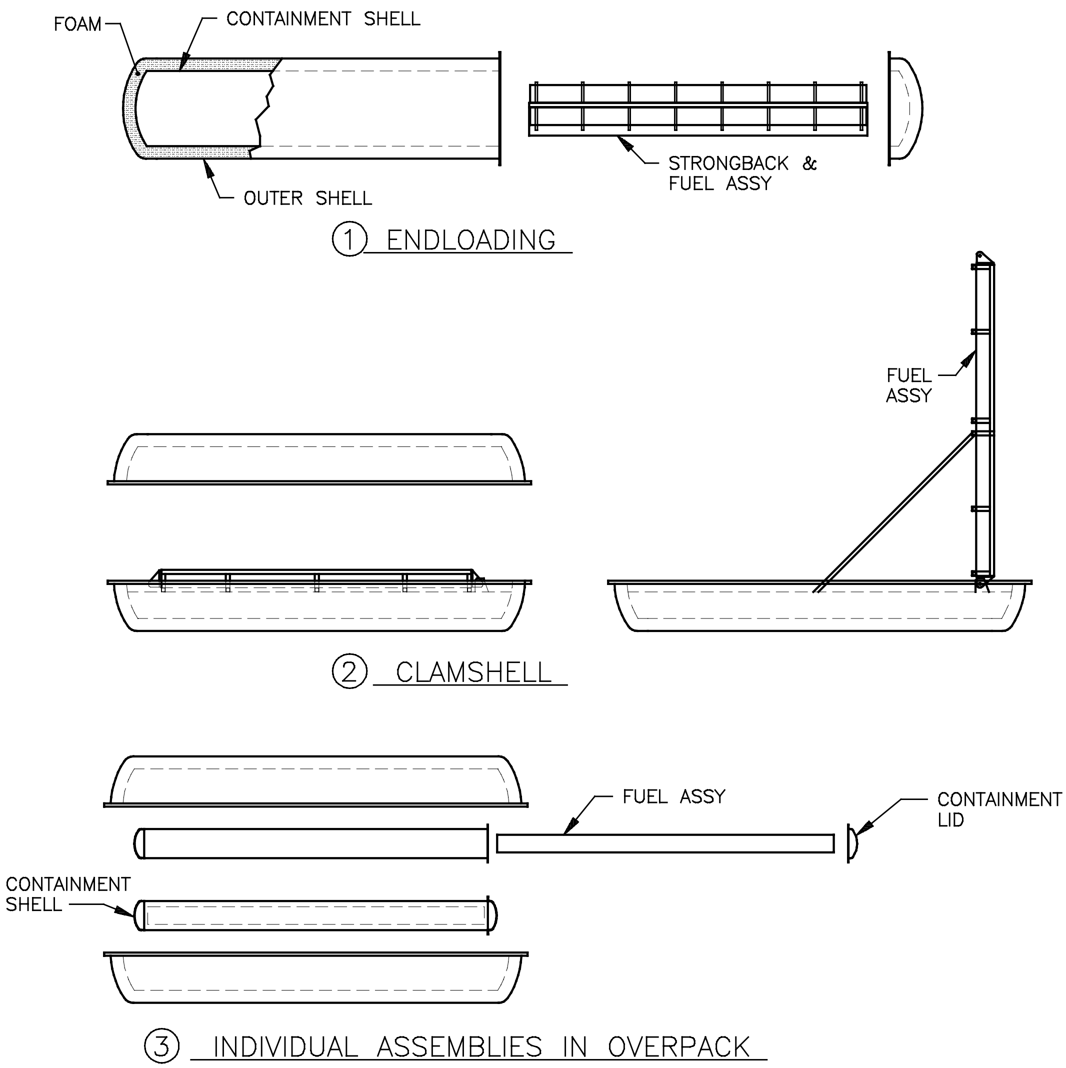

Figure 1 – Generic Package Configurations

As discussed earlier, the end loading design is a cylindrical package with an end closure that loads and unloads either horizontally or vertically, and the clamshell package is a cylindrical package with a "clamshell" closure (i.e., splitting in half, lengthwise) that loads and unloads horizontally. In the third case of individually contained fuel assemblies in a single overpack, each fuel assembly would be mounted on it's own strongback and installed inside a containment shell, then two or three of these assemblies would be installed inside an overpack (or other impact absorbing structure). In all cases, the packaging is to provide a level of containment in addition to the fuel itself and the inner "strongback" structure(s) are to allow tilting to a vertical position to allow fuel loading and unloading.

Since the fuel fabrication facility and the nuclear power plant fuel handling areas allow an end closure packaging configuration (which requires more facility space and/or crane capacity than other options), the package geometry can be relatively simple and straightforward from a design and licensing viewpoint. From a payload capacity viewpoint, the end load concept is also preferred in that it can result in the greatest ratio of payload weight to packaging weight.

Current facility operational practices are such that the clamshell packaging design is best suited because current LEU packaging is already of this configuration. However, in the "clamshell" configuration, the geometry will be sufficiently non-standard (i.e., not a simple cylinder with an end closure that is typical of most transportation packages having a containment vessel) to create significant design and licensing challenges. At best, a design and licensing process which relies heavily on physical testing (free drop, puncture and/or fire testing) would be required. The design process would be expected to require development and testing of an engineering prototype to clearly determine package vulnerabilities and the worst-case drop and puncture test orientations. This would be followed by a certification test unit to test these worst-case orientations. Another drawback of the clamshell design is that in order to protect the entire length of the containment/closure seal, the packaging would become heavy, thus limiting payload capacity.

In the case of the individually contained fuel assemblies located in a single overpack, the most desirable aspects of both the end loading and clamshell configurations can be combined. Each fuel assembly would be contained in an end loading, containment shell, which would provide ease of licensing. The overpack would be a clamshell box configuration similar to existing new fuel packages and allowing for ease of handling. The negative with this configuration is the fact that due to imposed weight and size constraints, at most only two MOX fuel assemblies could be shipped in such a package.

As a result of these considerations, once it was established that facilities could accommodate the size and crane capacity requirements associated with an end loading package, the end loading configuration was selected for as the design configuration to be developed for the MFFP. Figure 2 provides an overall view of the selected concept.

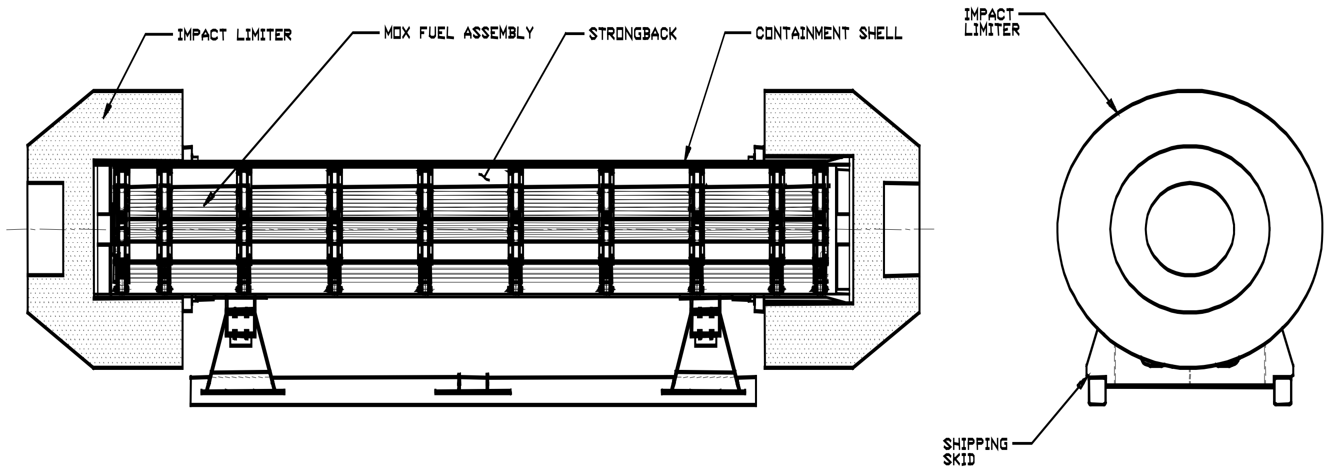

Figure 2 – MOX Fresh Fuel Package Concept Design

Concept Design

Given the preferred general configuration of the new MFFP, and considering prior design experience and licensing interactions, a list of design and certification issues that could prove challenging during development of the new package was identified which included the following:

- Package containment and closure design,
- Fuel assembly support and restraint system,
- Criticality control design,
- Potentially small thermal design margins, and
- Fit-up in the DOE TSD trailer

Strategies for addressing each of these potential issues are presented below. Confirmation and implementation of these strategies was initiated in late 1999 at the first of several planned NRC meetings and will continue throughout the design development phase of the project.

Package containment and closure design

The new MFFP design must address concerns similar to those raised on similar, previously licensed packages. In this case, similar packages are considered to be those where the payload-to-gross weight ratio is relatively high, structural shells are relatively thin and the closure region can be subjected to impact by a relatively rigid inner payload structure or by the puncture bar, either of which could cause substantial loads or deformations. To minimize concern in the closure region of the packaging, a relatively thick closure ring is used at the containment seal location and the outermost shell of the closure end impact limiter in the vicinity of the closure is sufficiently thick to preclude rupture by a puncture bar, or if ruptured, to minimize deformation of the closure ring. A bore seal configuration is also selected since such a configuration is less vulnerable than a face seal to failure when subjected to impact induced forces and/or deformations. Outboard of the seal/closure area, thinner, deformable containment boundary and impact limiter shell thicknesses are used to minimize packaging weight, thus allowing for a maximum payload capacity.

The result of this design approach is a deformable containment boundary and potential rupture of the impact limiter shells outboard of the closure region. Full-scale bench and certification tests are therefore planned, as was the case when demonstrating containment integrity of the TRUPACT-II and HalfPACT packages (3,4). On those programs, analysis methods were generally not even used for demonstrating package containment integrity due to the complex and deformable nature of the closure geometry and external load conditions acting on the package. Contrary to the TRUPACT-II and HalfPACT designs, the new MFFP design is expected to lend itself reasonably well to analysis for most load cases other than puncture, which will definitely be demonstrated via testing.

Fuel assembly support and restraint system

A second critical design consideration for the new MOX Fresh Fuel Package is criticality control. Criticality control is achieved by two means: 1) providing sufficient stand-off distance between adjacent fuel assemblies to reduce reactivity, and 2) utilizing a neutron absorbing material between fuel assemblies. The second method is being used to neutronically isolate the fuel assemblies from each other within the package, and to reduce reflection of neutrons. Each fuel assembly must remain immobilized (restrained) within the internal strongback and fuel assembly clamp arms.

Current PWR fresh fuel shipping packages immobilize individual fuel assemblies by clamping (pressure) pads on each grid strap. The clamp frames must restrain each fuel assembly throughout the regulatory normal condition of transport (NCT) and hypothetical accident condition (HAC) tests. Furthermore, the clamp frames must be operationally simple to use since they must be routinely opened and closed to allow fuel assembly loading and unloading.

Consequently, existing designs from currently licensed fresh fuel packages form the design basis for the MOX Fresh Fuel Package clamp frames. Special consideration is being given to the clamp frame attachment points. The attachment points must carry the clamp frame loads to the internal strongback. For successful design and licensing, analytical methods are being used to size the clamp frames and attachment points; confirmatory testing will demonstrate adequacy of the design.

Potentially small thermal design margins

Whereas a LEU fresh fuel assembly generates negligible decay heat, a single MOX fresh fuel assembly may generate up to 75 watts, resulting in up to 225 watts of decay heat within a package containing three assemblies, the currently expected payload capacity. The current design concept utilizes an impact limiter on each end of the package. Each limiter consists of an outer steel shell and a medium-to-high density, rigid polyurethane foam fill. The polyurethane foam serves two purposes relative to the containment vessel and its seals: 1) impact protection from the regulatory NCT and HAC free drop and puncture tests, and 2) thermal protection from the regulatory HAC thermal test. However, this highly insulating polyurethane foam material works against the package design under normal conditions by trapping the internal decay heat (i.e., a “thermos bottle” effect). The result could be containment seal temperatures which approach their maximum steady state allowable temperature.

Special care is therefore being taken when establishing final design details to ensure that seal temperatures do not exceed material capabilities. If thermal design features and analytic assessments are not inherently conservative, in addition to expected free drop and puncture structural testing, thermal testing for normal and/or accident conditions could become required.

Fit-up in the DOE TSD trailer

Early in the design process, it became apparent that weight and size limitations associated with transport in the DOE TSD trailer would present a major challenge and potentially compromise payload capacity. Some of the approaches identified above, such as adoption of a deformable containment boundary outboard of the closure seals, were used to help address this concern.

Other issues

Numerous other operational issues provide package constraints that are non-regulatory in nature but very important never-the-less. For example, the MOX fuel rods are wrapped in a plastic material which may off-gas and/or make leak testing of a two o-ring containment seal configuration difficult to test. Therefore, the package seal design utilizes three o-rings.

As already discussed, weight is a critical issue therefore the shipping skid is designed using aluminum. In addition, the package is strapped to the skid in a manner so as not to become part of the drop analysis.

SUMMARY AND NEXT STEPS

The MFFP concept design discussed in this paper meets the operational and regulatory requirements set by the shippers, users and regulators. As a precursor to the final design and certification phases, PacTec will be hosting a conceptual design review with the DOE and the DCS consortium members during the first quarter of 2000. Subsequently, necessary quarter or half- and full-scale testing will take place throughout 2000. Presentations to the regulators at critical points during the process will take place. At a minimum, meetings with the NRC to discuss planned test programs and subsequently to present and explain results of those tests will be included. By the end of 2000, SAR development is expected to be well underway and certification testing is expected to be planned and in progress.

REFERENCES

1. Title 10, Code of Federal Regulations, Part 71, Packaging and Transportation of Radioactive Material.

2. S. B. Ludwig, R.D. Michelhaugh, et al., “Programmatic and Technical Requirements for the FMDP Fresh MOX Fuel Transport Package,” ORNL/TM-13526, Oak Ridge National Laboratory(1997)

3. Safety Analysis Report for the TRUPACT-II Shipping Package, NRC Docket number 71-9218.

4. Safety Analysis Report for the HalfPACT Shipping Package, NRC Docket number 71-9279.