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The Traveller: A New Look for PWR Fresh Fuel Packages

Brian Bayley, William E. Stilwell, Norman A. Kent

Westinghouse Electric Company, LLC, Columbia, South Carolina, USA

Introduction

The Traveller PWR fresh fuel shipping package represents a radical departure from conventional PWR fuel package designs. This paper follows the development effort from the establishment of goals and objectives, to intermediate testing and analysis, to final testing and licensing. The discussion starts with concept origination and covers the myriad iterations that followed until arriving at a design that would meet the demanding licensing requirements, last for 30 years, and would be easy to load and unload fuel, easy to handle, inexpensive to manufacture and transport, and simple and inexpensive to maintain.

Background

The immediate noticeable feature of the Traveller package is that it carries just one fuel assembly instead of two. The initial design, however, was a two-fuel assembly concept. The Traveller design and development effort started in 1999 with the realization that a new PWR package was needed to replace the existing MCC series packages. The MCC package design was licensed to the 1973 version of the IAEA regulations. A new package was needed that would satisfy the licensing requirements of the current 10CFR71 and TS-R-1.

Recognizing that the new package must satisfy specific safety and compliance requirements of several competent authorities, the decision was made to report progress regularly to several competent authorities and their technical review branches throughout the design and testing phases of the project. This had the double benefit of (1) gaining a better understanding of the particular areas of interest and concern held by each competent authority with respect to demonstrating compliance with the regulations, so that (2) the package design could incorporate features that would address and satisfy these areas of concern. The design team obtained valuable insight from comments and sugges-

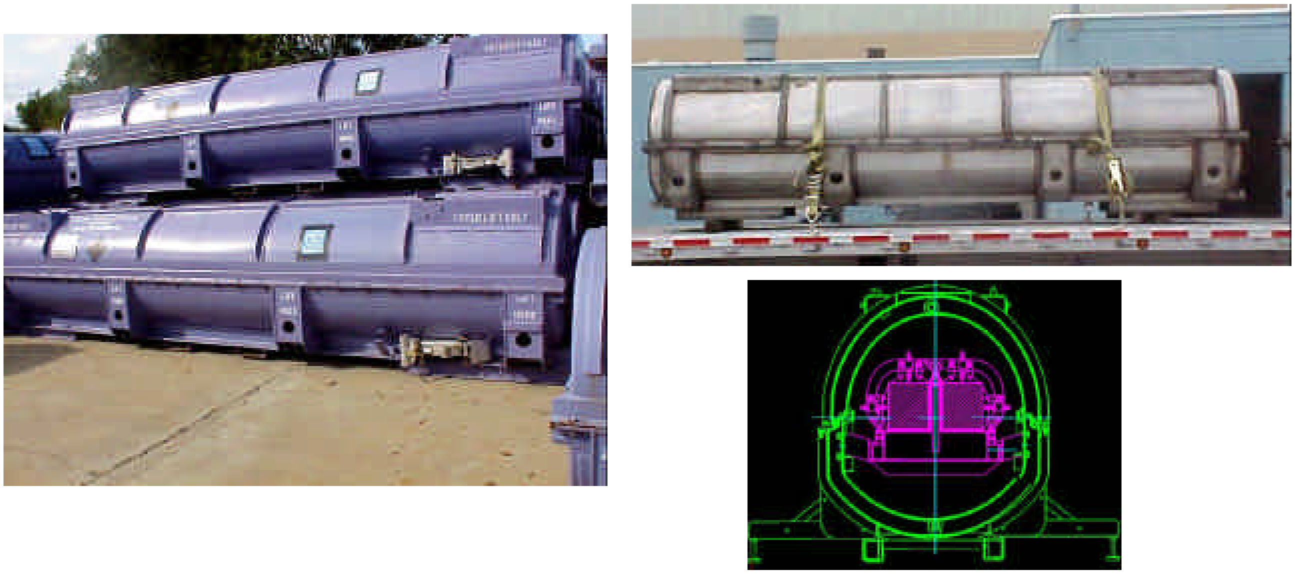


Figure 1: MCC (left) and Original Traveller Prototype (right top and bottom)

tions that were made and questions that were asked during these progress reports, and was able to incorporate numerous features into the packaging during the design phase which improved the overall safety and operability of the package.

Likewise, the team met regularly with selected customers in the United States and Europe in order to ensure that customer requirements and preferences for onsite handling were considered in the design. Customer input played an important role in arriving at the final Traveller design.

Initial Design

The initial Traveller design resembled a modified MCC, as can be seen in Figure 1. It combined a new outer shell with the internal components from the MCC. The outer shell consisted of concentric stainless steel shells with high-density polyurethane foam in between. The design objectives were to preserve the original shape after the 9-meter drop (criticality safety spacing), protect the fuel in the 1-meter puncture test, and provide thermal insulation for the fuel during the fire test. The internal components of the MCC were retained because they carried multiple fuel types and held the fuel firmly in place.

Prototype testing was conducted in late 2000 and, indeed, the testing demonstrated that the design met the objectives stated above. However, several things occurred following the testing that caused Westinghouse to reconsider the design approach.

Reconsidering the Design Approach

This initial design, while it performed well in the tests, did carry some licensing and operational concerns. Discussions with competent authorities following the drop tests raised doubt about its ability to satisfactorily address such issues such as brittle fracture of certain materials, fuel lattice expansion, certain flooding conditions, and variable-water density issues. It became apparent that additional modifications to the internal components and numerous additional calculations and tests might be necessary to resolve these issues.

The design also posed operational concerns. A comparison between the MCC and Traveller, normalized to fuel assemblies per consignment, showed that the Traveller and TravellerXL designs would be slightly larger and 29% to 39% heavier than their MCC counterparts. This additional size and weight translated into a 30%-40% increase in transportation costs (1/3 fewer fuel assemblies per truck) and increased aggravation for customers who would possibly have to retool their sites to handle a heavier, bulkier package.

To properly resolve these and other issues would add time and cost to the already demanding development schedule. The decision was made to abandon the current design path and, starting over "with a clean piece of paper," design a package that would meet the following goals and objectives:

- Do not be constrained by trying to modify an existing design; (i.e., do not design around old parts);
- Use the better concepts and properties of the first Traveller design (e.g. outer shell concept);
- Look at new design concepts that would clearly resolve nuclear criticality safety and structural concerns raised by Competent Authorities;
- Keep manufacturing cost equivalent to the cost of replacing existing packages;
- Put the same number of fuel assemblies on a truck in the Traveller as with MCC;
- Minimize impact on customers
- Make handling as simple as possible.

Arriving at the Final Design

Designing a package to meet the goals and objectives listed above resulted in the development of the package that carries a single fuel assembly. The concept went through several iterations before reaching the current design. The first configuration (Figure 2) featured a solid double-wall tubular outerpack with a single opening at the top, a removable inner "clamshell" which contained the fuel assembly, an external suspension system, and a cage-frame. The clamshell would be completely removed from the outerpack and raised to the vertical position to load or offload fuel.

This design, with no seams on the sides of the outerpack, made for a very strong package. However, the square clamshell design made fuel loading difficult.

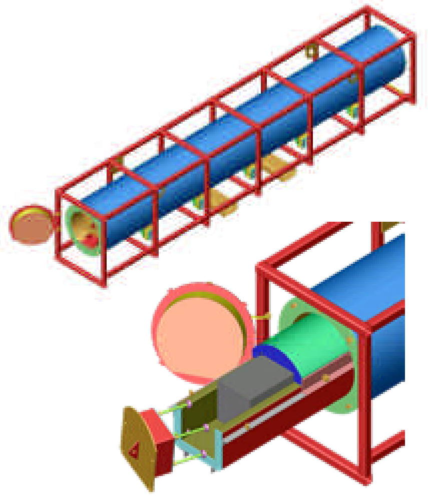


Figure 2: Birdcage Design with Clamshell Operation

Subsequent iterations retained the solid tube design and birdcage frame with external suspension but looked at other clamshell designs in an effort to improve fuel handling. The design team eventually decided on the "diamond" clamshell concept, which simply rotated the clamshell 45 degrees inside the outerpack. The diamond clamshell, seen in Figure 3, made fuel loading and unloading much simpler.

Once the diamond clamshell concept was accepted, there was renewed discussion with competent authorities and customers on the viability of the solid tube construction and the birdcage frame. It was recognized that the solid tube design, while providing the strongest margin of safety, would present significant handling difficulties because a great deal of space would be needed for fuel handling. It was further recognized that the birdcage concept would be a potential personnel safety hazard during handling, and would present continuous contamination problems. Therefore the packaging was modified further until the present design, shown in Figure 4, with the smooth, split outerpack with internal suspension system, was decided upon.

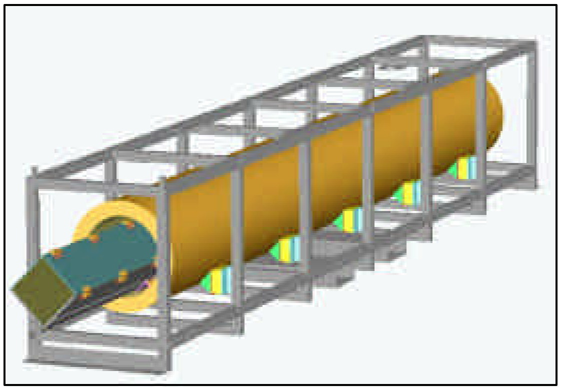


Figure 3: Diamond Clamshell Concept

The Design

The Traveller package, designed to carry one PWR fuel assembly or one container for loose rods, is made up of two basic components, the outerpack and clamshell. They are connected together with a suspension system that reduces the forces applied to the fuel assembly during transport. There are two types of packagings in the Traveller family: the Standard (Traveller STD) and the Traveller XL. Dimensions are shown in Figure 5. The gross weights are 2041-kg for the Traveller STD and 2313-kg for the Traveller XL.

The Outerpack is a structural component that serves as the primary impact and thermal protection for the Fuel Assembly. It also provides for lifting, stacking, and tie down during transportation. The Outerpack is a long tubular design consisting of a top and bottom half. Each half consists of a stainless steel outer shell, a layer of rigid polyurethane foam, and an inner stainless steel shell. The stainless steel provides structural strength and acts as a protective covering to the foam. At each end of the package are thick impact limiters consisting of two

Figure 4: Traveller Final Design

sections of foam at different densities sandwiched between three layers of sheet metal. The impact limiters are integral parts of the Outerpack and reduce damage to the fuel assembly during an end, or high-angle drop. The foam is an excellent impact absorber and thermal insulator. The steel-foam-steel "sandwich" is the primary fire protection.

The inside of the Outerpack is lined with blocks of Ultra High Molecular Weight (UHMW) polyethylene. The polyethylene has a dual purpose. It provides a conformal cavity for the Clamshell and fuel assembly to fall into during low-angle drops. It is also a significant component used for criticality safety. A typical cross-section showing key elements of the package is depicted in Figure 6

The Clamshell, also shown in Figure 6, is a structural component consisting of a lower aluminum "v" extrusion, two aluminum door extrusions, and a small top access door. Piano type continuous hinges connect each door to the "v" extrusion. The purpose of the Clamshell is to protect the contents during routine handling and in the event of an accident. During routine handling, the Clamshell doors are closed immediately after the contents are loaded. This provides a physical barrier to debris or accidental damage. During accident conditions, the Clamshell provides a physical barrier to rod bowing, lattice expansion, and loss of rods. It also provides neutron absorption.

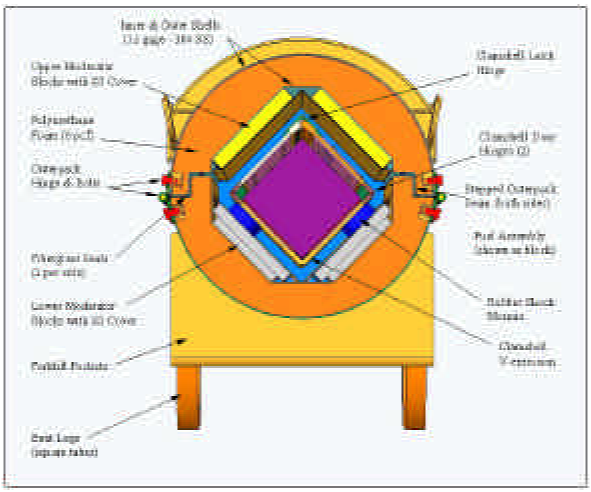


Figure 6: Traveller Cross Sectional View

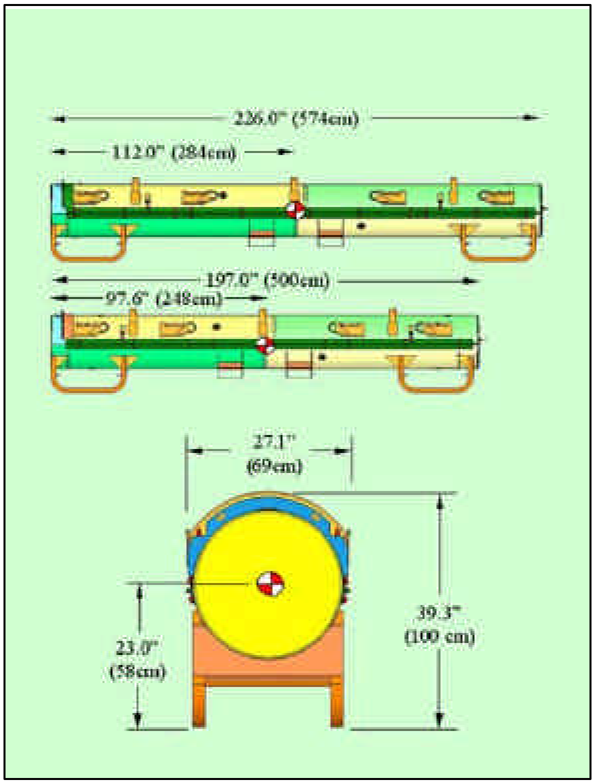


Figure 5: Traveller Dimensions

The Fuel Assembly is secured inside the Clamshell at three locations down the length. At the top end, two jackscrews with neoprene pads clamp the fuel assembly axially against the bottom plate. Adjustable spring-loaded pads are positioned at any axial location between end locations to secure the fuel assembly along its length. These pads will be located at mid-grid locations. The "v" extrusion is lined with a cork rubber pad to cushion the contents and prevent damage during normal handling and transport conditions. The bottom plate is similarly lined with cork rubber.

Neutron absorber plates are installed in each leg of the "v" extrusion and in each of the doors. The plates are inserted in a pocket in each extrusion and attached with screws. The plates are solely for neutron absorption and do not provide any structural support.

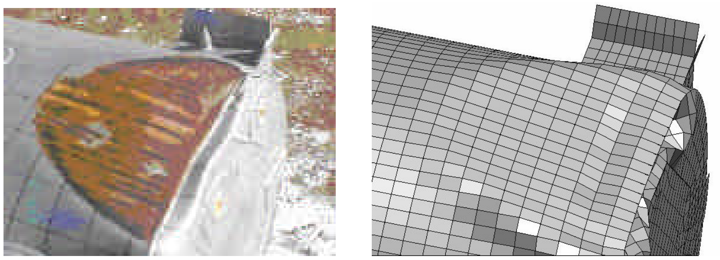
Scoping Tests and Analyses

The Traveller package design evaluation consisted of a combination of component scoping tests, full-scale prototype testing, mechanical design calculations, and finite element analyses. The testing phase spanned several months and consisted of dozens of tests.

Scoping tests began early in the design phase to quantify the critical characteristics of the components or subsystems of the design. These scoping tests included: Outerpack Hinge Strength-to-Failure Tests, Outerpack Hinge Alignments Tests, Clamshell Hinge Strength-to-Failure Tests, Polyurethene Foam Pouring Tests, Foam Burn Tests, Clamshell Weld Tests, Clamshell Impact Tests, and Impact Limiter Tests. The scoping tests provided designers with important performance data. However, proof of performance in the Traveller package was obtained through full-scale testing.

Mechanical design calculations were performed to demonstrate package compliance to the mechanical requirements described in 10 CFR 71 and TS-R-1 for which no formal testing was conducted. These included: lifting attachments, design temperature analysis, vibration, compression-stacking, and penetration.

The finite element analysis consisted of developing two finite element models for the Traveller XL package undergoing the prescribed regulatory drop tests. The first model reflected the prototype configuration used for initial exploratory ("scoping") tests conducted in January 2003. The second model reflected the Qualification Test Units tested in September 2003 that included modifications based on the prototype test results. The objectives of the FEA were (1) to validate the techniques used in the FEA models by documenting the conservative agreement found between predictions and results of the prototype drop tests; and (2) to determine the appropriate number of drop tests and their orientation(s) needed for the qualification drop tests. By regulation, the shipping package must be dropped at orientations that are most damaging to the fuel assembly and to the shipping package. The analyses provided valuable qualitative information with respect to the relative deformations, decelerations, and energy absorptions between drop orientations. The analyses showed that the most challenging drop orientations were a 9 meter vertical drop onto the bottom nozzle end of the package and a 9 meter CG (center-of-gravity) drop onto the top nozzle end. The analysis determined that the former had the greatest potential to damage the fuel assembly and the latter was most damaging to the package itself.



Actual

Simulatio

Figure 7: Prototype Test: Outerpack Deformation at Top Nozzle End

The FEA predicted that damage to the Traveller XL shipping package from the HAC drop tests would be minor and primarily involved localized deformations in the region of impact. Both the Outerpack and Clamshell structures would remain intact and closed. Fuel assembly damage is confined to the top or bottom region depending on drop orientation. This damage would primarily involve localized buckling and deformation of the nozzles.

Full-Scale Tests

The development of the Traveller included three full-scale test campaigns. These campaigns were called (1) Prototype Test, (2) Qualification Test, and (3) Certification Test. The Prototype Test and Qualification Test involved two test units each while the Certification Test involved just one. In general, the test units were very similar. The overall configuration of the Outerpack and Clamshell remained essentially identical throughout the design evolution. With each test campaign, the design was modified to increase structural or thermal margin, or to reduce excess design margin when appropriate. Design changes from the Prototype Test to the Certification Test included: reduction of outerpack shell thickness; adjusting of polyurethane foam densities; addition of a thin stainless steel covering for the moderator blocks; and replacement of short individual outerpack hinges with a continuous outerpack hinge.

Prototype Test

The Prototype Test, conducted in January-February 2003, involved the testing of two prototype test units (PTU-1 and PTU-2). The primary objective of the PTU-1 test was FEA validation. The test consisted of a 9-m low angle slap down drop, a 9-m high angle drop, a 1-m pin puncture (through CG, low angle), and a 35 minute pool fire burn test. The outerpack performed well throughout the drop tests, sustaining only minor, local damage. The clamshell failed the high angle drop test. And, the package failed the fire test as the outerpack failed to prevent ignition of polyethylene sheets in one location.

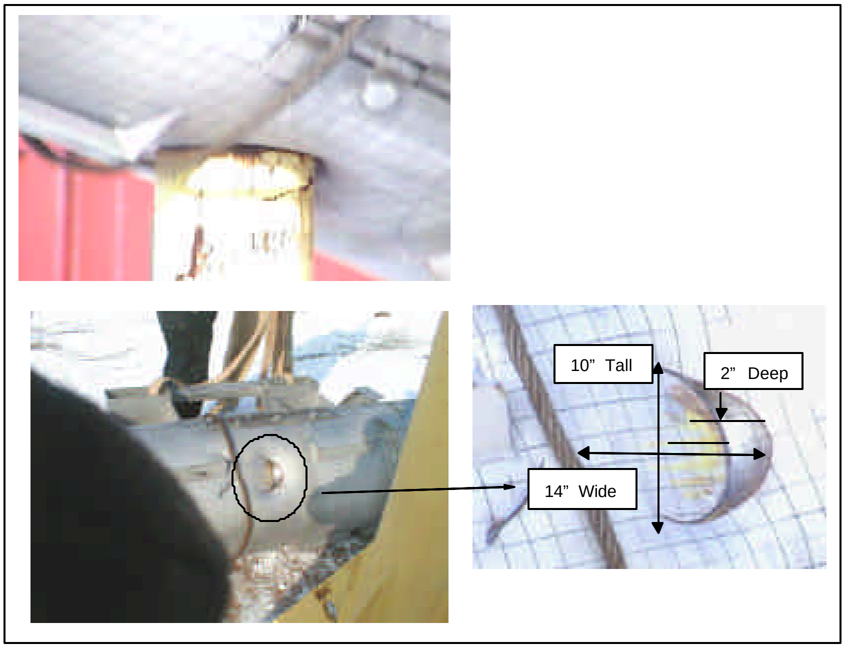


Figure 8: PTU-2 Pin Puncture Test

Modifications were made to the clamshell of PTU-2 and then the unit was subjected to the regulatory required tests for Normal and Hypothetical Accident conditions, namely a 1.2-m low angle slapdown drop, a 1-m pin puncture (through CG, low angle), and a 9-m high angle drop. PTU-2 passed this test sequence. Following this series of tests, PTU-2 was again modified (reduced number of outerpack hinge bolts and clamshell locking pins) and the unit was subjected to three additional 9-meter drops to assess the performance of the package in this condition.

The mechanical performance of the Prototypes (1 & 2) associated with the first testing campaign clearly demonstrated the strength of the outerpack and clamshell (with minor exception). In all, six (6) drops were performed on 2 full-scale prototypes from 9 m. The outerpack retained its overall integrity and functionality. Most importantly, all design features important to criticality safety performed as intended. Moderator blocks and simulated neutron absorber plates remained intact and attached to their respective structural components.

Qualification Test

The Qualification Test was conducted in September 2003. It also involved the testing of two test units (QTU-1 and QTU-2). As before, the units were drop tested in one location and then transported to another location for the fire test. The test objective was to verify design changes from earlier tests. The QTU-1 drop test sequence consisted of a 1.2-m low angle slapdown drop, a 9-m high angle drop onto the top nozzle, and a 1-m pin puncture drop, followed by a 37 minute pool-fire burn test. The QTU-2 drop test sequence included a 1.2-m low angle slapdown drop, a 9-m bottom nozzle end drop, and a 1-m pin puncture drop. Both test units satisfied the mechanical test requirements. At this point the mechanical design was established.

But QTU-1 failed in the fire test to prevent ignition of the moderator block inside the outerpack. Internal temperatures exceeded design limits. Inspection found that excessive distortion of the outerpack shells between the hinges allowed sufficient hot gases to ignite the moderator blocks in the top half of the outerpack. The burnt moderator blocks were directly in line with the gaps between the hinges. The four burnt zones were located only on the upper half of the outerpack, most likely due to the flanges on the mating outerpack halves which preferentially directed incoming gases to the upper portion of the outerpack

Following the unsuccessful fire test of QTU-1, the second unit was modified prior to its fire test, to improve thermal performance. Because QTU-2 had already been drop tested, it was determined that only modifications would be acceptable that would not have affected the drop characteristics and performance. The changes included (1) replacing the short outerpack hinge sections with a continuous hinge system, and (2) covering the moderator blocks (top and bottom) with stainless steel. These covers were welded to the inner shells of the outerpack along the sides but were sealed with adhesive at the ends. The QTU-2 fire test was conducted one month after the QTU-1 fire test. It also failed to prevent ignition of the moderator blocks. However, the maximum temperature of the Clamshell and contents remained below 200°C. Inspection determined that ignition occurred at the bottom end of the package, most likely caused by distortion of the outerpack halves at the bottom end. Also, the continuous hinge did not cover the last 3 inches of the outerpack seams, which may have allowed additional hot gases to enter the package. The hot gas ingress occurred at a location were there was exposed polyurethane foam (the inner axial limiter foam) due to the thin stainless steel limiter cover being punched out by the Clamshell. The sheet metal covers did not perform as anticipated. The covers distorted during the testing, opening at the adhesive joint, which allowed the moderator block to ignite.

Figure 9: QTU-1 During Fire Test (Left) and Still Burning Afterward (Right)

Figure 10: QTU-1 Gaps After Fire Test

The QTU-2 fire test demonstrated that the moderator block must be completely welded, or “canned”, by sheet metal to prevent ignition. However, this test was further evidence that the “bulk” heating of the inside of the Outerpack was acceptable, even with burning occurring within the Outerpack. This is a result of the fact that there is insufficient oxygen to support large amounts of burning. It was estimated that over the 7.5 hours of total burning, only about 10-15% of the moderator material was consumed.

Based on the structural success of the QTU units and the thermal failures of the units, several changes were made solely to improve the thermal performance of the design. These included: completely encapsulating the moderator blocks with sheet metal and installing sheet metal cones around each shock mount; inserting a thin ceramic insulating material between the moderator block and the metal covers; introducing impact limiter “pillows,” separate structures to prevent polyurethane foam from becoming exposed to the inside of the outerpack, even in end drops; and increasing the thickness of the impact limiter plates. Other changes included reducint the foam density within the inner section of the pillows to allow more crushing of the foam; and lengthening the four long outerpack hinge sections to cover the entire outerpack seam.

Ceritification Test

The Certification Test was conducted in February 2004 with one test unit (CTU). The drop test sequence was similar to that of QTU-2. The unit satisfied the mechanical test requirements.

Confinement and containment requirements were satisfied. The CTU was then transported to the fire test site, and five days after the drop test sequence the fire thest was conducted. This time the package survived the fire test. Inspection after the test showed that the clamshell and its contents remained below a maximum of 150°C. There was slight discoloration of the moderator but no melting or loss.

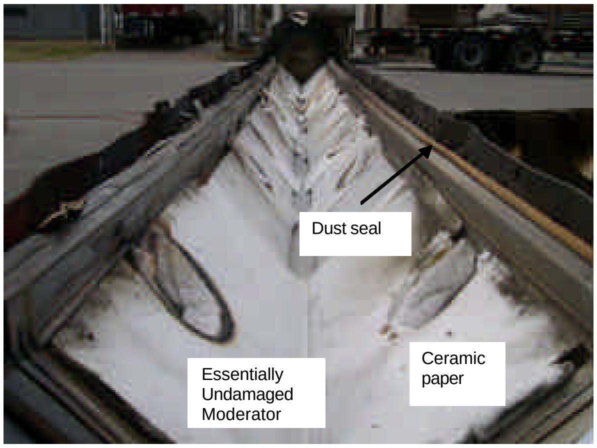


Figure 11: CTU Upper Outerpack Moderator after Fire Test

Licensing

The Traveller is currently in the licensing phase. The License Application (i.e. Safety Analysis Report) is being reviewed concurrently by competent authorities in the United States and Europe. Plans are to begin use in 2005 by Westinghouse and ENUSA. It is expected that the Traveller will completely replace the MCC, CE-927, and ABB-ATOM PWR packages over the next five to seven years.

Conclusion

The Traveller shipping package represents a new approach in PWR fuel package designs. This paper followed the development effort from the establishment of goals and objectives, to intermediate testing and analysis, to final testing and licensing. The Traveller design meets the demanding licensing requirements and is expected to have an operational life of 30 years. It has been designed to be easy to handle and fairly simple to load and unload fuel. It is relatively inexpensive to manufacture and operate, and simple and inexpensive to maintain.

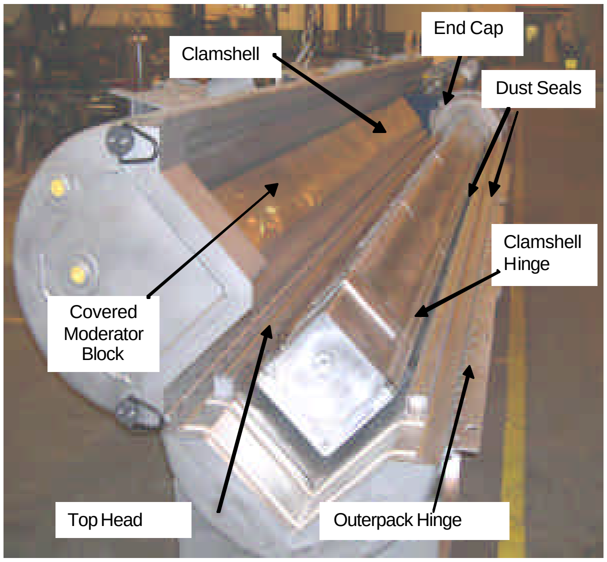


Figure 12: Certification Test Unit (CTU)

Involving competent authorities and their technical review branches from the United States and several European countries during the design process proved very beneficial to the design team. Valuable insight was obtained from comments and suggestions that were made and questions that were asked.

Similarly, regular meetings with selected customers in the United States and Europe helped ensure that customer requirements and preferences were incorporated into the design.