

# Development of Shipping Package Drop Analysis Capability at Westinghouse<sup>1</sup>

J. F. Staples

*Westinghouse Electric Company LLC<sup>1</sup>  
5801 Bluff Road  
Columbia, SC 29250, USA*

M. Pitzer, Ph. D.

*Hermes Engineering, NV  
Sint Denijsestraat 247  
B8500 Kortrijk, Belgium*

P. A. DuBois

*Hermes Engineering, NV*

## Abstract

*Westinghouse Electric Company LLC<sup>1</sup> is currently developing a new shipping package for transporting nuclear fuel to customer sites. This new design is designated as the Traveller<sup>TM</sup> shipping package.<sup>2</sup>*

*One of the many licensing requirements for the Traveller package is to demonstrate it will always maintain the fuel assembly in a (nuclear) non-critical configuration after being dropped from 9 meters onto an unyielding surface and from 1 meter onto a 15 mm diameter pin. In meeting these regulations, package orientation(s) which will most damage: 1. the fuel assembly; and, 2. the shipping package must be considered.*

*Westinghouse began the Traveller design effort with a need to supplement in-house analytical capability with experienced LS-DYNA consultants. However, the Traveller analysis was not simply “handed off.” Rather, a Westinghouse analyst worked closely with these consultants. This close interaction resulted in a shipping package model which included all features relevant to crashworthiness and correctly represented the final design. The resulting model was instrumental in the success of the drop tests and licensing efforts.*

---

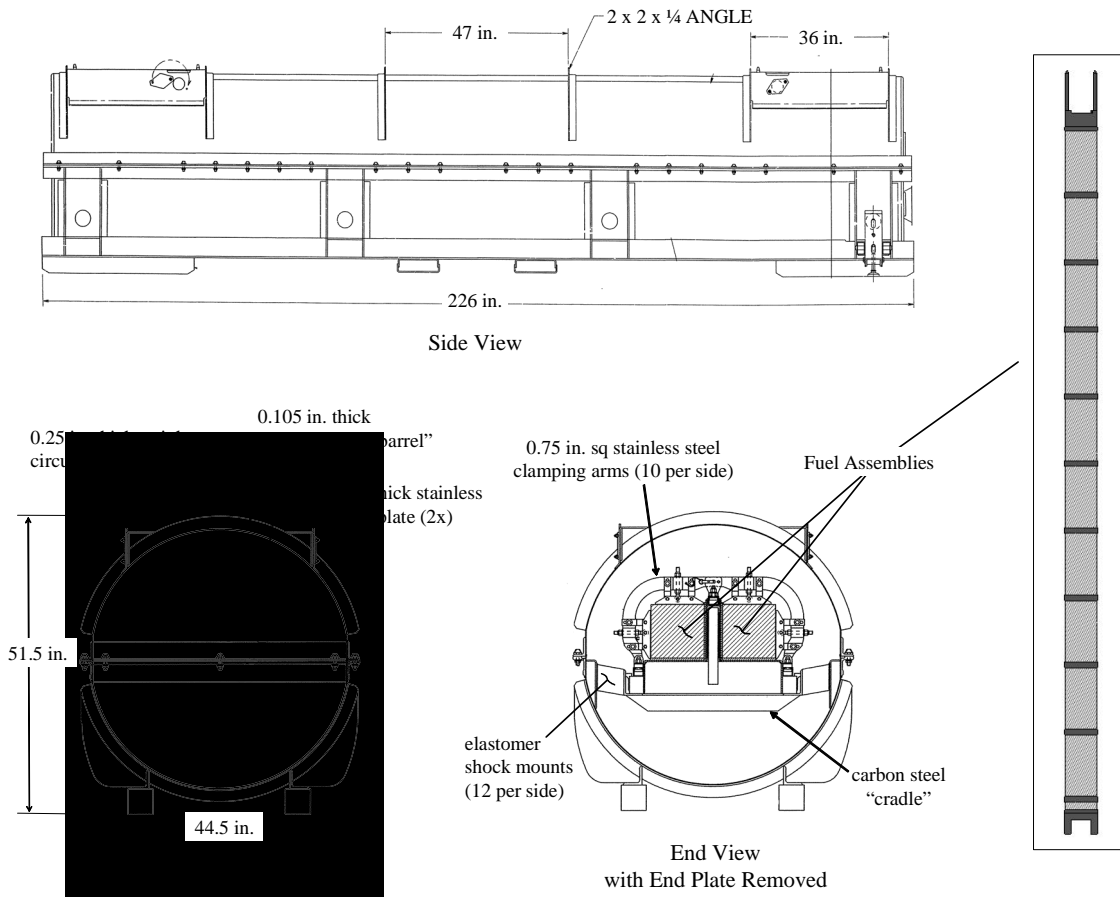
<sup>1</sup> Westinghouse Electric Company LLC (“Westinghouse”) is a wholly owned subsidiary of BNFL plc.

<sup>2</sup> *Traveller* is a Westinghouse trademark.

### Background

A new fresh fuel shipping package that complies with 10CFR71 and TS-R-1 regulatory requirements ([1]<sup>3</sup> and [2]) is being designed to replace existing Westinghouse packages for transporting light water reactor (LWR) fuel assemblies.

Westinghouse currently uses the ‘MCC’ type package for most fuel assembly shipments. This is an almost 30 year old package comprised of two reinforced sheet metal halves which surround two fuel assemblies as shown in Figure 1. There are two versions of the MCC container: a 160 inch long one used for most Westinghouse fuel shipments and a 226 inch long one (Figure 1) which is used to ship our very longest fuel assemblies.



**Figure 1. The currently used MCC shipping package.**

Westinghouse has licenses to use MCC packages for domestic (USA) shipments through 2008 and for international fuel shipments until the end of 2004. Westinghouse will use its new Traveller package for fuel shipments after these times.

TS-R-1 regulatory requirements include hypothetical accident scenarios involving a free drop from 9 meters onto an unyielding surface and a 1 meter drop onto a 15 mm diameter pin. To meet these requirements, the fuel assembly must be maintained in a (nuclear) non-critical

<sup>3</sup> Numbers enclosed in brackets, [ ], correspond to those in References.

configuration when dropped in the orientation most likely to cause failure. Following the drop tests, the shipping package must continue maintaining the fuel in a non-critical condition when subjected to a 30 minute burn test at 1472 °F (800 °C) and subsequently flooded with water.

### **Traveller Shipping Package Development**

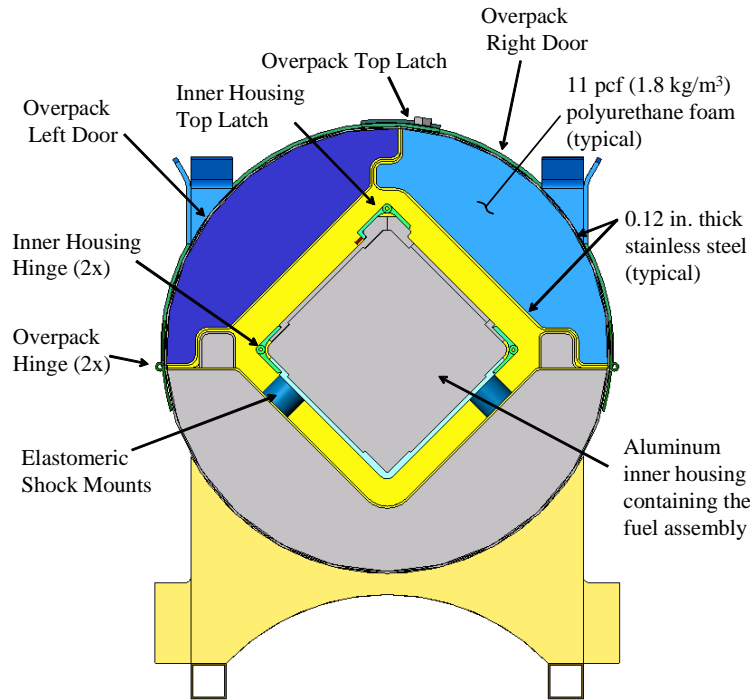
Westinghouse recognized that package weight is a key factor in passing both the 9 meter drop and 1 meter pin puncture tests. However, many new features/improvements were required in the new package that added weight relative to the existing MCC container. These included a thicker outer wall constructed of low-density polyurethane foam between two layers of sheet metal for added pin puncture and fire resistance. Also, it was decided to add an inner housing that completely surrounded the fuel assembly to reduce fuel rod deformations and add criticality margin. The concern was these features added significantly to the package weight and might impair drop performance. In order to avoid this possibility, Westinghouse began designing a completely new shipping package that would house only one fuel assembly.<sup>4</sup>

Westinghouse investigated many concepts for a single fuel assembly package. By necessity, many factors other than the ability to survive the drop tests were included in this study. Package length, for example, was limited by the economical need for the package to fit inside standard ISO shipping racks for sea transport. Other factors included package cost, manufacturability, weight with regard to shipping cost, and usability. Of course, it was always remembered the package had to pass the drop tests else its size, weight, cost, or ease of use would be of no practical interest. The challenge was to design the package with sufficient capability to pass the drop tests without unnecessarily burdening/restricting these other important concerns.

Finite element modeling played a significant role in the design process. In particular, one early version of the Traveller design consisted of a thick-walled outer structure containing a suspended inner aluminum housing which closely surrounded a single fuel assembly. As shown in Figure 2, the outer housing (or 'overpack') was a circular thick-walled construction of two stainless steel sheets encasing a 3 inch width of polyurethane foam. An inner aluminum structure was comprised of a 'V-shaped' aluminum extrusion and two extruded aluminum doors. This inner housing was attached to the outer housing with elastomer shock mounts at several axial locations. A clearance was maintained between the inner and outer housings to provide the clearance (or 'sway space') needed for shock isolation of the fuel assembly during normal transport and handling. Two hinged doors on the upper half of the overpack provided access to the inner housing and fuel assembly. When closed, these doors were latched together at the top of the overpack.

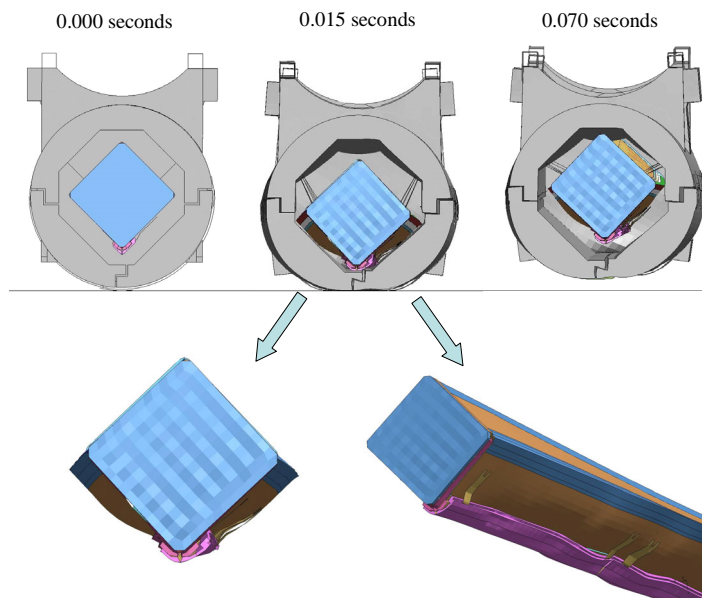
---

<sup>4</sup> The goal was to design the new package so that twice as many packages could be transported on a flatbed trailer. This would allow the same number of fuel assemblies to be shipped on a truck (an economic imperative) without increasing the individual package drop weight.



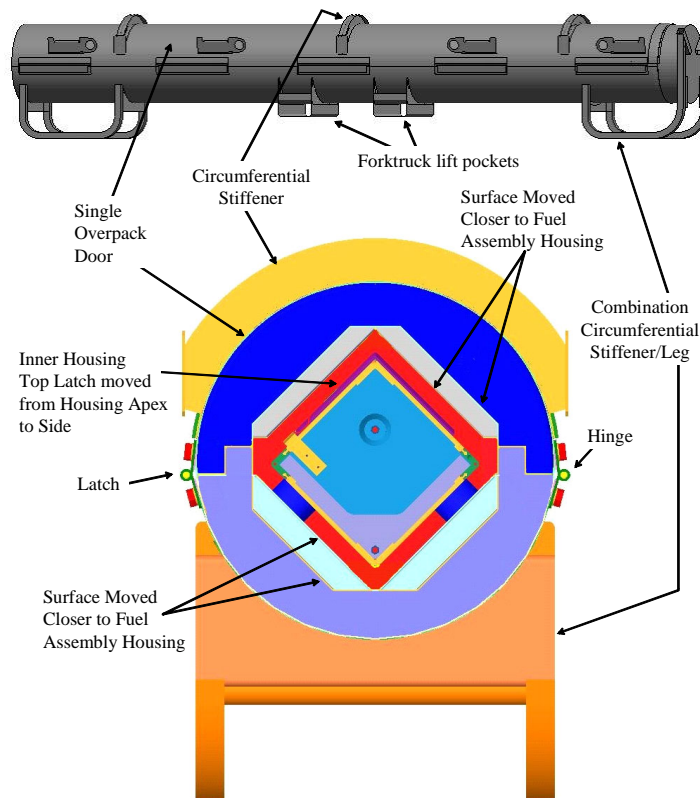
**Figure 2. An early version of the Traveller design had two doors for the overpack.**

LS-DYNA analyses identified a potential crashworthiness issue with this early version of the Traveller package (Figure 2). For example, in simulations of upside down horizontal drops, the inner housing containing the fuel assembly experienced high accelerations and large deformations. These deformations, as depicted in Figure 3, included the latch extrusion opening in a manner such that a fuel rod might be pinched or damaged. Additionally, the loads were so large that the structural integrity of this latch was questioned.



**Figure 3. Predicted deformations during a horizontal 9 meter drop onto the top cover.**

Based on these LS-DYNA predictions, design modifications were incorporated into the final Traveller design (Figure 4.) These included replacing the two overpack top doors with a single door, adding circumferential stiffeners to the outside of the overpack, and moving the overpack inner walls closer to the inner housing. The latter modification was intended to reduce deformation of the inner housing walls by “trapping” it in the conformal cavity (or “cradle”) created by the inner walls of the overpack. The first two modifications were intended to stiffen the conformal cavity created by the overpack.



**Figure 4. The final Traveller design.**

All subsequent references to the Traveller package refer to the design shown in Figure 4.

## Drop Performance

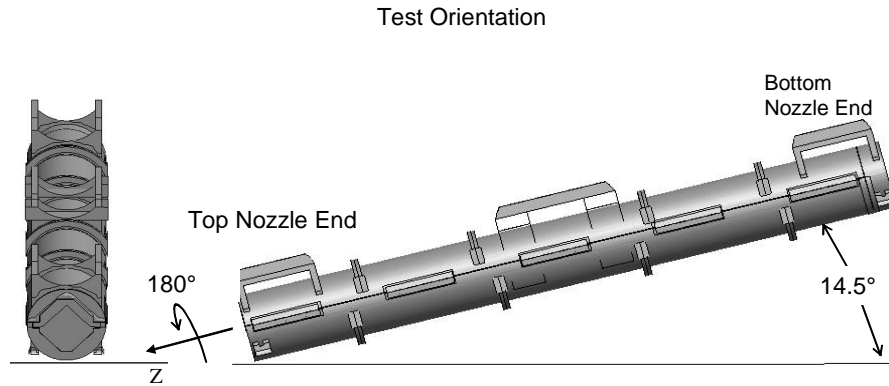
Drop test results for the Traveller shipping package were hugely successful with the package meeting/exceeding all licensing criteria. Indeed, the Traveller package readily passed both the 9 meter drop and 1 meter pin puncture requirements in numerous tests.<sup>5</sup> These latter results demonstrated the superiority of a package containing a single fuel assembly versus two. Further, actual and predicted 9 meter drop performance from LS-DYNA simulations agreed closely.

<sup>5</sup> Since drop weight is an obviously detrimental factor, all drop tests were conducted with the Traveller package designed for Westinghouse’s longest fuel assemblies (i.e., the heavier package).

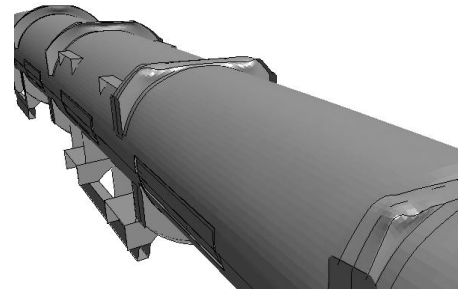
Drop Orientations

By regulation, the shipping package must be dropped at orientations that are most damaging to the fuel assembly and to the shipping package. Working closely with the Traveller package design engineers, the LS-DYNA analysts determined this requirement necessitated separate drops. Further, as the design progressed, both the package and the finite element model matured. Thus, some drop tests were done in orientations which were eventually determined not most damaging. These tests results were still useful for model validation.

Determining the drop orientation most damaging to the shipping package was facilitated by the Traveller design itself in conjunction with LS-DYNA simulations. We concluded that many orientations could be eliminated from consideration due to the circumferential stiffeners on the upper overpack and the legs/forklift pocket structure welded to the lower overpack (Figure 2). Our hypothesis, as confirmed by both LS-DYNA simulations and actual drop tests, was that drop orientations where one or the other of these structures directly contacts the drop pad, overpack damage is reduced in comparison to orientations where these features are not impacted. This is because the damage done to the circumferential stiffeners is isolated and does not reduce criticality margin and yet the energy absorbed in crushing these features is no longer available to do other damage.



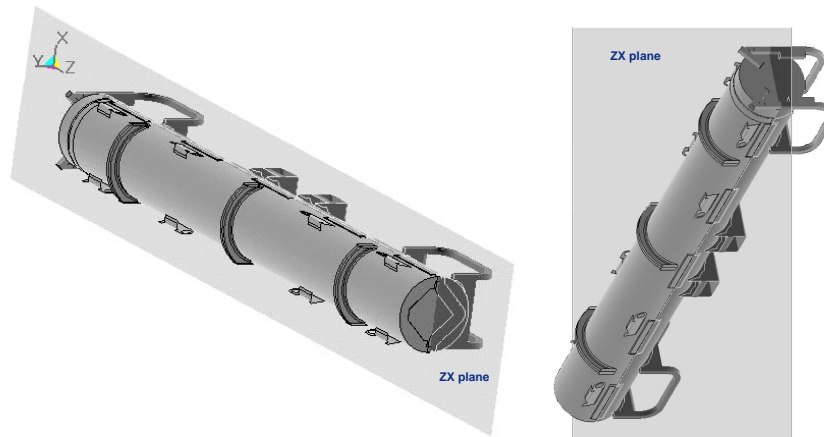
Actual



Simulation

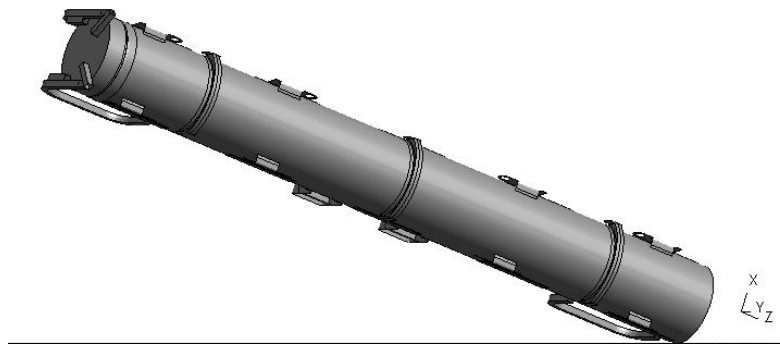
**Figure 5. Crushing of the overpack circumferential stiffeners protected the Traveller shipping package during an inclined 9 meter drop onto its top cover.**

Even so, neither the overpack stiffeners nor its legs hit first in orientations in which the overpack ZX plane (as defined in Figure 6) is perpendicular to impact. Such orientations include horizontal and inclined drops ('slap downs' as subsequently discussed) onto the hinged or opening side of the overpack and vertical drops onto the either end of the package. Thus, our analysis of the most damaging overpack orientations focused on these orientations.



**Figure 6. The overpack stiffeners and legs do not protect the overpack in orientations where the ZX plane is perpendicular to impact. Two example orientations are shown.**

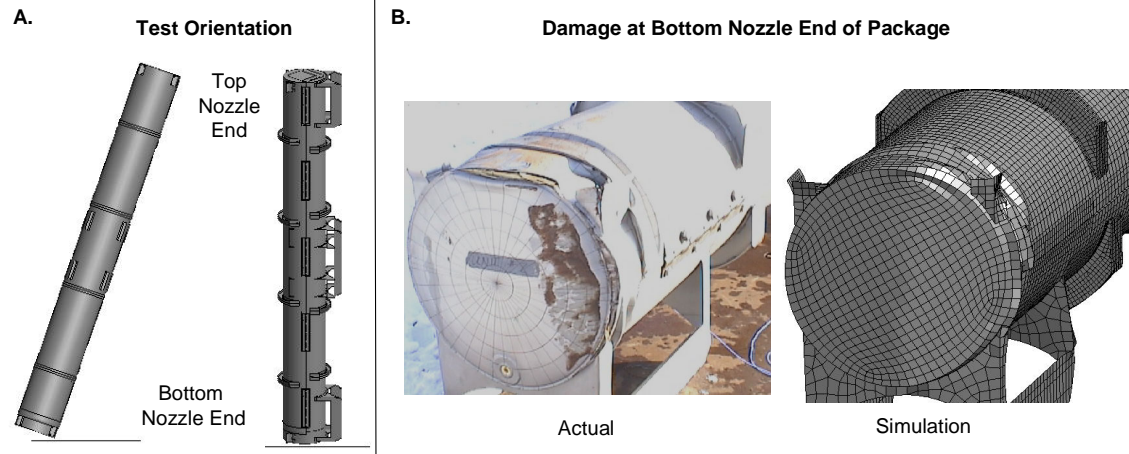
The Traveller design also facilitated our determination of the particular ZX drop orientation most damaging to the shipping package. In particular, ‘slap down’ drops (low- to medium-angle impacts where one end of the package hits before the other as shown in Figure 7) divide the impact energy primarily between the top and bottom impact limiters. Generally, this energy is absorbed in a manner that induces relatively little damage that would compromise criticality.



**Figure 7. “Slap down” drops involve a primary impact to one end of the package, rollover, and a secondary impact to the other end of the package.**

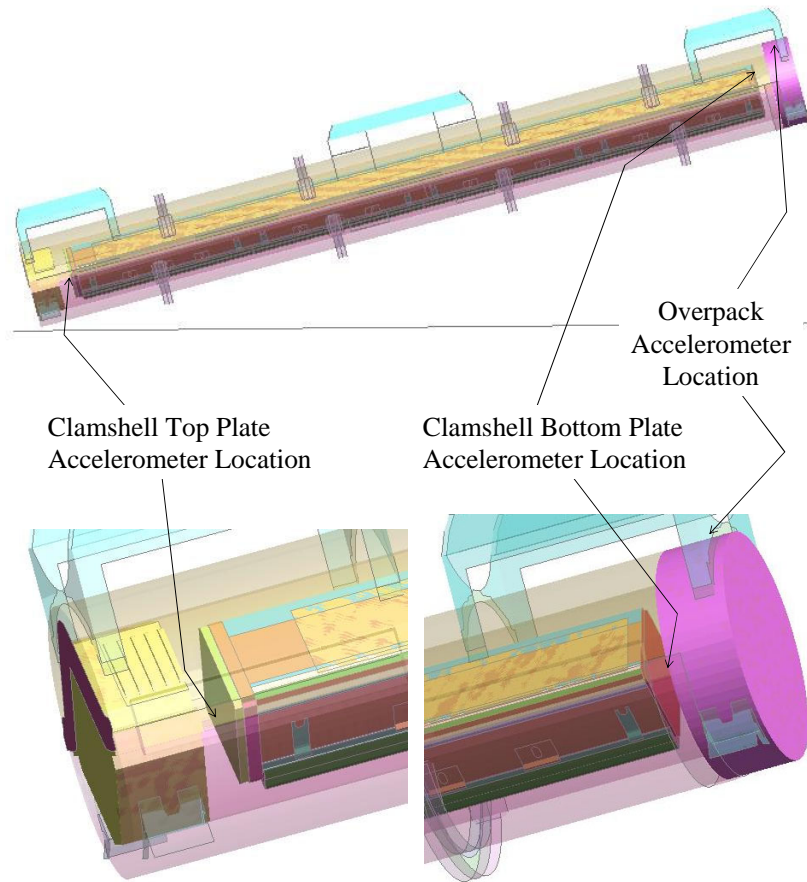
For example, the localized end damage shown in Figure 8 resulted from a ‘slap down’ drop. This result demonstrates that damage in slap down drops are focused at the package ends and do not create any criticality concerns. Note that the LS-DYNA simulation agreed with this test result.





**Figure 8.**

The prototype test unit shown in Figure 8 was instrumented with piezoelectric accelerometers prior to the 9 meter drop test. As shown in Figure 9, one accelerometer was attached to the top plate of the aluminum inner housing and was thus near the initial impact end. The other two were positioned on the secondary impact end at the inner housing bottom plate and on the bottom impact limiter. The intent was to measure the accelerations at a few critical points so that the forces involved in the drops would be better known and so that the FEA results could be validated.



**Figure 9.**

Agreement with measured vertical accelerations was good. Indeed, discrepancies between the two could easily be attributed to the inherent error associated with obtaining such data. For the overpack, both measured and predicted traces contained two peaks (Figure 10). These corresponded to the two impacts associated with a 'slap-down' drop test. While there were two visible peaks, the measured response was very small for the primary impact because the accelerometer was positioned far from the point of impact. For the secondary impact, the predicted acceleration was 1270 g's. This was in accordance with the measured peak acceleration which indicated accelerations were greater than 950 g's. (The larger acceleration with the secondary impact should not be interpreted as meaning larger forces were associated with the second impact. Rather, the larger magnitude simply reflects that the accelerometer was much nearer the secondary impact end.) For unknown reasons, the accelerometers on both the inner housing top and bottom plates gave erroneous readings late into the drop. Thus, only the first 0.05 seconds of these data are compared in this report. For the accelerometer on the top plate, measured and predicted accelerations corresponding to the first impact were 555 g's. This was also in accordance with measurements which indicated a peak acceleration greater than 525 g's was experienced (Figure 11.) As shown in Figure 12, peak accelerations of 205 g's were measured on the clamshell bottom plate. The corresponding predicted acceleration is also shown. Note the peak predicted acceleration was 155 g's.

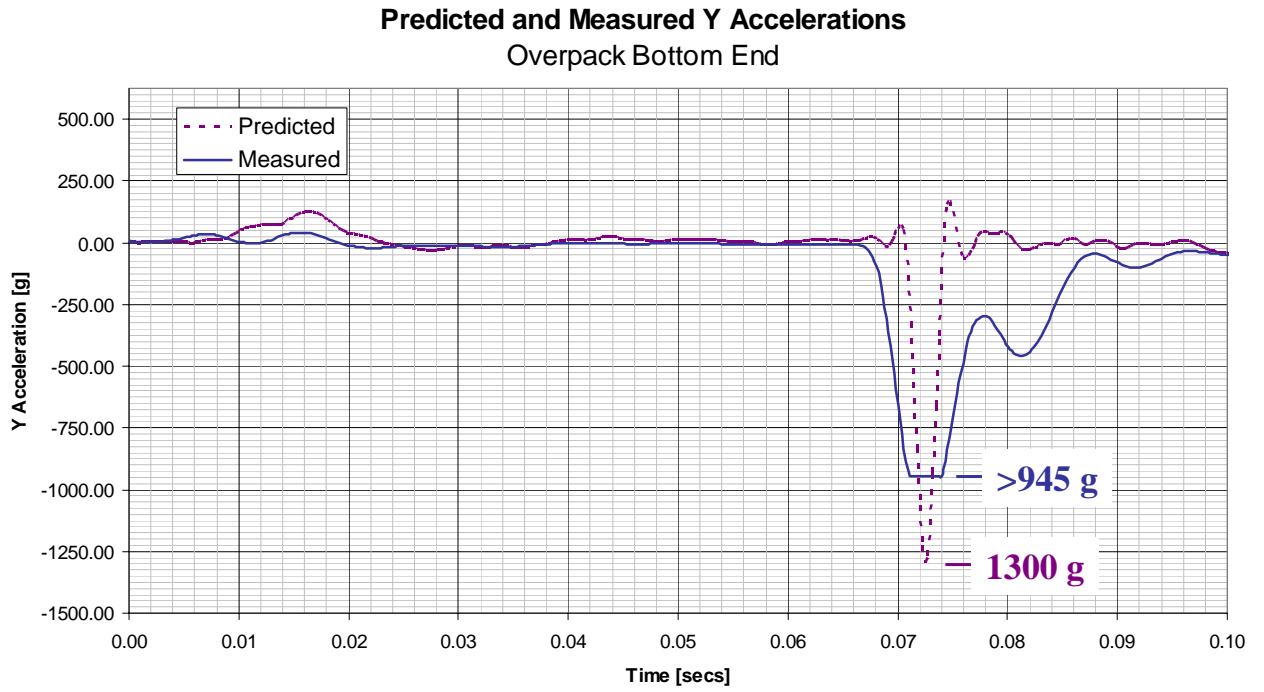


Figure 10.

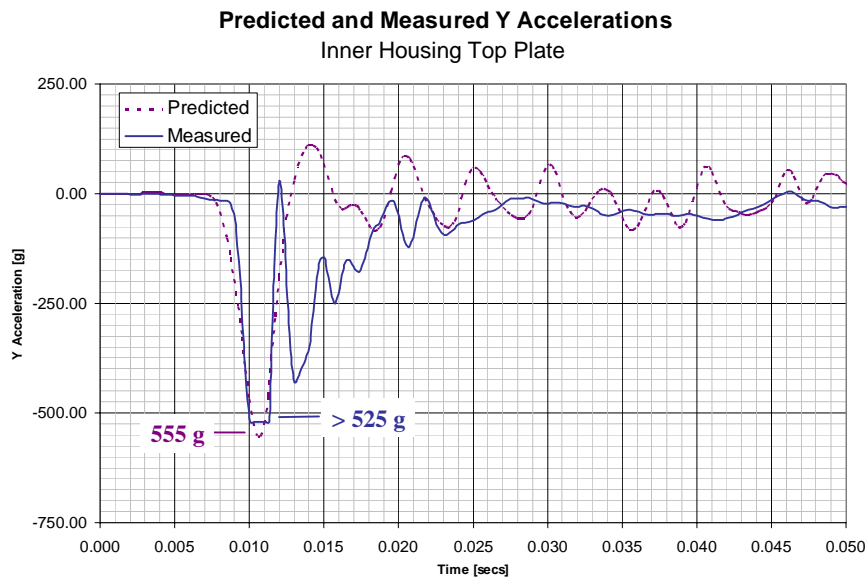


Figure 11.

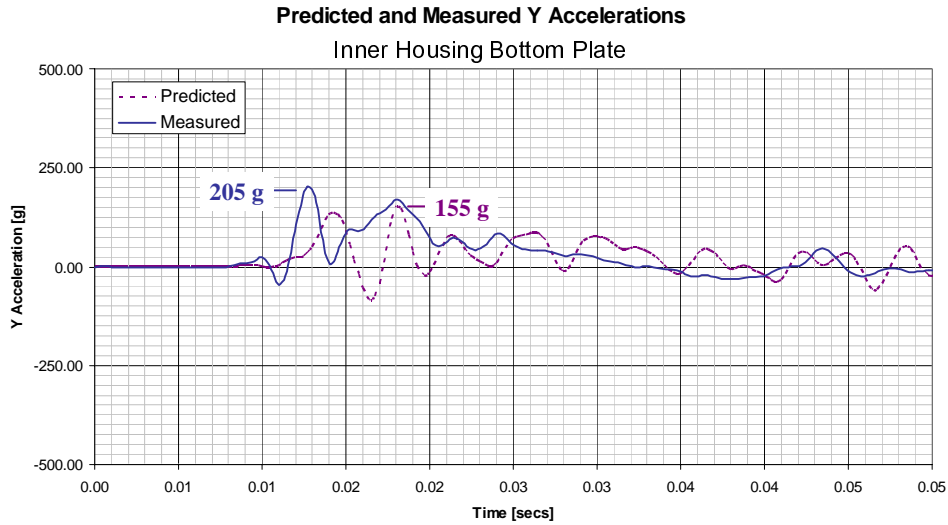


Figure 12.

Using LS-DYNA, the drop orientation most damaging to the fuel assembly was determined to be a vertical drop onto the bottom impact limiter. It might seem obvious that a vertical drop would be most damaging to the fuel assembly since Westinghouse fuel assemblies are primarily a bundle of long slender fuel rods. However, the issue of whether to drop onto the top or bottom end of the package and whether the drop should be exactly vertical or slightly offset was not at all clear. This is because differences in the ends of the fuel assembly, the shipping package, and the means of securing the fuel assembly in the aluminum inner housing greatly influence the drop forces imparted to the fuel rods. Specifically, the fuel assembly has two stainless steel pins permanently attached at diagonal corners of its top end as shown in Figure 13.) These pins are approximately 0.7 inches in diameter and 10 inches long. As also shown, a hold-down assembly contacts the other two corners of the assembly. In vertical drops onto the top end of the package, these structures will greatly influence the impact forces imparted to the fuel assembly. There are also features at the bottom end of the package which greatly influence fuel assembly forces. These are the bottom impact limiter and the fuel assembly bottom end fitting (the bottom nozzle) as identified in Figure 14.

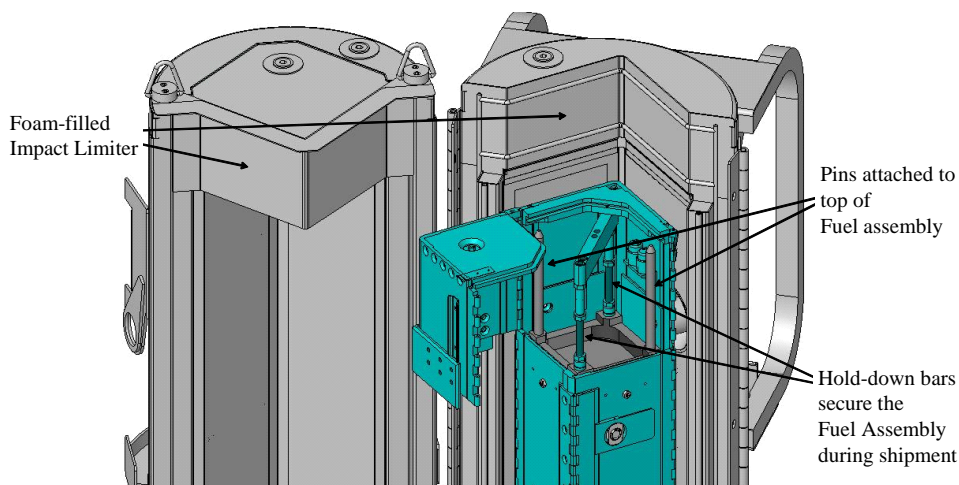
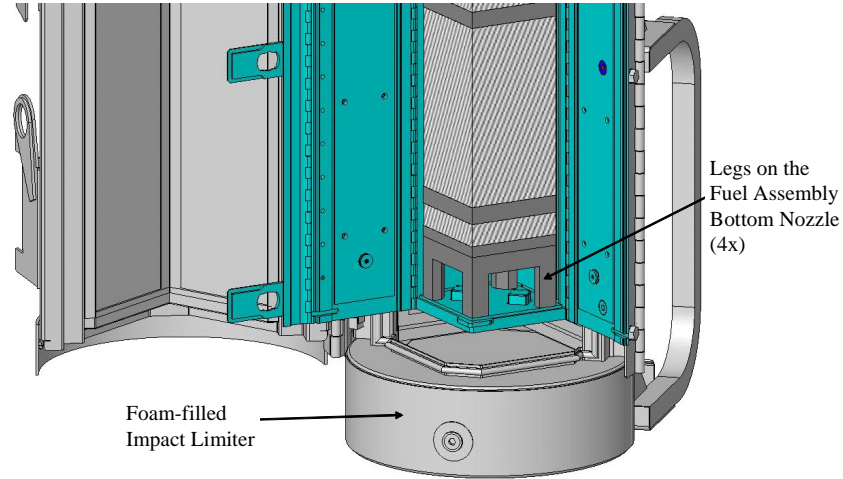
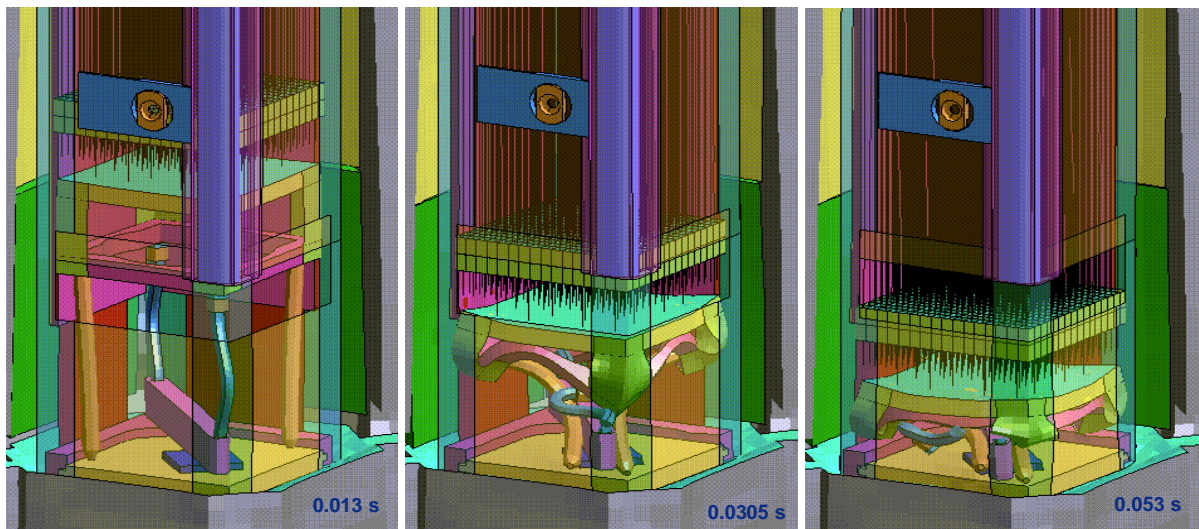


Figure 13.



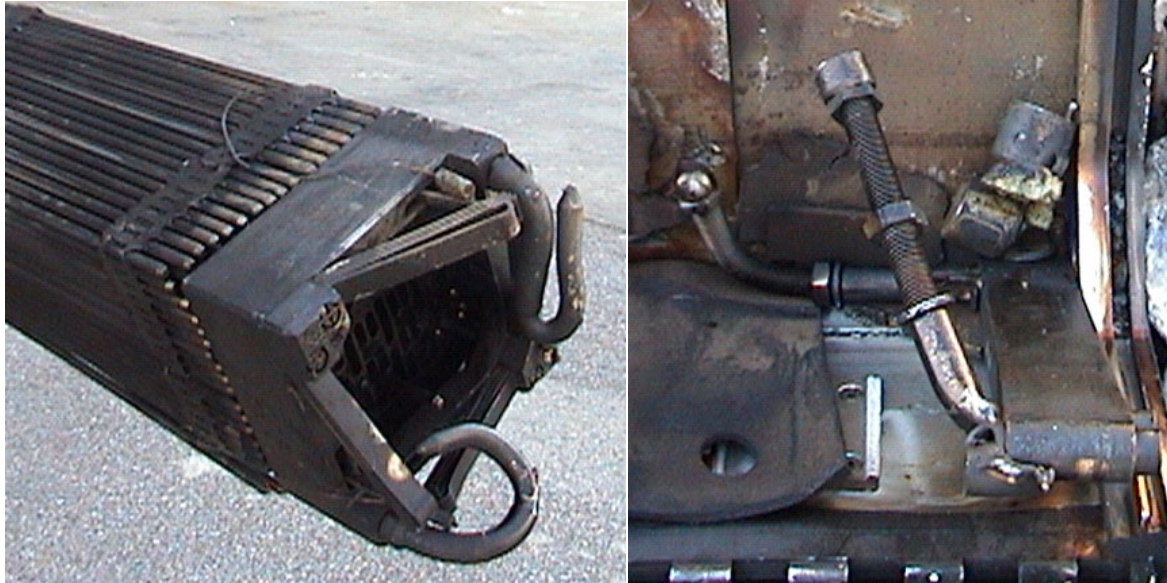
**Figure 14.**

With the LS-DYNA model, Westinghouse was able to predict the role each of these items had in protecting or causing damage to the fuel assembly. For example, both the fuel assembly pins and hold-down bars distort and are almost flattened under the weight of the fuel as shown in Figure 15. Indeed, the hold-down pins are predicted to break near their attachment point to the aluminum housing. This deformation protects the fuel assembly as it absorbs a significant portion of the drop energy.



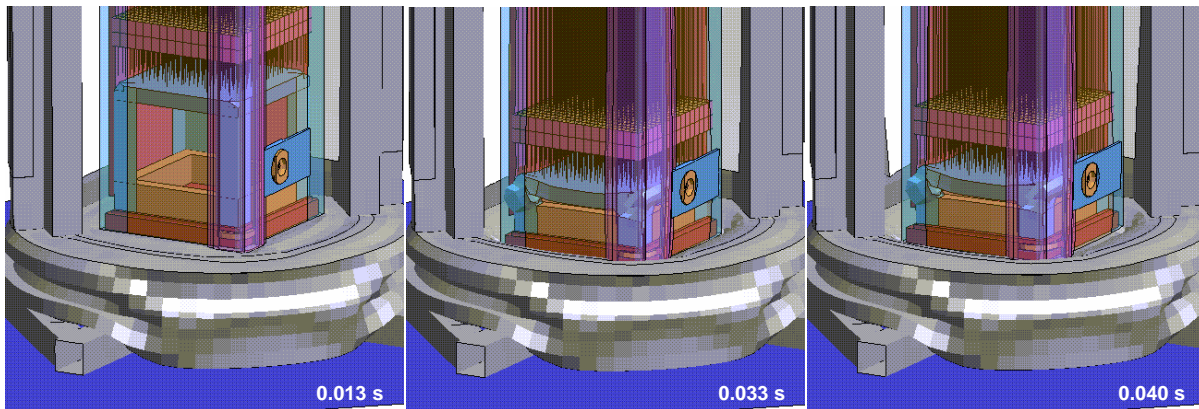
**Figure 15.**

These results were qualitatively verified by test. For example, note the extent of damage to both the pins and hold-down bars shown in Figure 16 resulting from a 9 meter vertical drop onto the top end of the package. (The pictures shown in Figure 16 were obtained after both a drop test and a 30 minute burn test.)



**Figure 16. Deformation of the fuel assembly pins at the top end of the fuel assembly (left); damage to the hold-down bars (right). These photographs were taken after the shipping package had survived a 30 minute burn test.**

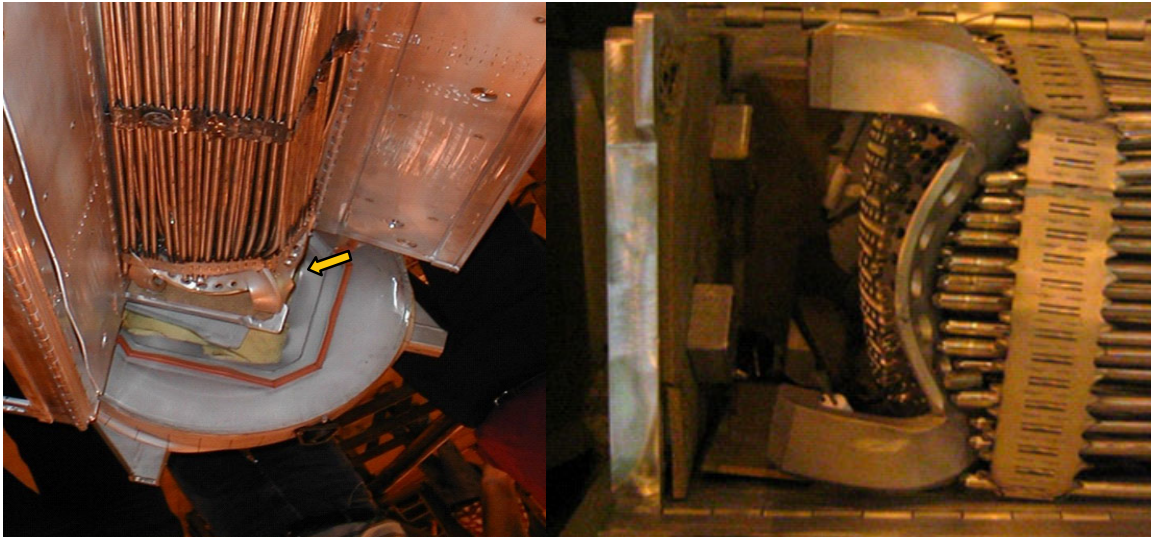
The predicted sequence for a drop onto the bottom nozzle end of the package is shown in Figure 17. Impact between the clamshell and inside covering of the bottom impact limiter occurs at approximately 13 milliseconds into the simulation; the maximum load between the aluminum housing and bottom impact limiter is predicted at approx. 33 milliseconds; and, the aluminum housing is in full rebound by 40 milliseconds. Note the extensive deformation predicted for the bottom nozzle legs.



**Figure 17.**

The results predicted for the vertical drop onto the bottom end of the package were qualitatively verified by test. This is shown in Figure 18 where the bottom nozzle and bottom nozzle legs are significantly deformed. The bottom nozzle protected the fuel rods by absorbing a significant amount of the drop energy. However, based on the LS-DYNA simulations, more energy was still available to damage the fuel in drops onto the bottom nozzle end of the package than for drops

onto the top end of the package. Thus, this orientation was selected for final qualification testing of the Traveller design.



**Figure 18.**

## Summary

Westinghouse Electric Company LLC is currently developing the new Traveller shipping package for transporting nuclear fuel. One of the licensing requirements for this package is to demonstrate it will always maintain the fuel assembly in a (nuclear) non-critical configuration after being dropped from 9 meters onto an unyielding surface and from 1 meter onto a 15 mm diameter pin. Working with outside consultants, Westinghouse developed finite element models of the shipping package undergoing drop and pin puncture tests. These models included all features relevant to crashworthiness and correctly represented the final design. These models were instrumental in the success of the drop tests and licensing efforts.

## References

1. Title 10, Code of Federal Regulations for the Packaging and Transport of Radioactive Material, Part 71.73.
2. "IAEA Safety Standard Series Number TS-R-1," Section VII, "Regulations for the Safe Transport of Radioactive Material."
3. LS-DYNA, A Program for Nonlinear Dynamic Analysis of Structures in Three Dimensions, Livermore Software Technology Corporation, 7374 Las Positas Road, Livermore, CA 94550, Tel: (925) 449-2500, [www.lstc.com](http://www.lstc.com).

