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Spent Fuel Cask Impact Limiter Attachment Design Deficiencies.

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Abstract

A recent structural analysis of the T-3 Spent Fuel Containment Cask found problems with the design of the attachment system. Assumptions in the original SARP concerning the loading in the attachment bolts were found to be inaccurate in certain drop orientations. Similar weaknesses in the attachment system designs of other casks were also noted. This paper documents the lessons learned and their applicability to impact limiter attachment system designs.

Introduction

The Fast Flux Test Facility (FFTF) is a 400-megawatt (thermal) Liquid-Metal (Sodium) Cooled Fast Neutron Flux Nuclear Test Reactor owned by the U.S. Department of Energy. The original purpose of the FFTF was to be a test bed for the Clinch River Breeder Reactor Demonstration Program. FFTF was designed with reactor components, plutonium fuel and liquid sodium metal coolant similar to a breeder reactor. In the late 1970s, a spent fuel cask designated as the T-3 was designed and built specifically for transport of spent nuclear fuel from FFTF.

FFTF experimented with different fuel types including fuel that contained large amounts of sodium metal (1500g) between the fuel and the fuel cladding. This fuel is referred to as sodium bonded fuel and both metal and carbide fuel of this type was irradiated at FFTF.

Expansion of fuel components in a fast flux reactor often leads to a gap between the fuel matrix and the fuel cladding that inhibits heat transfer. The placement of sodium within this region of the experimental fuel was used to alleviate this problem. The thermal conductivity of liquid sodium is more than 100 times that of liquid water at similar temperatures.

The difficulty with use of elemental sodium is the fact that it reacts explosively with water. Although non-sodium bonded fuel can be cleaned of sodium residue to a point where there is insufficient sodium to challenge fuel and cask integrity in the event of a water reaction during transport, this is not true of sodium bonded fuel.

Adding to the difficulty with the sodium bonded fuel at FFTF is the fact that a portion of the fuel has an experimental cladding that has never had sufficient post irradiation examination to credit its integrity during transport. The HT-9 cladding could therefore not be credited with preventing a sodium water reaction under the required water in-leakage scenario of 10CFR 71.55.

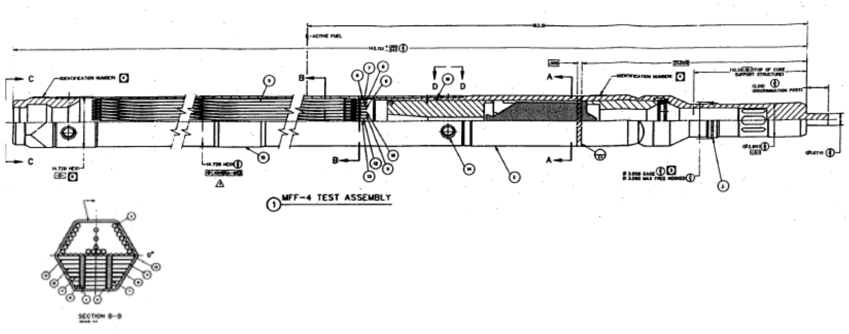

Figure 1
Sodium Bonded Fuel Assembly

A secondary containment vessel was added to the T-3 cask in order to ship the sodium bonded fuel. The containment vessel designated the 6CVL[a], was designed to contain a single sodium bonded fuel assembly or pin basket.

In the Application process for obtaining a Certificate of Compliance[1] for the shipment of sodium bonded fuel in the T-3 Cask, analyses were performed which found weaknesses in the impact limiter attachment points not previously documented in the T-3 Cask Safety Basis[2]. This paper described these deficiencies and their relation to cask design in general.

T-3 Cask

The Model T-3 Cask is a Type B package designed specifically to contain, shield and ensure subcriticality of irradiated fuel pins and assemblies from the Fast Flux Test Facility (FFTF) for transportation over public highways.[2] No full or partial scale testing was performed to validate the T-3 design during the development of the original safety basis.

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[a] 6inch Containment Vessel Long (6CVL)

The major design features of the T-3 Cask include two cylindrical and concentric stainless steel shells separated by 7¾ inches of lead gamma-shielding material. Closure and sealing of each shell is independent. The inner shell includes a length of 8-inch Schedule 40 pipe welded to a machined adapter that forms an open socket to receive the closure plug.

This tubular composite is terminated by steel endplates of varying thicknesses welded to the open ends. The endplate at the plug end is annular to permit entry into the inner shell and ranges in thickness from about one inch to over three inches. The endplate at the pusher end is also annular to permit entry of a slender push rod and ranges in thickness from 10¼ inches thick to over 12½ inches. This pusher endplate is 13 inches in diameter, welded to a 2-inch thick annular plate that bridges the radial distance to the outer shell and closes the outer shell/inner shell structure.

A stainless steel plug, approximately ten inches thick and double O-ring sealed, bolts to the open endplate of the inner shell to close the inner shell (Cask containment vessel) and provide gamma shielding. The 1-inch thick outer shell is welded to the same endplates, providing structural confinement for the lead shielding material and surrounding the inner shell. A carbon steel closure plate ranging in thickness from 4.0 inches to 6¾ inches fits over the inner-shell plug and bolts to the open endplate, closing the outer shell. A cutaway of the T-3 Cask is shown in Figure 2.

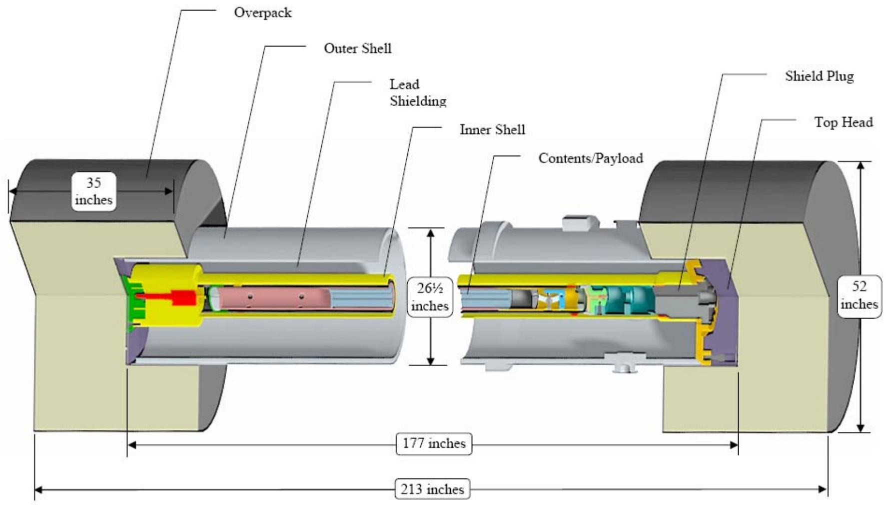


Figure 2
T-3 Cask

The impact limiters shown in Figure 2 consist of low-carbon steel shells filled with rigid polyurethane foam each mounted via four ⅝-inch bolts equally spaced around the circumference of the cask. These impact limiters surround the ends of the cask to protect these extremities from structural impact and thermal damage.

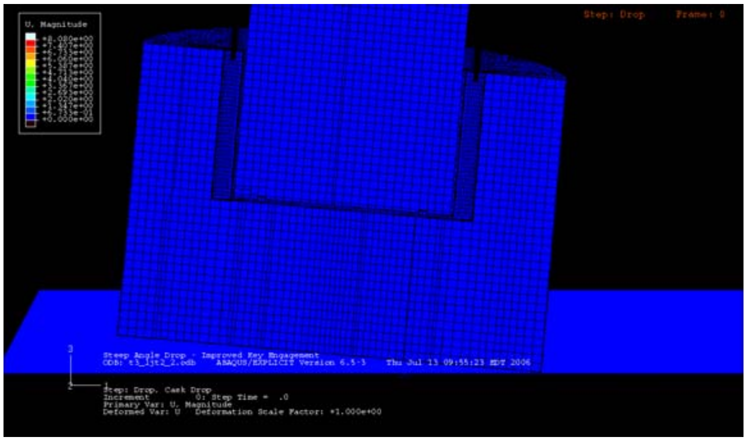


Figure 3
Impact Limiter Detail

A cross-section of an impact limiter is depicted in the finite element detail shown in Figure 3. The Cross-section bisects the cask so that two mounting bolts are shown. Each bolt is about four inches long and passes through an unthreaded lug on the cask body. The end of the bolt threads into an insert in the impact limiter that is attached to steel channel embedded in the polyurethane and runs parallel to the shaft of the cask as shown in Figure 3.

The finite element model shown in Figure 3 is an advanced dynamic model depicting the cask in a steep angle drop just before impacting from a 30 foot drop in the vertical direction. Impact limiter component material properties are fully modeled as are the bolts and lugs. The cask itself is composed of rigid elements since this model specifically evaluates the impact limiters.

The results of the steep angle drop indicated some unexpected results which were not documented in the T-3 existing Safety Basis. The existing Safety Basis considered that the only significant impact limiter bolt loads in a steep drop (CGOC) would be axial loads from the moment applied to an impact limiter (Figure 4). The detailed finite element analysis revealed that the bolts are actually loaded in shear.

Figure 5 shows the results of the detailed finite element analysis. As the cask impacts in a steep angle drop, the shaft of the cask rotates slightly more than the impact limiter pocket. This creates displacements between the bolt attachment point and the lugs which creates large shear strains in the short bolts.

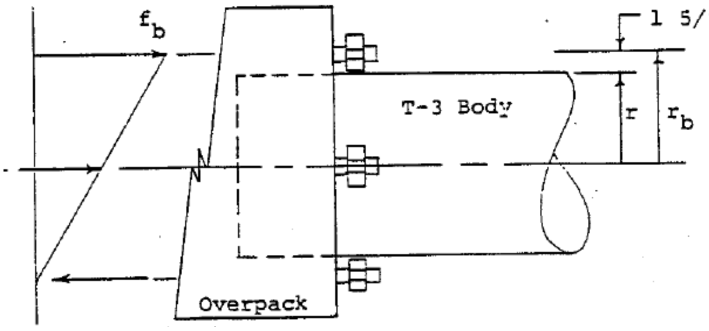
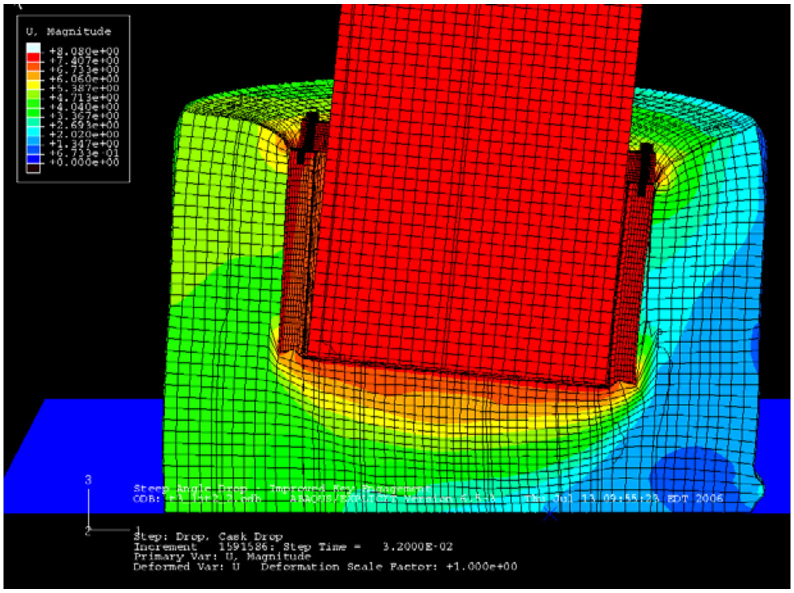


Figure 4
Original Analysis of Impact Limiter



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Steep Angle Drop - Improved Key Engagement
ODB: t3_1st2_2.odb    ABAQUS/EXPLICIT Version 6.5-3    Thu Jul 13 09:55:23 EDT 2006
Step: Drop, Cask Drop
Increment   1591586: Step Time =   3.2000E-02
Primary Var: U, Magnitude
Deformed Var: U   Deformation Scale Factor: +1.000e+00
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Figure 5
Results of Steep Angle Drop

Figure 6 is a close up of the far left bolt showing the shear load placed on it by the relative displacement between the cask shaft and the impact limiter insert. The impact limiter insert is well reinforced by the steel channel which is both embedded in the polyurethane foam and welded to the skin of the impact limiter pocket. The lug welded to the cask body is also a relatively stiff component and the gap between the insert and lug is less than an inch when the impact limiter is secured in place. The attachment bolts are therefore in highly constrained conditions that make them susceptible to high strains.

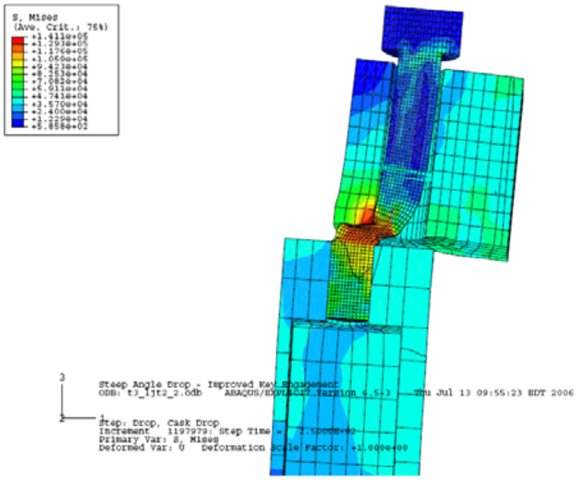

Figure 6
Deformation of Bolt Opposing Impact

The other three impact limiter attachment bolts also reached the failure strain of the bolting material. Figure 7 is a close up of the far right bolt which has the lowest strain of the four attachment bolts.

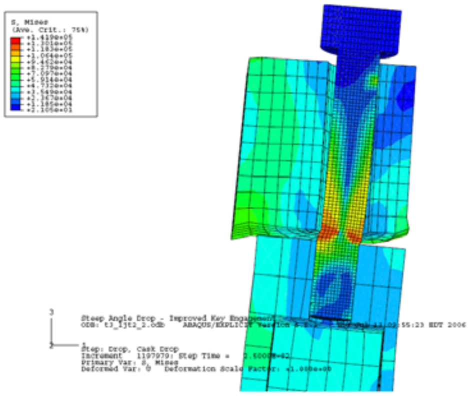

Figure 7
Deformation of Impact Side Bolt

These analysis results called into question the assumption that the impact limiters would be in place for a post impact fire event. The SARP Addendum for shipment of the sodium bonded fuel addressed this issue by analyzing the cask without the impact limiters in place for the fire event. O-ring seals and other component temperatures for both the cask and 6CVL were found to be acceptable for this event

A quick review of the impact limiter attachment systems of some more modern casks show that cask designers have incorporated the lessons learned from impact limiter attachment failures. One cask design where this can be seen is the Hanford Unirradiated Fuel Package or HUFP design whose impact limiter is shown in Figure 8[3]. Although this design has a similar layout as the T-3 cask with four bolts passing through lugs on the shaft of the cask, there are several key difference. The first notable difference is that the length of the bolts extends the full depth of the impact limiter pocket. Also, the bolt pockets in the impact limiter allows for significant bending in each bolt before shear loads are transferred to the bolts. The same relative displacements between the cask body and impact limit, lead to much smaller bolt strains in this design which was validated by testing.

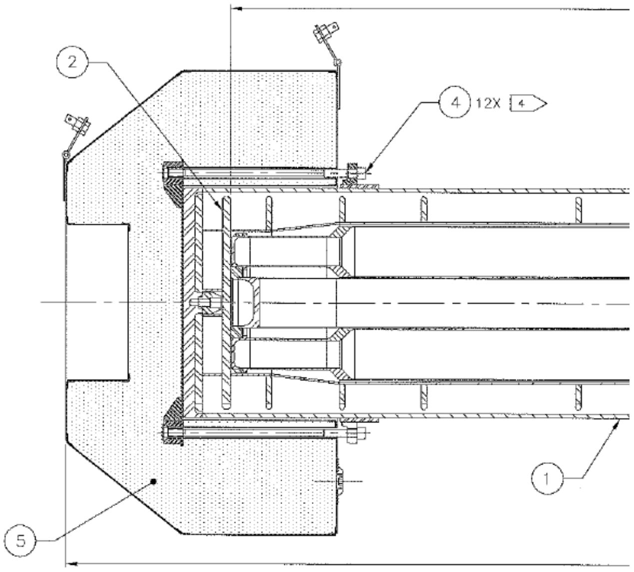

Figure 8
HUFP Impact Limiter Detail

Conclusions

Many older casks have impact limiter attachment systems which may fail in certain drop test orientations required by 10CFR 71.73. Care should be taken to ensure that the assumptions in Safety Analysis Reports for Packaging (SARPs) are correct. New cask designs should consider attachment bolt or pin loading conditions carefully when impact limiters are credited with remaining in place for the post impact fire.

References

1. Addendum to the Consolidated Safety Analysis Report for the T-3 Spent Fuel Shipping Cask Demonstrating Compliance to the Requirements of 10 CFR 71, Sodium-Bonded Fuel, FFTF-30866 Revision 1, June 2007.

2. Consolidated Safety Analysis Report for the T-3 Spent Fuel Shipping Cask, Westinghouse Hanford Company WHC-1990 Revision 6, August 1990.

3. Hanford Unirradiated Fuel Package (HUFP), HNF-28554, Revision 0, May 2007-