ZPPR Plates Structural Performance in HAC (19-A-1255-PATRAM)

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ABSTRACT
Zero Power Physics Reactor (ZPPR) are a radioactive material form used to study the physics of fast neutron spectrum reactors and for criticality studies of mixed uranium/plutonium nuclear processing systems. Any fast spectrum system could be studied in the ZPPR with a full-sized simulation that faithfully reproduced both the compositions and the geometry of the system under study. In order to ship the ZPPR plates in a packaging that is compliant with Title 10 of the Code of Federal Regulations Part 71 (10 CFR 71) the performance of the Plates to the Hypothetical Accident Condition tests specified in Section 73 of 10 CFR 71 was evaluated. Once the performance of the ZPPR Plates was established, any additional protection needed to meet the 10 CFR 71.73 criteria could be designed into the packaging. The performance of the ZPPR Plates to the HAC Tests is discussed in this paper.

Introduction

The Model 9977 (9977), see Figure 1, is a Type B radioactive material (RAM) Packaging compliant with Title 10 of the Code of Federal Regulations, Part 71 (10CFR71) [2] that is certified for use by the National Nuclear Security Administration (NNSA) Office of Packaging and Transportation (OPT). The 9977 is currently certified to ship thirteen different contents in various configurations.

The Zero Power Physics Reactor (ZPPR) Plates, see Figures 2 and 3, were designed for use in studying the physics of fast neutron spectrum reactors and for criticality studies of mixed uranium/plutonium (U/Pu) nuclear processing systems. The reactors were operated at critical, but zero power. The Plates consist of a Pu and/or U fuel plate/wafer contained within a continuous, gas-tight, 0.012-inch thick SS jacket. The ZPPR Plates are ⅛-inch or ¼-inch thick, 2-inches wide, and between 1-inch and 8-inches long. If the integrity of the SS plates and the welds which constitute the jacket cannot be verified, the ZPPR Plates would have to be considered to be "damaged" and compensatory measures taken. One of the ZPPR Plates Content configurations is shown in Figure 4, which shows the optional use of the 3013 Spacer.

The integrity of the ZPPR plate steel encasement was evaluated by Finite Element Analysis (FEA) simulation. The conditions that were evaluated are shown in Figure 5. For each condition, a ZPPR plate (or stack of plates) is placed inside the CV, with the load from a simulated 100-lb maximum content focused in a section to invoke the maximum damage. The 100-lb content is idealized as having a small (2 inch long by ¼ inch wide) contact area impacting the ZPPR plate. Simulations are performed to invoke bending the plate about its mid-length (A1, A2), and a simulation is performed to model the condition where a plate is held (as in a fixture) and a 100-lb content strikes the exposed section of the plate (combined shearing and bending) (B). The last simulation is performed to cause buckling and collapse of a ZPPR plate, in order to investigate an extreme deformation case (C). Only the results of the first case (A1) will be discussed in detail.

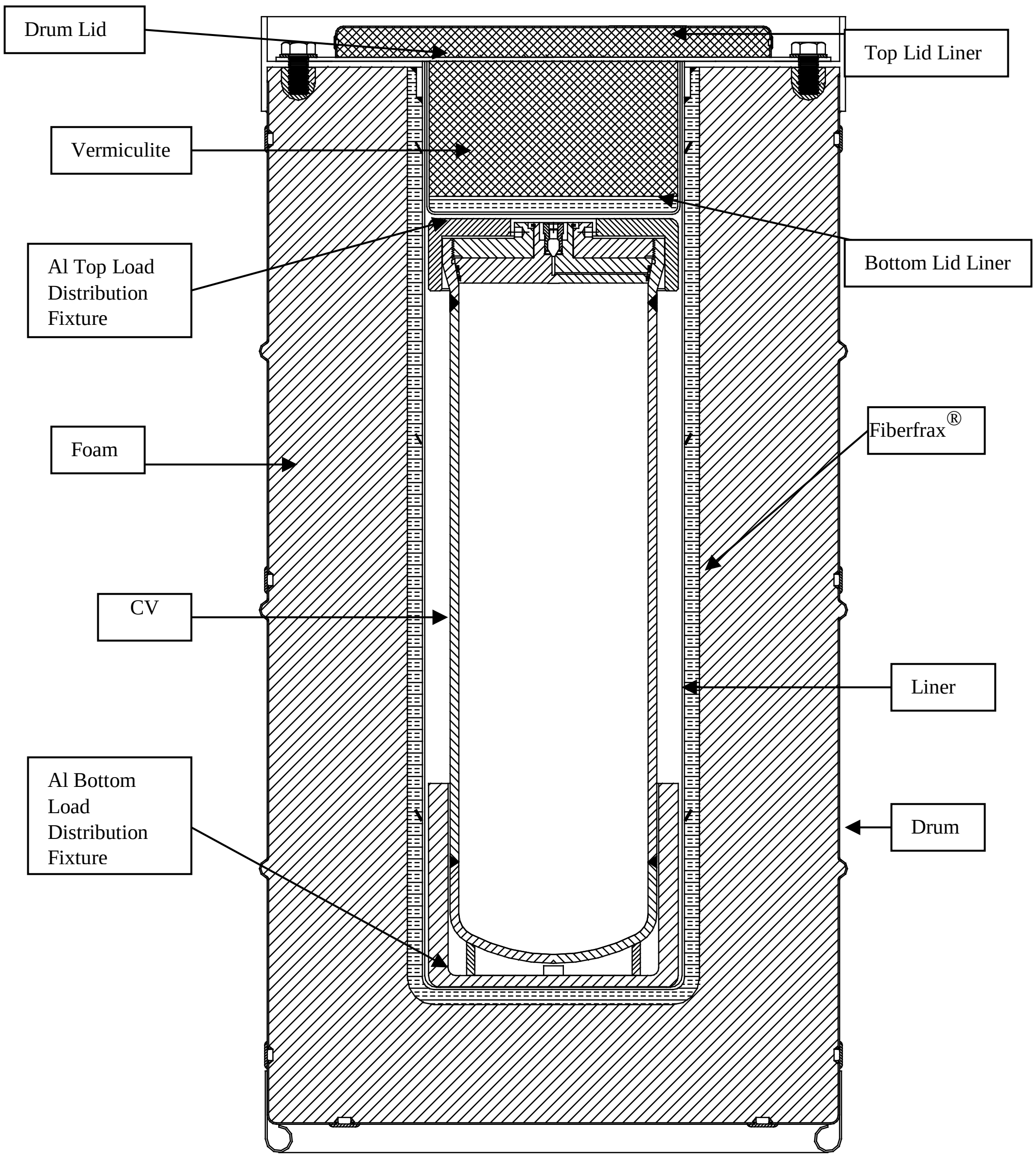


Figure 1 – The Model 9977 Packaging showing the Key Features

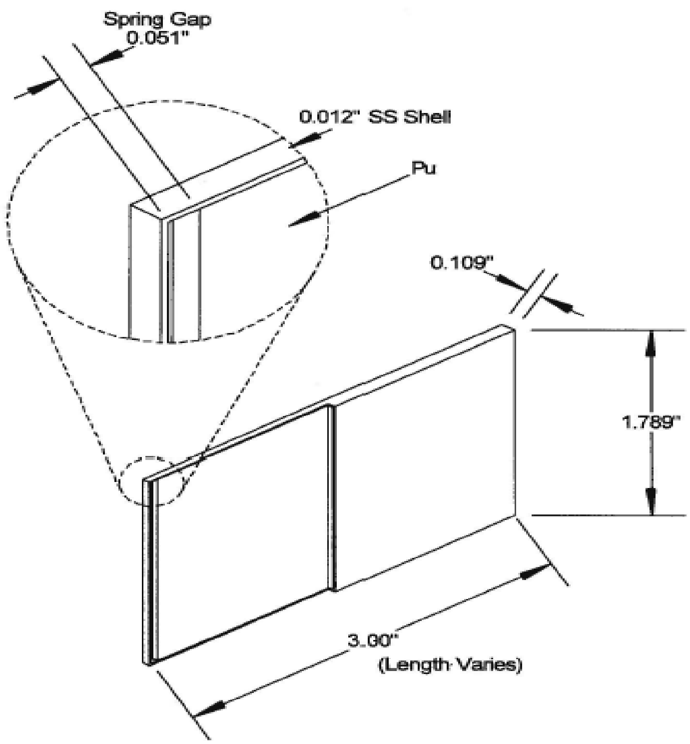


Figure 2 – Typical “Argonne Style” ZPPR Plate (1/4 cut-away)

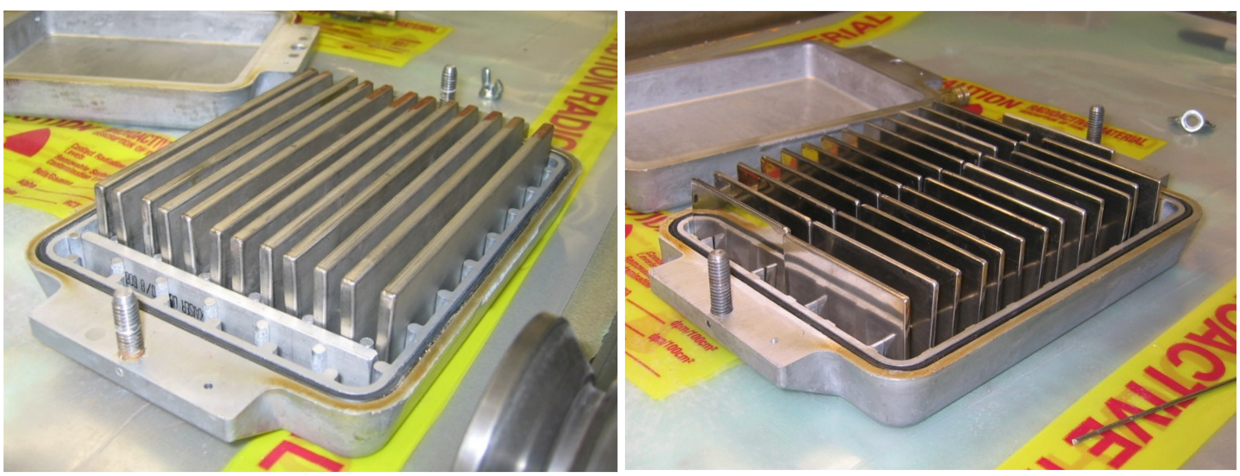


Figure 3 – Typical ZPPR Plates in INL Clamshell Vault Storage Containers (Top) and Loaded in Typical SAVY Tray (Bottom)

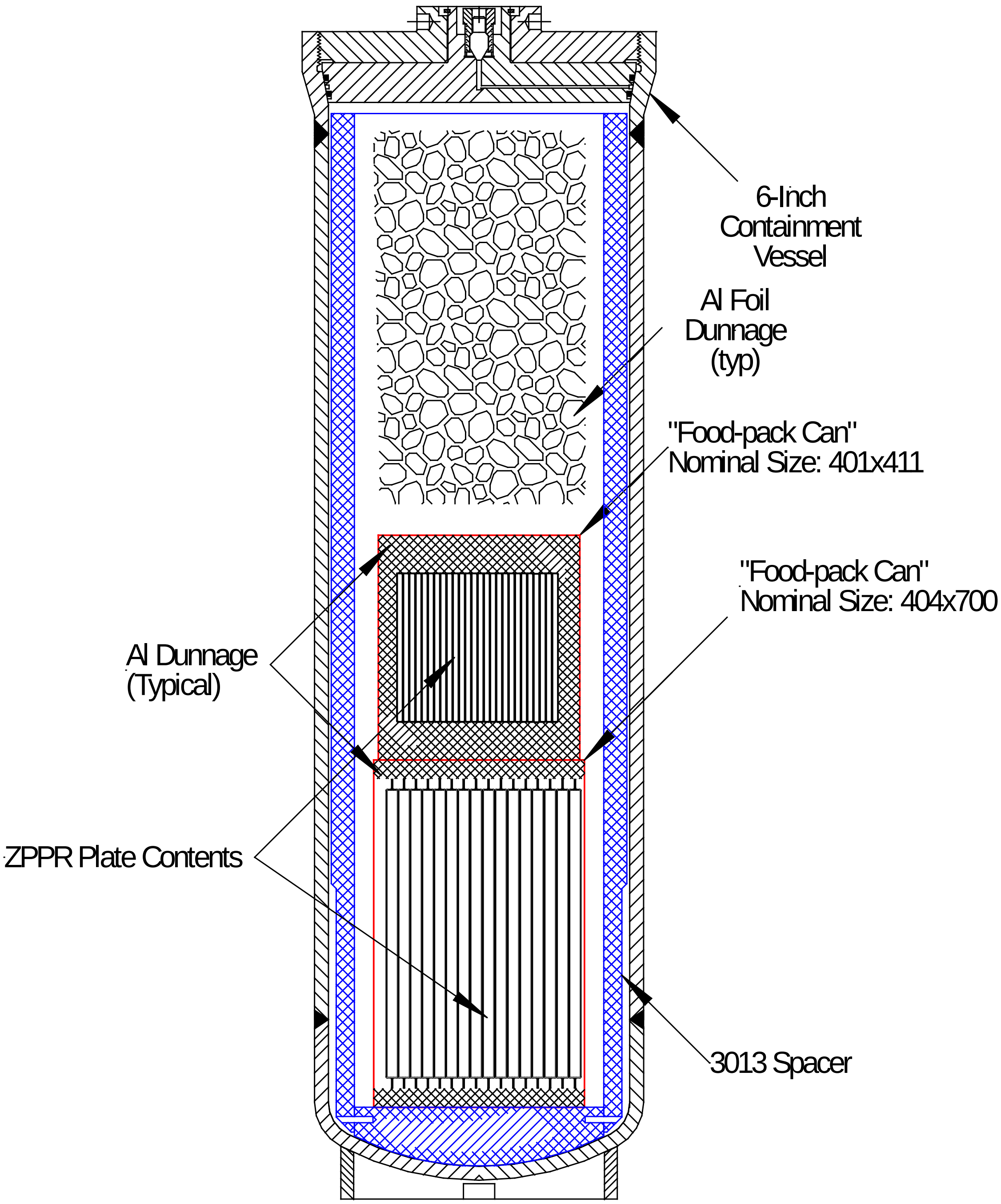


Figure 4 – Typical ZPPR Plates in Food-Pack Can Configuration (with optional 3013 Spacer) in 9977

Discussion

The Models

ZPPR Plates

There were several minor variations in construction details, but the ZPPR plate assemblies can be represented by the following two general configurations:

1. A 0.012-inch thick steel encasing consisting of mirror image top and bottom panels. Each is stamped to create a raised center section, where the skirt of the raised section is 1/8 inch deep, and the plate edge of the top section mates to the plate edge of the bottom section. The long edges of the plates are fusion-weld sealed. This type of plate assembly will be referred to as the GEAP style.
2. A single piece main steel jacket with welded-in end caps. The jacket panel is formed from 0.014- to 0.016-inch thick stainless steel into a complete rectangular loop using a full-penetration butt weld. The ends of the encasement are closed by fully welding rectangular bars to the ends of the jacket panel. The final minimum steel thickness is 0.012 inches. This type of plate assembly will be referred to as the Argonne style.

In each configuration, the core plate is placed inside during the forming process, and the final assembly is pressed to meet flatness and dimensional specifications.

9977 Containment Vessel

For this analysis the containment vessel (CV) is represented as a rigid, curved wall for the content to impact. The 9977 SARP shows that the CV remains undamaged throughout the NCT drop and the HAC Drop/Crush/Puncture events. Therefore, the basis of modeling a 6 inch diameter rigid surface is valid.

Contents

The maximum content weight of 100 lb is used. The content's temperature ranges from -20°F to 300°F which has only a mild influence on the structural response (elastic modulus) and the structural capacity (stress allowable and strain allowable). The analyses were performed based on standard temperature conditions for the stainless steel. The core material is modeled with properties to bound the full range of temperatures (elongation at low temperature, strength based on high temperature).

<u>10 CFR Dynamic Loads</u>

The bounding 10 CFR 71 dynamic event is the 30 foot HAC drop. In the 9977 side drop, the contents decelerate from free-fall speed to a stop in 0.0015 sec, equating to 910 G deceleration. By comparison, the ZPPR plate deformation response occurs over a much longer time period. Therefore, the dynamic loads can accurately be applied based on the 30 foot free-fall of the contents, with the CV wall acting as a fixed base. This is slightly conservative for the bending and deformation response modes of the ZPPR, and highly conservative for the crushing response modes.

Methods

The integrity of the ZPPR plate steel encasement was evaluated by the FEA simulations. The conditions simulated are shown in Figure 5. For each condition, a ZPPR plate (or plate stack) is placed inside the CV, with 100 lbs of content focused in a section to invoke the maximum damage. The 100 lb content is idealized as having a small (2 inch by ¼ inch) contact area to impact the ZPPR plate. Two simulations were performed to invoke bending the plate about its mid-length (A1, A2). A simulation was performed to model the condition where a plate is held (as in a fixture) and a 100-lb content strikes the exposed section of the plate (combined shearing and bending) (B). The last simulation was performed to cause buckling and collapse of a ZPPR plate, in order to investigate an extreme deformation case (C).

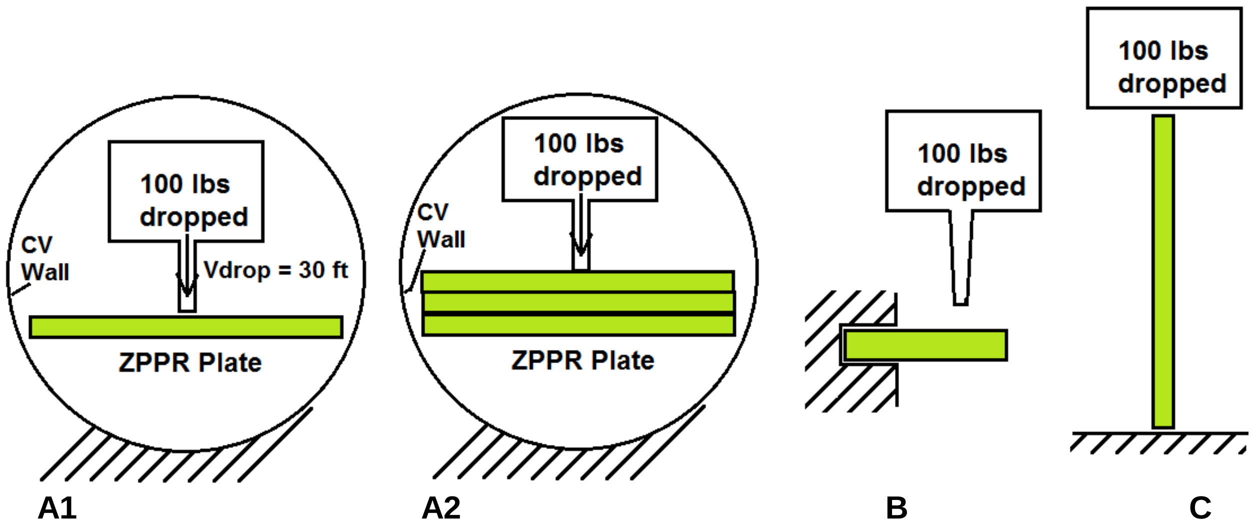


Figure 5 – Bounding Impact Configurations For ZPPR Plate Assemblies

Acceptance

A criticality evaluation was performed that demonstrated that if the Pu/U core plates remained separated by steel plates, the configuration remained sub-critical regardless of the amount of moderation present in the system. Therefore, the goal for these simulations was to demonstrate that the stainless steel shell remains an encasement structure around the Pu/U core (i.e. kept adjacent Pu/U core plates separated). With this encasement achieved, the condition of having multiple bare core plates stacking together will not occur and criticality is obviated.

Stainless Steel Strain Limits

The ZPPR plate shell is expected to deform during the 30 foot drop. To demonstrate integrity of the ZPPR plate shell during and after the HAC events, the multi-axial strain limit from ASME VIII-2 is used as a basis. To protect against local rupture in a multi-axial stress or strain condition, ASME VIII-2 specifies the following:

$$\varepsilon_L = \varepsilon_{Lu} \cdot \exp\left[-\left(\frac{\alpha_{sl}}{1+m_2}\right)\left(\left\{\frac{\sigma_1+\sigma_2+\sigma_3}{3\sigma_e}\right\}-\frac{1}{3}\right)\right]$$

For the thin sheet metal used on the ZPPR plate shell, a biaxial stress state (in plane of sheet metal) is an expected worst case, since the thru-thickness stress will be low, or compressive. For a bi-axial condition, the ASME VIII-2 prescribed strain limit for 304L SST is:

$$\sigma_1 + \sigma_2 + \sigma_3 = 1 + 1 + 0 = 2$$

$$\sigma_e = \sqrt{\frac{1}{2}\left[(1-1)^2 + (1-0)^2 + (0-1)^2\right]} = 1.0$$

$$\varepsilon_L = 100\% \cdot \exp\left[-\left(\frac{0.6}{1+0.48}\right)\left(\left\{\frac{2}{3*1}\right\}-\frac{1}{3}\right)\right] = 87\%$$

Bending or Surface Strain: = 87 % [per above].

Welds

The strength of the welds will be limited to the 70%/90% criteria imposed for the base metal. The method for implementing this will be built into the FEA model.

<u>Finite Element Models</u>

Several ZPPR plate models are developed using ABAQUS/Explicit. The model consists of the CV inner surface, modeled as a rigid target, one or more ZPPR plates, and a rigid impactor representing the 100 lbs of contents configured in a worst case condition. Two styles of ZPPR plates were evaluated and three impact scenarios were simulated.

The GEAP style (Figure 6) and the Argonne style (not shown) ZPPR plates were modeled. Each model was nominally 5-inches long x 2-inches wide by ¼-inch thick. The FEA model consisted of three separate parts for the GEAP style (top, core, and bottom) with connector elements placed along the plate edges to represent the seam weld.

Five model variations are made. Three of these models target mid-span impacts that bend the plate lengthwise. Two of these three are with the GEAP style ZPPR and the third is with the Argonne style. A fourth model simulates a bending/shearing impact condition. The fifth model is for the buckling response of the ZPPR plate.

The impact from a 30-foot drop is modeled by imposing the 30-ft drop velocity on the 100-lb contents and treating the CV as a fixed boundary. A comparison of the impact durations from M-CLC-G-00358 show that the CV deceleration occurs in a significantly shorter time span than the response time of the ZPPR plate.

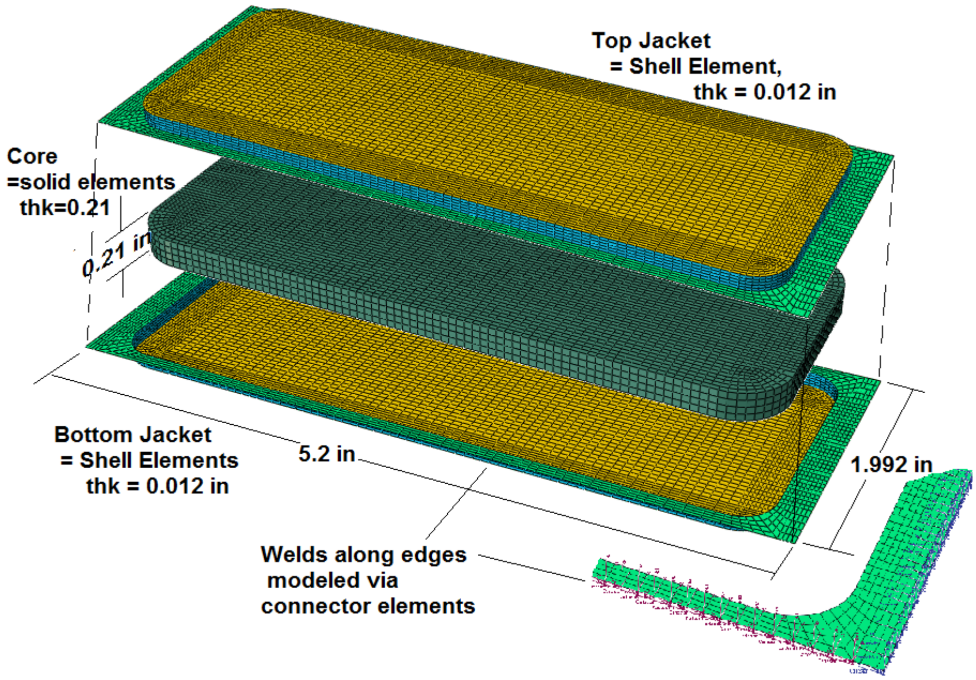


Figure 6 – View of GEAP Type ZPPR Plate Assemblies

Mid-Span Impact onto Single GEAP Plate

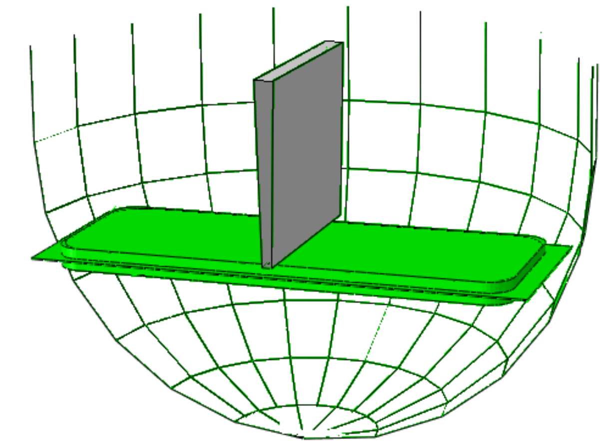
Deformed Shape

The deformed shape of the GEAP style ZPPR plate after the 30 foot drop accident is shown in Figure 8. The plot shows that the ZPPR plate deforms to the shape of CV inner wall and that the stretched shape of the steel encasement is limited by the fact that there is only one plate between the impactor and the target. The effect is different when multiple ZPPR plates are between the impactor and target.

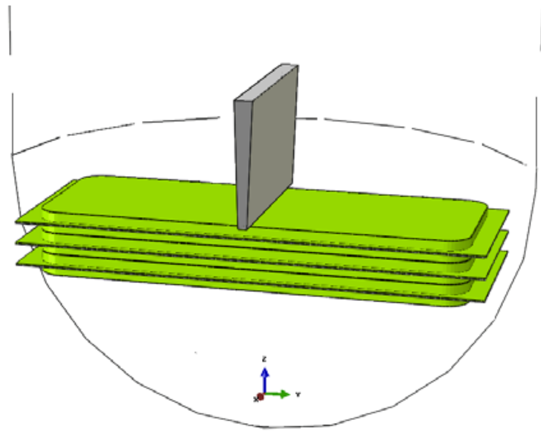
Maximum Jacket Demands

The strain levels in the steel encasement are shown in Figure 8. The contour plot shows strains less than 7% over most of the steel shell. This secondary strain condition at the shell surface is less than the strain capacity of the stainless steel shell and is also less than the primary membrane strain allowable. High strains do occur at the inner crease, just at the outside. This is localized and will not cause release of the core.

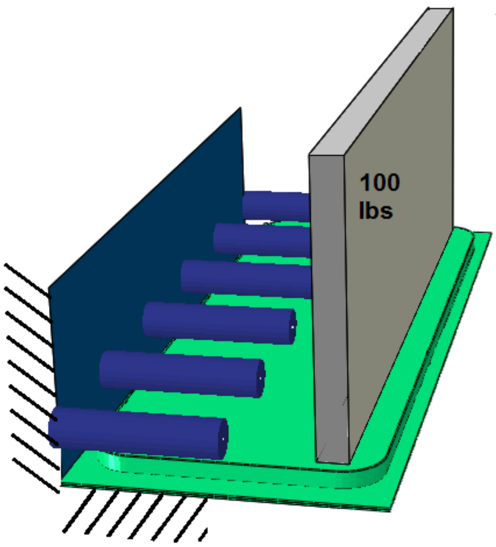
ZPPR Plate Shell maintains encasement



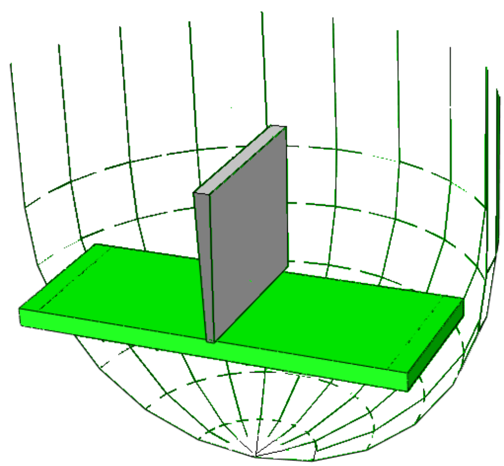
Mid-Span Impact onto a Single ZPPR Plate



Mid-Span Impact onto Multiple ZPPR Plates



Wedged in ZPPR Plate, Impact on Exposed Side



Mid-Span Impact onto Argonne Type ZPPR Plate

Figure 7 - Isometric Views of ZPPR Plate Impact Scenarios

Maximum Weld Demands

The metal strains are generally low in the regions around the weld joint. The maximum component force in the weld remains below 15 lbs throughout the 30-foot drop impact.

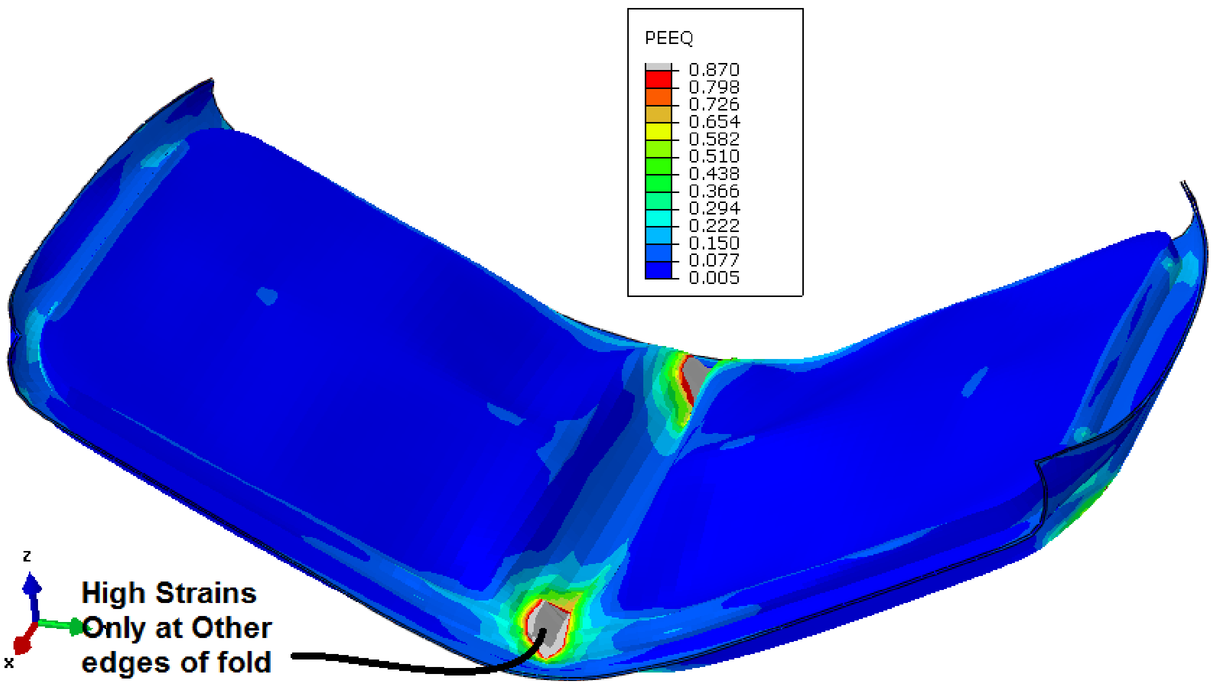


Figure 8 - Strain Levels in Outer Jacket of GEAP Style ZPPR Plate After 30 foot drop.

<u>Summary of Results</u>

During a 30-foot drop of a 9977 shipping package with ZPPR plates positioned in the 6CV, and impacted by a maximum of 100 lbs total contents at worst case conditions:

- ZPPR plate steel shell does not undergo gross rupture that would un-encase the ZPPR plate core
- The ZPPR plate welds do not fail in a manner that would un-encase the ZPPR plate core
- During severe deformation modes, the steel shell stays generally adhered to the shape of the core, such that the steel encasement will remain around the core.

Therefore, the simulations successfully demonstrated that the stainless steel shell remains an encasement structure around the Pu/U core (i.e. kept adjacent Pu/U core plates separated) and the condition of having multiple bare core plates stacking together will not occur and criticality is obviated.

References

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