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Impact Analysis of the UC-609 Shipping Package

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Shipping Package**

by

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Abstract

The inner containment vessel of the UC-609 shipping container must remain intact and sealed after undergoing a thirty foot drop onto an unyielding surface. The drop scenarios which were considered in this study included top corner down and top down drops. Results of the calculations performed for this study predict structural damage, as measured by accumulated effective plastic strains, but no failure of the inner primary containment vessel for both drop configurations. The top down impact is predicted to produce a higher impact deceleration in the payload but the amount of damage to the primary containment vessel is predicted to be greater for the top corner impact configuration. The critical damage region for both drop scenarios is confined to the containment canister flange region. Verification of the analysis methodology was accomplished by comparing measured top corner crushes with calculated top corner crushes. Acceptable damage levels in this study were determined from calculated damage comparisons between the top corner drop, which remained intact during a top corner impact test, and the calculated top down impact damages. Comparisons were also made on the calculated maximum shear stress levels, which remained near or within NRC regulatory guidelines for both scenarios.

Introduction

The Model UC-609 shipping package was developed for the transportation of tritium payloads. A Safety Analysis Report for Packaging (SARP) for the UC-609 shipping package has been written¹ and documents the package description and structural responses to normal operating conditions. The SARP also documents a top corner drop from a height of thirty feet onto an unyielding surface which resulted in a five inch corner crush of the outer stainless steel drum. The top corner drop was originally assumed to result in the most localized damage to the shipping package but recent concerns have been raised about a direct top down impact of the UC-609 container.

For this study, two thirty foot drop impact configurations were considered. The impact scenarios which were studied included a top corner down impact with the center of gravity over the point of contact and a top down drop. The responses of the UC-609 shipping package to

¹ Ron Sandberg, *Safety Analysis Report on Model No. UC-609 B(U) DOE Shipping Package*, Lawrence Livermore National Laboratory, UCRL-ID-111494 [1992]

these impact configurations was simulated with the nonlinear finite element code DYNA3D². Verification of the analysis methodology was accomplished by comparing the predicted DYNA3D results with the top corner drop test results for the UC-609 shipping container. The analysis methodology employed in this study is similar to that which was employed in a previous impact analysis on a similar shipping container. The UC-609 shipping package assembly is shown in Figure 1. Details of this assembly can be seen in Reference 1.

Finite Element Analysis Description

The half symmetry 3-D finite element mesh of the Model UC-609 shipping package is shown below in Figure 2. The mesh components and weights are:

- 1) Outer SSTL-304 drum - 100 lbs.
- 2) Celotex/plywood insulation - 110 lbs.
- 3) Inner SSTL-316 containment vessel - 170 lbs.
- 4) Payload - 120 lbs.

The total simulated weight of the modified Model UC-609 shipping package was 500 lbs. The analysis assumed that the shipping container components were in a *packed* condition, i.e., no initial gaps were assumed between model components. Constants for the material constitutive relationships were obtained from the UC-609 SARP. All materials except the Celotex packing material were modeled as bi-linear elastic plastic materials. The elastic-plastic material constants which were used in the analysis are given below in Table 1. The Celotex was modeled as a crushable foam. This constitutive model, originally developed by Krieg³, allows for the specification of a nonlinear pressure vs. volumetric strain relationship. The deviatoric behavior in the model is elastic-perfectly plastic with a pressure dependent yield function. The shape of the pressure-volumetric strain curve is given below in Figure 3 and the yield-pressure relationship is given in Figure 4. In the Figures 3 and 4, the deviatoric stress S_{ij} is given by $s_{ij} = \sigma_{ij} - \frac{1}{3}\sigma_{kk}\delta_{ij}$, where σ_{ij} is the Cauchy stress tensor and the effective stress is defined as $\bar{\sigma} = \sqrt{\frac{3}{2}S_{ij}S_{ji}}$.

² Whirley, Robert G. , *DYNA3D, A Nonlinear, Explicit, Three-Dimensional Finite Element Code For Solid and Structural Mechanics - User Manual*, Lawrence Livermore National Laboratory, UCRL-MA-107254 [1991]

³ Krieg, R.D., *A Simple Constitutive Description for Soils and crushable Foams*, SC-DR-72-0833, Sandia Laboratories, Albuquerque, New Mexico, [1972]

Table 1. Elastic-Plastic Material Constants

Location	Outer Drum	Containment Vessel
Material	SS-304	SS-316
Young's Modulus	28.4x10 ⁶ psi	28.0x10 ⁶ psi
Poisson's Ratio	.27	.29
Yield Strength	30,000 psi	36,000 psi
Ultimate Strength	75,000 psi	75,000 psi
Ultimate Elongation	50%	50%

Finite Element Model Verification - Previous Calculations

The finite element methodology which was employed in this analysis was verified in a previous shipping container impact study. The shipping container in that study was very similar in geometry and construction to the UC-609 container, with an SSTL-304 outer drum, Celotex packing material and an inner stainless steel primary containment vessel. In the previous study⁴, top corner thirty foot drop tests of the Rocky Flats Model FL Shipping Container were reported as producing crushes of 4.0 and 4.5" and a DYNA3D simulation is documented as predicting a crush height of 5.350" (crush distances were measured parallel to the longitudinal axis of the container). Calculated side impact deformations were also compared to FL test results. The calculation predicted crush heights along the longitudinal axis of the FL shipping container which varied from 1.284" at the bottom of the container to .321" in the region adjacent to the interior containment canister flange edge. Measured crushes under the same impact conditions varied between 1.25" and .25" along the length of the container.

⁴ Kay, G.J. and Hendricks, J.T., *Mechanical and Thermal Analysis For Rocky Flats Model FL Shipping Container*, Lawrence Livermore National Laboratory, END92-026 [1992]

Finite Element Model Verification - Current Study

A top corner impact simulation of the UC-609 shipping container produced a crush height of 4.724", measured parallel to the longitudinal axis of the container. This can be compared to the measured crush of approximately 5.0" for the UC-609 shipping container under the same impact conditions, i.e., an error of 5.52%. As documented in Reference 1, this impact did not impair the functionality of the UC-609 primary containment vessel. For this report, the responses of the UC-609 primary containment vessel due to a top down drop will be compared to the calculated responses of a top corner drop. The structural integrity of the UC-609 primary containment vessel will be determined by the relative magnitudes of these maximum effective stresses and accumulated effective plastic strains. Adherence to the NRC Regulatory Guide 7.6⁵ which set limits on the maximum acceptable stress intensities, i.e., 70% of twice the maximum shearing stress is also demonstrated in this report.

Results of the Top Corner Down Impact Simulation

The calculated deformed shape of the UC-609 Shipping Container resulting from a thirty foot top corner drop onto an unyielding surface is shown in Figure 5. A summary of test results is also shown in Table 2. The predicted maximum deceleration of the payload for this configuration is 230 g's at 9 msec after impact. Deceleration to zero velocity is expected to occur at 12 msec after impact. Localized effective plastic strains of 14.72% were calculated in the SSTL-316 containment canister flange region for this load case. Calculated accumulated effective plastic strains in the primary containment vessel flange are shown in Figure 6. In that Figure, the color fringes represent regions which have undergone permanent deformation. As mentioned above, damage at this level (14.72% effective plastic strain) did not produce failure in the top corner drop test the UC-609 container. The maximum effective stress which was calculated for the flange region was 47,530 psi and the maximum stress intensity (twice the maximum shear stress) was 56,900 psi. The later level is close to the NRC Regulatory guideline limit of 0.7 times the ultimate stress, i.e., 52,500 psi. Damage to the buckled SSTL-304 outer drum is represented by calculated effective plastic strains of 44.27%. In the top corner drop test the drum tie downs were deformed but the drum assembly stayed intact.

⁵ U. S. Nuclear Regulatory Commission Regulatory Guide, *Design Criteria For The Structural Analysis of Shipping Cask Containment Vessels*, May 1977

Results of the Top Down Impact Simulation

The predicted deformed shape resulting from a top down thirty foot drop of the UC-609 shipping canister onto an unyielding surface is shown in Figure 5. The predicted amount of Celotex crush, measured parallel to the longitudinal axis, is 0.536". The predicted maximum deceleration of the payload for this impact configuration is 412 g's at 5 msec after impact. Deceleration to zero velocity for this configuration is expected to occur at 7 msec after impact.

The SSTL-316 primary containment vessel flange region is expected to see permanent damage as a result of a top down impact where localized effective plastic strains of 8.02% are expected in the flange region of the inner containment vessel. Predicted fringes of accumulated effective plastic strains in the flange region are shown in Figure 6. The highest intensity effective plastic strain regions, represented by the red and red-yellow fringe regions can also be compared for the top down and top corner drop impacts in Figure 6. As can be seen, the top down impact produces less accumulated damage to the flange region than the top corner impact. The maximum effective stress which was calculated for the flange region was 42,230 psi and the maximum stress intensity was 48,560 psi. The latter level being within the NRC Regulatory guideline of 52,500 psi. This maximum stress intensity can also be compared to the 56,900 psi intensity calculated for the top corner impact configuration. Effective plastic strains of 14.07% are predicted to occur in the outer SSTL-304 drum but the outer drum assembly is expected to retain intact as these strains can be compared to the 44.27% outer drum effective plastic strains which were calculated for the top corner drop.

Summary of UC-609 Impact Simulations

Top corner and top down drops from heights of 30 feet should produce structural damage but no rupture of the outer drum of the UC-609 Shipping Container. The top down impact is calculated to produce a higher impact deceleration in the payload but the amount of damage to the primary containment vessel is predicted to be greater for the top corner impact scenario. Based on a comparison of damage between the top corner and top down accident scenarios, the top down impact is expected to remain functional.

**Table 2. Top Down Drop Simulation Results For
the Model UC-609 Shipping Container**

Load Case	Top Corner Drop	Top Down Drop
Celotex Packing Material Crush	4.724 inches	0.536 inches
Max. $\bar{\epsilon}^P$ in Outer Drum¹	44.27%	14.07%
Max. $\bar{\epsilon}^P$ in Containment Vessel Flange Region	14.72%	8.02%
Twice Max. Shear Stress in Containment Vessel Flange Region	56,900 psi	48,560 psi
Max. Effective Stress in Containment Vessel	47,530 psi	42,230 psi
Max. Acceleration of Payload	230 g's	412 g's
Deceleration Time for Payload	.012 msec	.007 msec

1) $\bar{\epsilon}^P$ = effective plastic strain

Figure 1. Shipping Container Overall Assembly

Figure 2. UC-609 Shipping Canister Finite Element Model

Figure 3. Assumed Volumetric Strain vs. Pressure Relationship for Celotex

Figure 4. Assumed Effective Stress versus Pressure Relationship For Celotex

Figure 5. UC-609 Deformed Shapes Resulting From
a 30 Foot Drop Onto An Unyielding Surface

Top Corner Impact

Top Down Impact

fringe levels

Fringed regions represent permanent damage to containment vessel

Figure 6. UC-609 Effective Plastic Strain Regions Resulting From a 30 Foot Drop Onto An Unyielding Surface

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