Analysis of the Non-Cylindrical GA-4 and GA-9 Spent Fuel Casks

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INTRODUCTION

The Nuclear Waste Policy Act (NWPA) of 1982 mandates that the U.S. Department of Energy (DOE) establish an integrated waste management system for permanent disposal of spent nuclear fuel, commercial and defense high-level wastes, and any other waste form declared by the U.S. Nuclear Regulatory Commission (NRC) to require permanent isolation. The mission goals of DOE's Office of Civilian Radioactive Waste Management (OCRWM) require that the system be designed for maximum capacity at minimum cost within existing regulations. To support this objective, OCRWM has awarded General Atomics (GA) a contract to develop the GA-4 and GA-9 legal weight truck (LWT) transportation systems to transport pressurized-water-reactor (PWR) and boiling-water-reactor (BWR) spent fuels.

CASK DESIGN

The GA-4 and GA-9 Casks maximize cargo capacity while complying with the weight limits imposed on legal weight truck transport. These casks will carry up to 4 PWR or 9 BWR spent fuel assemblies, a capacity four times greater than comparable existing designs. The cask design is shown in Figure 1.

To minimize weight, the cross-sections of the GA-4 and GA-9 Casks have been shaped to conform to the profile of the fuel assemblies, thereby eliminating the wasted void volumes and the large diameters of steel and shielding required to fit square fuel assemblies into cylindrical shells. The casks are constructed primarily of XM-19 austenitic stainless steel with depleted uranium gamma shielding in the sidewalls. A layer of solid neutron shielding surrounds each cask body. Shielding thicknesses and criticality control are optimized for each type of cask.

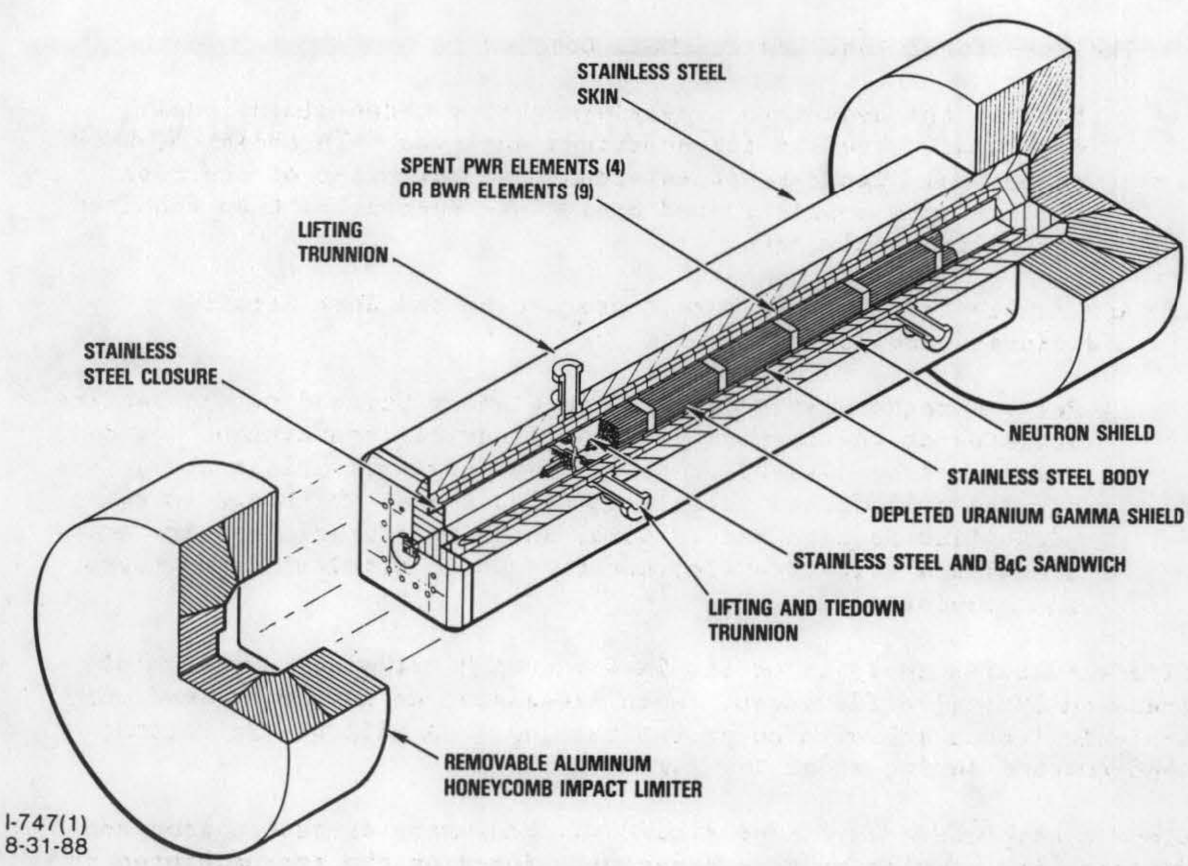

Figure 1. Design of GA-4/GA-9 Legal Weight Truck Spent Fuel Shipping Cask

STRUCTURAL ANALYSIS APPROACH

The design criteria for the two casks were selected to assure a certifiable design within existing regulations. The structural analyses meet DOE and NRC requirements:

- The casks are evaluated for load combinations and events that envelope 10CFR Part 71, USNRC Regulatory Guide 7.8, and the submergence requirements of IAEA Safety Series 6.

- The containment boundary stress allowables used are obtained from USNRC Regulatory Guide 7.6.

The approach to the structural analysis of a non-cylindrical cross-section differs from a cylindrical design. These differences include:

- More Orientations are Evaluated for Impact Analyses

  Since the impact orientation varies both the angle between the cask and the unyielding surface and the axial rotation of the cask, the evaluation has more variables than evaluations of cylindrical casks. The number of calculations required to demonstrate a worst-case orientation is greatly increased.

- The Structural Analyses are More Complex

  Because the casks are non-axisymmetric, three-dimensional models are required for numerical analyses. In addition, the structural discontinuities around the perimeter of the cask require more sophisticated analytical approaches than required for cylindrical casks.

- Applicable Criteria are More Conservative and Some Require Additional Development

  Per the requirements of USNRC Regulatory Guide 7.6, the bending stresses at the corners of non-cylindrical containment boundaries must be classified as primary stresses, unlike the joints between cylindrical vessels and flat plates which are instead classified as secondary. Also, buckling criteria require additional analytical development to justify critical load values and combination of loads.

GA's structural analyses of the GA-4 and GA-9 Casks address each of these analytical differences. When necessary, we have confirmed our analytical approach with component testing. GA will obtain further confirmation during model testing in 1990.

Since a complete analysis of a cask involves many different load conditions, for simplicity this paper will focus on the approach used to analyze the drop events onto an unyielding surface. Figure 2 shows in schematic form the approach used to analyze the 30-ft and 1-ft drop events. The elements of this schematic are discussed below.

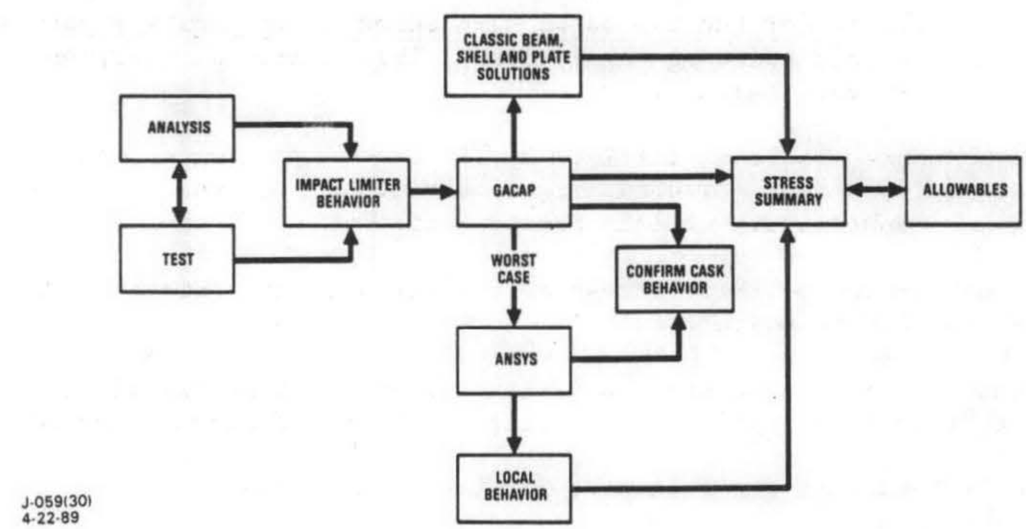

Figure 2. Approach Used to Analyze the GA-4 and GA-9 30-ft and 1-ft Drop Events

Impact Limiter Behavior

Developing a set of load versus deflection curves for the impact limiter at different orientations is the first step for performing the impact analyses of casks. Using a combination of test and analytical results, we obtained loading curves of the impact limiter for crush orientations ranging from end drop to side drop at 15° increments.

GACAP Analyses

The GACAP (General Atomics Cask Analysis Program) was then used to analyze the casks impact load conditions. The code uses a two-dimensional, lumped mass, single axis beam representation of the cask body and can analyze drops at different heights and angles. GACAP models the cask using linear elastic material properties without structural damping. Both rigid body and flexible body models of the cask are available for analysis. The impact limiters dissipate the drop energy. These impact limiters are modeled using nonlinear force-deflection tables which are interpolated for cask impact angles not provided in the input.

GACAP prints time history information on accelerations, velocities and displacements, as well as bending moments, and axial and shear forces along the length of the cask. It also prints a summary of the maximum values of each of these variables and the time at which they occur. It also provides the impact limiter depth of crush, maximum impact force, and energy dissipation information.

We studied the effects of the 1-ft and 30-ft drops using GACAP and calculated the expected stresses using the moment and force information provided by the code. Results show that the maximum containment boundary stresses occur during a side drop impact orientation. The stresses are due to the moment developed at mid-span.

ANSYS Analyses

Since GACAP analyzes the cask as a beam, it does not provide information about the stresses developed in directions perpendicular to the axis of the cask. Stresses due to local discontinuities are also not provided. To determine these stresses, we performed more detailed analyses of the casks using finite element models. The finite element meshes were generated using PATRAN PLUS. These models were analyzed using ANSYS.

The end drop impact was analyzed with ANSYS to determine the stresses at the discontinuity between cask side walls and the flange. In addition, the side drop orientation was selected for more detailed analysis since GACAP showed that the maximum containment boundary stresses occur during this event. The loads due to the mass of the cask internals and the depleted uranium shielding material are also maximum during this event.

Because of the non-cylindrical shape of the cask (rounded corner cross section), we developed two three-dimensional models to analyze the side drop. One model represents the impact on the flat areas of the cask and another the impact on the corner of the cask. Figures 3 and 4 show the cross section of the two models at the cask mid-span.

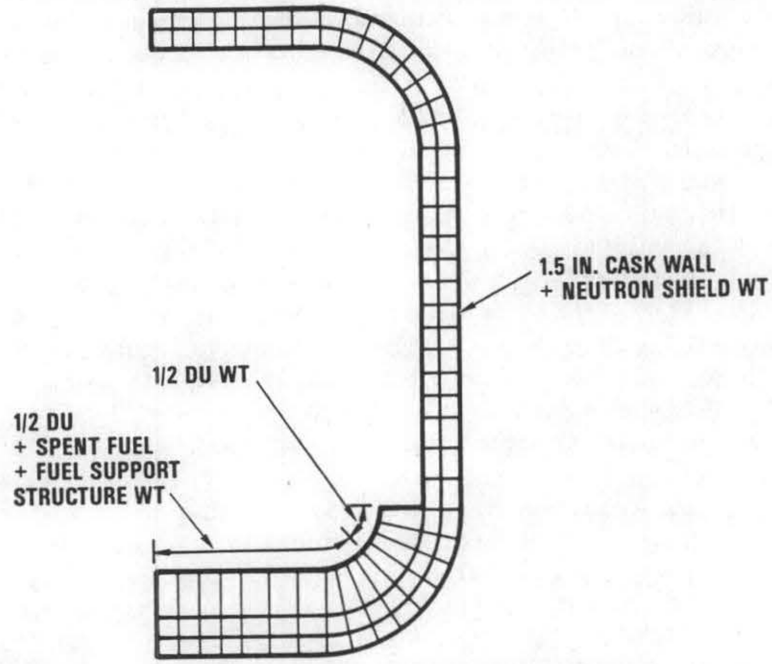

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Figure 3. ANSYS Model of Side Drop onto the Flat Areas of the Cask. Cross-Section Taken at Mid-Span.

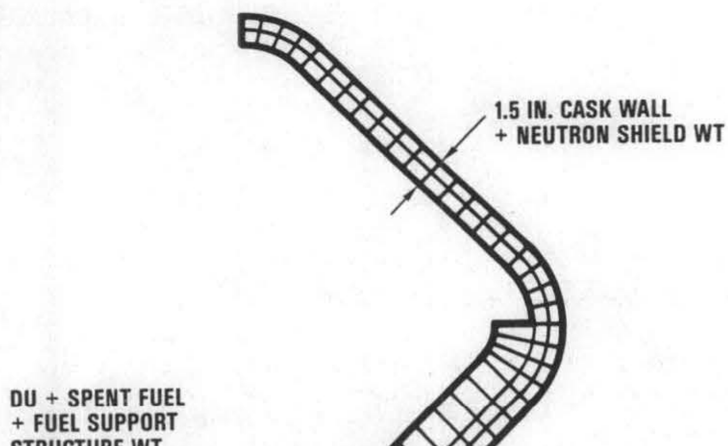

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Figure 4. ANSYS Model of Side Drop onto the Corner of the Cask. Cross-Section Taken at Mid-Span.

The models take advantage of symmetrical boundary conditions in order to limit the number of elements required to describe the geometry. The resulting models represent half of the cask length and half of the cask cross section. The models include loading on the cask wall to simulate the depleted uranium (DU) and cask internals. This loading was accomplished with additional elements that have a low elastic modulus; therefore, they do not provide significant cask stiffness.

The model uses the 3-D isoparametric solid element in ANSYS (STIF45). This element is defined by eight nodal points having three degrees of freedom at each node: translation in the X, Y, and Z directions. Bar elements (STIF4) model the bolts. A gap element (STIF52) separates the two mating surfaces of the closure and cask flange. The initial setting on the interface gaps was zero indicating a closed condition (preloaded bolts). Spring elements (STIF14) simulate the shear pins (in the X and Y directions). These elements transfer load between adjacent nodes of the interface at the shear pin locations. The model across-flats consists of 12,100 nodes and 8594 elements and the model across-diagonals consists of 9752 node and 7057 elements.

The models simulated the drop events by using an acceleration on the mass of the elements. A pressure force on the elements expected to be loaded by the impact limiter reacted this loading. Figure 5 shows the location of the impact limiter load. In order to avoid rigid body translation of the model, one node on the closure was fixed in the X and Y directions, the loads on this node were latter checked to confirm that no significant load was reacted through it.

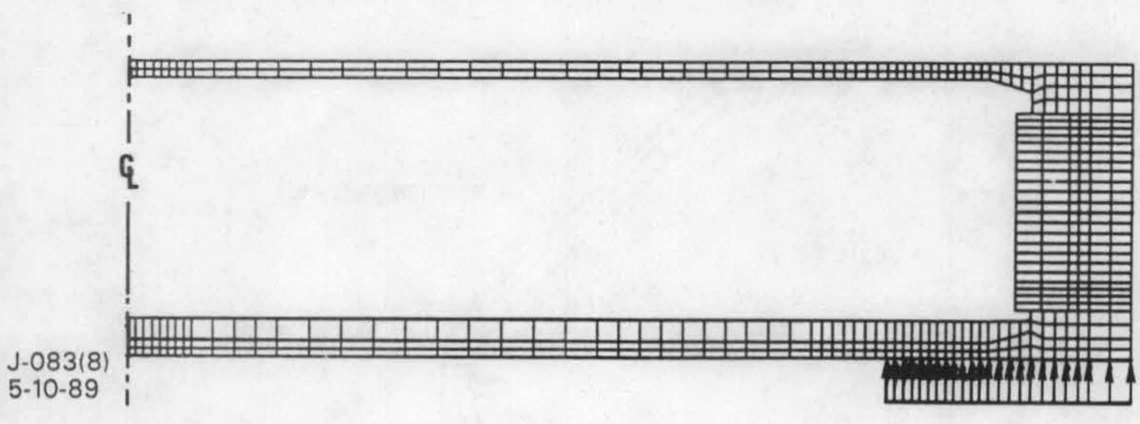
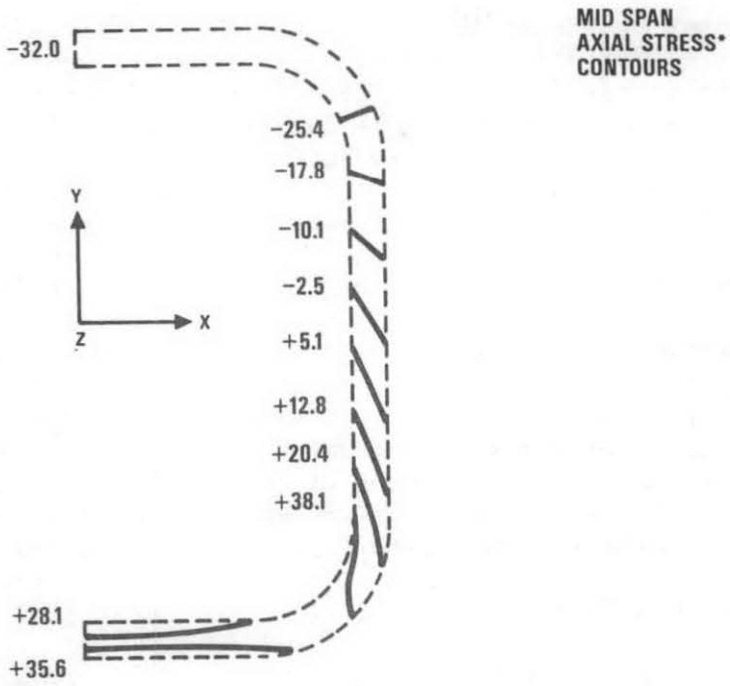


Figure 5. Lengthwise Cross-Section of ANSYS Side Drop Model Showing Impacter Limiter Reaction Force

Local Behavior

GA used the results of the ANSYS analyses to study local behavior due to (1) structural discontinuities, (2) loads from the cask internals and DU shielding, and (3) impact limiter loads. As expected, the ANSYS results showed that the highest stress condition occurred at the mid-length position of the cask during the side drop events. The axial stress contours for that cross section, for the two side drop models, are presented in Figures 6 and 7.



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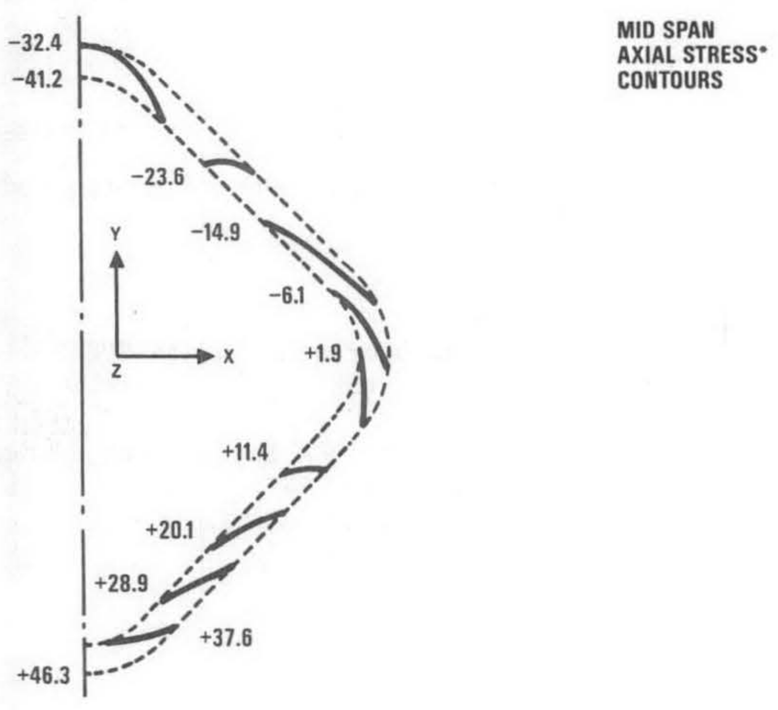
*STRESSES INCLUDE EFFECT OF FUEL SUPPORT STRUCTURE

Figure 6. Axial Stress Contours of Side Drop onto the Flat Areas of the Cask. Cross-Section Taken at Mid-Span.



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*STRESSES INCLUDE EFFECT OF FUEL SUPPORT STRUCTURE

Figure 7. Axial Stress Contours of Side Drop onto the Corner of the Cask. Cross-Section Taken at Mid-Span.

Confirmation of Cask Behavior

To confirm that the overall behavior of the cask can be studied using a beam representation of the cask, comparison between the GACAP and ANSYS results were made. The results showed that the overall beam bending behavior of the cask is still the primary mode of response on the cask wall. The maximum ANSYS axial membrane stresses at mid-span deviated a maximum of 12% from the GACAP expected results. This variance was due to local effects due to the internal loading.

Other Components

We used classic beam, shell and plate solutions to study the stress behavior of the components not included in the ANSYS models. The g-levels developed with GACAP were used to perform the analyses. The analyses assumed the depleted uranium material provided only mass and no structural resistance to bending.

Comparison With Allowables

After obtaining the stress components by the above methods, we combined the stresses due to the different loading conditions as defined in USNRC Regulatory Guide 7.8. The combined stress intensities were compared with the allowables obtained from USNRC Regulatory Guide 7.6. All stresses produced in both the rigid body and dynamic loading conditions were within the design stress criteria for all components.

ACKNOWLEDGMENTS

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