Design Features that Enhance Spent Fuel Canister Integrity Under Drop Impact

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ABSTRACT

In many spent fuel dry cask storage systems a welded steel canister provides the confinement boundary that prevents the release of radionuclides, not only during normal conditions of storage, but also, in the unlikely event of a drop or tip-over accident. Transfer and storage casks that contain steel canisters are typically lifted and moved, and the canister transferred, in a vertical upright position. Any drop of the cask or canister, therefore, induces high longitudinal compressive stresses in the canister shell and, depending on the drop height, possible buckling of the shell at the base of the canister. The buckling of the canister shell, in turn, can introduce high bending strains in the circumferential weld joining the shell and base plate. (This weld and the longitudinal welds in the canister shell are 100% radiographed and hydrostatically tested.) The strains at this location caused by such an accidental drop can be significantly increased, however, by local design features, such as welded attachments and basket supports, which may act to constrain the free buckling of the shell. This paper evaluates one such design feature, longitudinal basket supports, and shows how a simple modification to the design can reduce the maximum plastic strain at the circumferential weld resulting from an accidental drop by more than 25 percent and, in turn, reduce the probability of weld failure by more than a factor of 5.

INTRODUCTION

In many spent fuel dry cask storage systems a welded steel canister provides the confinement boundary that prevents the release of radionuclides, not only during normal conditions of storage, but also, in the unlikely event of a drop or tip-over accident. Transfer and storage casks that contain steel canisters are typically lifted and moved, and the canister transferred, in a vertical upright position. Any drop of the cask or canister, therefore, induces high longitudinal compressive stresses in the canister shell and, depending on the drop height, possible buckling of the shell at the base of the canister. The buckling of the canister shell, in turn, can introduce high bending strains in the circumferential weld joining the shell and base plate. (This weld and the longitudinal welds in the canister shell are 100% radiographed and hydrostatically tested.) The strains at this location caused by such an accidental drop can be significantly increased, however, by local design features, such as welded attachments and basket supports, which may act to constrain the free buckling of the shell. This paper evaluates one such design feature, longitudinal basket supports.

Longitudinal basket supports are typically fabricated from solid steel bar stock or formed shapes and act as a spacer between the edges of the fuel assembly basket and canister shell. These supports are either continuously fillet welded or stitch welded to the shell along their entire length. The basket supports extend along most of the canister shell length, but typically terminate a few inches above the top of the base plate. This termination of the basket support just a few inches above the base plate creates a hard discontinuity and constraint that prevents the free buckling of the canister shell during a drop impact event. The results provided herein show that by simply not welding the basket support to the canister shell over the bottom 32 to 48 cm (12 to 18 inches) allows the free buckling of the shell to take place, which drastically reduces the maximum strain in the circumferential weld that joins the shell to the base plate.

METHODOLOGY

To evaluate the influence of basket supports on canister response due to a 6.1 meter (20 foot) vertical drop impact onto an unyielding surface, an LS-DYNA [1] finite element model was constructed. The model consists of a 1.27 cm (0.5 inch) thick cylindrical steel shell 173 cm (68 inches) in diameter and 457 cm (180 inches) long with a 25 cm (10 inch) thick welded lid and 13 cm (6 inch) thick base plate also welded to the shell. The basket supports, made from 2.5 cm (1 inch) by 5.1 cm (2 inch) bar stock, are continuously fillet welded to the shell on each side and circumferentially spaced at 22.5 degree intervals. Each basket support terminates 3.8 cm (1.5 inches) above the base plate.

To accurately capture the canister's response to drop impact, the canister shell finite element mesh consists of 5 solid elements through the shell thickness with a uniform element height to thickness ratio of 0.156 in the longitudinal direction. Figure 1 is a vertical (longitudinal) section taken adjacent to the basket support near the bottom of the canister and shows the finite element mesh of the base plate, shell and basket support bar. All elements use single point reduced integration.

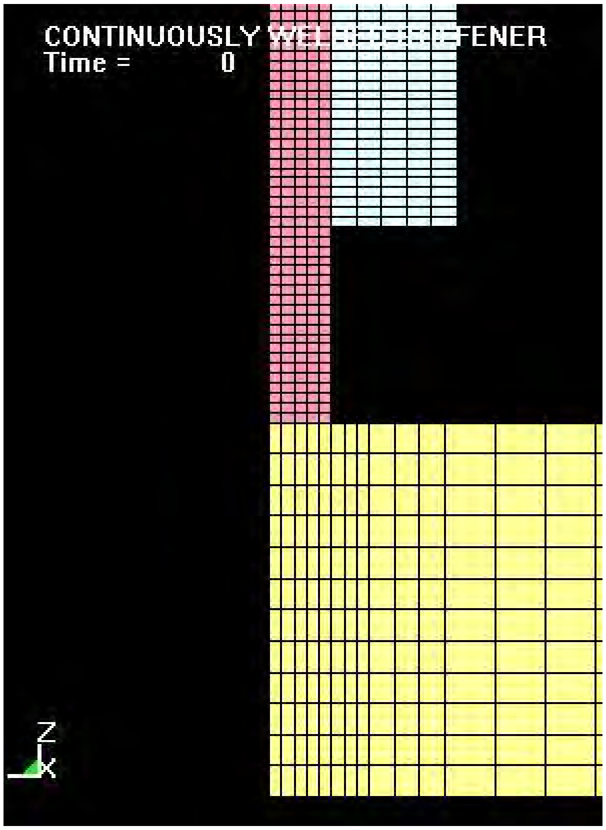

Figure 1: Vertical Section adjacent to basket support bar showing the finite element mesh of the shell, base plate and basket support.

The canister shell, lid, base plate and basket supports are made of stainless steel, which is represented in the model by a bilinear stress strain curve with an elastic modulus equal to179,400 MPa (26,000,000 psi), yield stress equal to 264 MPa (38,300 psi) and a tangent modulus equal to 407 MPa (59,000 psi). These mechanical properties are representative of an engineering stress strain curve at temperature, and therefore produce conservative results since LS-DYNA assumes the input is a true stress strain curve.

Two drop analyses are performed. In the first analysis the longitudinal basket support is continuously welded to the shell on each side along its entire length. In the second analysis the continuous fillet weld is eliminated from the bottom 48 cm (18 inches) of the bar. This is a simple and cost-effective modification and constitutes the only change.

RESULTS

For the fully welded basket support model, shell deformation due to the 6.1 m (20 foot) drop impact is primarily confined to the 3.8 cm (1.5 inches) between the base plate and the bottom of the basket support bar, as shown in Figure 2. The maximum effective plastic strain in the shell is 0.34 in/in and occurs in the circumferential weld, which joins the shell to the base plate.

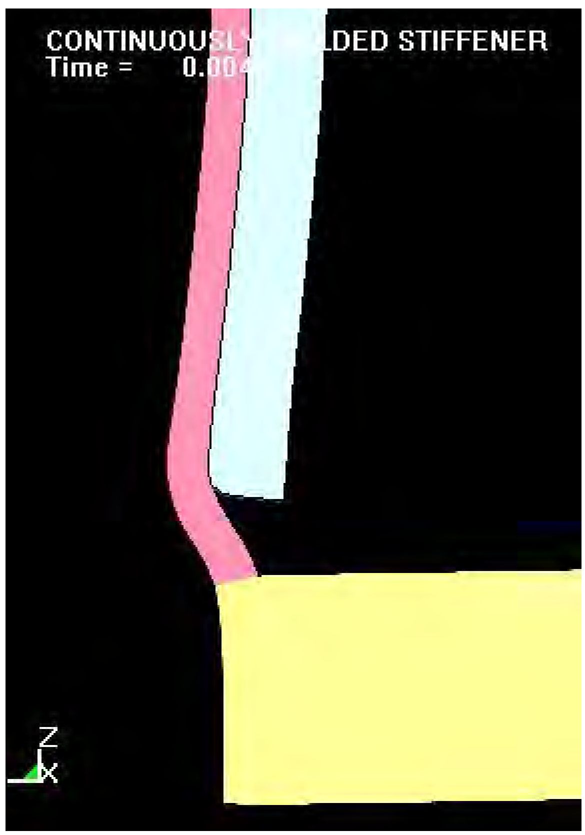

Figure 2: Canister shell deformation due to drop impact for the case of a fully welded basket support.

For the second analysis, the canister did not have the basket support bars welded to the shell along the lower 48 cm (18 inches) of the bar, and the behavior is quite different. In this case buckling is allowed to take place freely in the absence of any constraint imposed by the basket support bar, as shown in Figure 3. The maximum effective plastic strain in the shell is 0.27 in/in, which also occurs in the circumferential weld. Thus, the simple modification of not welding the lower 48 cm (18 inches) of the bar to the canister shell reduced the maximum effective plastic strain by more than 25 percent. At these strain levels, such a reduction in strain reduces the probability of weld metal failure by more than a factor of 5. [2]

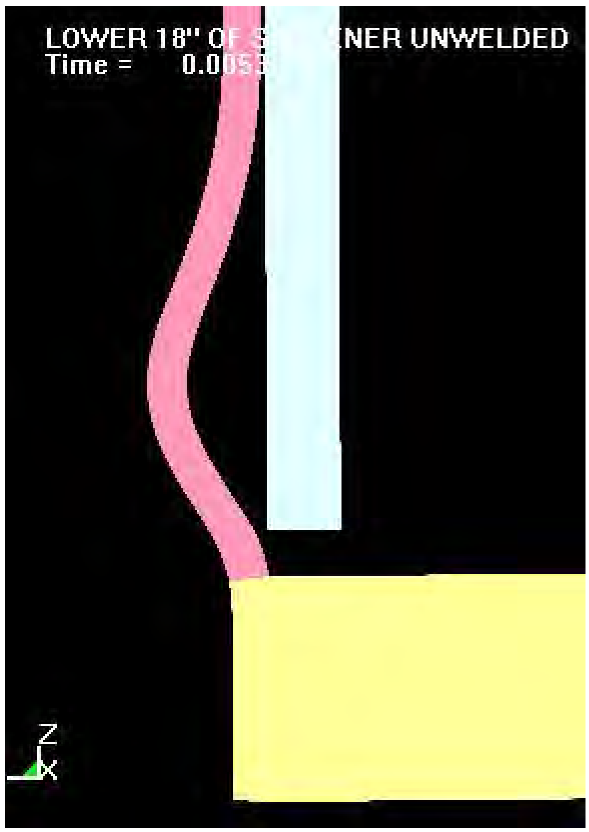

Figure 3: Canister shell deformation due to drop impact for the case of a partially welded basket support.

CONCLUSION

In the unlikely event of an accidental drop of a spent fuel canister, the canister would very likely impact in a near vertical orientation. If dropped from a sufficient height in this orientation, buckling of the canister shell just above the junction with the base plate would be expected to occur. Not welding the basket supports to the shell in this region eliminates the constraint to shell buckling imposed by the basket supports and results in a 25 percent reduction in maximum effective plastic strain in the shell to base plate weld. In turn, this reduction in strain reduces the probability of weld failure by more than a factor of 5 [2]. Based on these results it would be beneficial for canister designers to minimize discontinuities and constraint to shell buckling in the lower regions of the canister.

REFERENCES

1. Livermore Software Technology Corporation, LS-DYNA Computer Code, Version 970.

2. U.S. Nuclear Regulatory Commission, "A Pilot Probabilistic Risk Assessment of a Dry Cask Storage System at a Nuclear Power Plant," *NUREG-1864*, 2007.