LEGAL WEIGHT TRUCK CASK RESPONSE TO REGULATORY FORMAT THERMAL EVENTS,
PART 2: CONTAINMENT SEAL

M. Greiner, Y. Jin and R.J. Faulkner
University of Nevada
Reno, Nevada 89557
(702)784-4873

I. INTRODUCTION

The objective of this work is to evaluate the response of the GA-4 Legal Weight Truck Cask\(^1\) to a range of regulatory format fire/post-fire events. Specifically, we wish to determine the fire durations which cause the zircaloy fuel cladding and/or the two ethylene propylene seals (between the stainless steel cask body and the stainless steel closure) to reach their respective containment-integrity temperature limits for a relevant range of fire temperatures and cask damage levels\(^2\).

This article is the second of a two part series. Part 1 describes a GA-4 cross-sectional model used to determine the regulatory format fire conditions which cause the fuel cladding to reach different critical temperatures when the cask has experience different levels of initial neutron shield damage\(^3\). In the current article (Part 2), an axisymmetric cask model is developed and used to find fire conditions which cause the package containment seal to reach its critical temperature for different levels of initial impact limiter and neutron shield damage.

II. DESCRIPTION OF WORK

A. Computational Model

Figure 1 shows the axis-symmetric, finite element model of the 27.5-ton GA-4 Legal Weight Truck Cask employed in our computer simulations. The left-hand edge represents the axis of symmetry. Large impact limiters are at the top and bottom, and a neutron shield covers the outer portion of the cask midsection. Gray tones differentiate cask materials and labels show the locations of the fuel center, fuel edge, and containment seal. In this paper, the seal and cladding are assumed to operate satisfactorily if their respective temperatures remain below 204\(^{\circ}\)C and 740\(^{\circ}\)C, respectively\(^4\). The actual GA-4 design has a square cross-section with beveled corners. The current axis-symmetric model assumes there are no variations in the circumferential direction. Equivalent cask dimensions and material properties are therefore employed to allow the use of this simplified geometry, as described in Section III.A.

The following thermal boundary conditions are imposed to evaluate the cask performance. Initially, the package is assumed to operate at steady state under normal conditions of transportation (38\(^{\circ}\)C ambient air, 388 W/m\(^2\) insolation). It is then exposed to a fully-engulfing thermal radiation environment for a specified duration and with a given temperature. This fire environment is assumed to have an effective emissivity of 0.9, and the cask skin is assumed to have an absorbivity of 0.8. After the fire period, the external boundary conditions return to the initial environment. These "regulatory format" conditions are an extension of the 10-CFR.71 half-hour,
800°C regulatory fire test in that simulations are run for a range of fire durations and temperatures. We note that the fully-engulfing conditions and thermal emissivity and absorptivity assumptions of regulatory format thermal events may be substantially different than those of historical or probable transportation accidents.

Transient thermal conduction in the package solid structure and helium-filled region is simulated using the commercial finite element computer code ANSYS. Radiation heat transfer across internal helium filled gaps is included through the use of modified thermal conductivity values. The fuel assembly/support structure region is modeled as a smeared solid having uniform volumetric heat generation and an effective, temperature-dependent thermal conductivity.

In this study, simulations of the cask subjected to regulatory format thermal boundary conditions are performed for a range of fire temperatures and durations, as described in Part 1 of this work. These simulations are used to determine the maximum fuel clad and seal temperatures during the fire and post-fire periods. A trial and error technique is used to determine the fire durations which causes the seal and fuel cladding to reach their respective critical temperatures, for a range of fire temperatures. Curves of critical duration versus fire temperature are referred to as cladding or seal performance envelopes.

B. Neutron Shield and Impact Limiter Damage

A cask may be subjected to impact or puncture events before a thermal event begins, resulting in different levels of initial neutron shield and/or impact limiter damage. Baseline cladding and seal performance envelopes in this paper assume the cask is intact. Additional damaged-cask performance envelopes are also calculated which assume: (1) total neutron shield loss before the thermal event begins, but the impact limiter is intact, and (2) impact limiter loss, but the impact limiter support structure and external neutron shield are both intact.

III. RESULTS

A. Equivalent Cask Dimensions and Properties

Equivalent radial dimensions for each region of the cask were developed to allow the use of the simplified axisymmetric model. Equivalent material properties were evaluated for some of these regions based on mixture laws. In Fig. 2, the cladding performance envelopes for casks with and without neutron shields from the axisymmetric model (marked “A.S.” in the figure) are compared to results from the geometrically-accurate cross sectional model (marked “C.S.”) from Part 1 of this study. The critical duration for a given fire temperature for the two models are within 20%. We therefore conclude that no further adjustments to the equivalent dimensions or material properties are required.

B. Performance Envelopes

The curves marked “Clad” and “Seal” in Fig. 3 are the calculated thermal performance envelopes which cause these containment components to reach their respective critical temperatures for an undamaged cask. A steady state analysis shows that fires with temperatures below an asymptotic value of 200°C are not capable of causing the seal temperature to reach its critical value of 204°C, no matter how long they last. We see that the critical duration decreases rapidly as the fire temperature increases above 200°C, and at a fire temperature of 1300°C, the critical fire duration is only 1.3 hours. By comparison, the asymptotic fire temperature for the fuel cladding in an intact GA-4 is 715°C, and the critical duration for a 1300°C fire is 3.0 hours.

The cladding envelope for a cask without its impact limiter is not shown in Fig. 3 since it is essentially the same as that for the undamaged cask. This is not surprising since the hottest fuel location is near the cask center but the impact limiters are at the ends. The curve marked “Clad w/o NS” is the clad envelope for a cask without its neutron shield. Loss of the neutron shield...
causes the critical duration for a $1300^\circ$C-fire to decrease by a factor of ten compared to an undamaged package. This is in agreement with the result of Part 1 using the cross sectional model.

The seal performance envelopes for casks without a neutron shield (marked "Seal w/o NS") and without an impact limiter ("Seal w/o IL") are also included in Fig. 3. Loss of the neutron shield reduces the seal critical duration for a fire temperature of $1300^\circ$C by a factor of 1.6 compared to an intact cask, while impact limiter loss causes a nine-fold critical duration decrease at this fire temperature. The impact limiter surrounds the end of the cask, thereby providing more significant protection to the seal than is provided by the neutron shield.

We see that the seal reaches its critical temperature in shorter duration fires as compared to the cladding for both the undamaged cask and for a cask without its impact limiter for the range of fire temperatures investigated in this work. For the case of no neutron shield, however, the seal reaches its limit first in fires with temperatures below $860^\circ$C, while the cladding reaches its critical temperature first in higher temperature fires.

The square in Fig. 3 indicates the characteristics of the half-hour, $800^\circ$C Regulatory fire. A margin of safety is observed between the characteristics of the regulatory fire and all of the GA-4 performance envelopes presented in this paper.

IV. CONCLUSIONS

The calculated cladding and seal thermal performance envelopes for the GA-4 cask are significantly affected by assumptions regarding the neutron shield and impact limiter damage levels. The cladding performance is more greatly effected by loss of the neutron shield than loss of the impact limiter. The opposite is true for the containment seal. The margin between the conditions of the 10-CFR.71 test and all of the performance envelopes presented in this paper indicate that the GA-4 adequately contains the spent fuel payload under regulatory fire conditions, regardless of the cask damage level assumptions employed.

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REFERENCES


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