HI-STORM 100MB LAR 9378-1
Responses to Requests for Additional Information
Enclosure 2 to Holtec Letter 5026009

CHAPTER 1 GENERAL INFORMATION

1-1 Provide tolerances for all Important to Safety (ITS) components on the licensing drawings so that the parameters used to calculate stresses, strains, and load distribution during drop tests can be assessed, and the "as-built" package can be verified as being manufactured in accordance with the analyzed design.

Holtec's response to RAI 1-1 (ADAMS No. ML20097E190) is incomplete because the response only included a few tolerances that were quantitative in nature (clearances and plate thicknesses, fit-up tolerances, package weight). However, most Important to Safety (ITS) components still do not have any tolerances, nor are there any tolerances on the overall dimensions for the package.

For instance, some information has been provided for the thickness of certain parts or groove dimensions, but most ITS components themselves do not have any tolerances nor do any non-ITS components which are missing from the drawings altogether. In addition, most overall dimensions of the package have no tolerances: the height and width of the impact limiters have no tolerances, nor do the crush material layers themselves, all of which could affect the behavior of the impact limiter during drop tests.

Without tolerances placed on overall package dimensions for instance, the length of the package could be increased to an extent that would allow additional g-loads to present themselves during a "slap down" scenario for which the package was never analyzed for. Given that most analyses provided in the application only use nominal dimensions, without any tolerances, any significant deviation from the nominal dimensions in a fabricated package/component could be considered as being noncompliant with the conditions of approval of the package.

Pertinent tolerances that support analyses for all ITS components in the application should be placed on the licensing drawings so that the staff can assess whether the results of the analyses, including shielding and thermal analyses, are valid. Tolerances for non-ITS components should also be included, if they have a potential to impact any ITS component performance. The staff also notes that it does not have access to the fabrication drawings, while performing the licensing review.

This information is required to determine compliance with the requirement of 10 CFR 71.33(a)(5), 71.71(c)(7), 71.73(c)(1), and 71.73(c)(3).

Holtec Response:

All licensing drawings have been updated to include tolerances for ITS components.

Shielding sensitivity studies have been performed and documented in the shielding calculation package (HI-2188049 R6) evaluating the effect of minimum shim liners' widths on dose rates. These minimum shim liners’ widths have been added to the latest cask licensing drawing.

CHAPTER 2 MATERIALS AND STRUCTURAL REVIEW

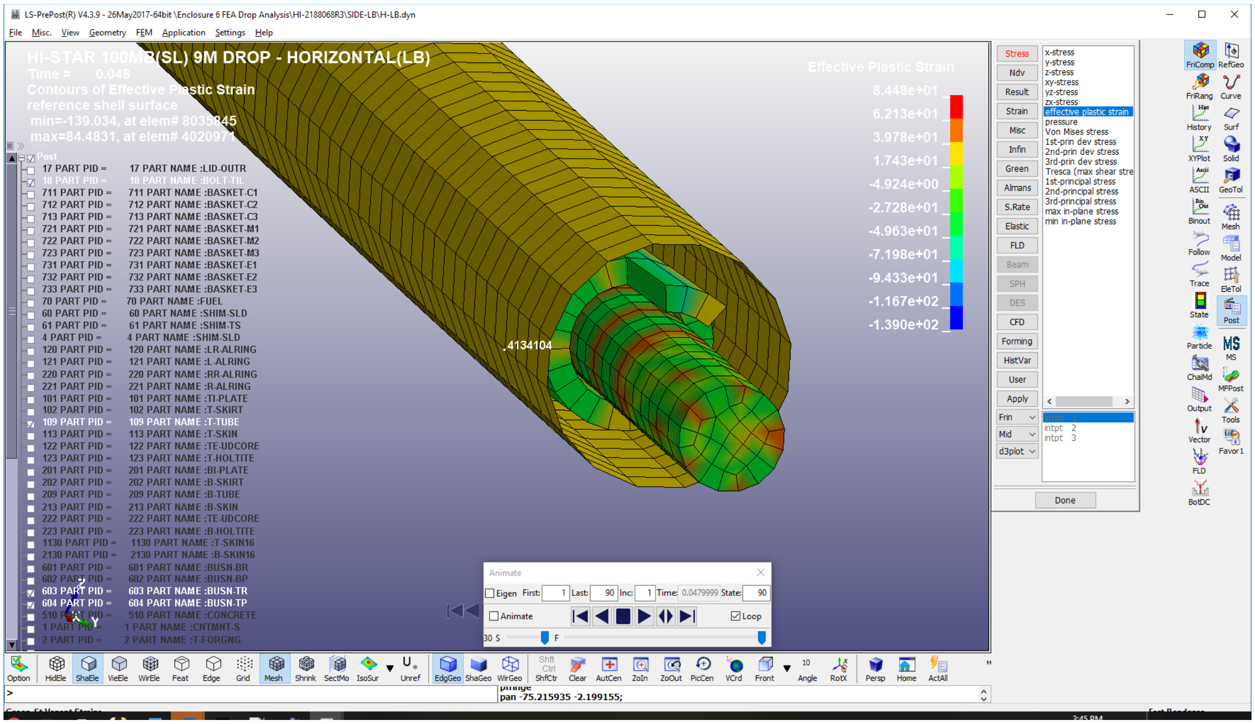
2-1 Clarify the behavior, dimensions, and material properties of the Fastener Strain Limiters (FSLs aka bushings) that are used to ensure that impact limiter bolts adequately retain the impact limiters post drop test scenarios. Justify how the access tubes that house those FSLs are NITS and why they do not need dimensions and material properties.
Describe the structural integrity of the impact limiter bolts with appropriately dimensioned access tubes and bushings (FSLs) with a more realistic failure model used for the bushings. Place access tube (BOM 9) dimensions along with bushing dimensions on the licensing drawings, mark them as ITS, and describe the material of the access tubes.

In its RAI response (ADAMS No. ML20258A052), the applicant stated that FSLs (ITS) help ensure impact limiter bolts (Part 12 on Sheet 1 of DWG 11101) retain impact limiters to the package, post 9m HAC drop. The applicant stated that the design of the bushings is described in Appendix D Holtec document Report HI-2188068, where they are expected/intended to fail in tension, so that the impact limiter bolts are not overloaded in tension.

After reviewing the new HAC drop simulations (LS-DYNA) provided in response to RAI 2-2, it was observed the design of the bushings in Report HI-2188068 appears incomplete since the maximum tensile stress experienced by the bushings ($S_{failure\_max}$) was never compared to the yield strength of the material of construction to appropriately size the bushings.

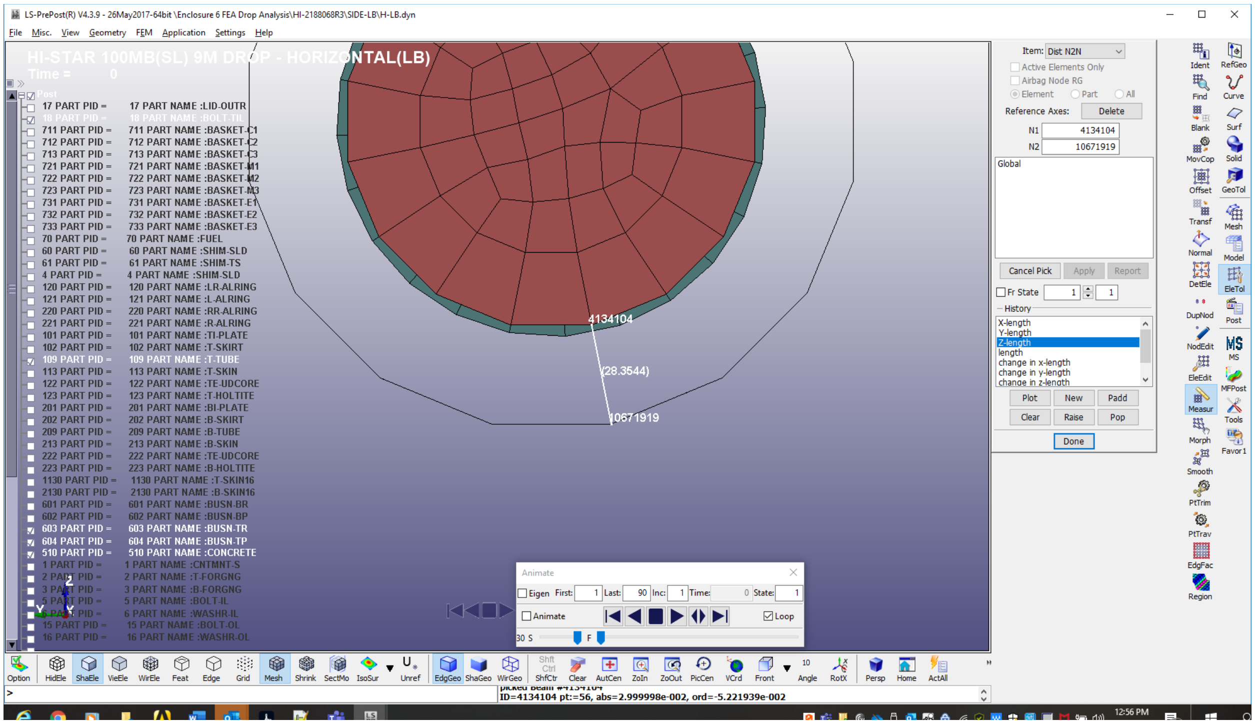
In addition, the dimensions of the bushings do not appear to be on the licensing drawings. The bushings have material models that are identified as being steel (LS-DYNA parts 602 and 604) and not SB211-6061-T6 or SB209-6061-T6 or SB241-6061-T6 for FSL Parts 10 and 11, as identified on the drawings. The bushing calculations in Appendix D also discuss drawing 9848, but this drawing is not part of the application.

Additionally, the bushings also appear to fail in a combination of compression and bearing according to simulation, and not just tension. The calculations/LS-DYNA drop simulations assume that when the bushings reach a very small amount of inelastic strain (0.001) during the simulation, the bushing material that has yielded will be removed from the simulation. This does not appear to be a conservative assumption since the material will most likely remain in the simulations and will continue to impart shear/tension and bearing forces on to the impact limiter bolts when in contact with the access tube past this very small inelastic strain. In effect, by removing bushing material prematurely, the load path is also removed prematurely. The force in the impact limiter bolt, access tube, and bushing is not insignificant despite the applicant's non-conservative assumption, as inelastic strain plots indicate (9m side drop shown below):



In addition, the access tube shown above (yellow tube) (i) has no dimensions defined in the drawing (assumed to be 1/8" thick in LS-DYNA), (ii) is generically assigned stainless steel material properties, and (iii) comes into contact with the bushing/impact limiter bolts contained within the access tube. To demonstrate this, the gap between the tube and busing is tracked during the 9m side drop (see graph below). The graph suggests that additional shear and bearing forces are being transferred into the impact limiter bolt.

This information is needed to meet the requirements of 10 CFR 71.71(c)(1), 71.73(c)(1), and 71.73(c)(3).



Holtec Response:

The Fastener Strain Limiter (FSL) is designed to limit the tensile load experienced by the impact limiter attachment bolt as the impact limiter tries to detach from the cask during a drop accident. [

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To address the concern that the larger diameter lower bushing, following the failure of its internal lip, may slide towards the attachment bolt head and get trapped by the deformed access tube resulting in a greater interaction than that between the upper bushing and the access tube, the ODs of the two FSL cylinders in LS-DYNA model are increased to 2.75” (i.e., the OD of the actual lower bushing) to maximize the interaction between the access tube and the FSL in a sensitivity analysis for the side drop event. This conservatively augmented tube-to-FSL interaction occurs over the entire FSL length at every attachment bolt location, regardless of the actual condition of the FSL lower bushing. Comparing with the original side drop analysis, this sensitivity run results in failure of one FSL installed on the bottom impact limiter, and the net effect is best measured by comparing the peak decelerations of the cask baseplate of the two simulations presented in Figures 2-1.A and 2-1.B. It is shown that the maximized tube-to-FSL interaction only slightly increases the peak deceleration at the cask baseplate by 3.9% (i.e., from 76.31 g’s to 79.29 g’s). Therefore, the undersized FSL lower bushing OD used in the LS-DYNA drop analysis has minimal impact to the analysis results. The sensitivity run described above is documented in revised Holtec report HI-2188068, Appendix G.

Finally, the primary function of the impact limiter access tubes is to ease the impact limiter installation. The access tube itself does not play any safety role as a collapsed access tube will not result in any radiological consequences. Moreover, access tubes absorb a negligible amount of energy during impact as compared to the substantial volume of aluminum crush material. Regardless, the access tubes have been redesignated as ITS-C components on licensing drawing No. 11758 to assure that their material strength properties conform with the analysis.

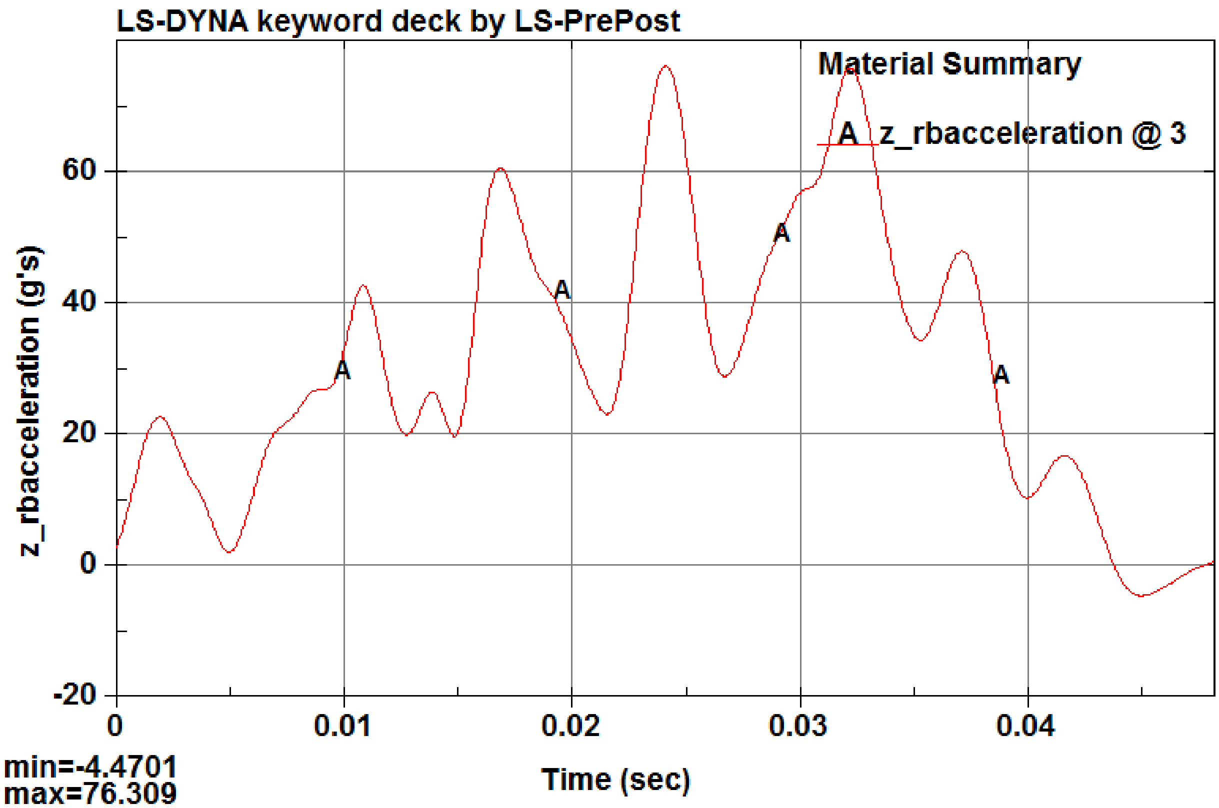

Figure 2-1.A: Cask baseplate Deceleration Time History - Original Side Drop Analysis

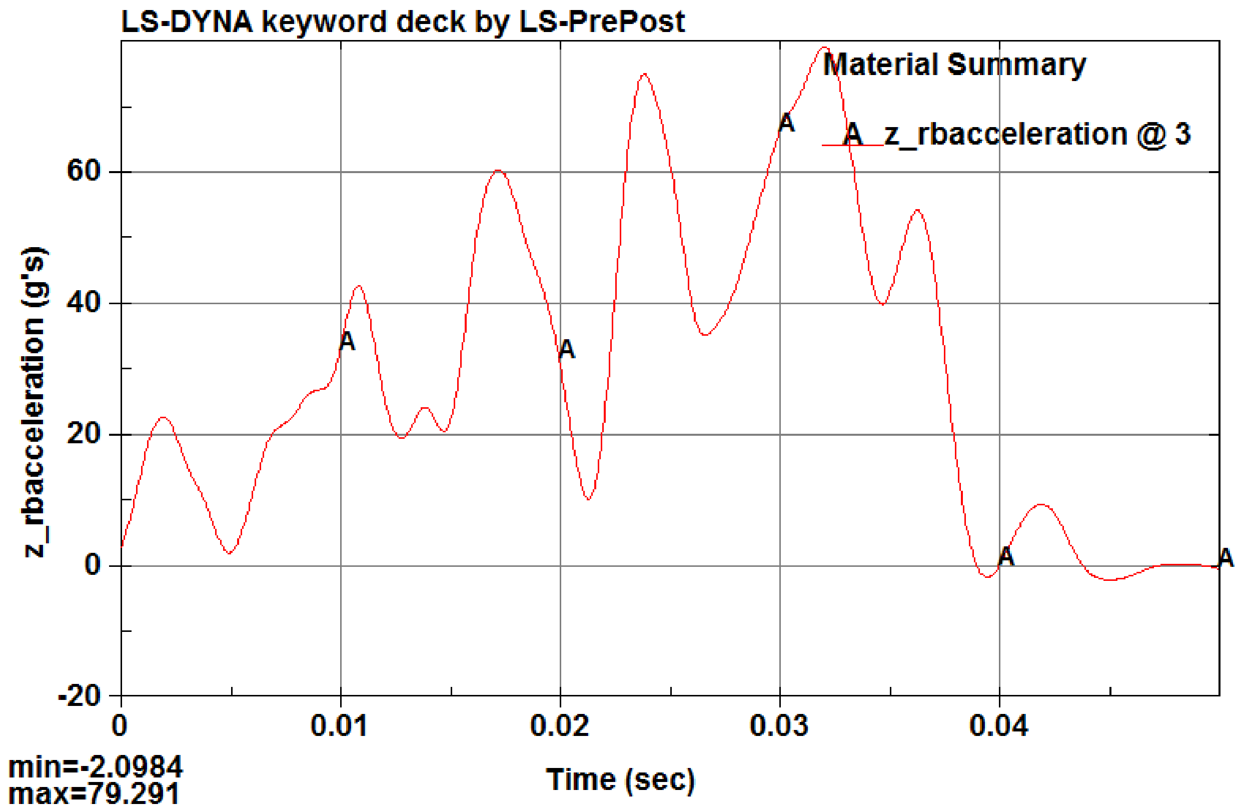

Figure 2-1.B: Cask baseplate Deceleration Time History – Sensitivity Side Drop Analysis with the Maximum Tube-to-FSL Interaction Effect Considered

2-2 Provide mechanical properties validated by test data for materials whose post-yield behavior is described in Holtec Report HI-2188068.

The structural evaluation/finite element analyses of HI-STAR 100 MB package for drop accidents has been described in Holtec Report HI-2188068. This evaluation uses a strain-based methodology to determine the structural integrity of ITS components (such as aluminum, stainless steel, and Metamic for impact limiter components, the basket, etc.) subjected to NCT and HAC drop conditions. True-stress true-strain data used to construct material flow curves for use in finite element simulations such as LS-DYNA are found in Appendix B of Holtec Report HI-2188068.

The methodology used to compute material flow curves follows the Holtec Position Paper DS-307, “Construction of True-Stress-True-Strain Curves for LS-DYNA Simulations.” The staff notes that the use of the methodology outlined in this position paper has previously been found inadequate by the staff due to its failure to provide material properties based on test data.

Specifically, constants used to develop material flow curves (e.g., constants “K” and “n”) have been “guessed”. The staff’s position (ML18331A184) is that these constants should be based on physical testing for a sample size of at least 5 to support a 98% exceedance probability value for a true uniform strain limit.

Materials, mentioned in Appendix B with unspecified material properties, include the containment shell SA-350 LF-3 (and SA-203 GR E which has not been presented in Appendix B), SA193 GR. B8 for lid and port cover plates,SA-516/SA 240 for various components, SB211-6061-T6 and SB209-6061-T6 for bushings.

Other material properties that need to be based on physical testing, but which have not been provided in the application, include strain rate effects and triaxiality effects (in the case of the true uniform strain limit being exceeded). Finite element simulations and other analyses which use these material flow curves should be updated as necessary.

This information is required to determine compliance with 10 CFR 71.71(c)(7), 71.73(c)(1), and 71.73(c)(3).

Holtec Response:

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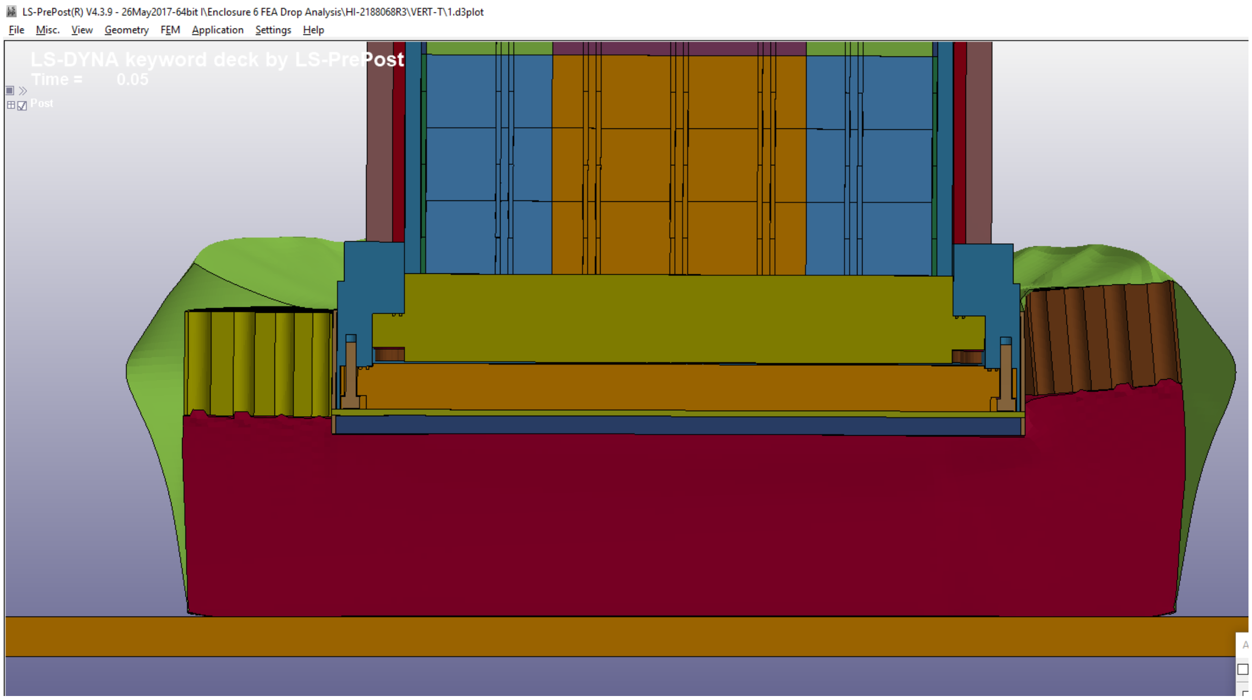
The fidelity of the true-stress-true strain curve established per the method discussed above can be demonstrated by performing LS-DYNA simulations of actual material tensile tests. Holtec generic report HI-2210251 documents this numerical benchmarking effort for three different materials (i.e., aluminum 6061, stainless steel, and Inconel) and demonstrates that the LS-DYNA simulation using the established true-stress-true-strain curve can accurately predict the tensile test results (i.e., specimen elongation and the final diameter of fractured specimen cross-section) for all tensile test specimens of each material.

The engineering strength properties of the Appendix B materials identified in this RAI are taken from Part D of the ASME B&PV Code, Section II, as mentioned in the beginning of calculation. For aluminum alloy 6061-T6, the engineering strength properties are based on the mean values of the room temperature test results for the specific lots of material to be used for the perforated aluminum rings, with appropriate adjustment for service condition temperatures per the material handbook, "Properties of Aluminum Alloys". Strain rate effects and triaxiality effects used in the analysis are taken from literature, as described in Holtec reports HI-2200863 and HI-2188068.

2-3 Confirm and/or revise all LS-DYNA drop simulations due to unsymmetrical results existing in symmetric analyses and confirm/revise the modeled part behavior such as impact limiter skin and lead. In addition, update the licensing drawings with missing connection and material specification details for those items that have been modeled in LS-DYNA.

The applicant's response to the first round of RAIs (ADAMS No. ML20258A052) included revised simulations such as the 9m end drop simulation, which incorporated changes to the impact limiter This simulation should result in symmetric output for quantities such as deformation and stress due to the symmetric of the model and loading. The results are not symmetric as can be seen below (several parts have been removed for clarity):


LS-PrePost(R) V4.3.9 - 26May2017-64bit I\Enclosure 6 FEA Drop Analysis\HI-2188068R3\VERT-T\1.d3plot
File Misc. View Geometry FEM Application Settings Help
LS-DYNA keyword deck by LS-PrePost
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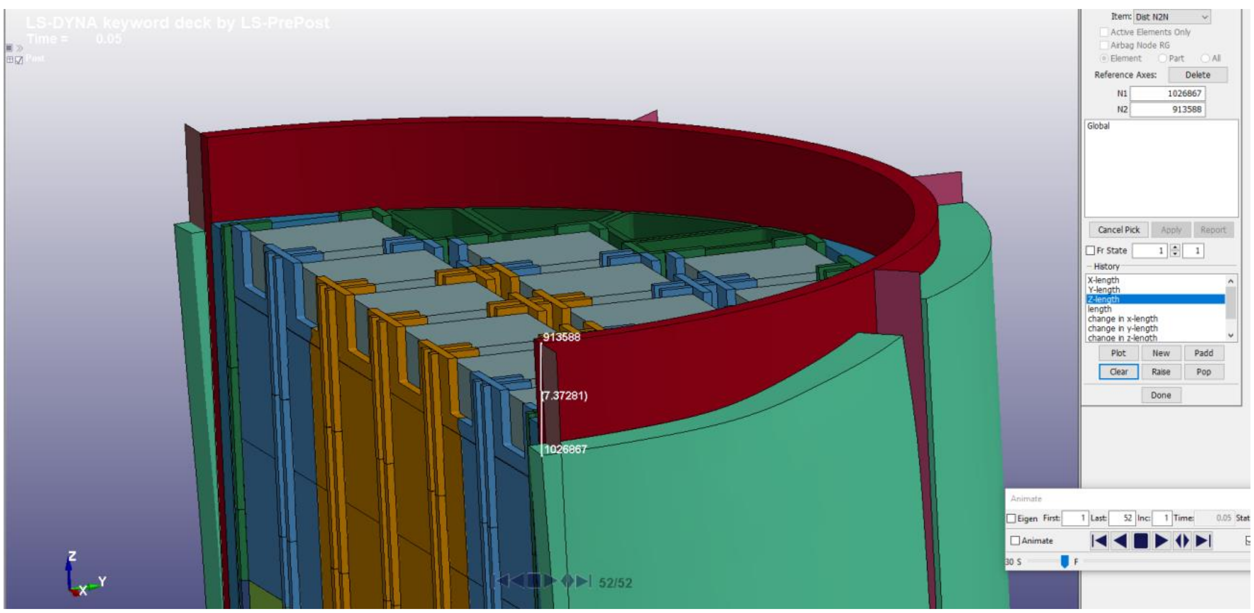
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History
X-length
Y-length
Z-length
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change in x-length
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change in z-length
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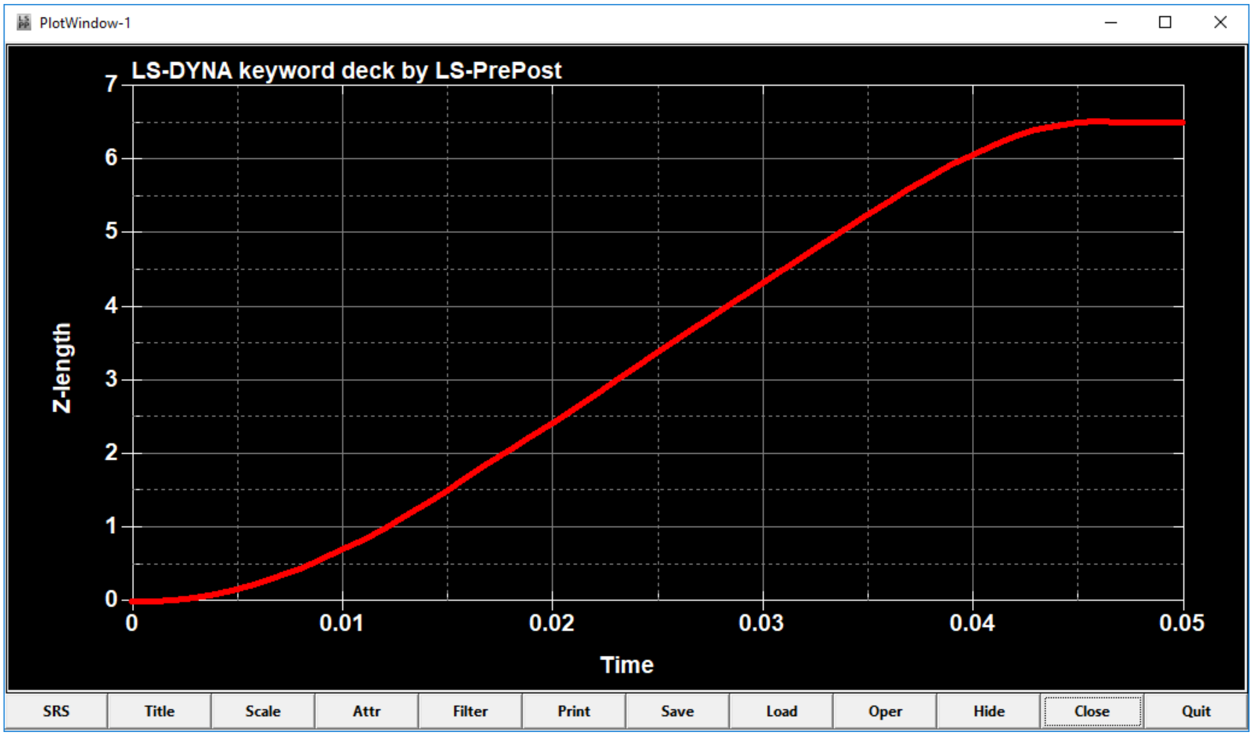
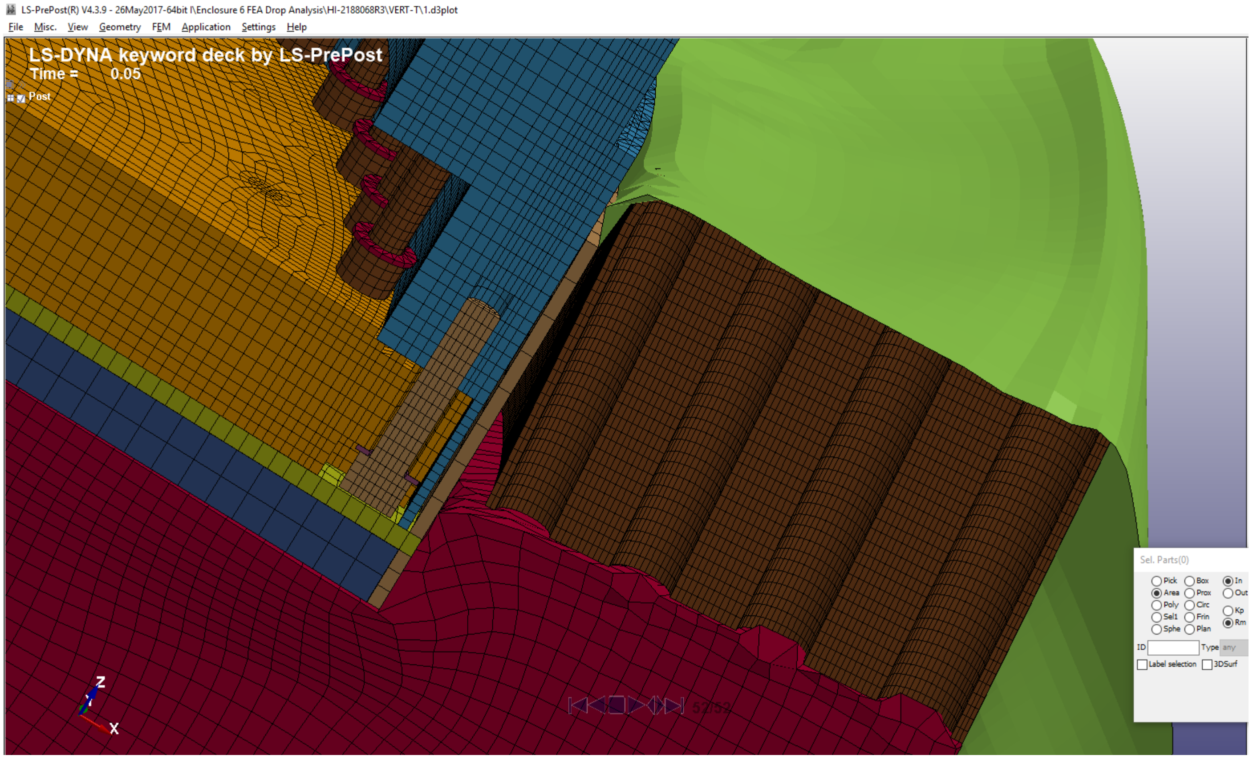
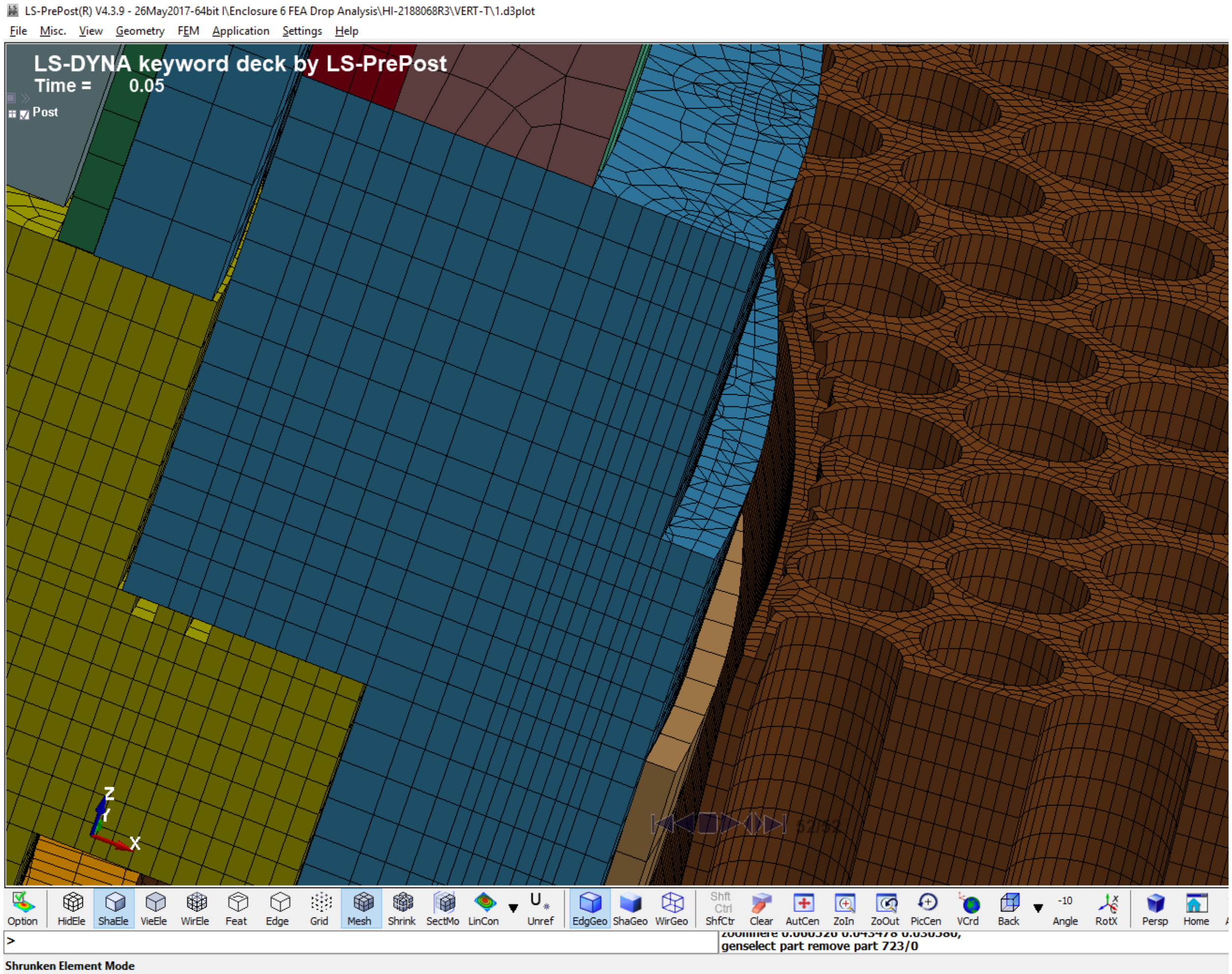


In addition, boundary conditions appear to be assigned incorrecty, as lead shielding appears to be “ghosting” past other parts, especially in the plane of symmetry of the half model, leading to a lead slump of approximately 6.5 inches and opening a “seam” between the lead and the gamma shield rib that is 2.5”wide, (0.75” originally) and approximately 24” long (several parts have been removed for clarity). Staff notes also that the lead slump is not symmetric away from the plane of symmetry either.

In addition, material erosion in LS-DYNA should apply to parts other than the perforated ring. Specifically, the impact limiter skin which is made of unknown 10/16 gauge material (details are not provided on the licensing drawings), does not appear to ever fail (tearing, puncture, etc) when in contact with the sharp corners of the solid aluminum perforated ring. Instead, the perforated ring erodes unrealistically when in contact with the skin at certain ponts in the simulation, particularly where the impact limiter skin wraps over the perforated ring, and never detachs from the skirt (Part 102 (T-Skirt) in LS-DYNA). Staff notes that the impact limiter skin to skirt connection is not provided on the licensing drawings while the impact limiter skin sustains stresses beyond 100,000 psi without tearing or “failing”:


LS-PrePost(R) V4.3.9 - 26May2017-64bit I:\Enclosure 6 FEA Drop Analysis\HI-2188068R3\VERT-T\1.d3plot
File Misc. View Geometry FEM Application Settings Help
LS-DYNA keyword deck by LS-PrePost
Time = 0.05
Post
Sel. Parts(0)
Pick Box In
Area Prox Out
Poly Circ
Sel1 Frin Kp
Sphe Plan Rm
ID Type any
Label selection 3DSurf
Z
Y
X

Region of eroded elements in the perforated ring region at the end of the 9m drop simulation:



Given that the model used for the 9m end drop is most likely identical to all other NCT and HAC drop simulation models and only altered in orientation for a given drop:

a) Revise and/or confirm all LS-DYNA drop simulations for the issues mentioned above: (i) unrealistic boundary conditions, (ii) unrealistic material assignment, and (iii) unrealistic/unspecified material erosion for all components. These issues are easier to identify in symmetric scenarios but more difficult in non-symmetric drops. ITS and non-ITS component structural integrity cannot be determined as a result.

b) Specify materials and dimensions for all NITS and ITS components on the licensing drawings that are modeled in LS-DYNA (impact limiter skin, access tubes, bushings, etc.). The impact limiter skin, for example, helps to maintain the proper configuration of the impact limiter for all drops. Component dimensions used in any calculation should match the dimensions placed on the licensing drawings.

c) Revise/confirm all g-loads, stresses, and strains experienced by the package and update the application as necessary. Unsymmetrical results could cause higher g-loads than reported or excessive stresses and strains.

d) Identify and provide the code requirements (fabrication and examination) for the connections (welds) for all NITS and ITS components such as access tubes and impact limiter skin on the licensing drawings. The impact limiter skin, for instance, appears to be made of several thicknesses and is connected in an unknown manner. Access tube buckling performance can affect impact limiter performance depending on the access tubes connection to other impact limiter components (end conditions).

e) Verify the lead slump values reported in the FSAR (6.5" was calculated above, 6.4" is the max allowable according to Table 2.7.3A) and confirm that the lead slump separation observed in the 9m drop and other drops is acceptable.

This information is required to determine compliance with 10 CFR 71.71(c)(7), 71.73(c)(1), and 71.73(c)(3).

Holtec Response:

The issue of lead penetration through the symmetric plane of the half model found in the vertical drop simulation is the result of a missing contact definition between the lead and the cask ribs on the symmetric plane of the HI-STAR 100MB package half model. The penetration problem did not occur in other drop orientations. The predicted package deformation obtained from the revised model and shown in Figure 2-3.A below demonstrates that the lead penetration problem has been corrected. The unsymmetric impact limiter deformation noticed in the previous vertical drop simulation is an unintended consequence of a modeling simplification that is employed for the side and oblique drop simulations. For those drop orientations, the perforated aluminum ring is modeled as a deformable body with element erosion enabled only over its lower half (nearest to the target surface), while the upper half is modeled as rigid. This modeling approach is used to increase the run time efficiency of the LS-DYNA solution for the lateral drops, with minimal effect on the results, since the permanent deformation/damage to the perforated aluminum is localized near the point of impact. The same half rigid, half deformable model of the perforated aluminum ring was mistakenly carried into the vertical drop simulation, which caused the unsymmetric impact limiter behavior. The revised LS-DYNA model fixes the error by treating the entire ring as a rigid body for a conservative analysis of the vertical drop accident since the impact energy is essentially absorbed by the honeycomb crush material at the very end of the impact limiter. The symmetric impact limiter deformation obtained from the new vertical drop analysis is also demonstrated in Figure 2-3.A.

The maximum lead slump obtained from the newly obtained vertical drop analysis is less than 4.2 inches as shown in Figure 2-3.B. The predicted lead slump is bounded by the value considered in the shielding analysis. The acceleration and stress results obtained from the revised model are slightly different than before and are documented in the revised drop analysis report HI-2188068 Rev. 4 and in Chapter 2 of the updated HI-STAR 100MB SAR.

The impact limiter enclosure skin is made of a very ductile type 304 stainless steel with a true failure stress greater than 100,000 psi, for material temperatures below roughly 800°F, as demonstrated in the following true-stress-true-strain curve (see Figure 2-3.C) taken from the book *Atlas of Stress-Strain Curves* (Second Edition, ASM International). Consistent with Holtec licensing drawing No. 11758, the impact limiter stainless steel enclosure skin is 16 GA thick at the end surface of the package and 11 GA thick at other locations. The revised licensing drawing will be updated to include the material information for the impact limiter enclosure skin and show how the skin and the access tubes are connected. Code requirements (fabrication and examination) for the weld connections and for all NITS and ITS components will also be identified in the revised licensing drawings. To address the concern that the impact limiter enclosure skin may fail due to an unfavorable stress state, an LS-DYNA sensitivity run is performed for the governing oblique drop scenario documented in Appendix G of HI-2188068 Rev. 4. In addition to the lower bound service temperature (-40F) considered for the enclosure skin material property, the LS-DYNA sensitivity run accounts for triaxiality effects on the failure strain of the enclosure skin material (SA-240 304). The triaxiality effect is incorporated per the general statement in ASME BPVC.III.A, Appendix EE. Namely, the strain at failure in a general case is equal to the uniaxial tension failure strain divided by the triaxiality factor, where the triaxiality factor is the larger of calculated value and unity (1.0). The sensitivity run yields similar enclosure skin plastic deformation as shown in Figures 2-3.D and 2-3.E. Both the original LS-DYNA simulation and the sensitivity run indicate that the impact limiter enclosure skin only experiences local plastic deformation without gross failure. Therefore, the concern of increased package vulnerability to the HAC fire accident due to enclosure skin gross failure is not credible. Holtec's 9-m drop tests performed in 1990s for HI-STAR 100 package also arrived at the same conclusion for the same stainless steel impact limiter enclosure skin. In addition, a published ASME paper [2-3.1] reports a similar test result for a dropped canister, which experiences a plastic strain of 107% without initiating any cracks per the post-impact non-destructive examination. The deformed shaped of the dropped canister is shown in Figure 2-3.F. The sensitivity run described above is also documented in the revised drop analysis report HI-2188068 Rev. 4.

References

[2-3.1] "Strain-Based Acceptance Criteria for Energy-Limited Events", S.D. Snow, D.K. Morton, E.L. Pleins, and R. Keating, INL/CON-09-15509, 2009 ASME Pressure Vessels and Piping Conference.

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Figure 2-3.A: Deformed shape of HI-STAR 100MB package

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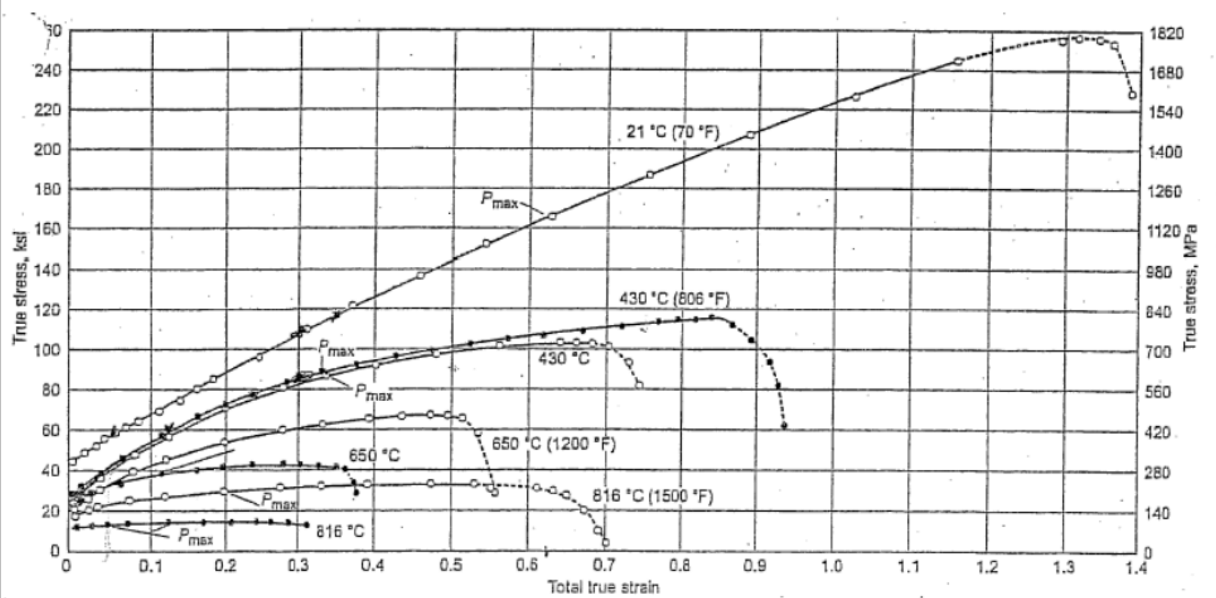
Figure 2-3.B: Lead Slump after Vertical Drop Accident



SS.044 304 annealed stainless steel bar, true stress-strain curves at room and elevated temperatures

Figure 2-3.C: 304 Type Stainless Steel True Stress True Strain Curves

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Figure 2-3.D: Plastic Strain of Impact Limiter Enclosure Skin at the End of the Slapdown Drop Event Analyzed in the Main Body of Appendix G

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Figure 2-3.E: Plastic Strain of Impact Limiter Enclosure Skin at the End of the Slapdown Drop Event Reanalyzed for the Sensitivity Study

Figure 2-3.F: Deformed Canister with No Cracks Initiated after the 9m Drop Test that Results in Maximum Plastic Strain of 107% [2-3.1]

CHAPTER 3 THERMAL REVIEW

3-1 Clarify the elastomeric seal performance criteria that is used to confirm that the seals can meet the low temperature operating limit and justify the use of the prequalified seals that are stated to meet that criteria.

In its RAI response (ADAMS No. ML20258A052), the applicant provided a manufacturer data sheet for the VM125-75 seal material (one of the prequalified seals) to justify its use at a revised lower temperature operating limit for the elastomeric containment seals from -30°C to -40°C. This limit is defined as a required critical characteristic in Table 2.2.11a of the application.

However, the staff notes that the manufacturer's data for the VM125-75 seal material, as provided by Holtec, does not appear to support its use at the proposed -40°C lower operating temperature. The seal material's "TR-10" temperature is -22°F (-30°C).

As stated in ASTM D1329, Standard Test Method for Evaluating Rubber Property—Retraction at Lower Temperatures (TR Test), this parameter is considered to correlate with the temperature the seal becomes brittle. As a result, it is unclear to the staff how seal procurement is controlled to ensure that seals can perform at the low temperature limit.

Revise the application to clarify the specific material performance criteria that must be met to demonstrate a seal material is suitable to operate at -40°C. In addition, demonstrate that all prequalified seals identified in the application meet that criteria.

This information is required to demonstrate compliance with 10 CFR 71.51(a).

Holtec Response:

For clarification, revision 2 of the SAR listed the TR-10 temperature as a critical characteristic where revision 3 lists the minimum operating temperature as a critical characteristic. The change was not modifying the temperature limit from -30 degrees C to -40 degrees C, the change was modifying which temperature limit is a critical characteristic. The manufacturing data sheets provided for the prequalified seals explicitly state that both seals can meet the low temperature operating limit specified in Table 2.2.11a. For VM125, this can be seen under Product Features on page 24 of 28.

The new minimum operating temperature critical characteristic is captured in a Holtec purchase specification that is imposed on the qualified vendor. The vendor will provide documentation to confirm that all requirements in the purchase specification are met.

While the TR-10 temperature is an easy demonstrated value, it is still subject to vendor testing that produces varying results and vendors may require different TR-10 temperatures based on their particular tests for the material. Additionally, specifying a TR-10 temperature may mislead an individual to believe that the seal cannot operate in the ambient temperature, thus leading to false rejection. Therefore, Holtec determined the lowest operating temperature to be a more critical characteristic than the TR-10 temperature.

CHAPTER 5 SHIELDING REVIEW

5-1 Provide details on the fabrication and acceptance criteria of the neutron shield, or provide an updated shielding analysis that accounts for potential gaps in the neutron shield.

In its updated notes to the drawings as part of the first round of RAI response on drawings notes and tolerances (ADAMS No. ML20258A052) , the applicant stated that the neutron shield, Holtite-B, may be constructed of “multiple pieces with joints that are not mechanically fastened together.” The applicant stated the neutron shield is “restrained by the cavity it is captured within.” However, the applicant did not provide any details to describe the shape and orientation of potential gaps within the neutron shield, nor did the applicant provide any information on how the restraint of the Holtite-B material is verified to eliminate any potential gaps.

The applicant did not address any potential streaming paths in the neutron shield within the confining cell in its own analysis. These potential streaming paths may increase dose rates from the package. Therefore, the staff has determined more information is needed because the staff did not consider gaps in the neutron shield to be credible prior to the applicant’s update and revision to Drawing No. 11758.

This information is required to demonstrate compliance with 10 CFR 71.47(a).

Holtec Response:

Holtite-B material option has been removed from Drawing 11758 to eliminate the concern.