Meeting with NRC to discuss RSIs for HI-STAR PBT

02/10/22

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  - ❑ Other Industry Examples
  - ❑ Proposed Resolution Path

- RSI-2
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  - ❑ Current Results of Analyses & Observations from Testing
  - ❑ Proposed Resolution Path

- RSI-3
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  - ❑ Proposed Resolution Path

Current Impact Limiter Testing & Benchmarking (RSI-1)

- Polyurethane foam is a homogeneous, isotropic material, whose crush strength is independent of impact direction unlike the orthotropic materials such as aluminum honeycomb or wood
  - ❑ Drop orientations and degree of similarity between physical test specimen and analyzed transport package are less important for foam material benchmarking due to isotropy

- Benchmarking performed by Holtec considers multiple drop orientations (i.e., end, side, and CGOC) and different drop heights (15" and 9 meters)
  - ❑ Different drop heights result in different strain rates

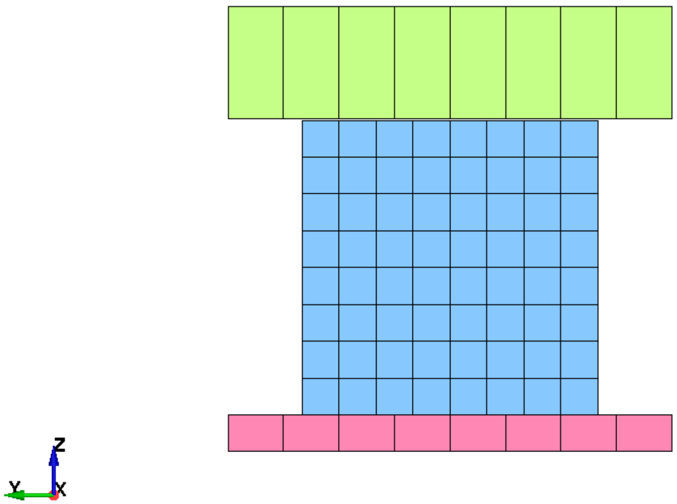
Current Impact Limiter Testing & Benchmarking (RSI-1) (Cont.)

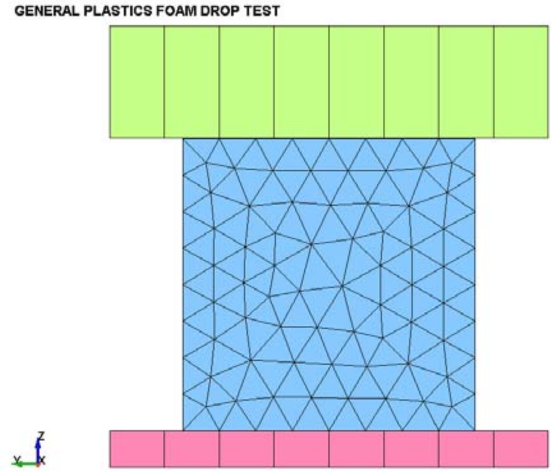
- Benchmark analysis for polyurethane foam is documented in Holtec Report No. HI-2210574 (submitted with HI-STAR PBT application)
- Benchmarking is based on three (3) independent sets of physical test measurements for a range of geometries and constructions
  - ❑ Component level (1" cube specimen)
  - ❑ Assembly level (HI-STAR 63 & NuPac 125-B)
  - ❑ Confined and unconfined test specimens
- All physical tests used for benchmarking utilize the same polyurethane foam material as the one proposed for HI-STAR PBT
- Benchmark work culminated in a universal foam material model with a singular strain rate curve that shows excellent agreement (within 7%) with all 3 sets of physical tests

Current Impact Limiter Testing & Benchmarking (RSI-1) (Cont.)

Table 1: Benchmark Comparison for 1-Inch Cube Specimen	
Result	Percentage Difference between Physical Test Measurement and Numerical Prediction
Impact Duration	1.6%
Maximum Foam Deformation	-0.4%

Source: HI-2210574 Rev. 1

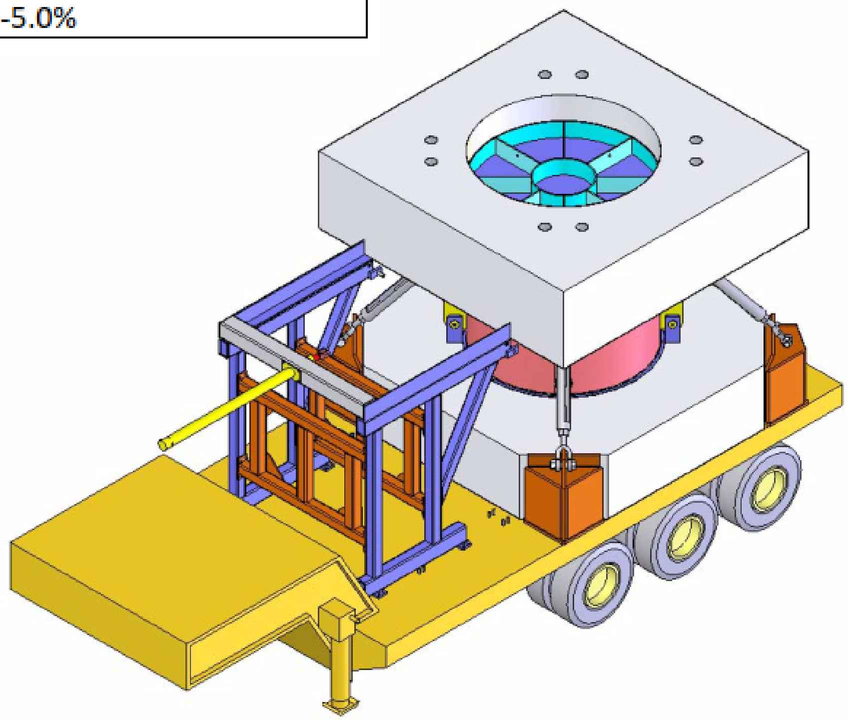




Current Impact Limiter Testing & Benchmarking (RSI-1) (Cont.)

Table 2: Benchmark Comparison for HI-STAR 63 Scale Model (9-Meter Top End Drop)	
Result	Percentage Difference between Physical Test Measurement and Numerical Prediction
Peak Cask Deceleration	3.2%
Impact Limiter Deformation	-6.7%
Impact Duration	-5.0%

Source: HI-2210574 Rev. 1



Current Impact Limiter Testing & Benchmarking (RSI-1) (Cont.)

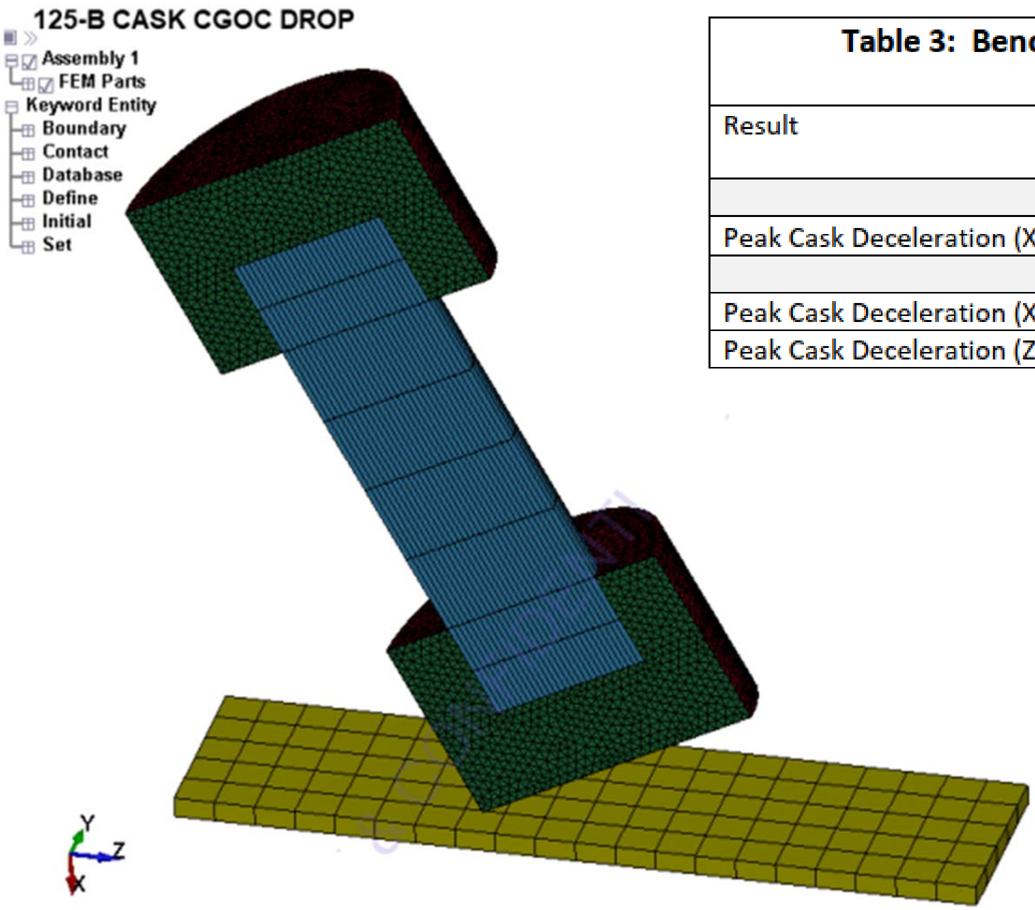
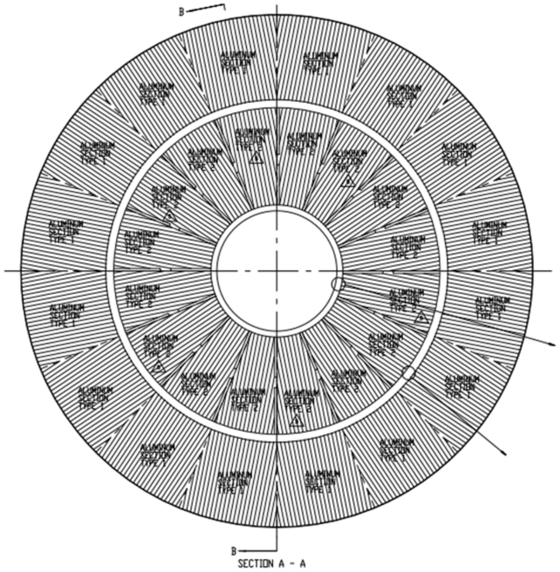


Table 3: Benchmark Comparison for NuPac 125-B Scale Model (9-Meter Side & CGOC Drops)	
Result	Percentage Difference between Physical Test Measurement and Numerical Prediction
Side Drop	
Peak Cask Deceleration (X-Dir)	-5.7%
CGOC Drop	
Peak Cask Deceleration (X-Dir)	2.8%
Peak Cask Deceleration (Z-Dir)	-6.3%

Source: HI-2210574 Rev. 1

Other Industry Examples (RSI-1)



- HI-STAR 100 (ca. 1995)
  - ❑ Aluminum honeycomb IL with stainless steel skin
  - ❑ Physical testing of ¼ -scale prototype (static and dynamic
  - ❑ Benchmarked non-linear LS-DYNA model
- HI-STAR 180/180D (ca. 2009-2014)
  - ❑ Aluminum honeycomb IL with stainless steel skin
  - ❑ No prototype testing
  - ❑ Uses benchmarked model from HI-STAR 100 (similar construction) as starting point for qualifying analysis
- HI-STAR 100MB Version SL (ca. 2021)
  - ❑ Aluminum honeycomb (uni-directional) & perforated aluminum IL with stainless steel skin
  - ❑ No free drop tests of prototype IL assembly
  - ❑ Static testing of 1:15 scale perforated aluminum ring segments
  - ❑ LS-DYNA model of perforated aluminum ring benchmarked against static test results

Other Industry Examples (RSI-1) (Cont.)

- Level of testing and benchmarking for HI-STAR PBT application exceeds that of HI-STAR 100MB Version SL
- Diversity of tests used to benchmark the polyurethane foam material is suitable for an isotropic material, especially considering the accuracy and precision of the numerical results

Proposed Resolution Path for RSI-1

- Enhance existing benchmark report (HI-2210574) and HI-STAR PBT SAR to further describe and justify benchmarking of polyurethane foam material

- Perform additional testing of polyurethane foam material, as necessary, to supplement current benchmark work
  - ❑ Component level vs. assembly level testing
  - ❑ Static vs. dynamic testing

Design of Impact Limiter Skin for HI-STAR PBT (RSI-2)

- Impact limiter skin is made from stainless steel material
  - True failure strain exceeds 100% (highly ductile)
- Crush strength of polyurethane foam increases monotonically with deformation
  - Foam is stiffer than aluminum honeycomb for comparable impact limiter design (same impact energy)
  - Deformed shape of HI-STAR PBT impact limiter is less than that of typical aluminum honeycomb impact limiters → less strain on IL skin
- Weld seam geometry can be further improved to provide more metal overlap and mitigate direct exposure of foam to HAC fire event

Current Results of Analyses & Observations from Testing (RSI-2)

- LS-DYNA drop simulations for HI-STAR PBT show no breach of IL skin, but weld seams are not explicitly modeled

- Drop testing of other packages with similar stainless steel enclosure (HI-STAR 100, NuPac 125-B) indicate that weld seams may fail at the point of impact where the impact limiter is permanently deformed

- SAR Chapter 3 contains thermal analysis of HI-STAR PBT package under HAC fire event which conservatively assumes a severe puncture of impact limiter enclosure and places fire flame boundary in close proximity to the cask (subject of RSI-3)

Proposed Resolution Path for RSI-2

- Improve geometry of weld seams for impact limiter skin to provide more metal overlap and mitigate the direct exposure of foam to HAC fire event following a 9-meter drop

- Perform additional LS-DYNA simulation for 1-meter puncture where the puncture bar strikes the top impact limiter at the same location postulated in SAR Chapter 3 for the thermal analysis of the HAC fire event
  - ❑ Show that the predicted damage to the top impact limiter is less than what is conservatively assumed in SAR Chapter 3

RSI-3 : Foam Specification and Properties

- Thermophysical properties of air and the foam used in thermal analyses are presented in Tables 3.2.2 and 3.2.5 of SAR.
  - Char properties assumed to be same as those of foam during 30-minute fire phase. This is reasonable since the amount of char is negligible compared to that of foam.
  - Air thermal conductivity assumed during postfire phase for foam and char.

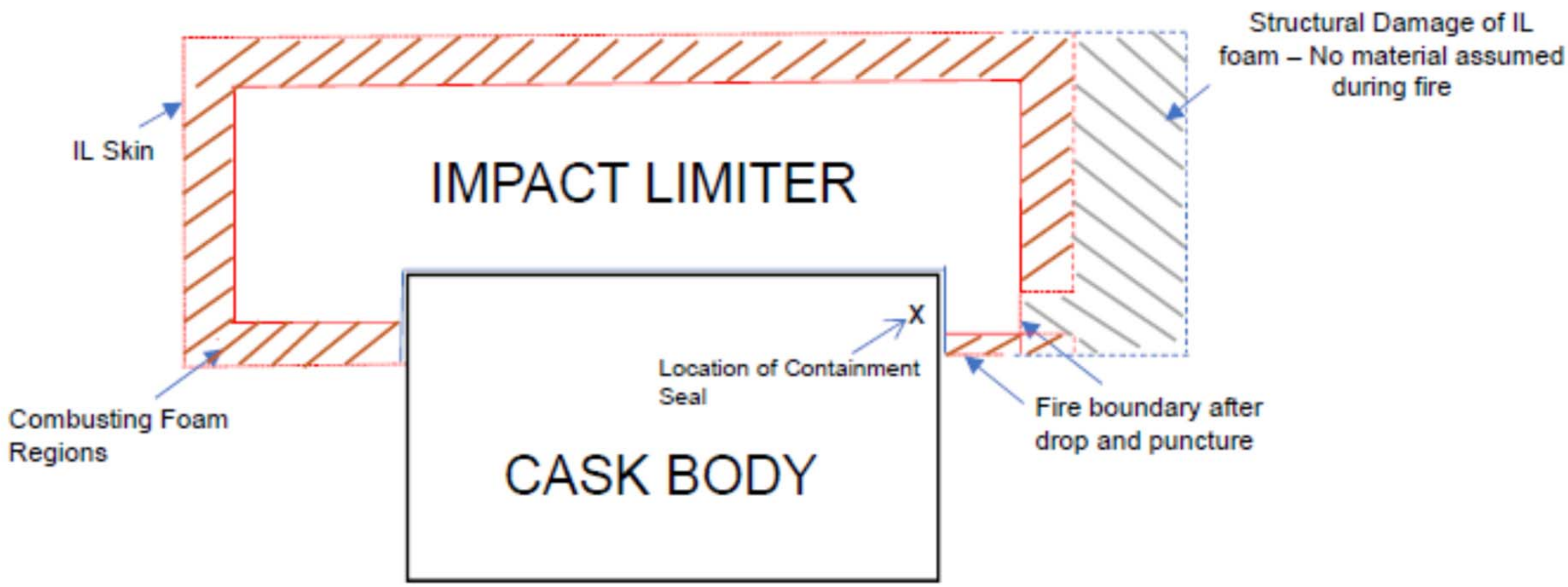
- Specification of the foam used in the HI-STAR PBT analyses will be presented in licensing drawings.
  - Connects the behavior and test results presented in the papers in HI-2200641 to those used in the thermal analyses.

RSI-3 : Thermal Evaluation of HAC

- Thermal Evaluation of HAC accident conservatively models cumulative structural damage to the foam after drop and puncture events.
  - ❑ Heat due to combustion of exposed foam is also included in thermal analysis.

- Square-shaped penetration purported from the puncture event is highly conservative based on structural assessment.
  - ❑ Documentation will be updated to provide the supporting structural assessment.

RSI-3: Schematic of Thermal Model for HAC



RSI-3 : Proposed Resolution Path

- Specification of foam will be presented in SAR/licensing drawings to provide clarity that the properties and behavior of foam adopted in the thermal analysis is consistent with the test data presented in the attachments of the thermal calculation package.

- The modeling methodology for thermal HAC analysis will be expounded using detailed figures to assist staff in the review.

- Callbacks to structural analyses will be made in thermal calculation package to justify the cumulative drop and puncture damage assumed in thermal analysis.