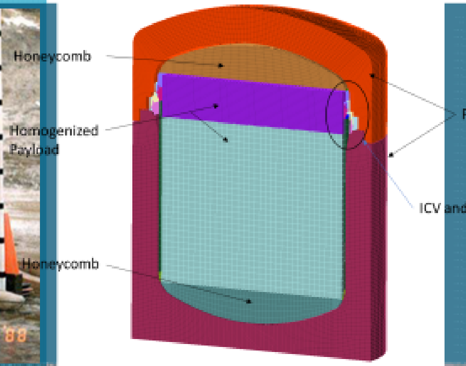
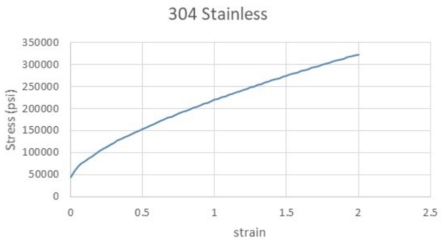
SAND2023-04244C

Response of the TRUPACT-II to Extra-Regulatory Impacts





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Presented by Doug Ammerman

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Introduction

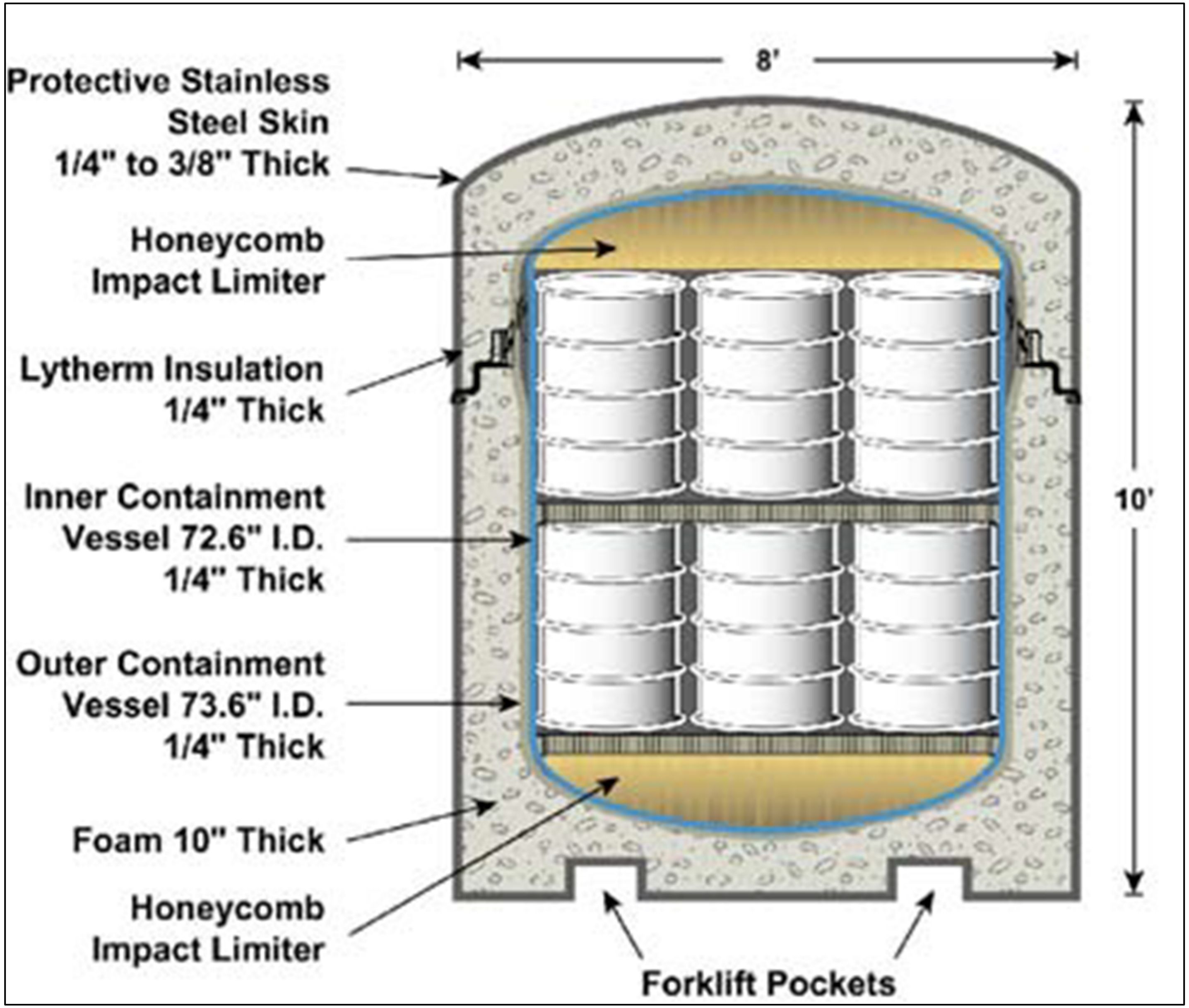
- Improvements in finite element analyses allow more difficult problems to be solved than has been possible in the past.

- Previous transportation analyses completed for the Waste Isolation Pilot Plant (WIPP) were not able to include analyses on the response of the TRUPACT-II to impacts that were more severe than that of the regulatory hypothetical accident sequence.

- In this work we analyzed the response of the TRUPACT-II to end-on, side-on, and CG-over-corner impacts at 30 and 60 MPH and an additional corner impact at 45 MPH.

- The 30 MPH impact analyses were compared to certification test results to calibrate the finite element modeling.

TRUPACT-II Package



Diameter: 94 inches (2.4 m)

Height: 122 inches (3.1 m)

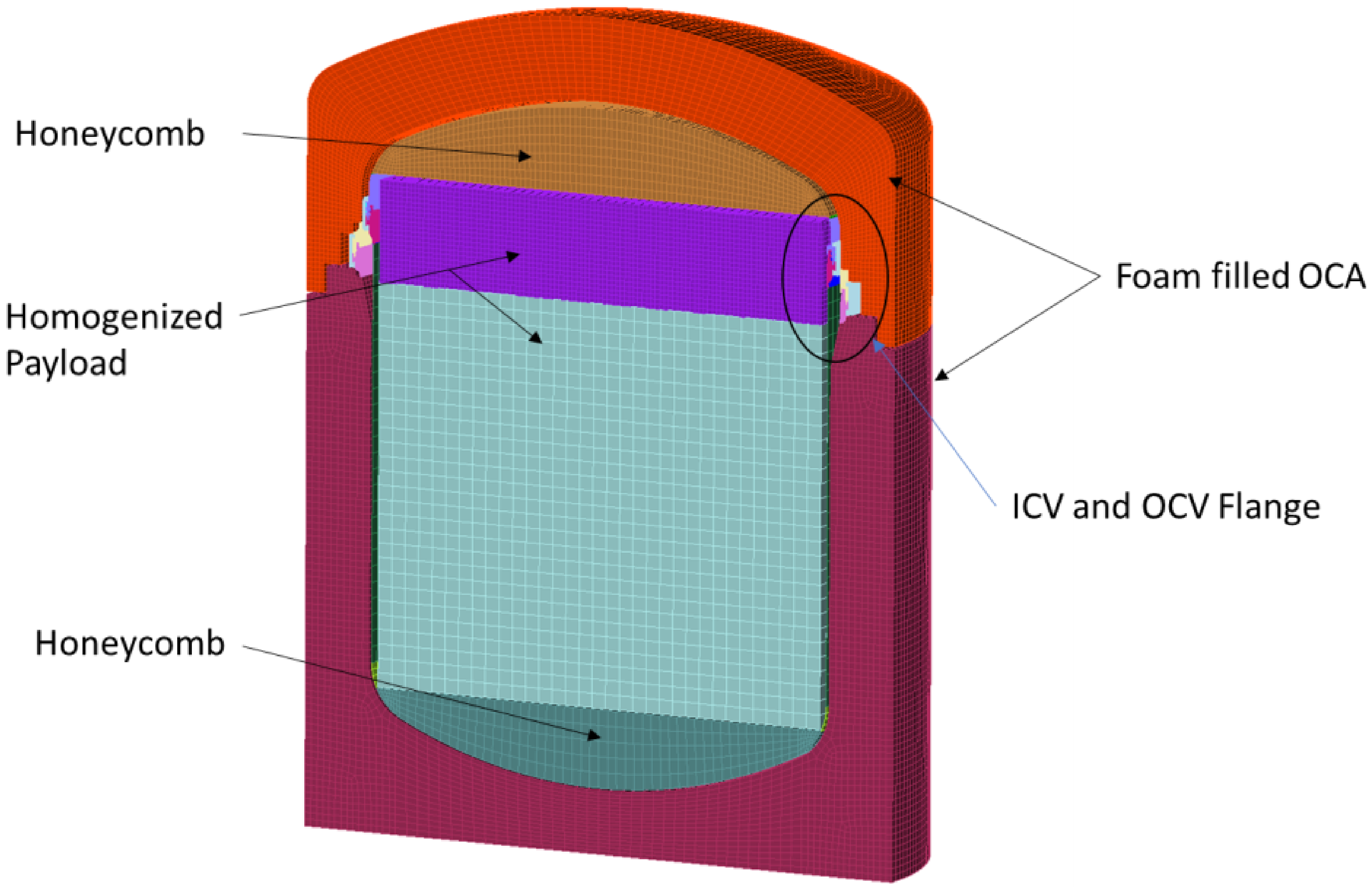
Loaded Wt: 19,250 lbs (8,730 kg)

Payload: 14 55 gal. (200 liter) drums

Vessel configuration: Internal Containment Vessel (ICV) and Outer Confinement Assembly (OCA)

Finite Element Model

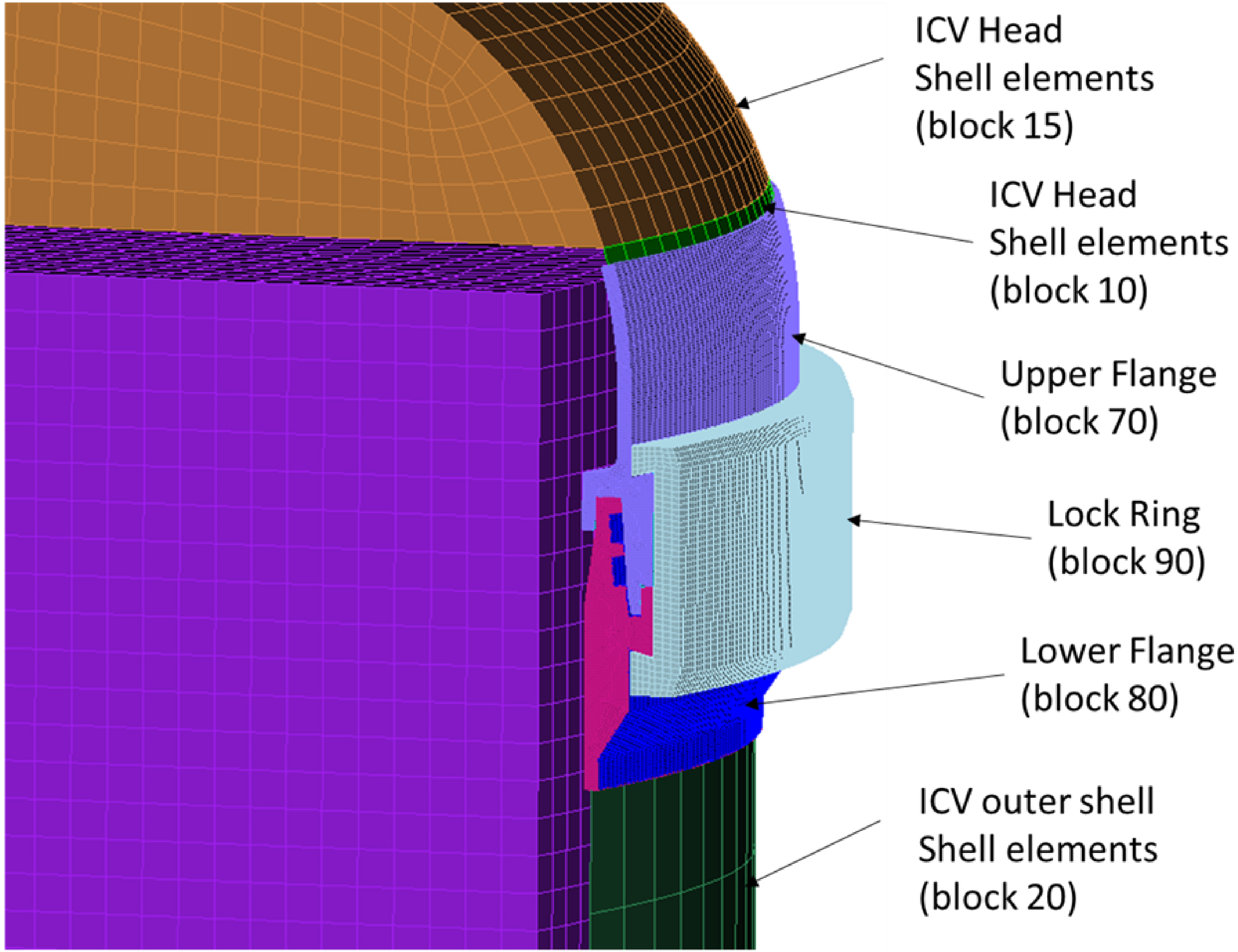
- Individual payload containers and contents are homogenized.
- Symmetry of design and loading allowed a model of only ½ of the package.
- Model contains 2,780,089 elements.



Details of the closure region of the ICV

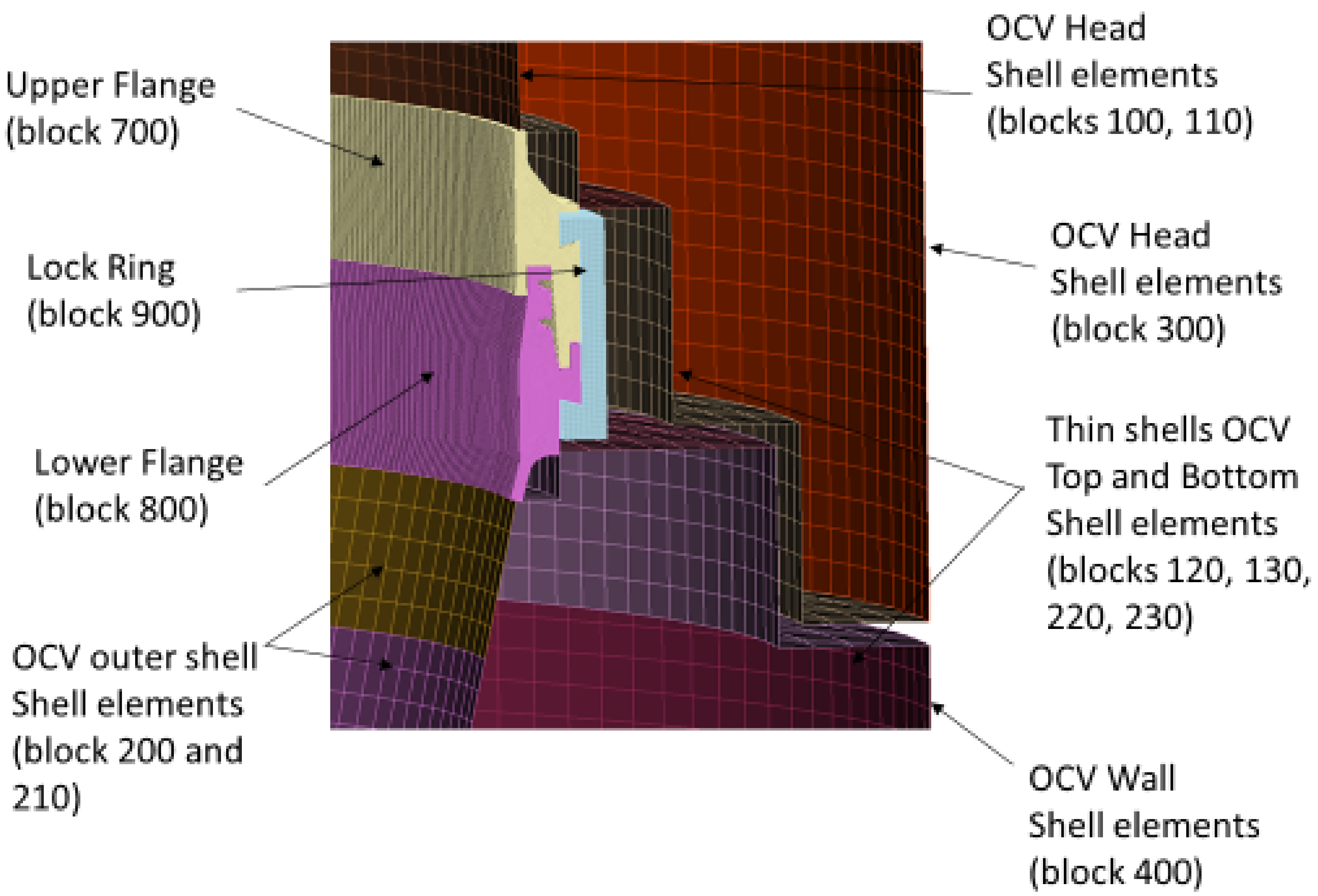
- Away from the locking ring, loss of containment will be the result of tearing in the shells.

- This phenomenon is adequately predicted with a relatively coarse mesh of shell elements.



Details of the closure region of the OCA

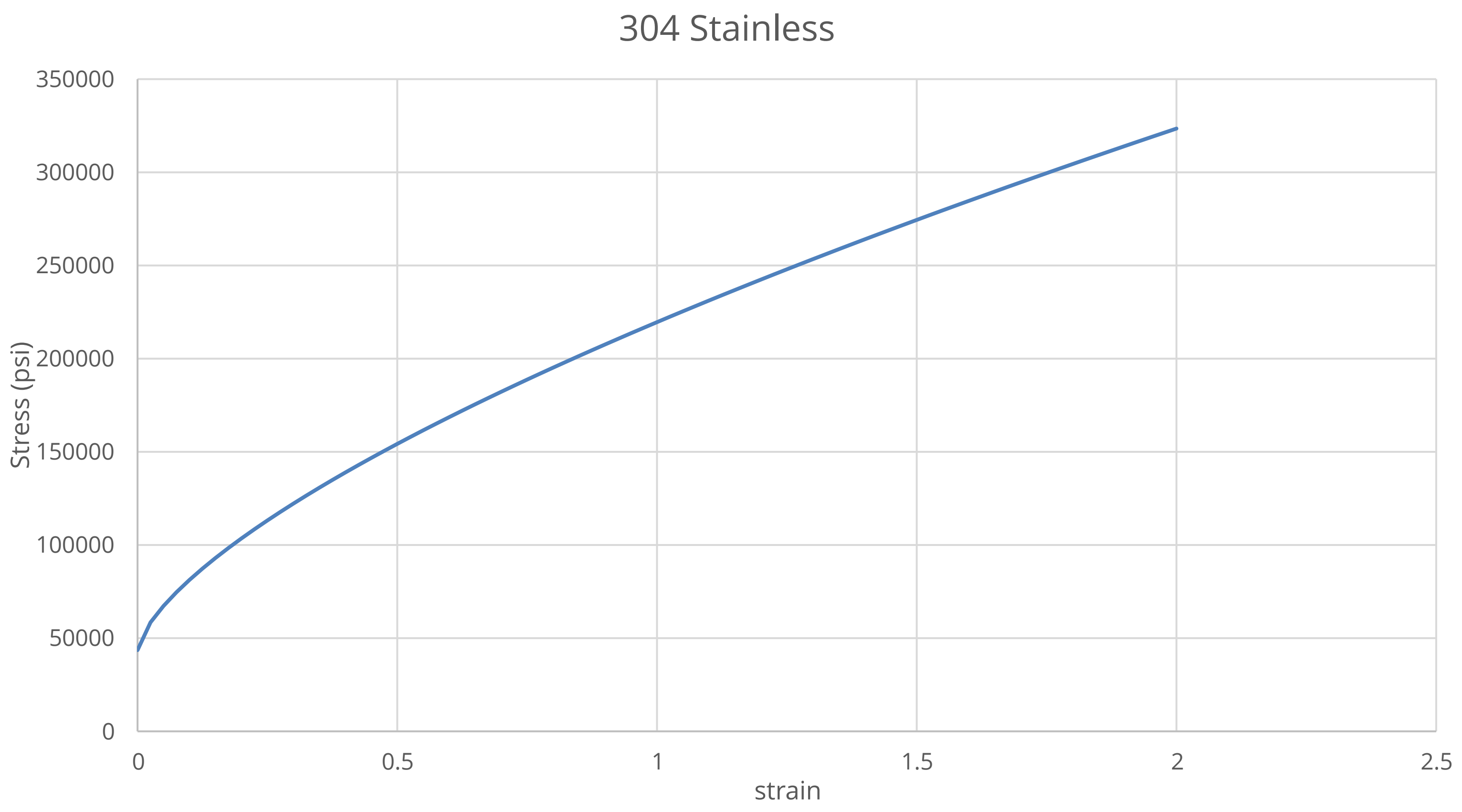
- In the region of the locking rings a more detailed mesh of hexahedral elements is required to accurately capture the interfaces between the different parts and the relative motion between them that could result in leakage through the joint.



Material Model – Stainless Steel Components

- The shells and flanges of the ICV and OCA are all made of 304 stainless steel.

- This material was modelled with a multi-linear Elastic-Plastic hardening model.



Modeling of Failure of the Stainless Steel

- Material failure based on Appendix FF of the ASME Boiler and Pressure Vessel Code is assumed.

- $[(TF)(\varepsilon_{eq}^{p})]_{max} \leq [\varepsilon_{uniform} + 0.25(\varepsilon_{fracture} - \varepsilon_{uniform})]$

- ε_{eq}^{p} is the equivalent plastic strain
- $\varepsilon_{uniform}$ is the true strain at the onset of necking in a uniaxial tension test
- $\varepsilon_{fracture}$ is the true strain at fracture

- $TF = \frac{(\sigma_1+\sigma_2+\sigma_3)}{\sqrt{\frac{1}{2}[(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2]}}$

Material Model – Rigid Polyurethane Foam

- The layer between the OCA outer shell and the OCA inner shell is filled with 8.25 lb/ft^3 polyurethane foam.
- It is modelled using the Low-Density Foam model.
- This model was based on decomposition of the foam response into two parts:
    - (1) response of the polymer skeleton
    - (2) volumetric response of the air inside the cells
- The foam material is very compliant and the high velocity impacts of the extra-regulatory analyses can generate large distortions in the foam elements.

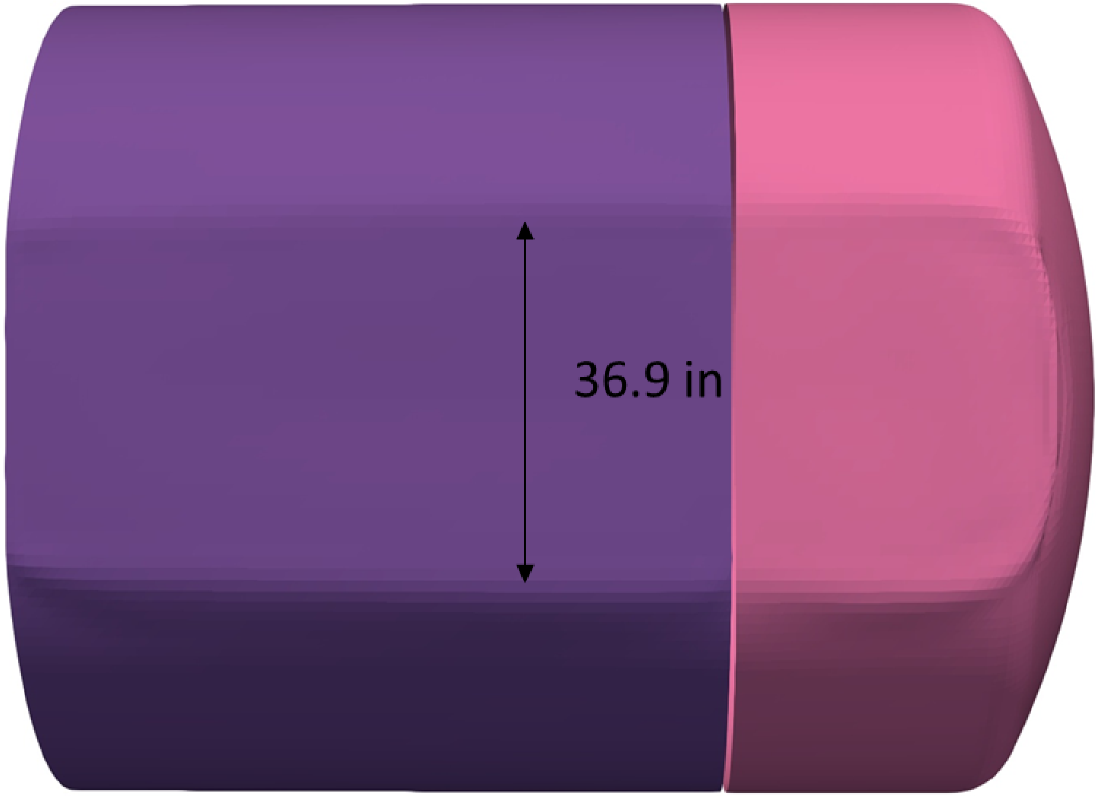
Modeling Failure of the Foam

- Foam elements that meet any of the following criterial are deleted from the model:
  - element inversion
  - nodal jacobian ratio <= 0.0
  - solid angle <= 0.0
  - timestep < 2.5E-08

- These criteria can remove a large number of elements from narrow regions of the impacted foam.

- Deleting these elements can cause higher, more localized loads to be transmitted to the ICV.

Model Validation with 30 MPH Impacts (side-on)

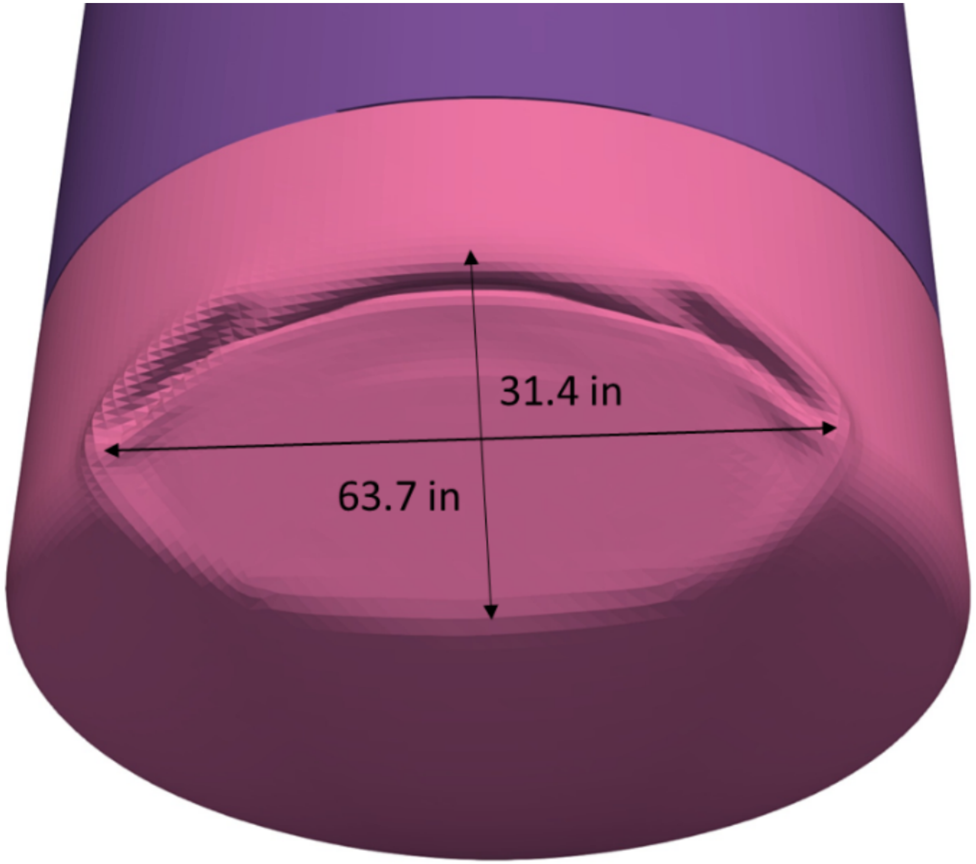


36.9" wide flat at top (OCA lid) × ~**3.75**" deep

37" wide flat at top × ~**3.63**" deep

Model Validation with 30 MPH Impacts (CG-over-corner)

30" wide × 53" long flat at top (OCA lid) × ~3¾" deep



31.4" wide × 63.7" long flat at top (OCA lid) × ~10" deep

Model Validation with 30 MPH Impacts (end-on)

53" diameter flat at top (OCA lid) × ~3¾" deep

64" diameter flat at top × ~5.3" deep

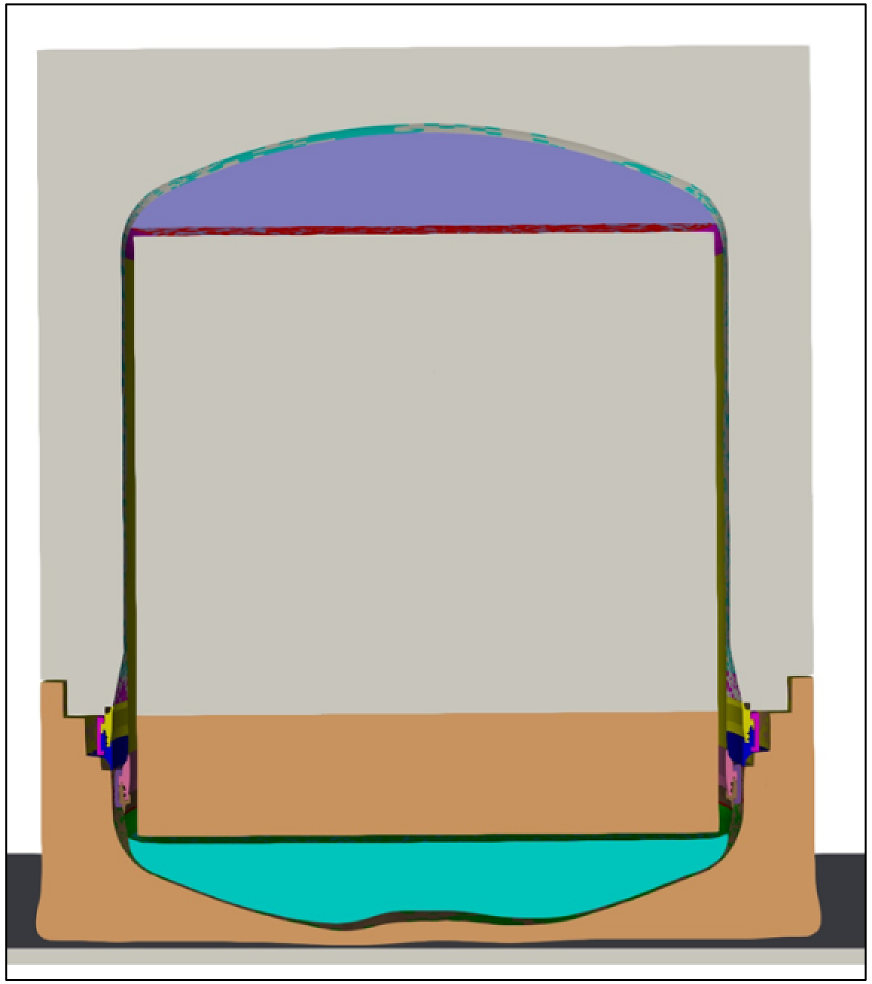
Discussion of Model Validation Analyses

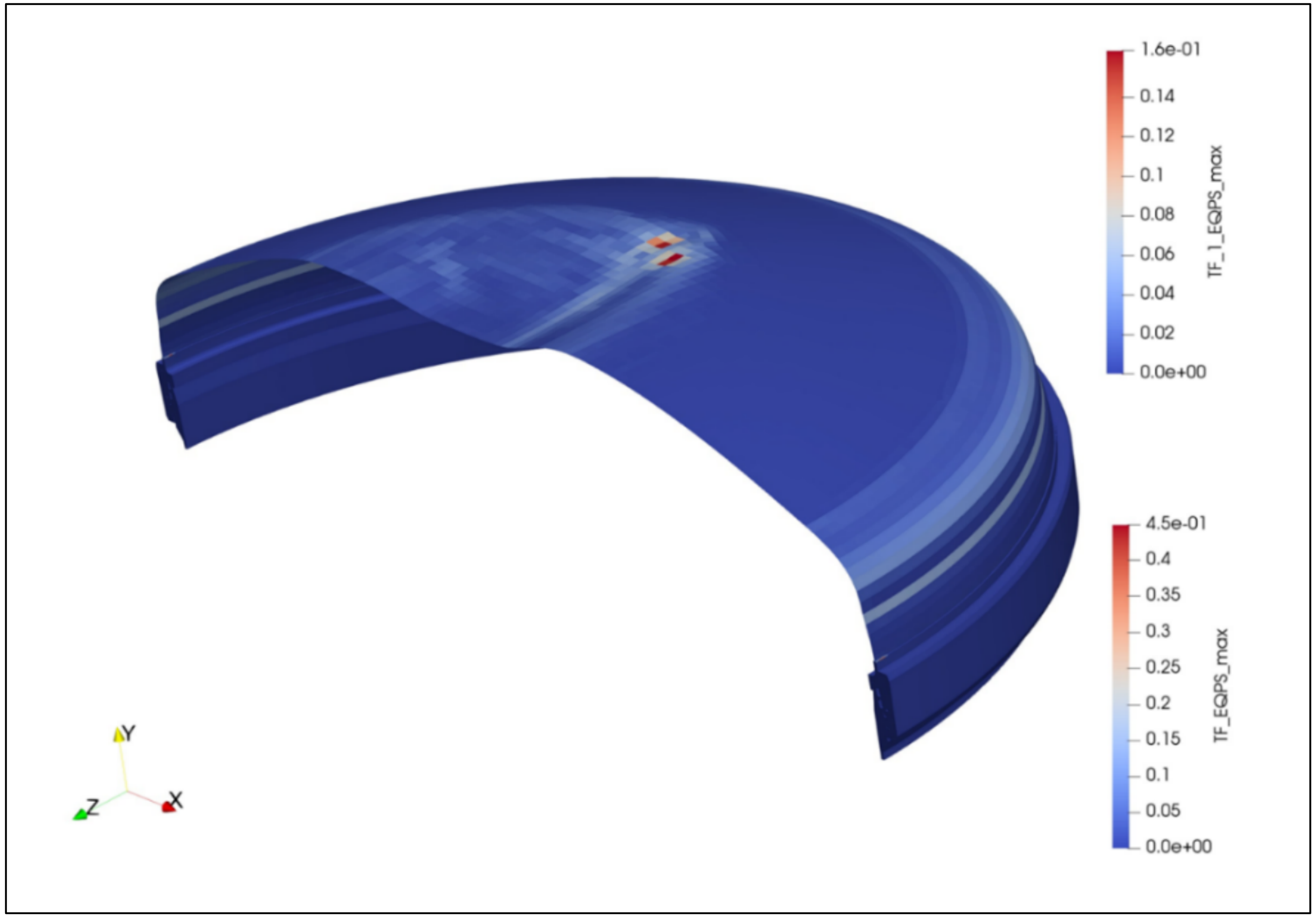
- For the side impact orientation, the analysis shows good agreement with the test deformation and measurements in both width and depth.
- For the end impact orientation, the model has a larger impact diameter and crush than the test results (64.9 x 5.3 inches versus 53 x 3.74 inches). This indicates that the model foam material in the parallel to rise direction is slightly softer than the foam material in the test units.
- For the corner impact the model also slightly over-predicts the crush footprint (31 x 63.7 inches versus 30 x 53 inches). The geometry of the package suggests the crush depth for the corner impact test should have been about 8 inches, rather than the reported 3.75 inches, only slightly less than the 10 inch model results.

Extra-Regulatory Impacts

- Four impact analyses were performed to determine the TRUPACT-II response to extra-regulatory impacts.
- Three analyses were performed in the top, side, and CGOC orientations at an impact velocity of 60 MPH.
- The structural integrity of the ICV was used to determine whether the package remained leak tight.
- The limits developed for the ASME strain-based criteria were used as a failure criterion for the potential rupture of the ICV.
- A fourth analysis was performed in the CGOC orientation at an impact velocity of 45 MPH.

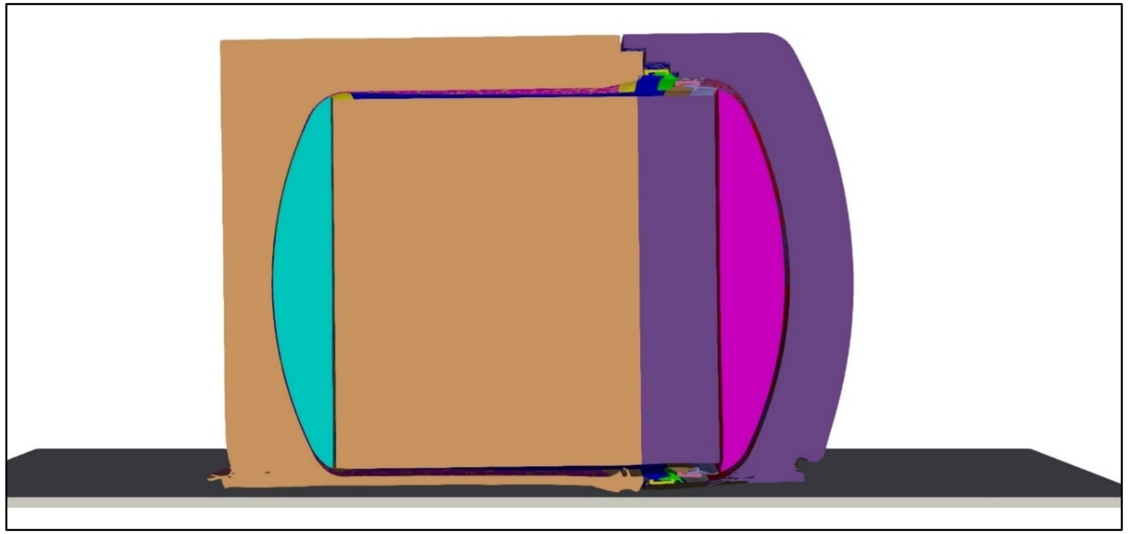
60 MPH Top Impact

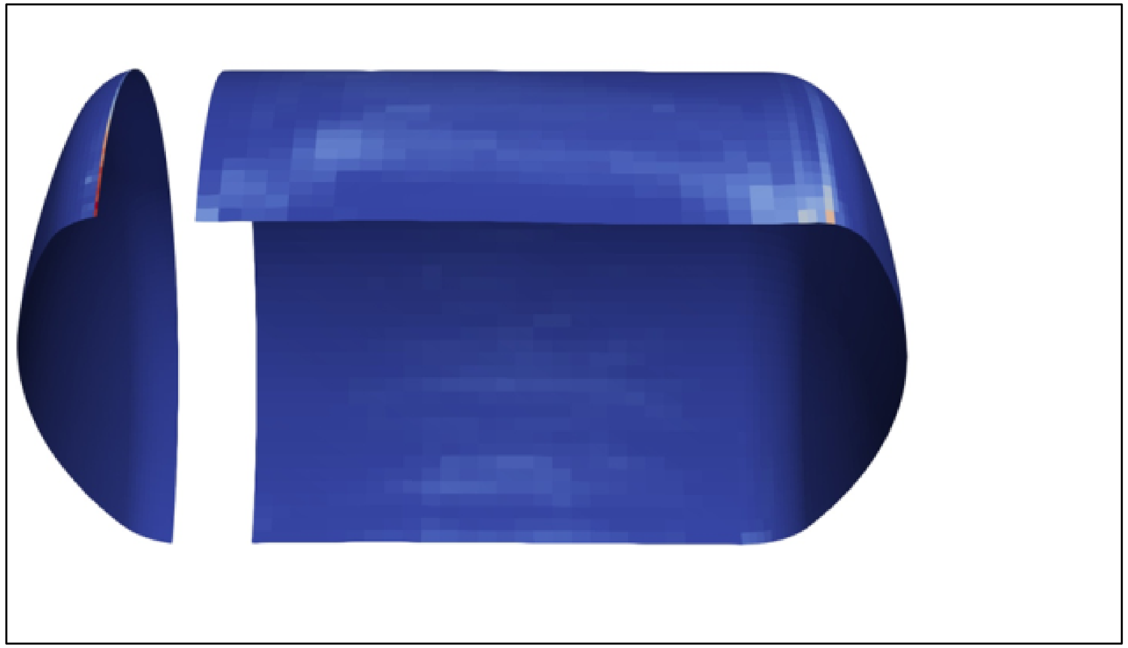


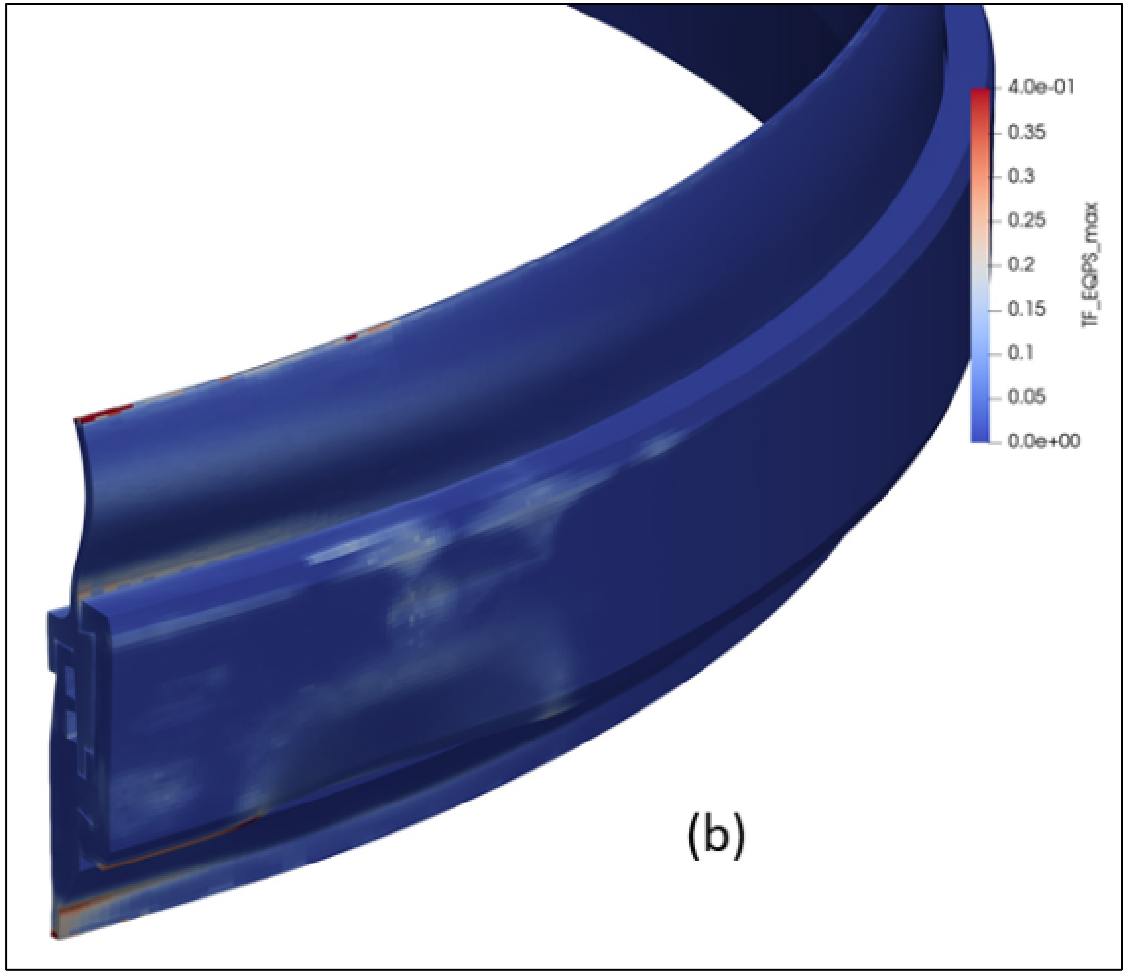


Results indicate the ICV will survive this impact.

60 MPH Side Impact

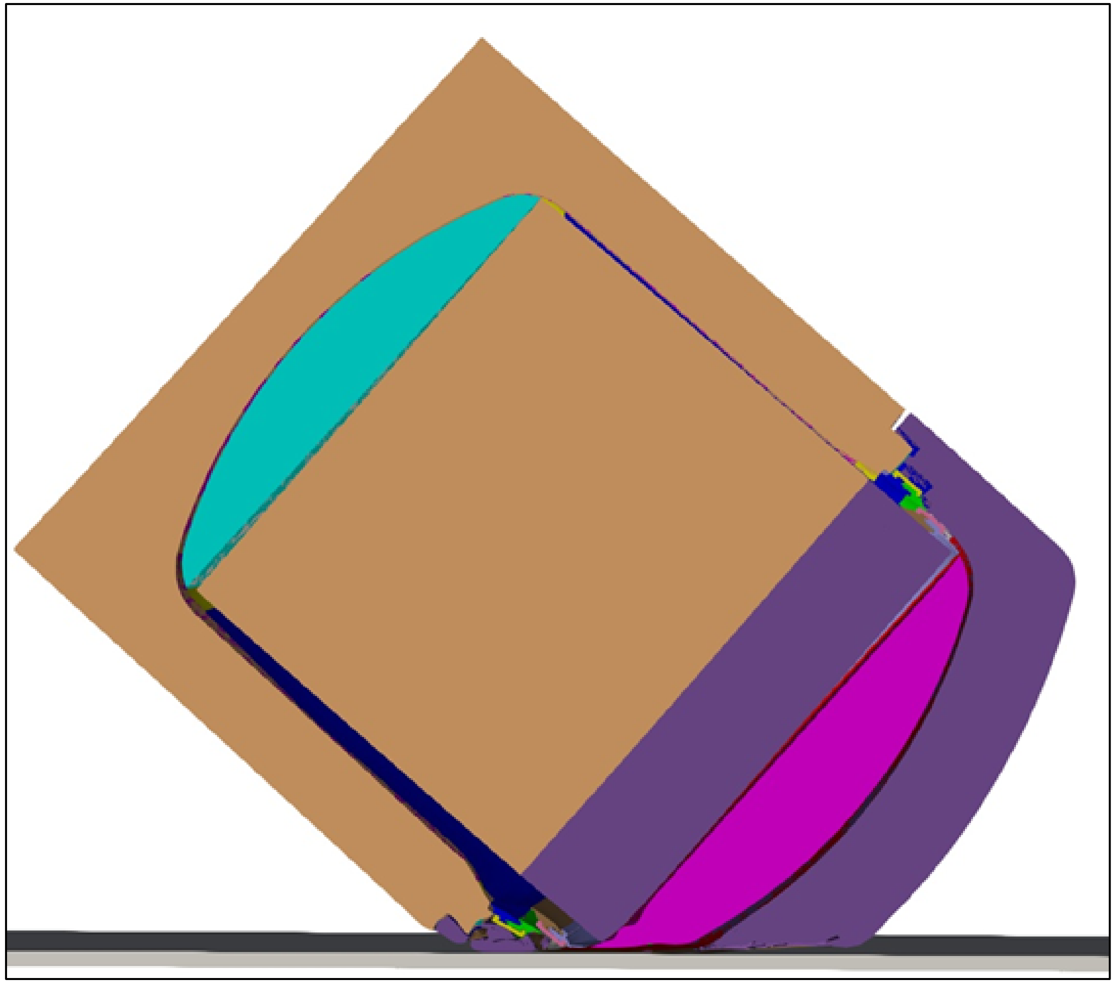


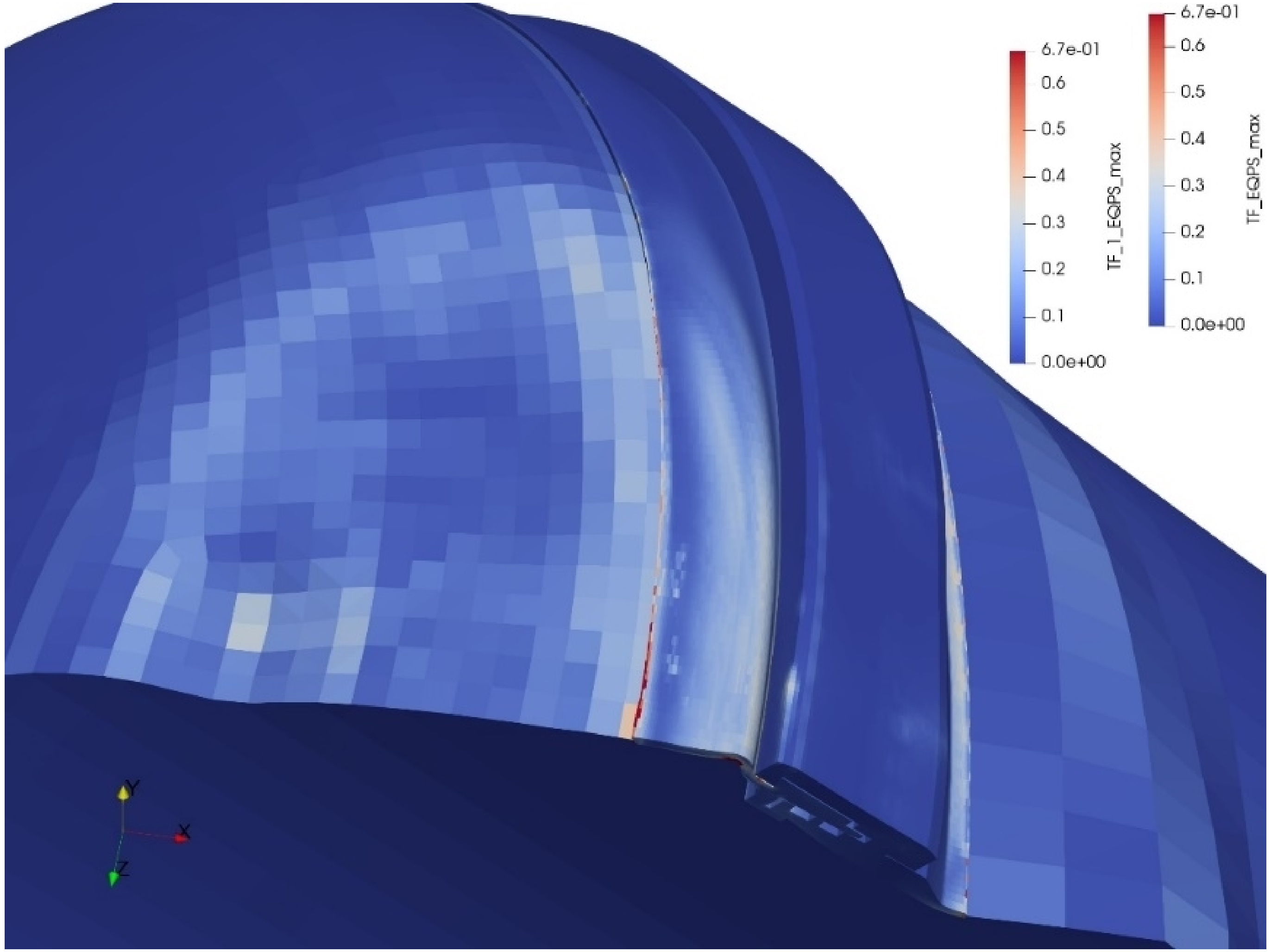




Results indicate the ICV will survive this impact.

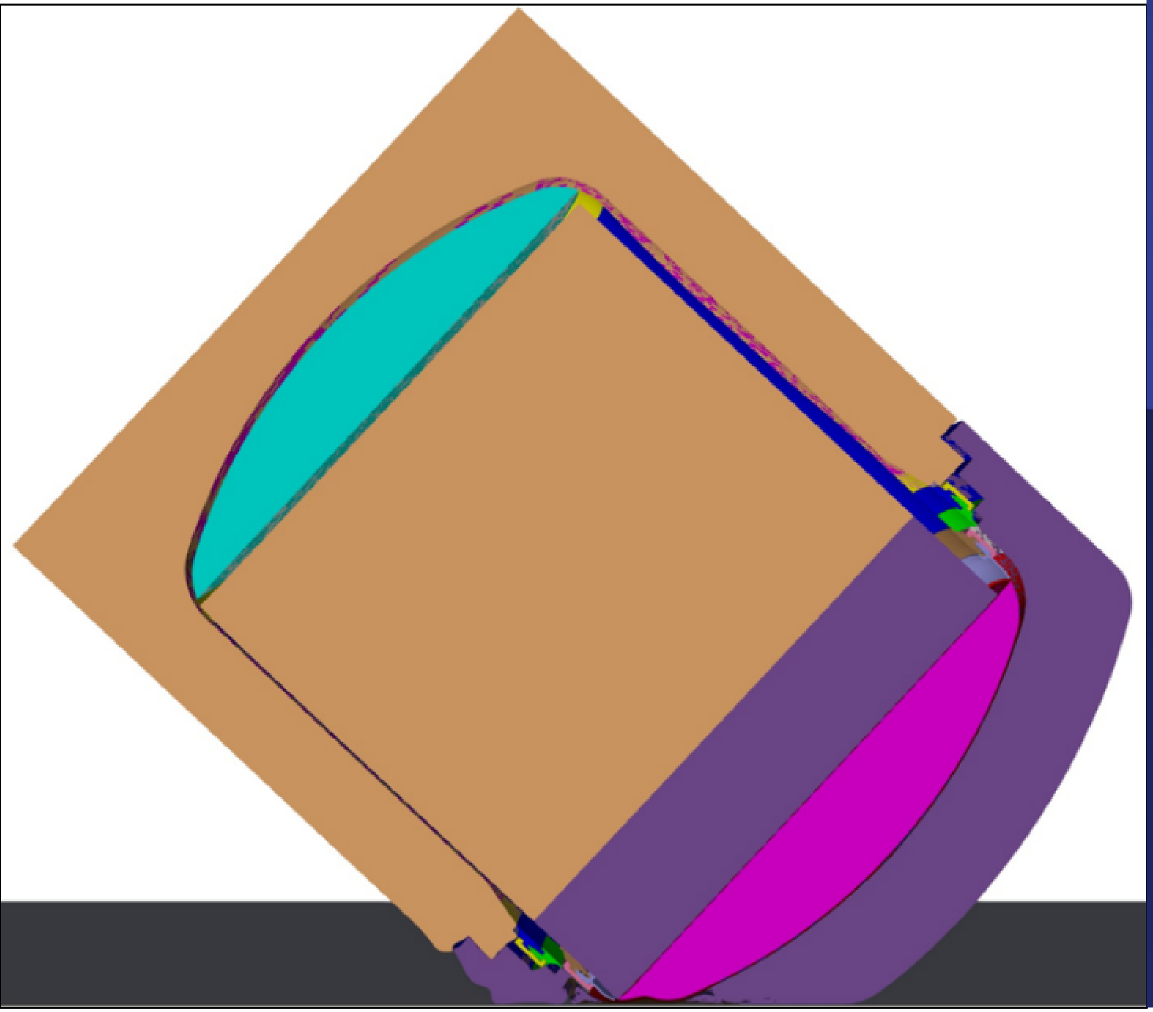
60 MPH Corner Impact

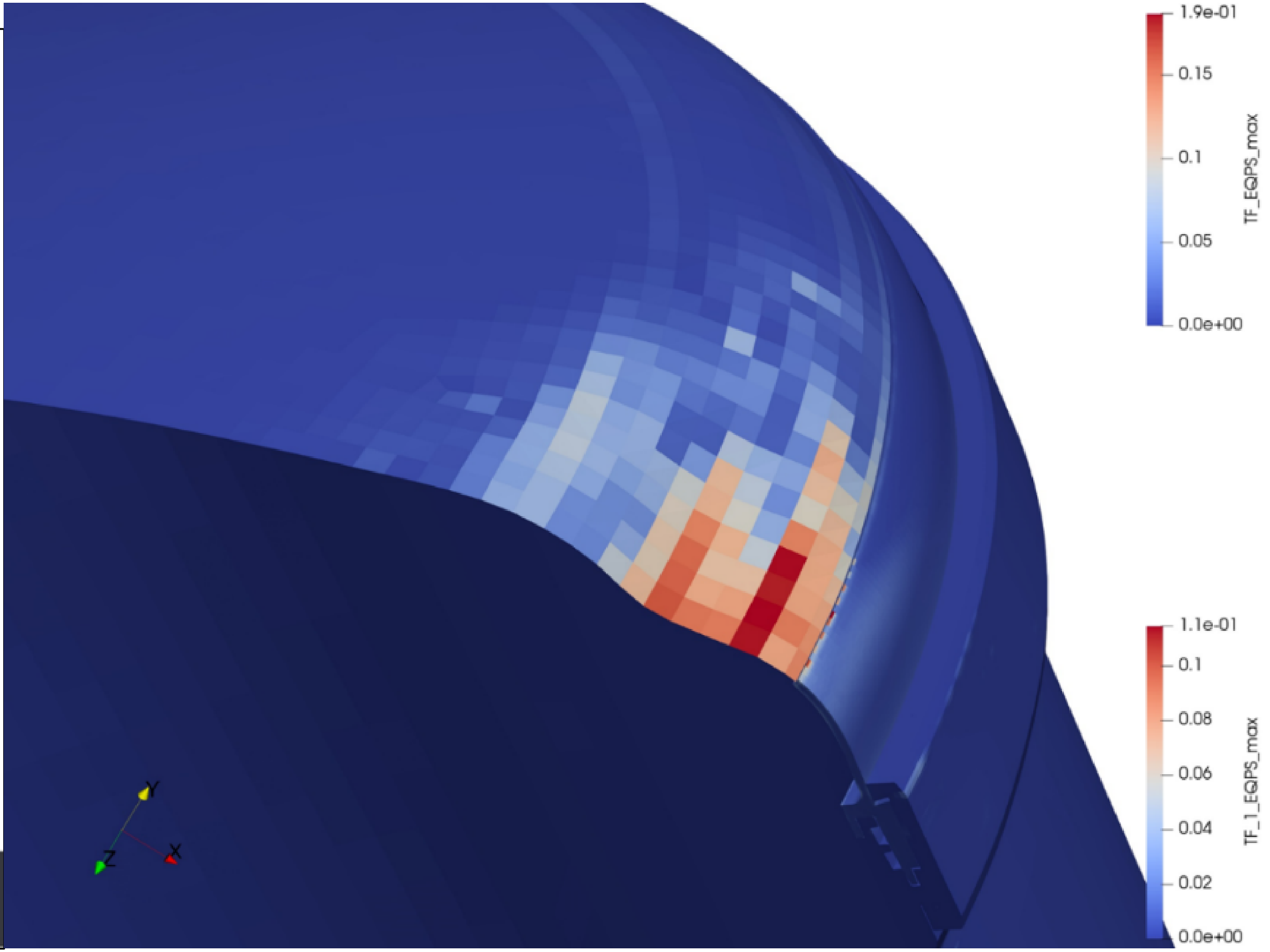




Peak product of plastic strain times triaxiality factor is larger than ASME failure criteria indicating the ICV may not survive this impact.

45 MPH Corner Impact





Results indicate the ICV will survive this impact.

Conclusions

- Seven structural analyses were conducted of the TRUPACT-II package as part of the WIPP Transportation Assessment.
- The first three were to calibrate the model by comparing the model results to the certification free drop tests.
- These analyses showed good agreement with the deformation produced during the tests.
- Four additional analyses were performed to determine the package response to higher impact velocities.
- These analyses focused on maintaining the integrity of the ICV, using the ASME strain-based failure criteria.
- The ICV would remain leak tight for 60 MPH top and side impacts.
- In the CGOC orientation, the ASME strain-based criteria showed that a break in the ICV flange may occur.
- An additional analysis demonstrated the ICV would remain leak tight for a 45 MPH impact in the CGOC orientation.