TO: **Phil Heitzenroeder**
FROM: **Steve Raftopoulos**

DATE: **September 13, 2008**

SUBJECT: **Cryostat Design & Fabrication: 9450-1***-1701**
Cryostat Procurements: 9450-1*-1705**

<u>Scope</u>

This elements cover design and fabrication (1701) and M&S (1705) for the NCSX Cryostat, which is an insulating, semi-hermetic structure required to maintain a ~77Kelvin cryogenic environment around the NCSX device.

The scope included design, prototyping and fabrication (or procurement of vendor fabricated components).

<u>Status</u>

The Cryostat design had evolved through several iterations is currently considered in the conceptual phase.

The first version , described as Tub-Panel consisted of fiberglass " tubs", that were filled with insulating material, bolted together to form the cryostat structure. The design incorporated pliable foam between tub panels to provide a compliant, semi-hermetic seal that would function at LN2 temperatures. Due to high fabricating cost, and little fabricating vendor interest, this design was abandoned.

The second design concept, which was not developed further developed in CAD, consisted of a system of G-11 boards with a 6-inch layer of foam panel insulation (six, one-inch thick boards laminated to each other to form a stepped pyramid shape). The panels are supported on a light, inexpensive space frame and pliable (solomide) foam is used to seal joints between panels. Although considerably less expensive and easier to custom fabricate in the field, the main drawback of this design is the significant use of open cell foam to provide seals between panels.

The third concept was being developed when the project was terminated. Based on feedback from external cryogenic experts, we were adopting a strategy that prototyping the seal design (between adjacent removable panels), was a critical step prior to detailing those elements. Prototype test fixtures were being developed so that various insulating/seal concepts could be validated. Parallel to this effort, the System Integration Engineer was designing the inner and outer boundaries of the cryostat, and interfacing this design with present design of other NCSX systems. The degree of panelization of the cryostat was also being examined in an effort to reduce the number of panels.

Interfaces
The Cryostat interfaces with the entire NCSX – Everything is either within or passes through the cryostat. Specific system that pass through the cryostat include, the coil buss systems, LN2 supply for Coil cooling and structure cooling, vacuum vessel ports, cabling for power, signal and instrumentation.

Specifications
A draft B_SPEC (NCSX-BSPEC-171-00-dB) was developed and was being updated as the requirements and design were evolving. A copy is posted on the NCSX Engineering Web.

Schematics and PIDs
N/A.

Models
Models of the cryostat concept are posted in Intralink. Several recent conceptual ideas for a cryostat shell and prototype text fixture are attached to this close out note. These include a report from a March 2007 Working Group, a design concept proposed by ORNL, and a prototype test fixture also proposed by ORNL.

Drawings
No detailed drawings were generated

Analyses
An FEA thermal and stress analysis of the Tub panel design was prepared for the April 2005 preliminary design review and the results are tabulated in that PDR report. However, this design has now been superseded.

In addition, several analyses presentation of proposed design configurations are also attached and include a report from a March 2007 working group, a support thermal analysis, and a shell temperature distribution analysis.

Testing
Other than dunk-testing (in LN2) of a couple of candidate boot seal materials, no other tests of significance were performed.

Costs
Cost estimates were being developed for the conceptual and preliminary phases of the design. These are available through the project office.

Remaining Work
- Evaluate and determine best compromise between high degree of panelization (many small panels that allows access) vs. smaller number of larger cryostat sections (increases cryostat reliability).
- Prototype and test sealing options.
- Design cryostat shell.

Lessons Learned:

- Incorporate the help of the cryogenic community sooner in project

Conclusions:

- The success of the cryostat as an operating system will be largely determined by the integrity of the sealing mechanism between joints. After this challenge is met, designing the shape around the NCSX will be straightforward.
- In mid-April 2005, a preliminary design review of both the cryogenics and cryostat was conducted. The design presented at this review was subsequently revisited. A copy of the material presented at this review is posted on the NCSX Engineering Web under the Design Review tab (marked as superseded).
- A peer review of the cryostat systems was conducted in late April 2008 with a team of cryogenic systems experts. This is posted on the NCSX Engineering Web page under the Design Review tab. The concept presented at this peer review reflects the current design concepts at the time of NCSX Project termination.

Cryostat Design Concepts Following the 2005 PDR

- **March 2007 Working Group Presentation**
- **May 2008 Cryostat Design Concept (ORNL)**
- **May 2008 Cryostat Prototype Test Fixture Concept (ORNL)**

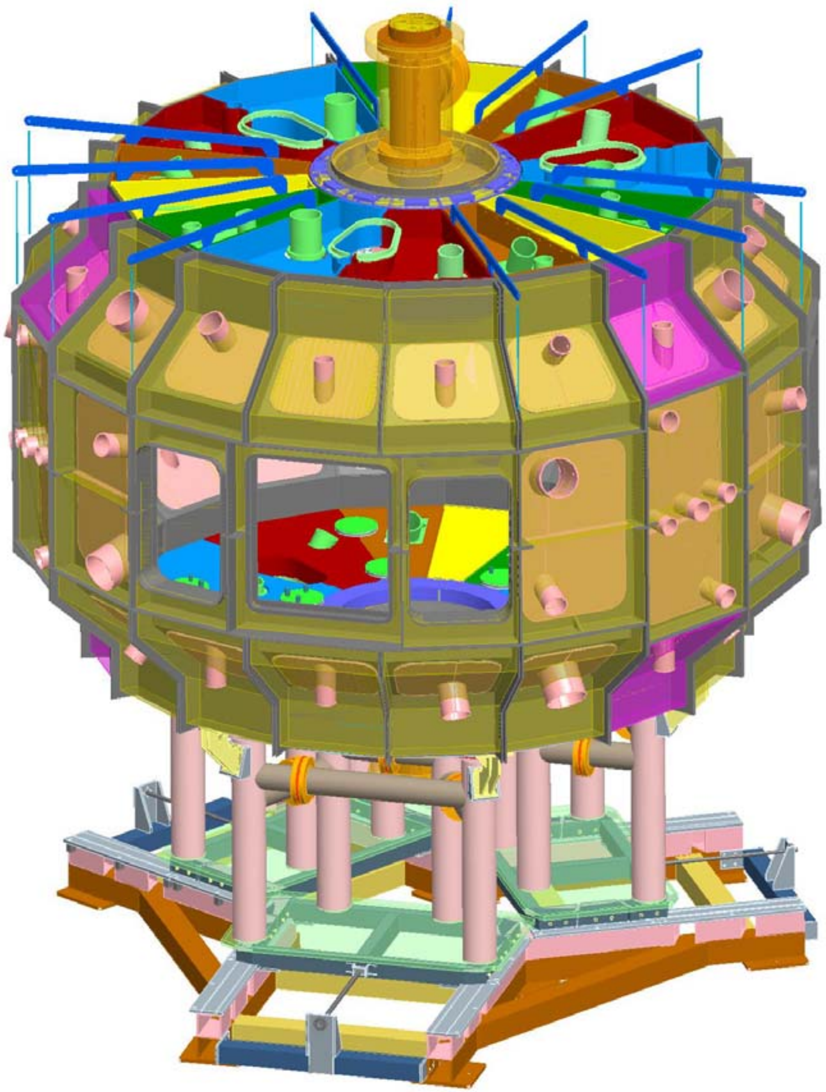
Cryostat Architecture WG

March 15, 2007

WG Scope

- This is not a design review.
- This is a “free thinking” session.
- A concept will be shared.
- PLEASE improve it with your ideas.
- PLEASE leave your managerial roles at the door.

April 22, 2005 Cryostat



It's complicated.

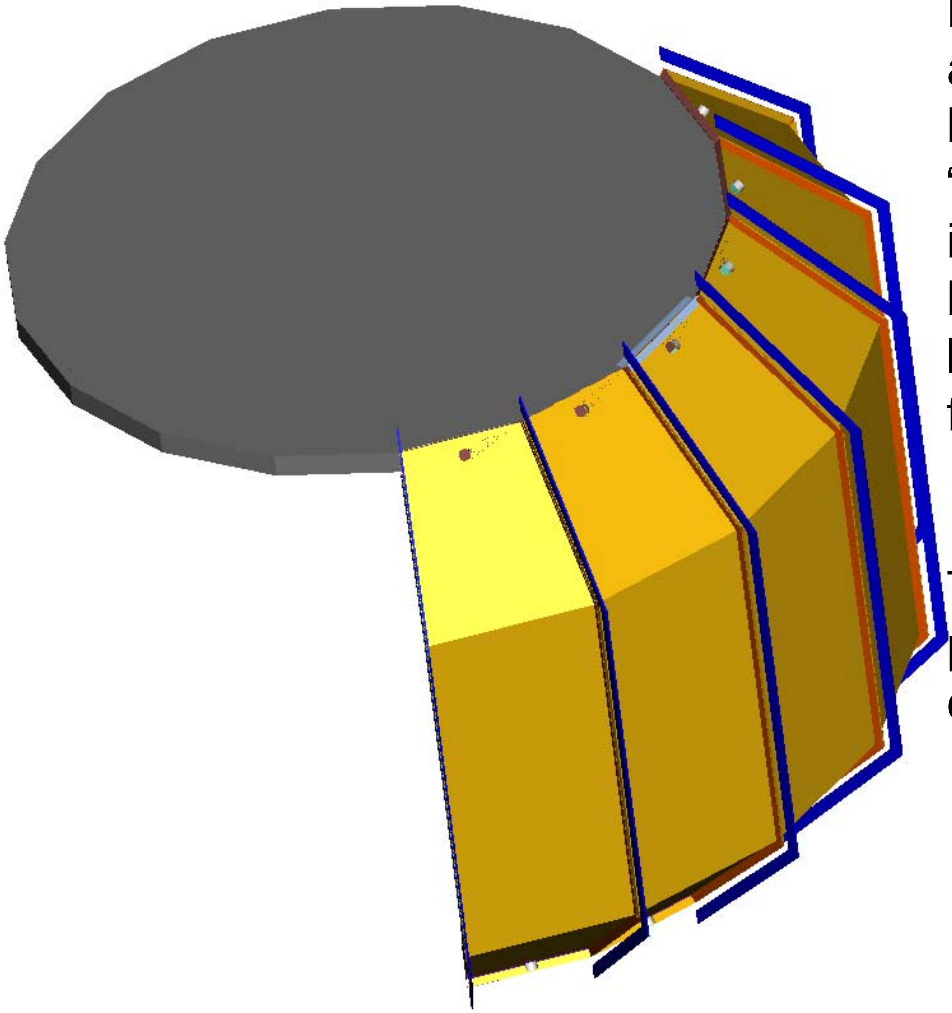
It's expensive.

The volatility factor for this estimate must be huge.

There were only seriously weak responses to the FedBizOps disclosure.

Note: Panel covers and insulation are not shown

A Better Approach?



Rushinski, Zarnstorff, and Gettelfinger have been wrestling with “bags” of loose insulation bridging between upper and lower disks of urethane foam.

This design assumes no port extensions at TF coils.

Panel Fabric

Panels (bags) are made of thermo-sealed urethane with integral Kevlar or Nylon mesh.

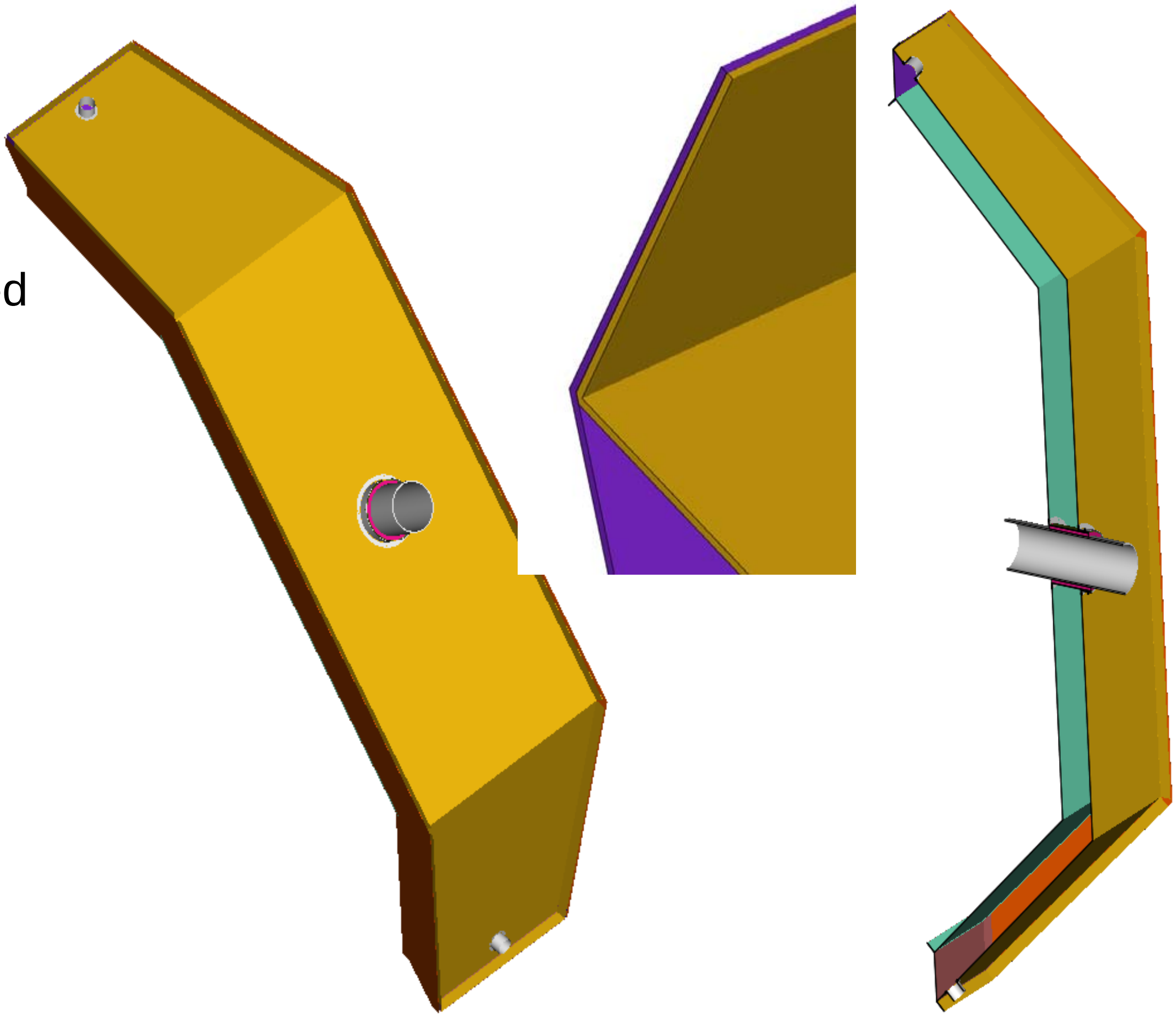
This is a seasoned, Mil-Spec industry.

Fabric has survived "Ho Ho" dunk test; joint scraps are "in the mail" for testing

Individual Panel

6” gap is filled with loose insulation.

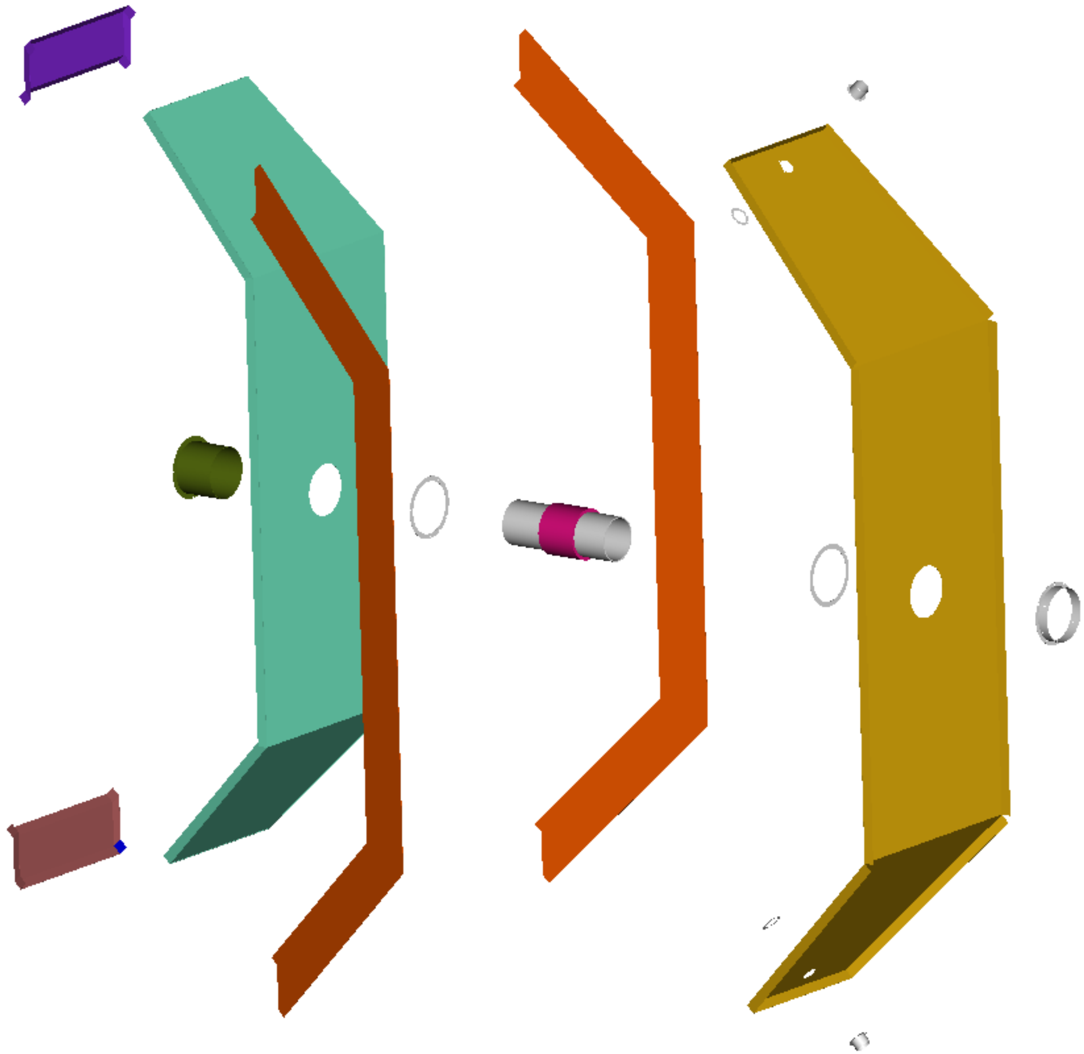
Internal tension ties are provided to maintain 6”.



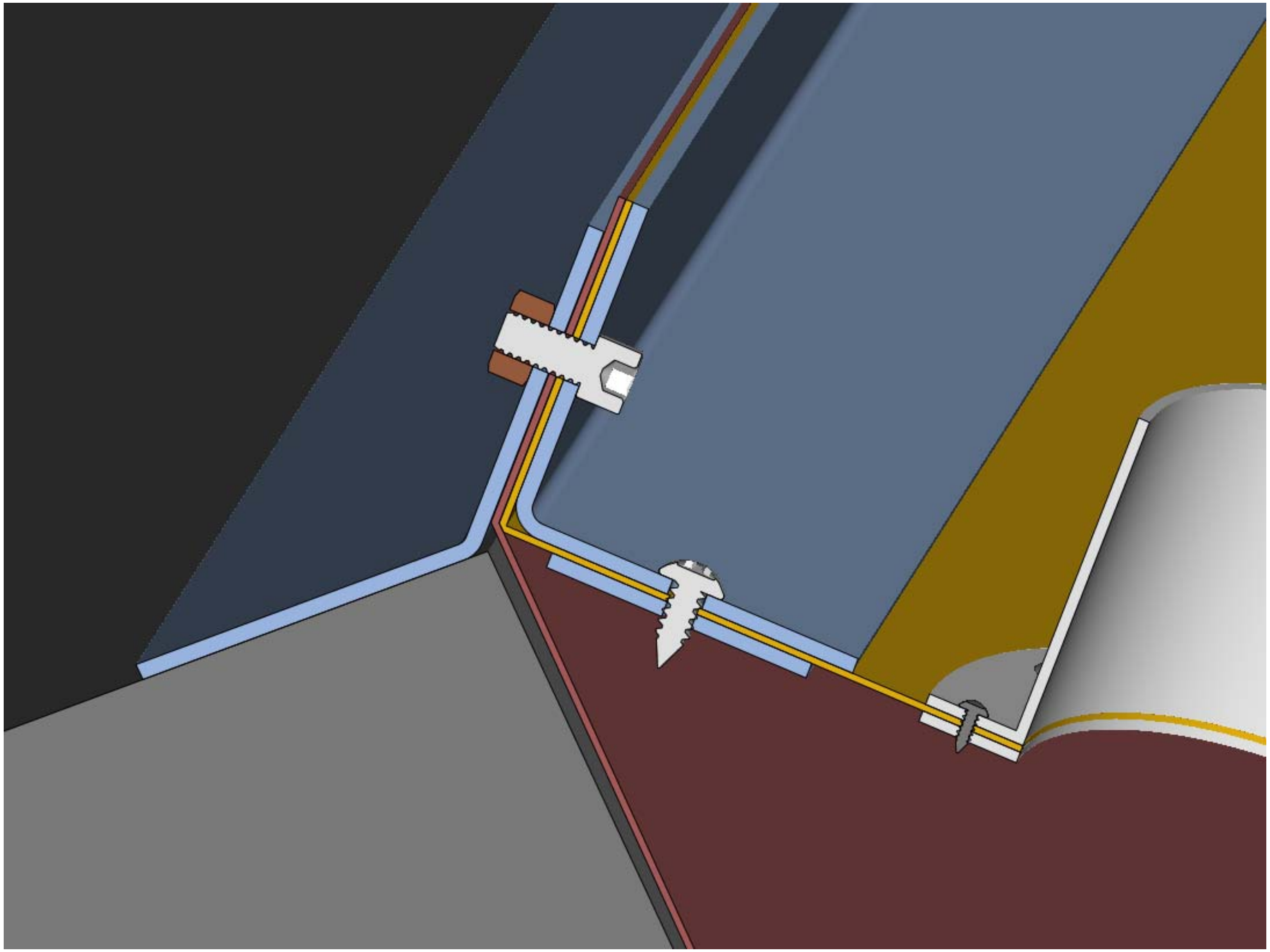
Insulation Comments

- k stagnant 77K gas - 7.23 mW/m-K
  - Damn good if you can keep it still
- k aerogel 280K - 18 mW/m-K
  - Best solid insul you can buy
- k urethane foam - 33 mW/m-K
  - bad CTE (Space Shuttle)
  - PPPL techs have developed laminating/shingling method that accommodates the cracking problem
- Cabot Nanogel
  - Used to insul LNG supertankers
  - NCSX's 14 m**3 is a "small" quantity
  - $4.5k/m**3 for non-IR coated
  - $9.0k/m**3 for opacified IR transmission-resistant version

Exploded View



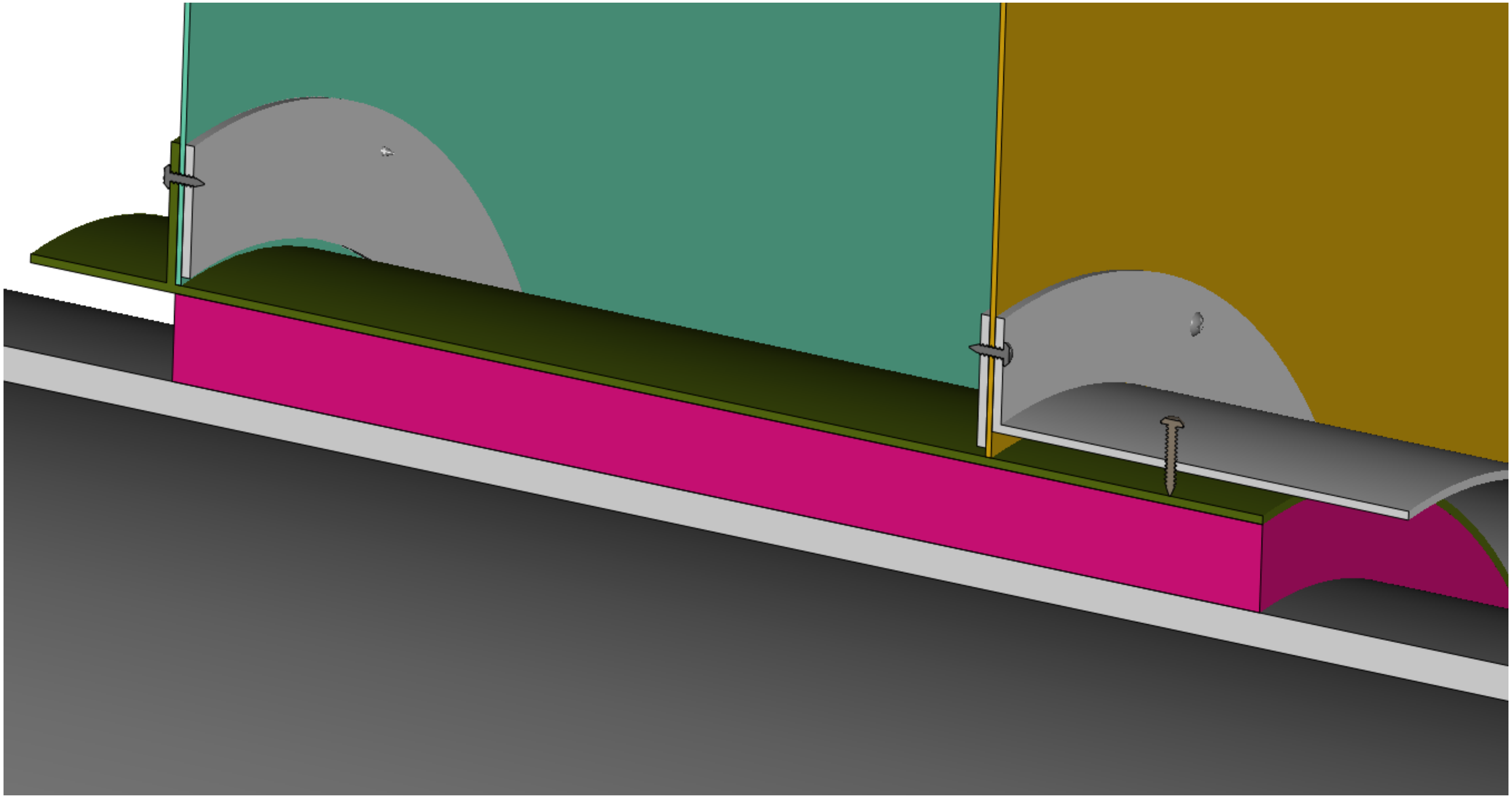
Upper Joint to Disk



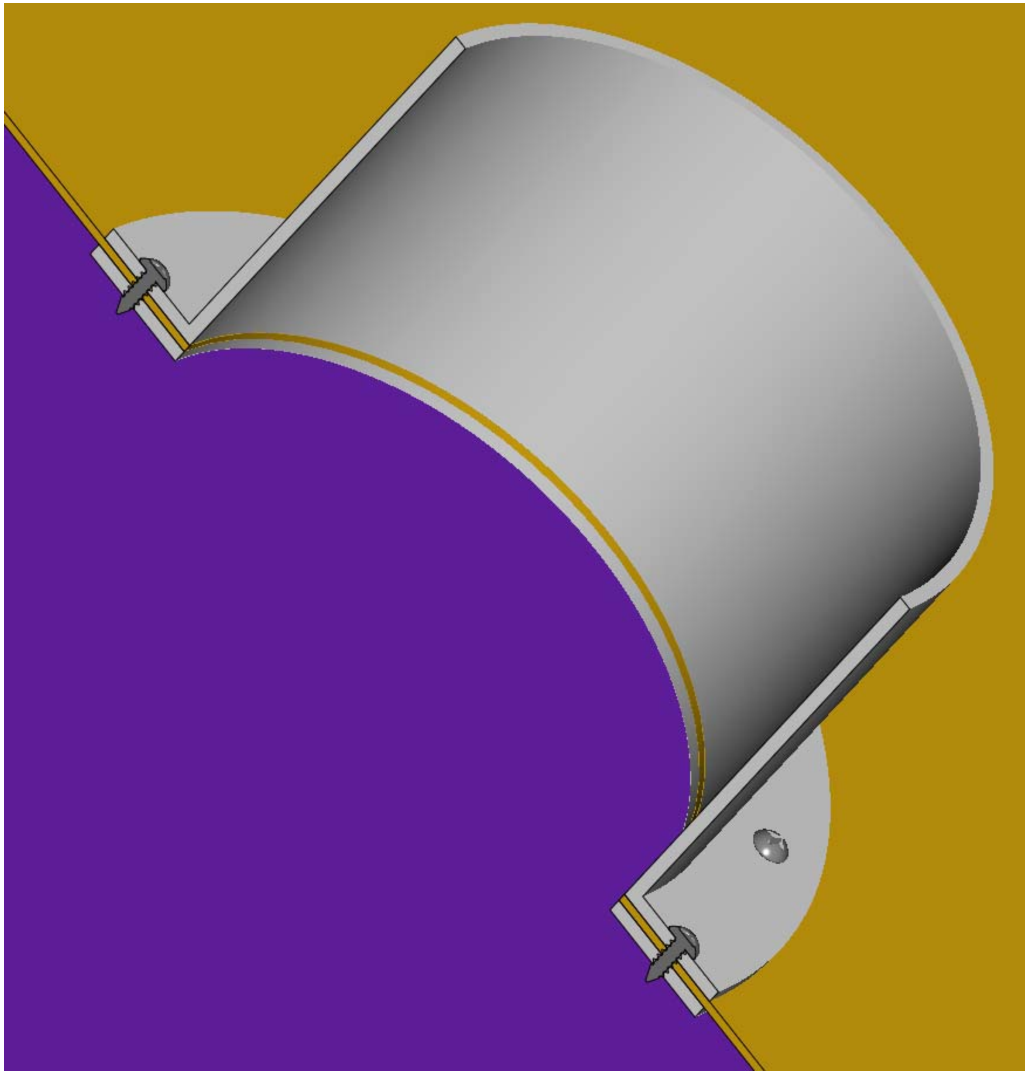
Panel Comments

- The pressure generated by an 18' high column of cold gas is about 1
- Two strips of 3"-wide Velcro conductance limiter is planned a each panel-panel and panel-disk interface
- Simple mechanical clamps will be the outboard gas seal with stagnant gas across the 6" panel interfaces
  - Panel-panel clamps will react weight into ribs
  - Insul is 70 kg/m**3 or 110 lbf per panel
- The differential pressure (flow) across the Velcro will be zero unless faults develop.

Generic Penetration



Fill/Drain Fitting

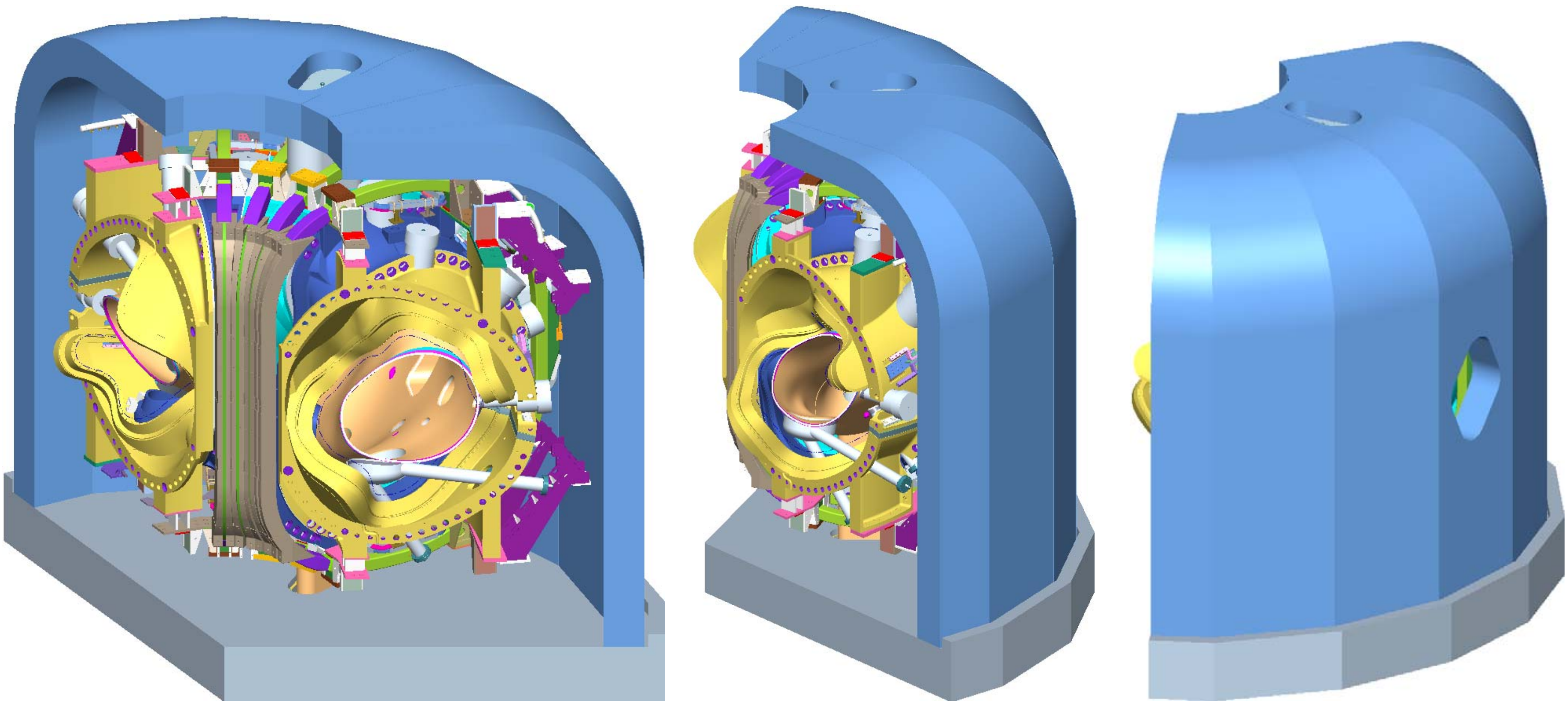


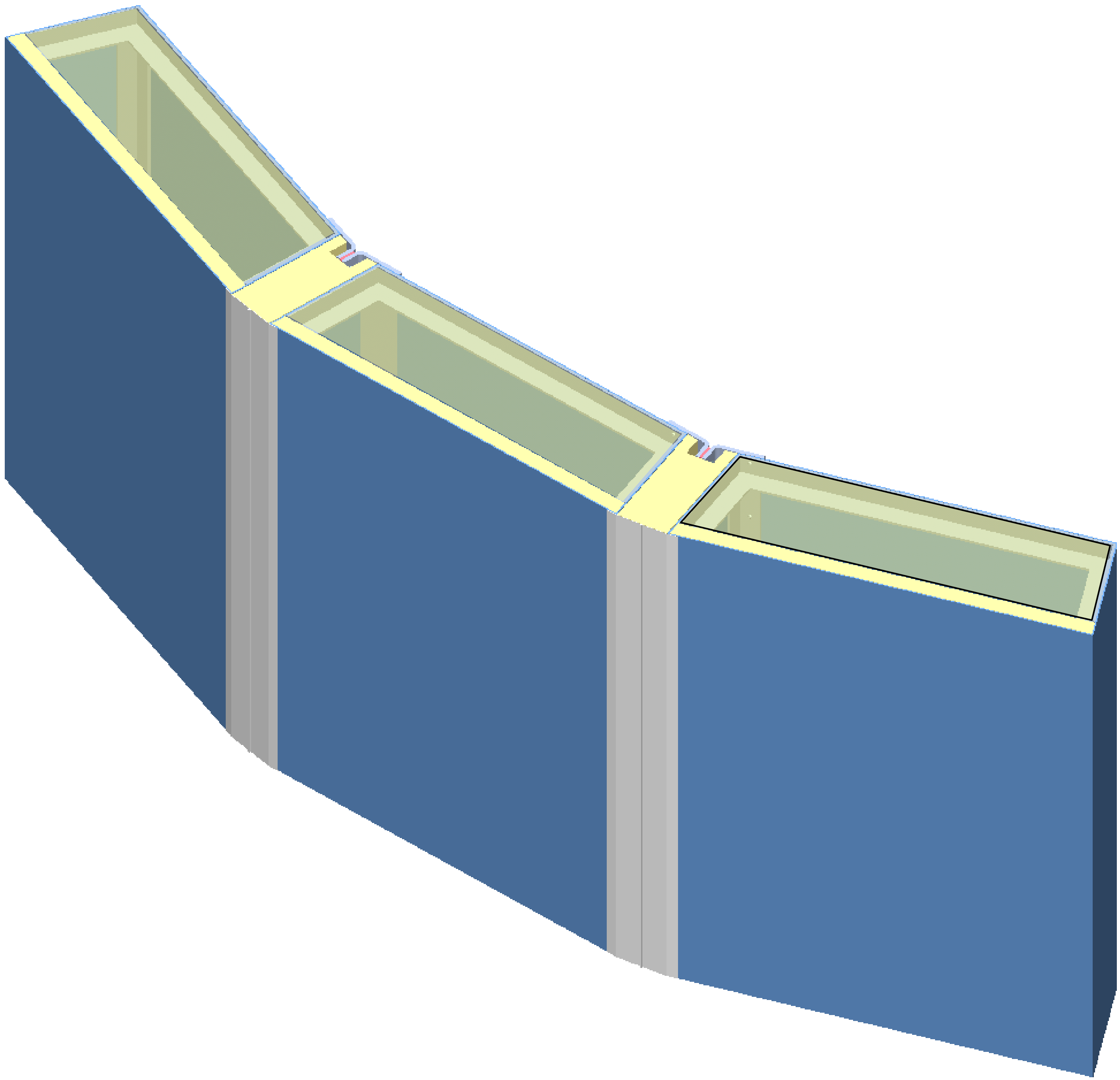
Penetration Comments

- Penetrations can be installed as required.
- Thinwall FG wet exhaust tube is fine.
- Why not FG in non structural apps? Seemed fine in CTF.
- Project must generate listing of port extensions, bus, pipes, and instrumentation feedthroughs for rebaselining estimate.
- Penetrations are sealed with Solimide foam and outer seal.

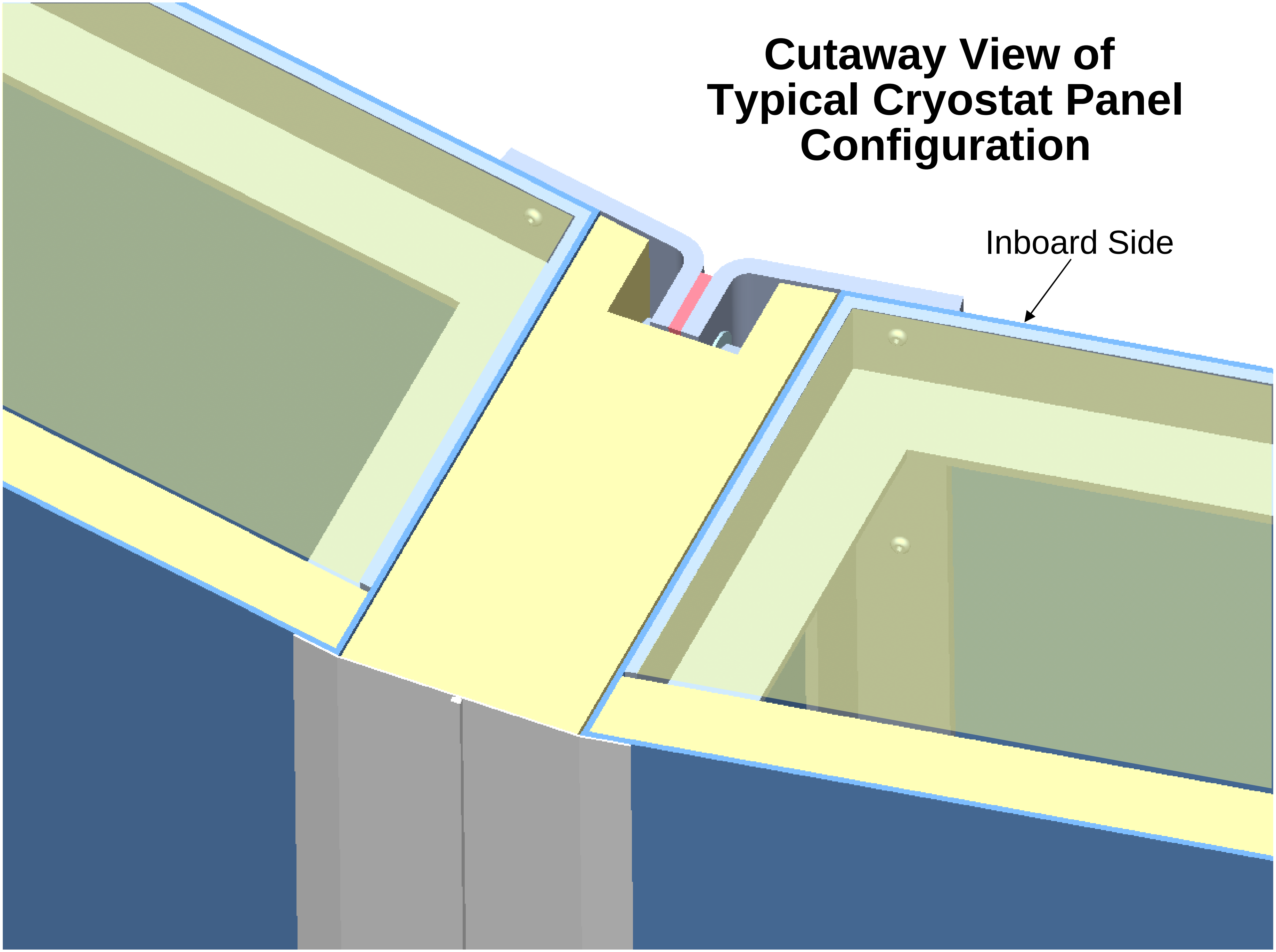
Moving Forward

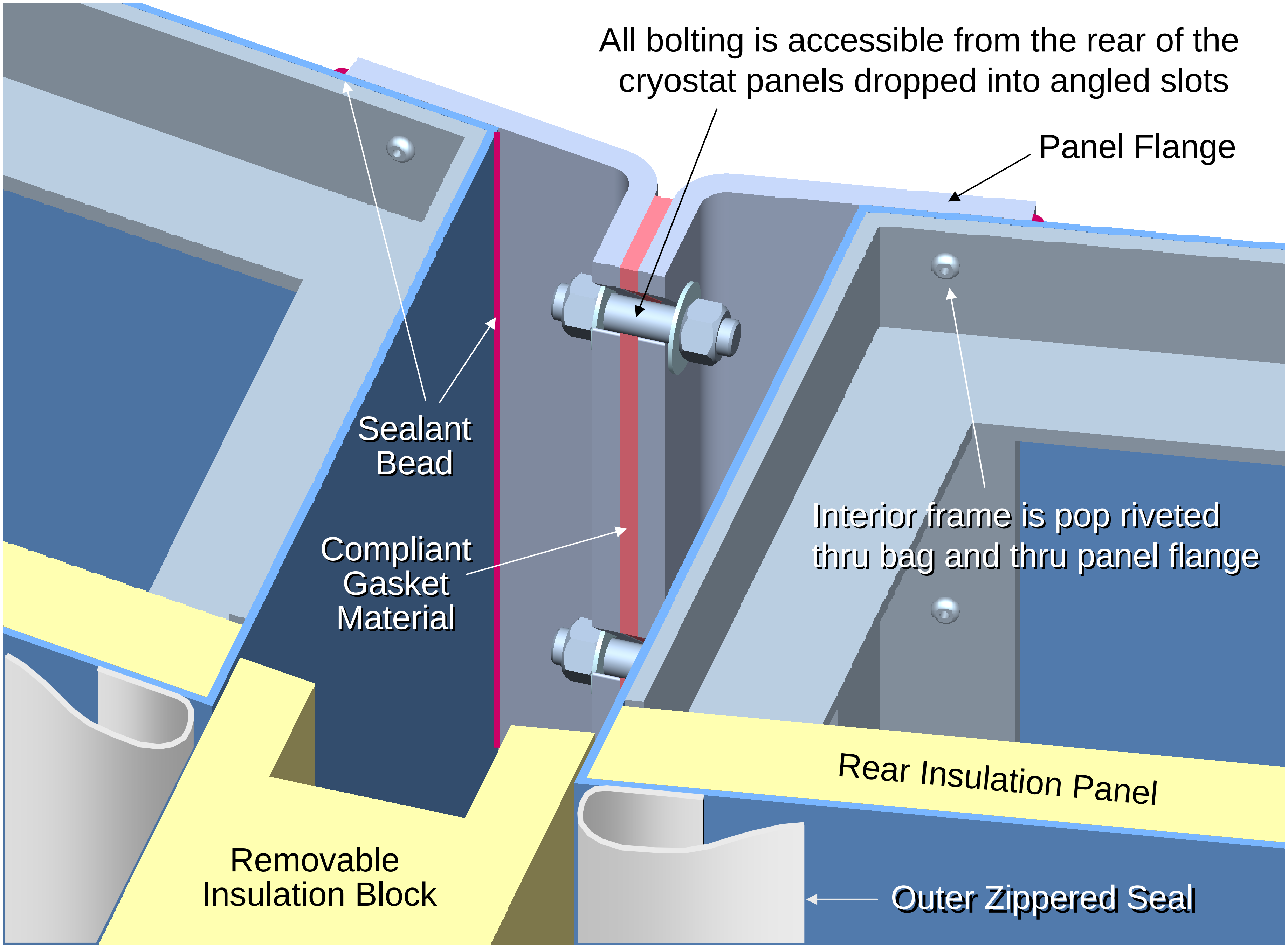
- 3'cube with a few penetrations should be funded for test



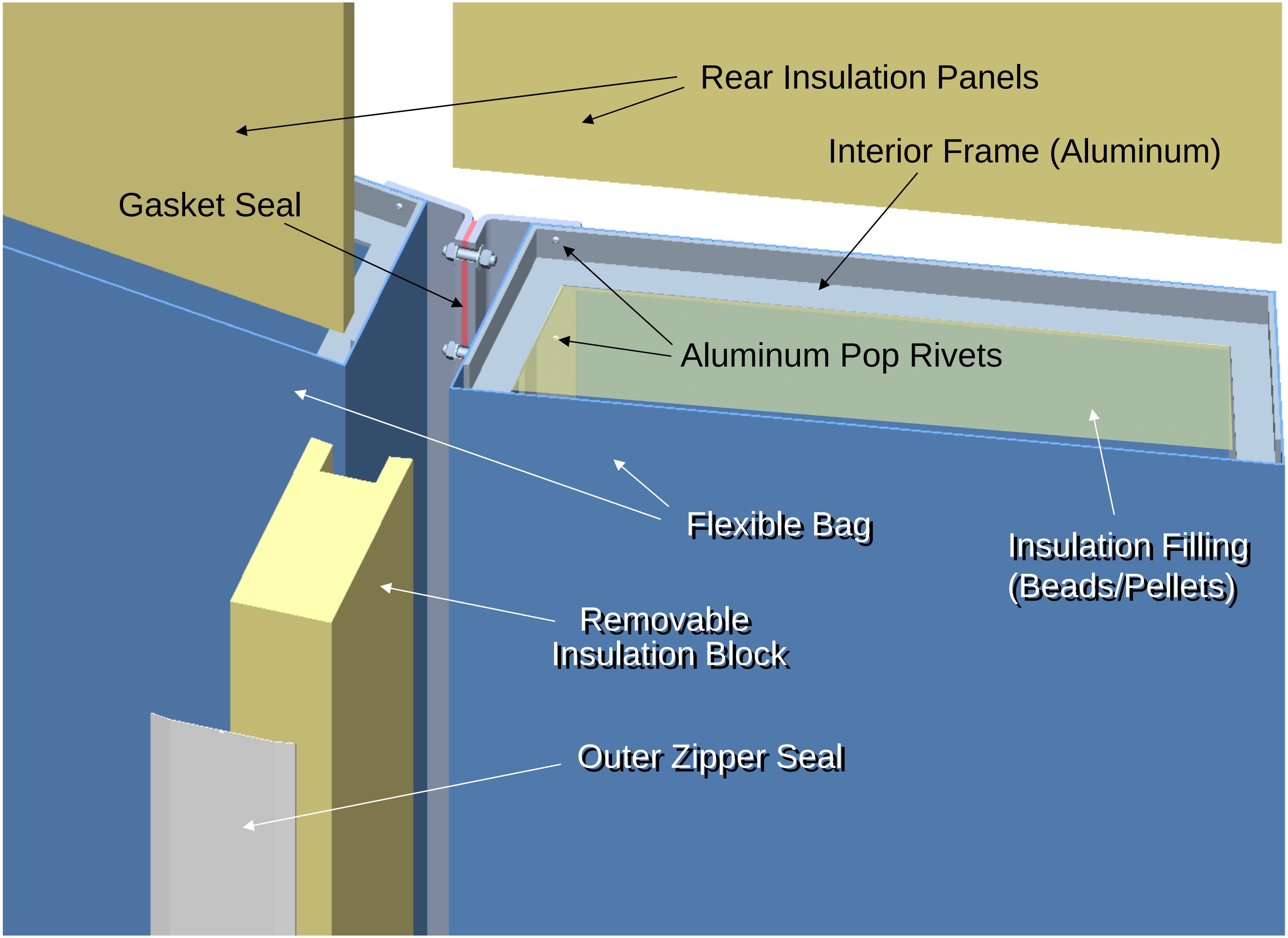


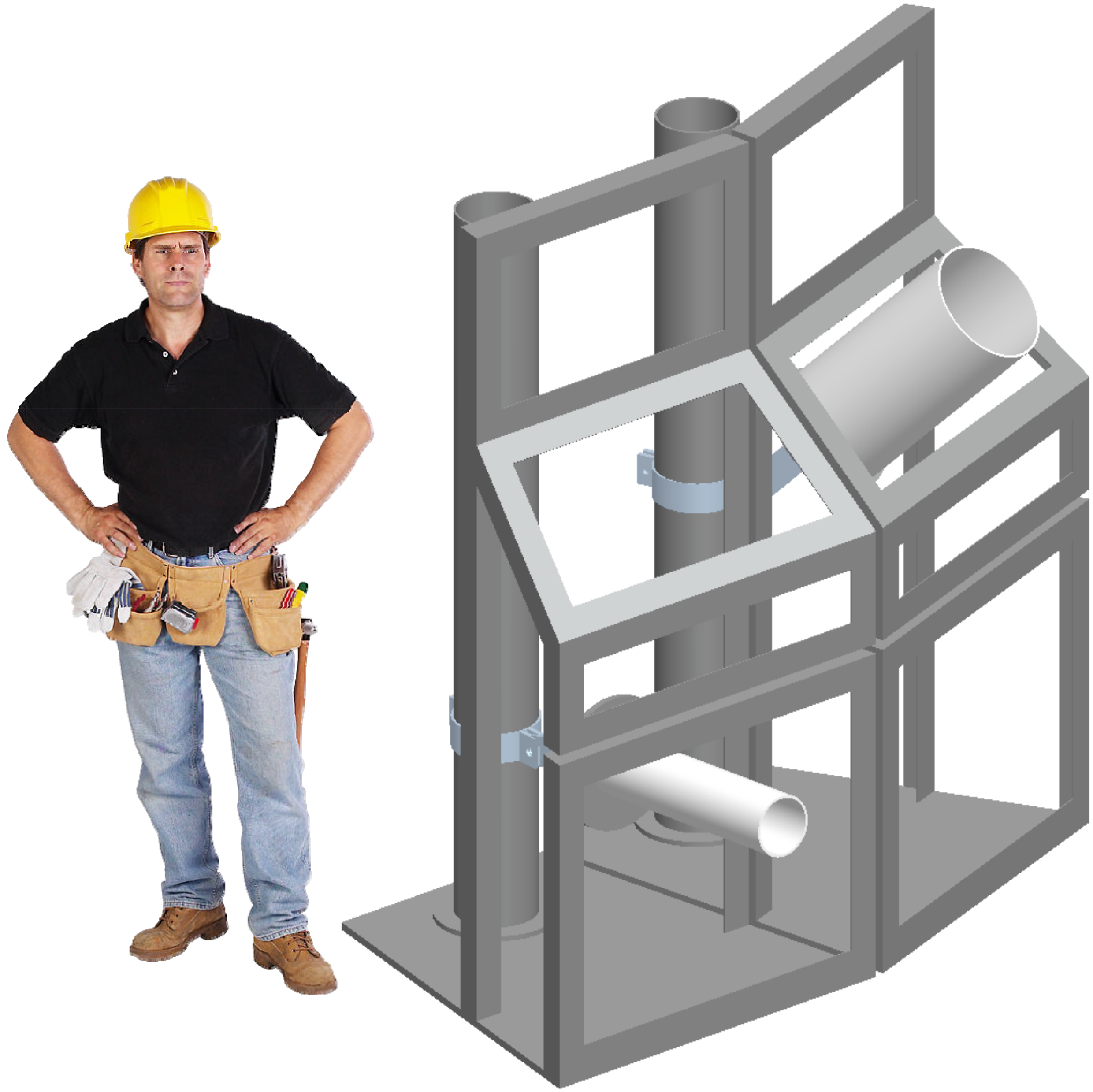
Cutaway View of Typical Cryostat Panel Configuration



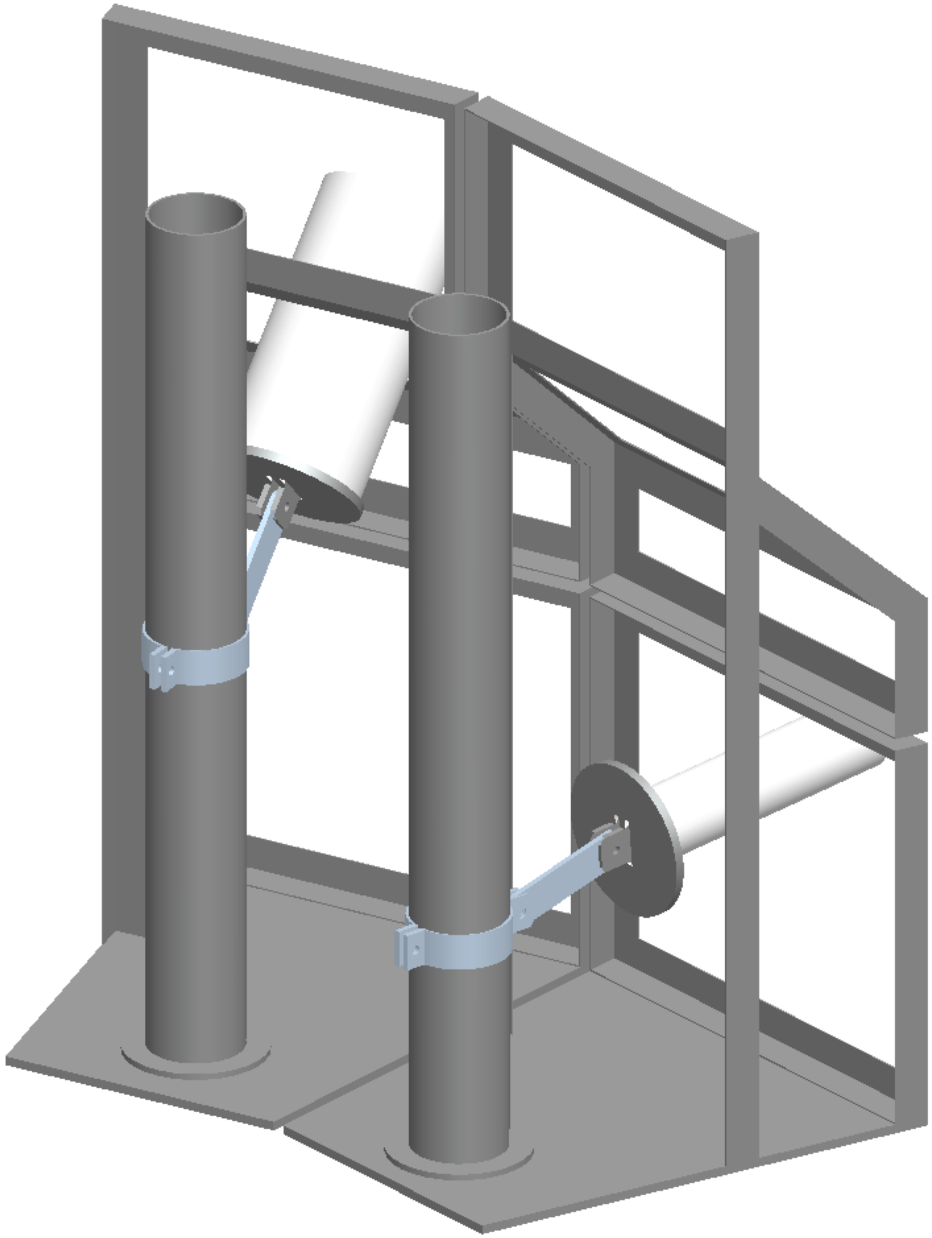


All bolting is accessible from the rear of the cryostat panels dropped into angled slots
Panel Flange
Sealant Bead
Compliant Gasket Material
Interior frame is pop riveted thru bag and thru panel flange
Rear Insulation Panel
Removable Insulation Block
Outer Zippered Seal

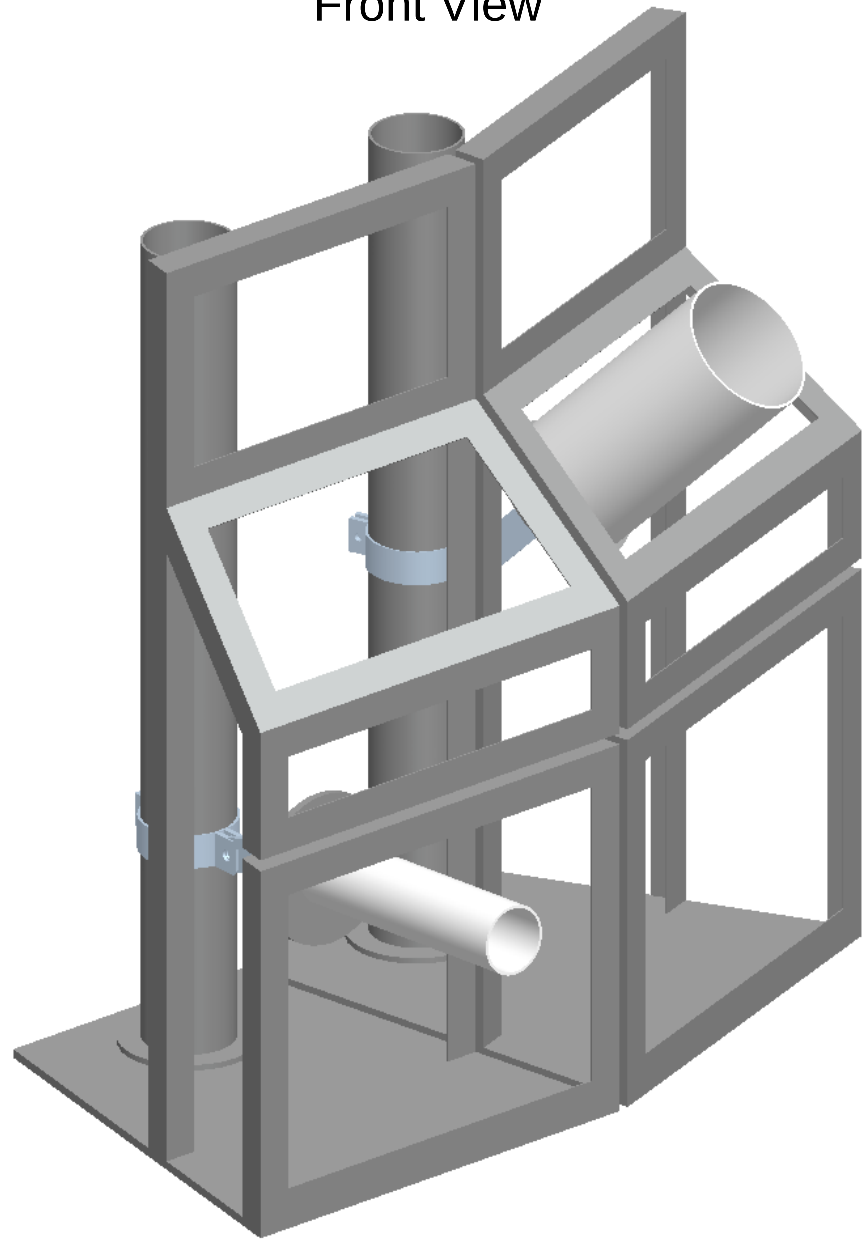

Rear Insulation Panels
Interior Frame (Aluminum)
Gasket Seal
Aluminum Pop Rivets
Flexible Bag
Insulation Filling
(Beads/Pellets)
Removable
Insulation Block
Outer Zipper Seal

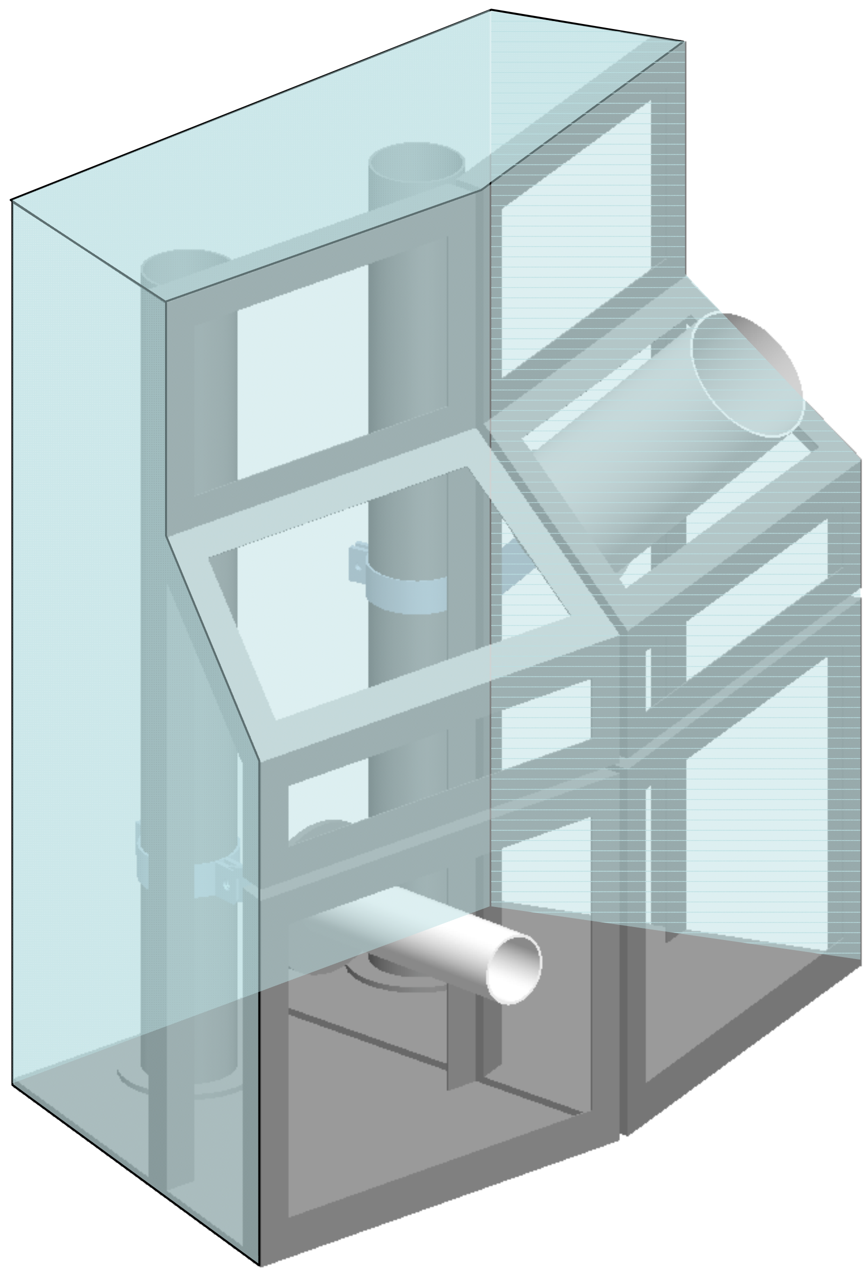


Rear View



Front View





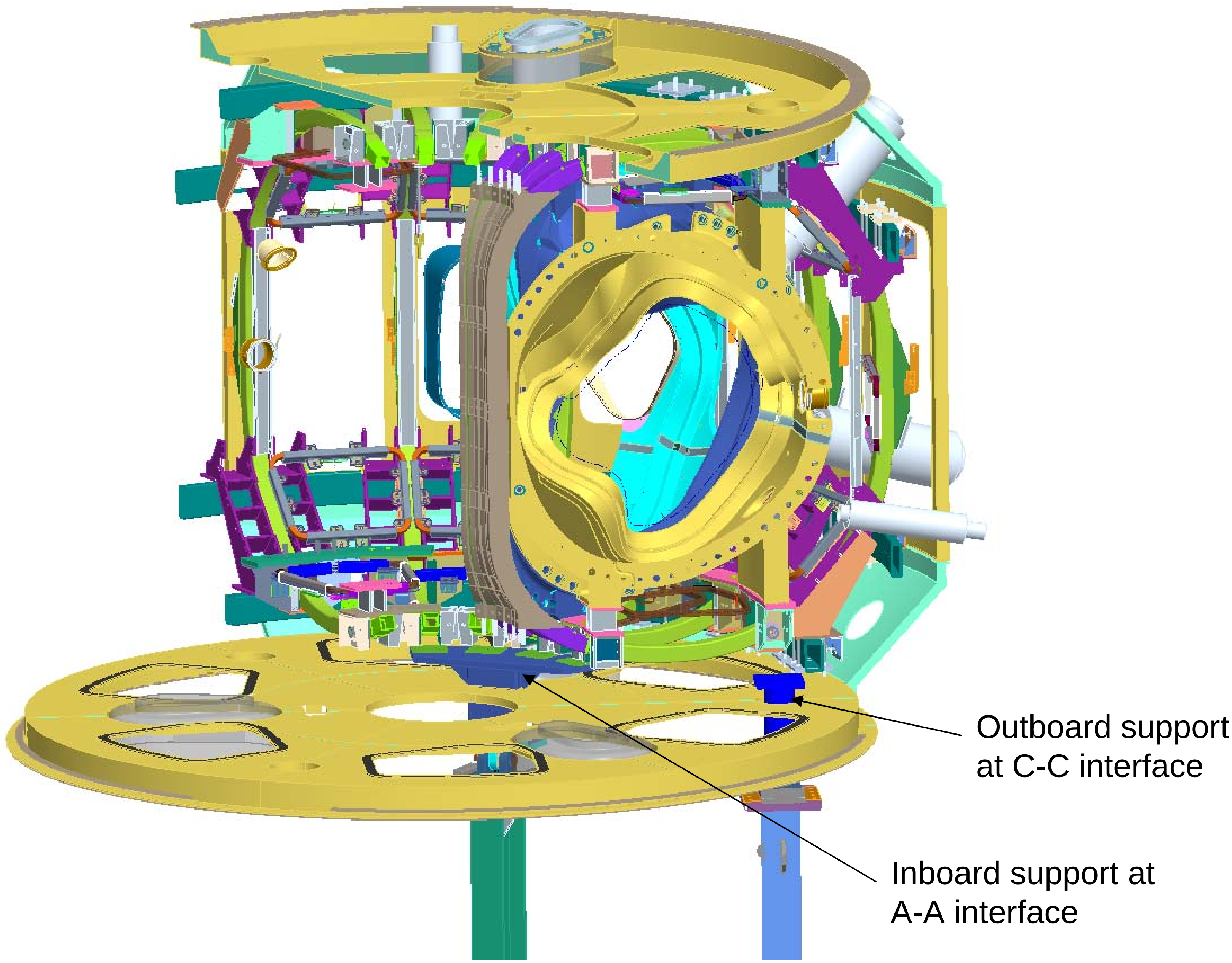
Analyses Presentations

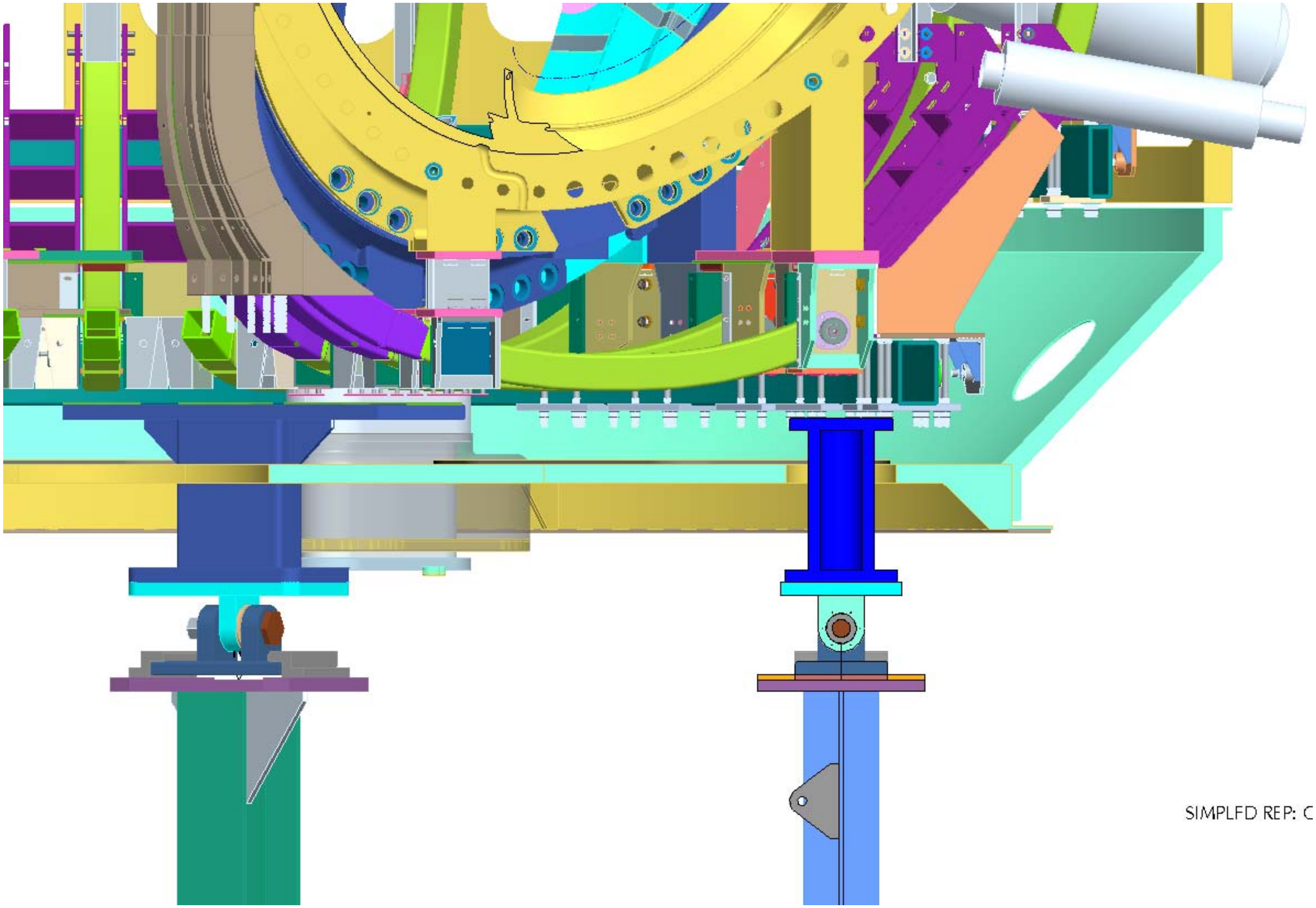
- **Support Thermal Analyis**
- **Thermal Deflection Analysis**
- **Shell Temperature Distribution Analysis**

Machine support / Cryostat / Core Interface

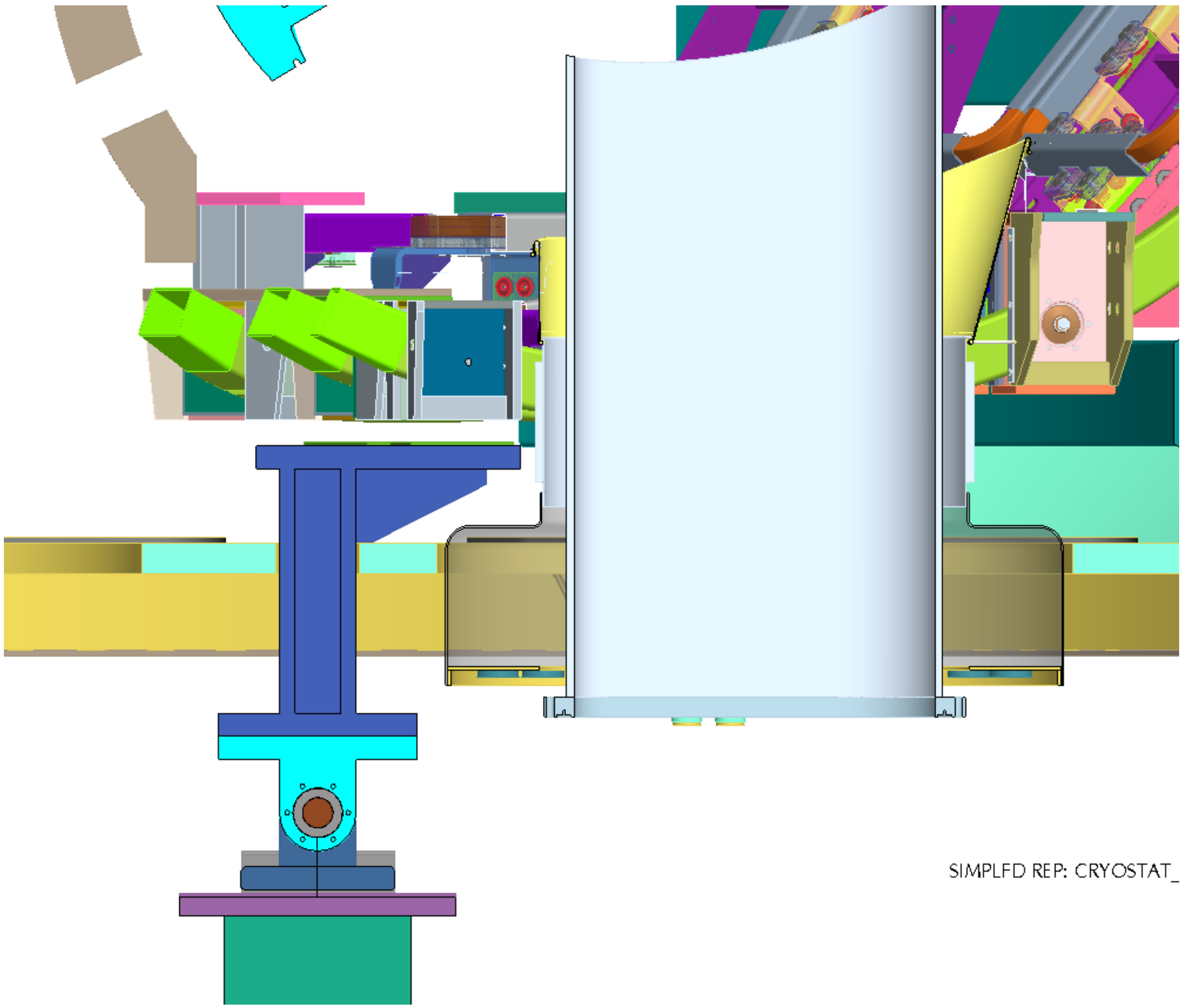
4/20/08

T. Brown

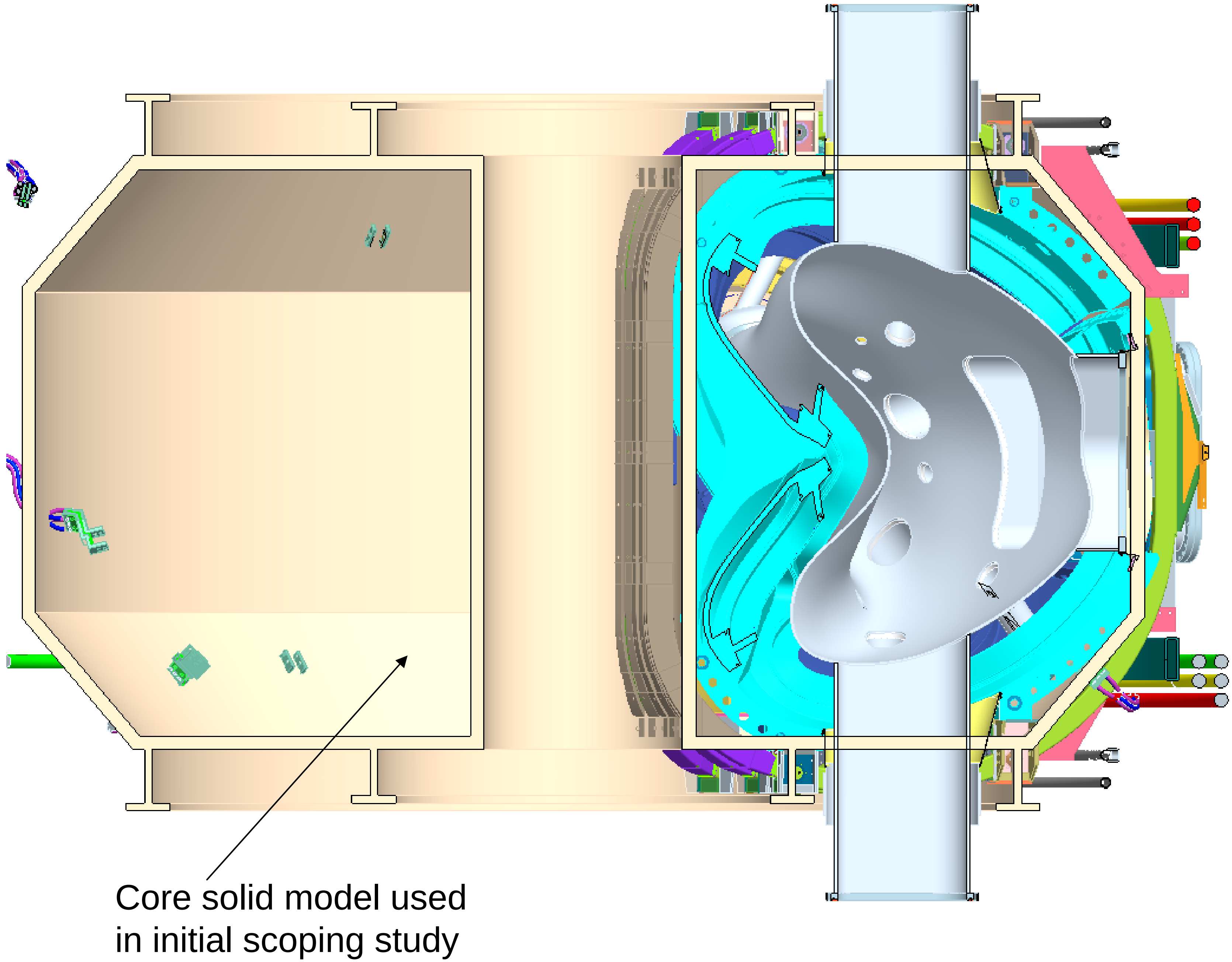

Outboard support
at C-C interface
Inboard support at
A-A interface

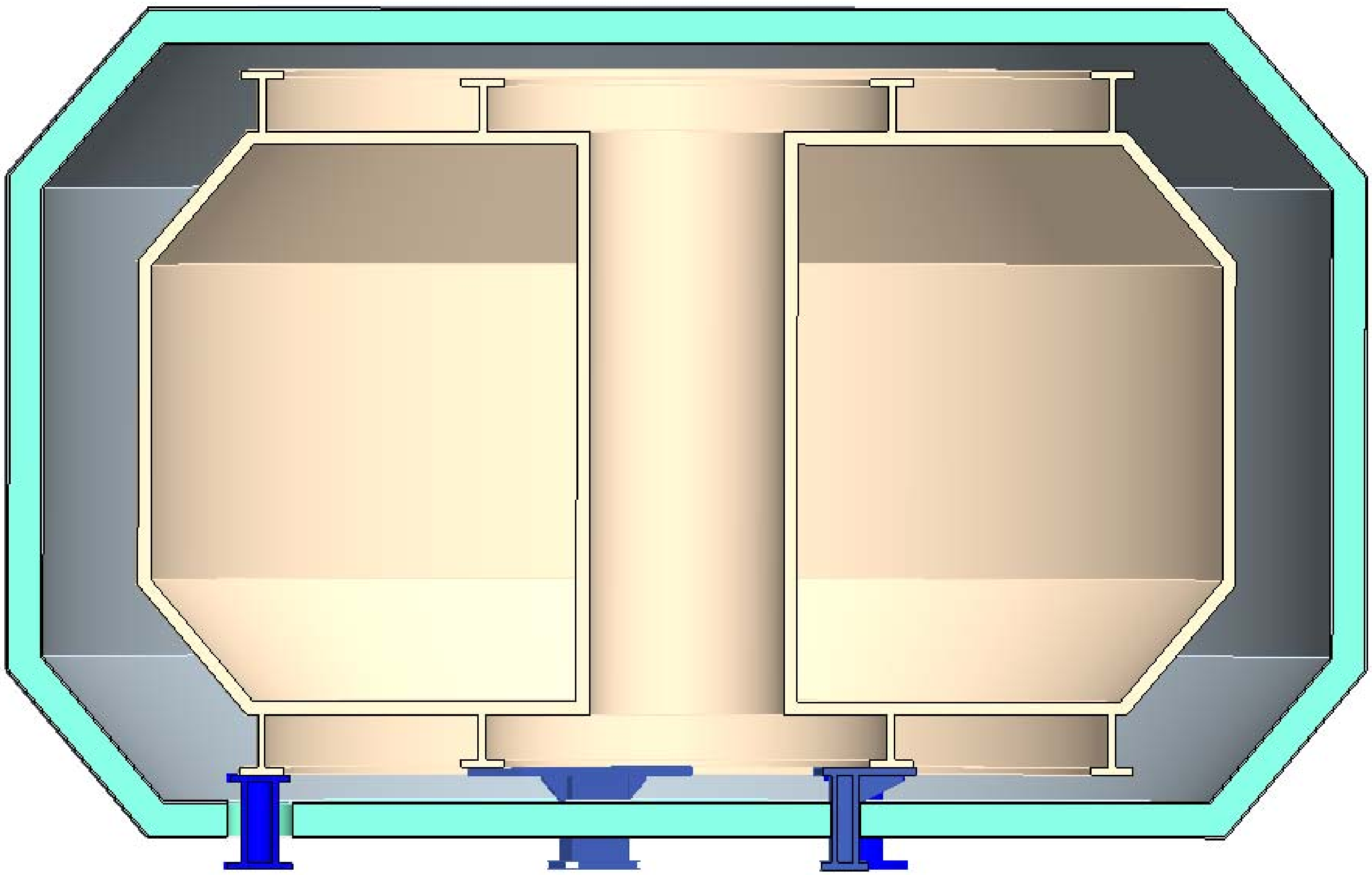


Section cut at C-C interface



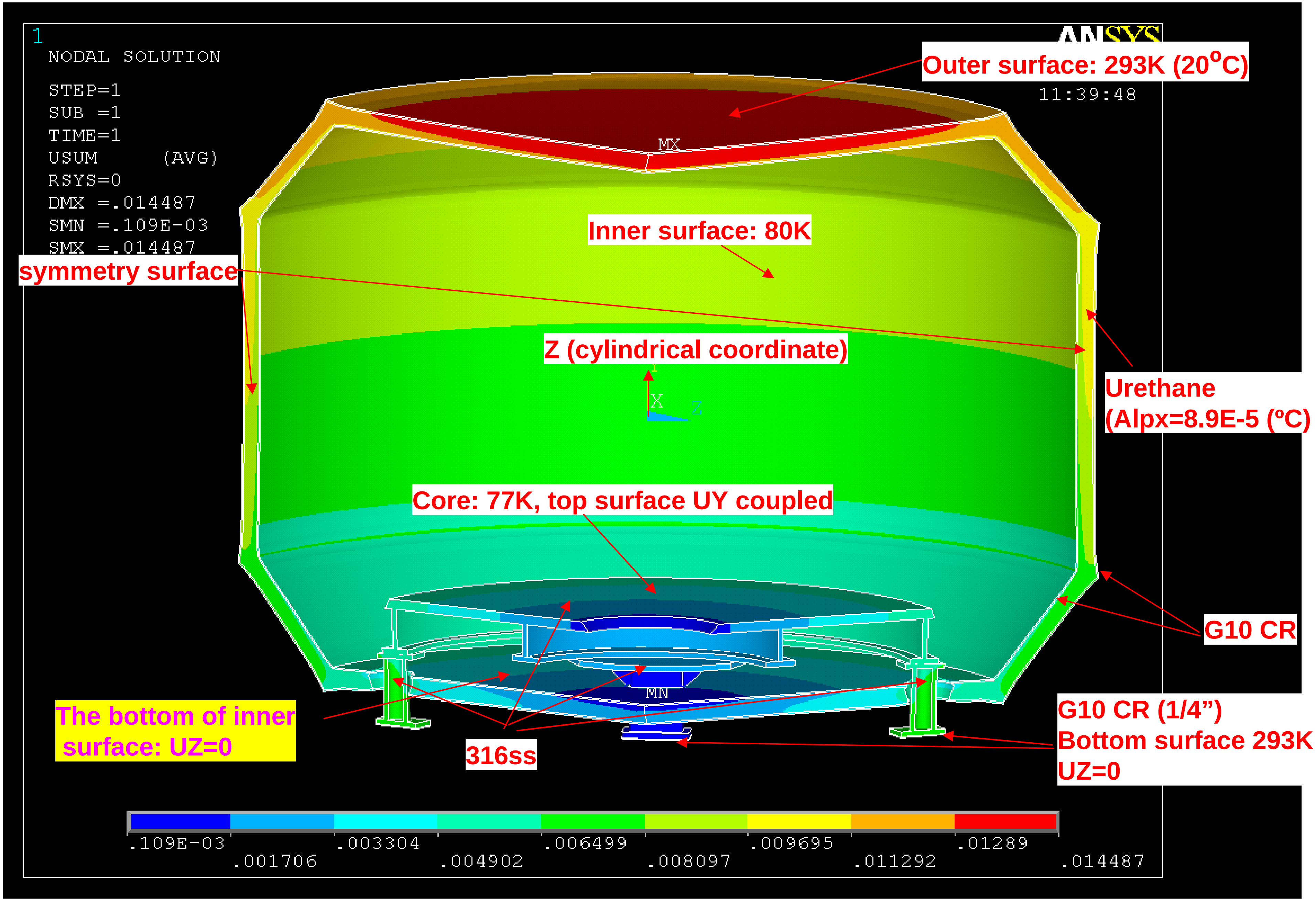
Section cut at B-B interface


Core solid model used
in initial scoping study

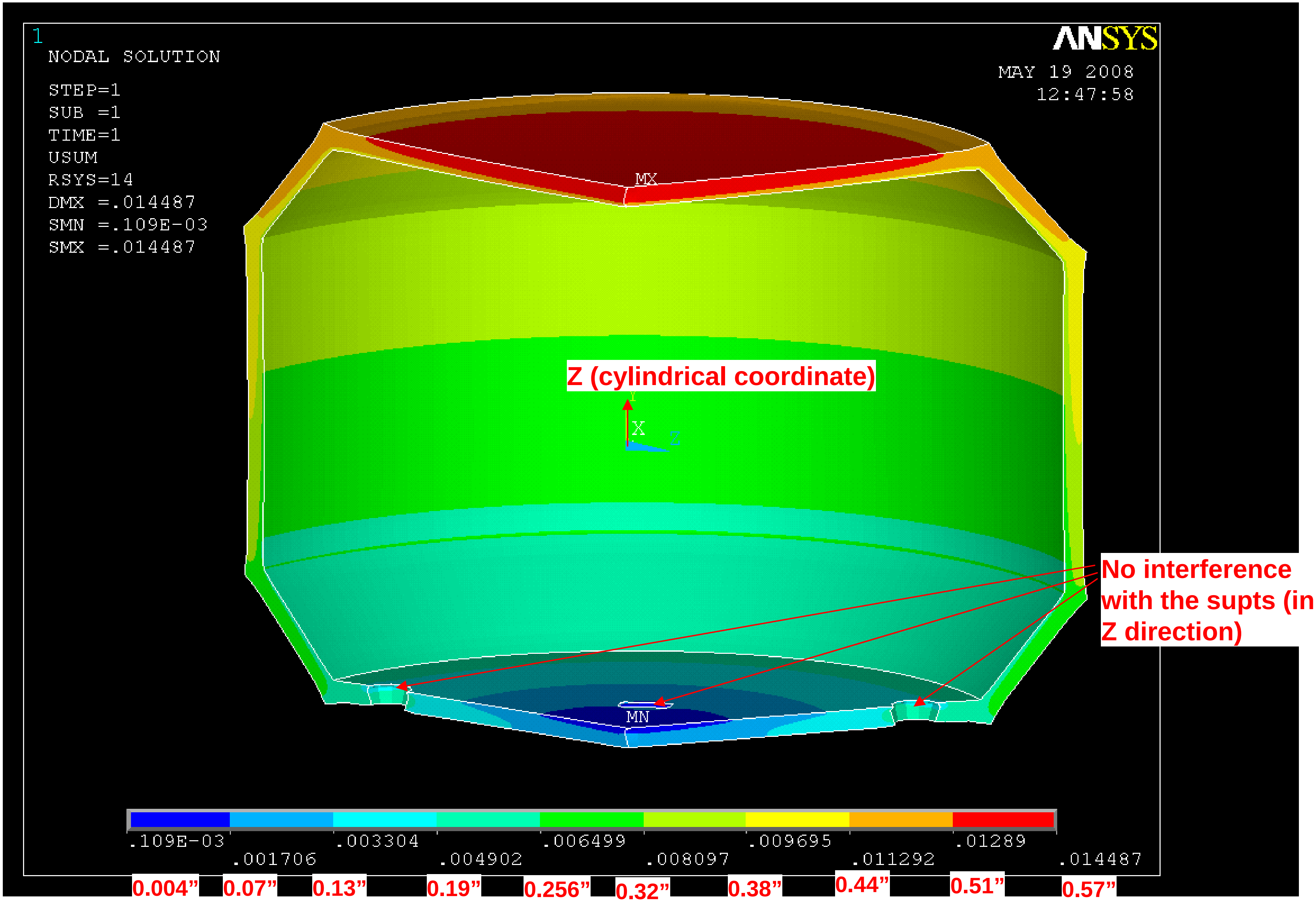


Scoping model showing section cut of Core / Cryostat / machine support interface

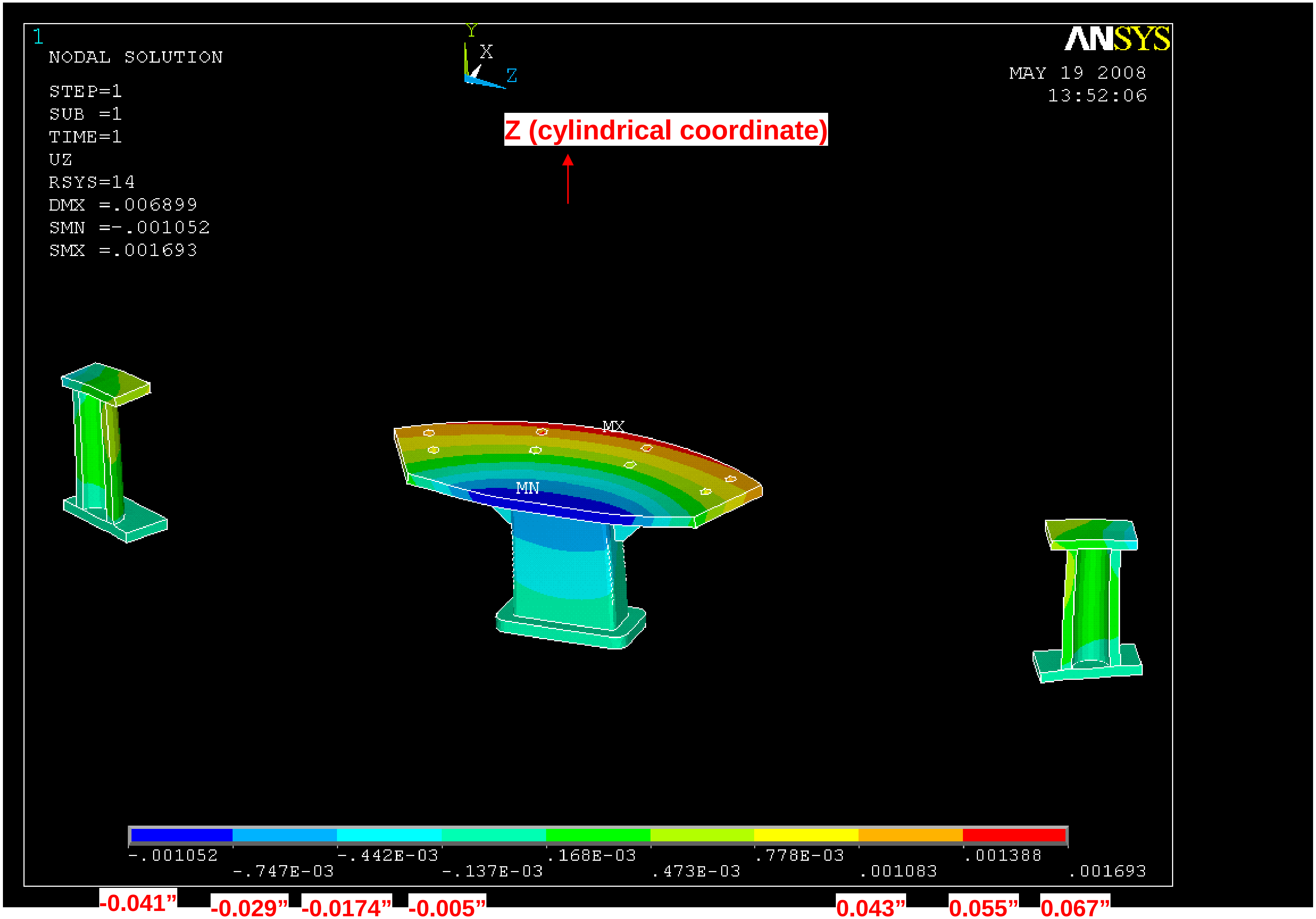
Thermal deflection analysis



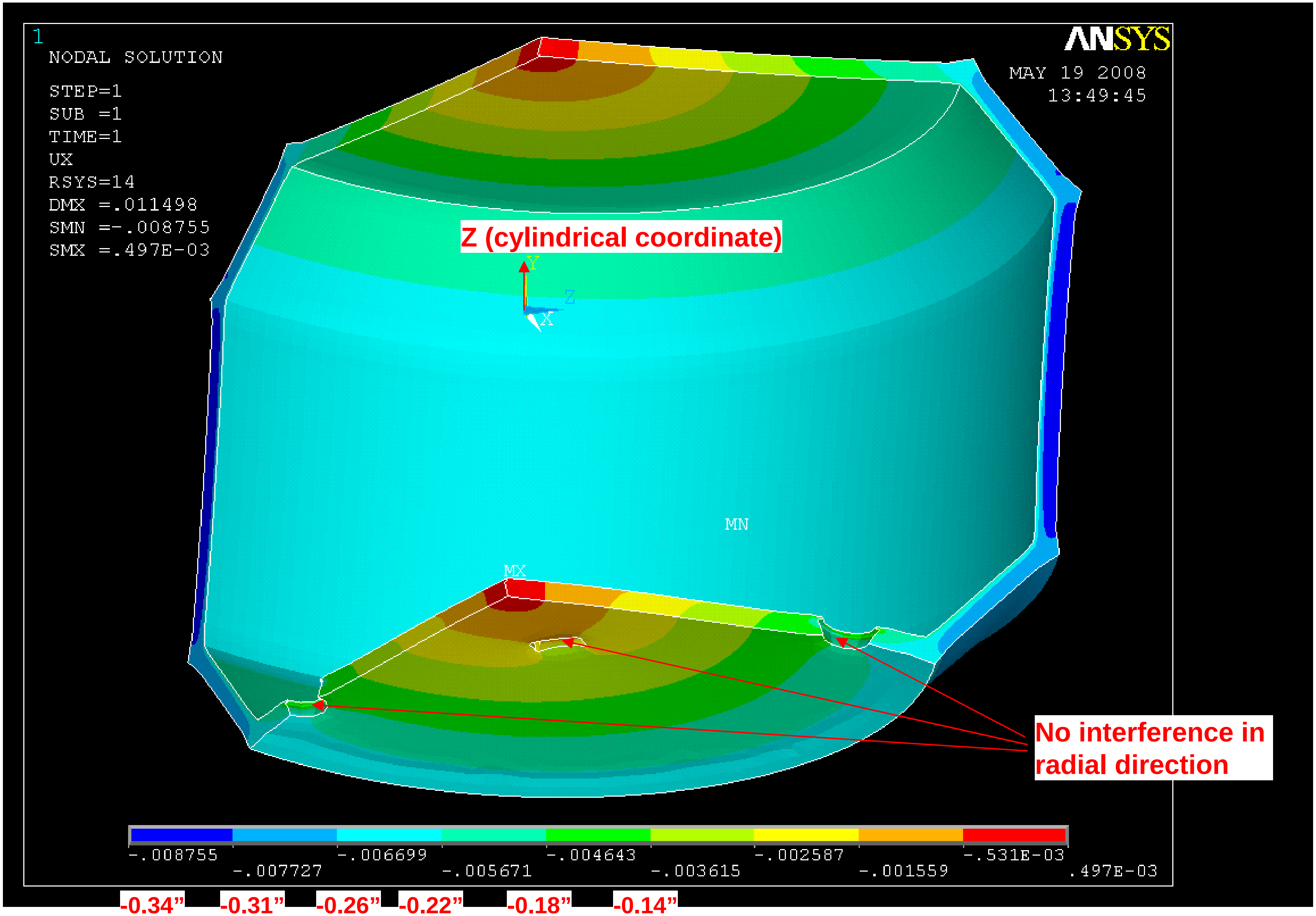
Z Displacement (m)



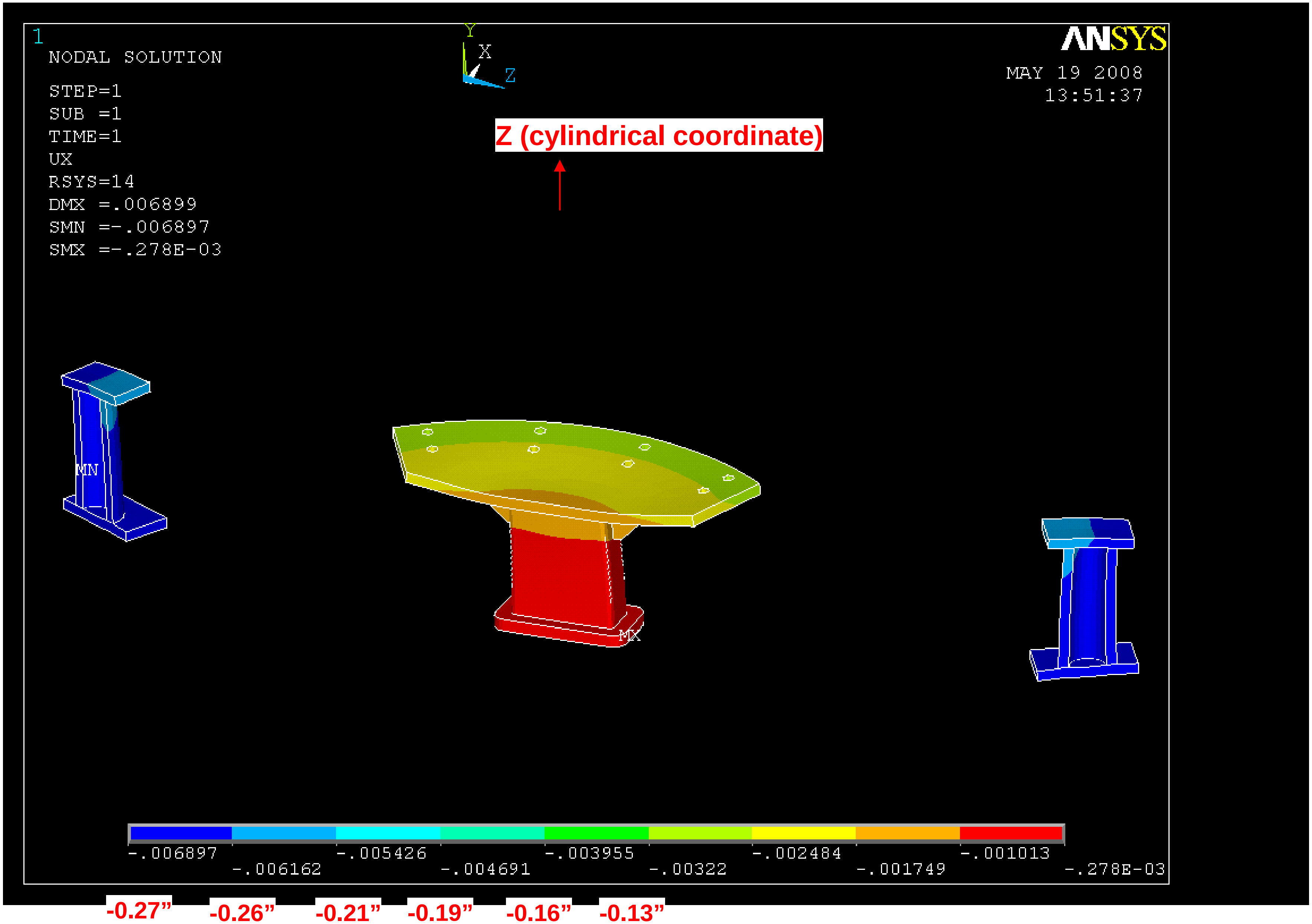
Z Displacement (m)



Radial Displacement (m)

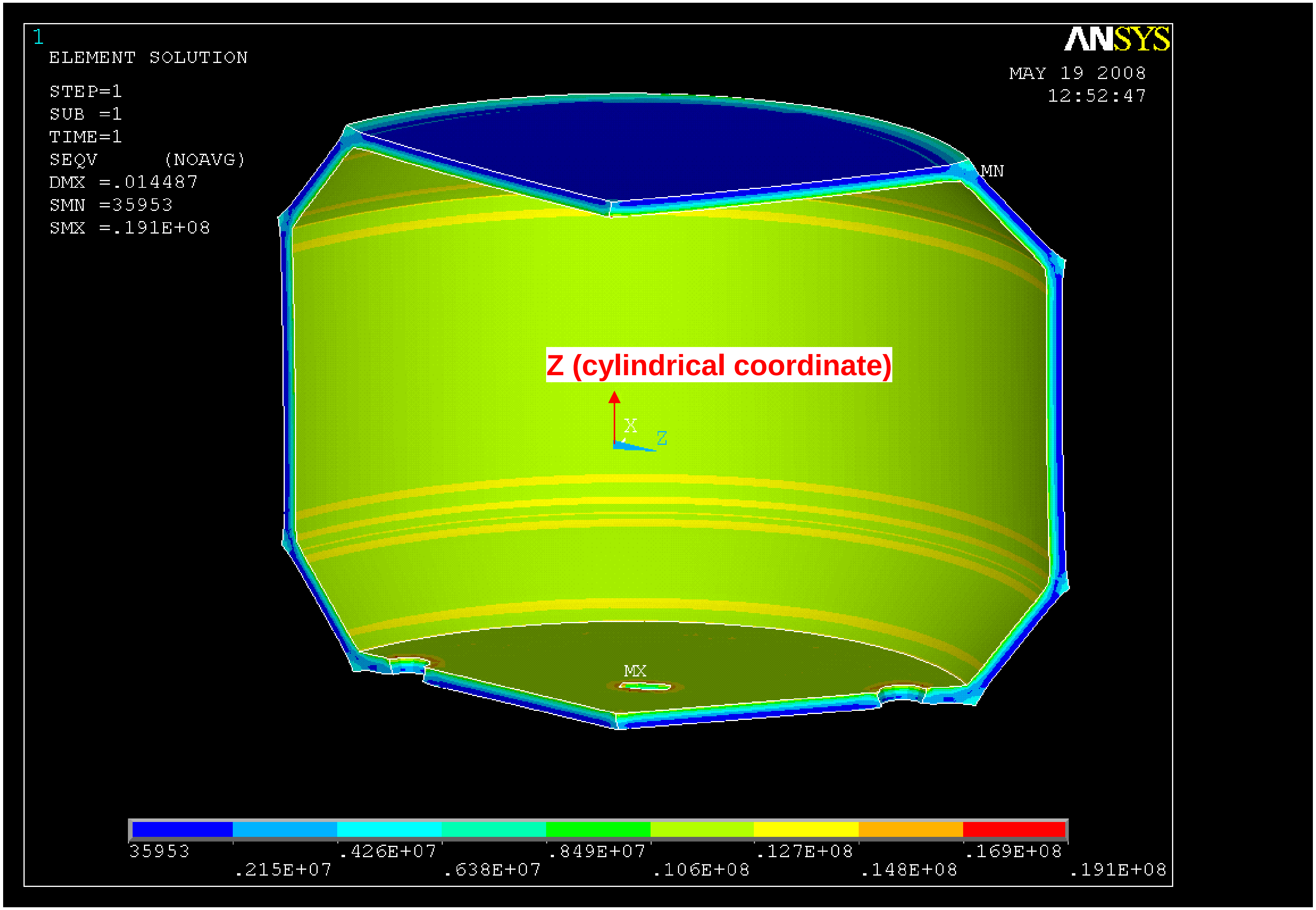


Radial Displacement (m)



Urethane thermal stress (Pa)

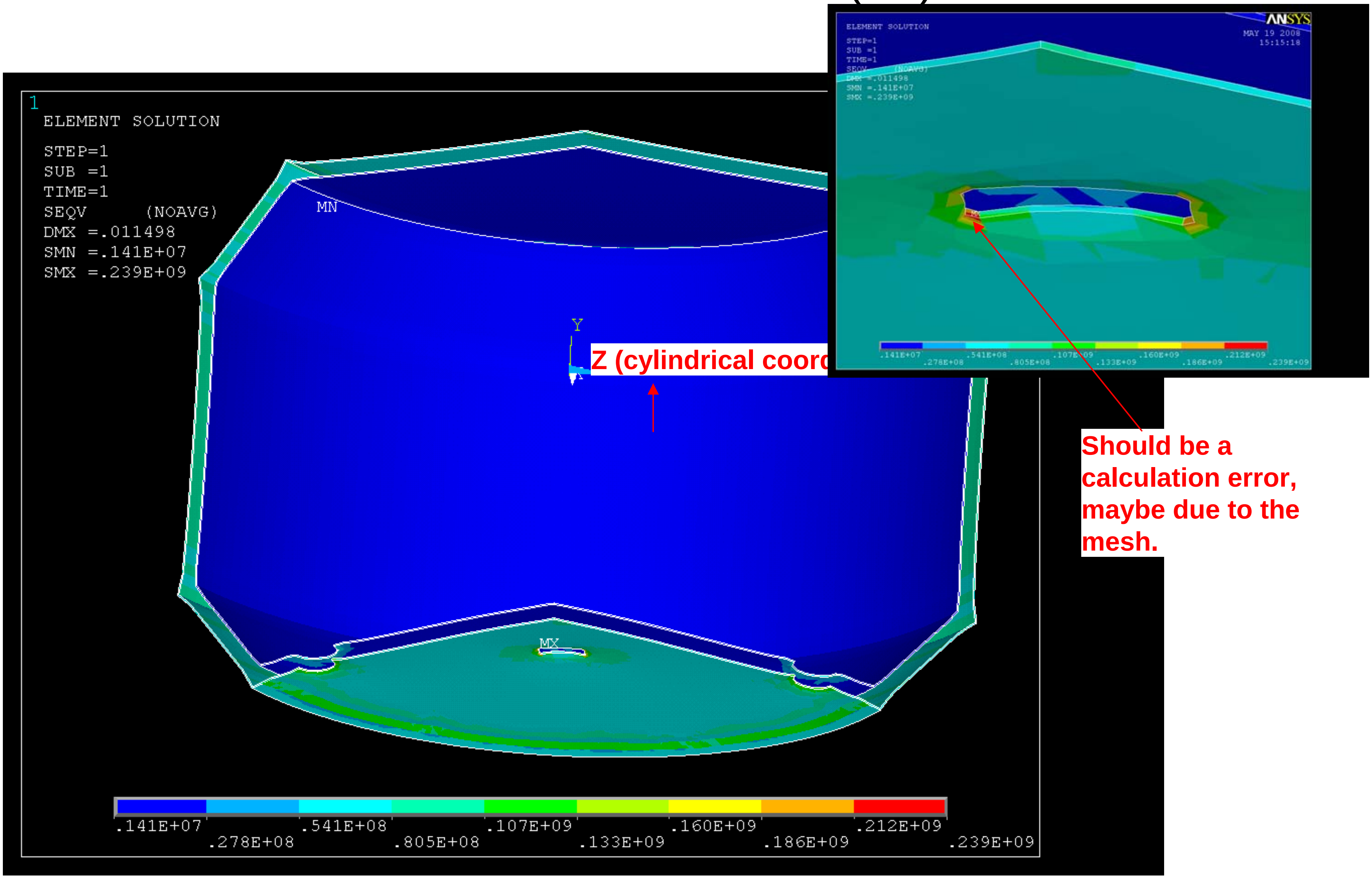
1 MPa=0.145 ksi



Max 19MPa (2.76 ksi), should not make the urethane broken? Is urethane a more compliant material?

G10 shell thermal stress (Pa)

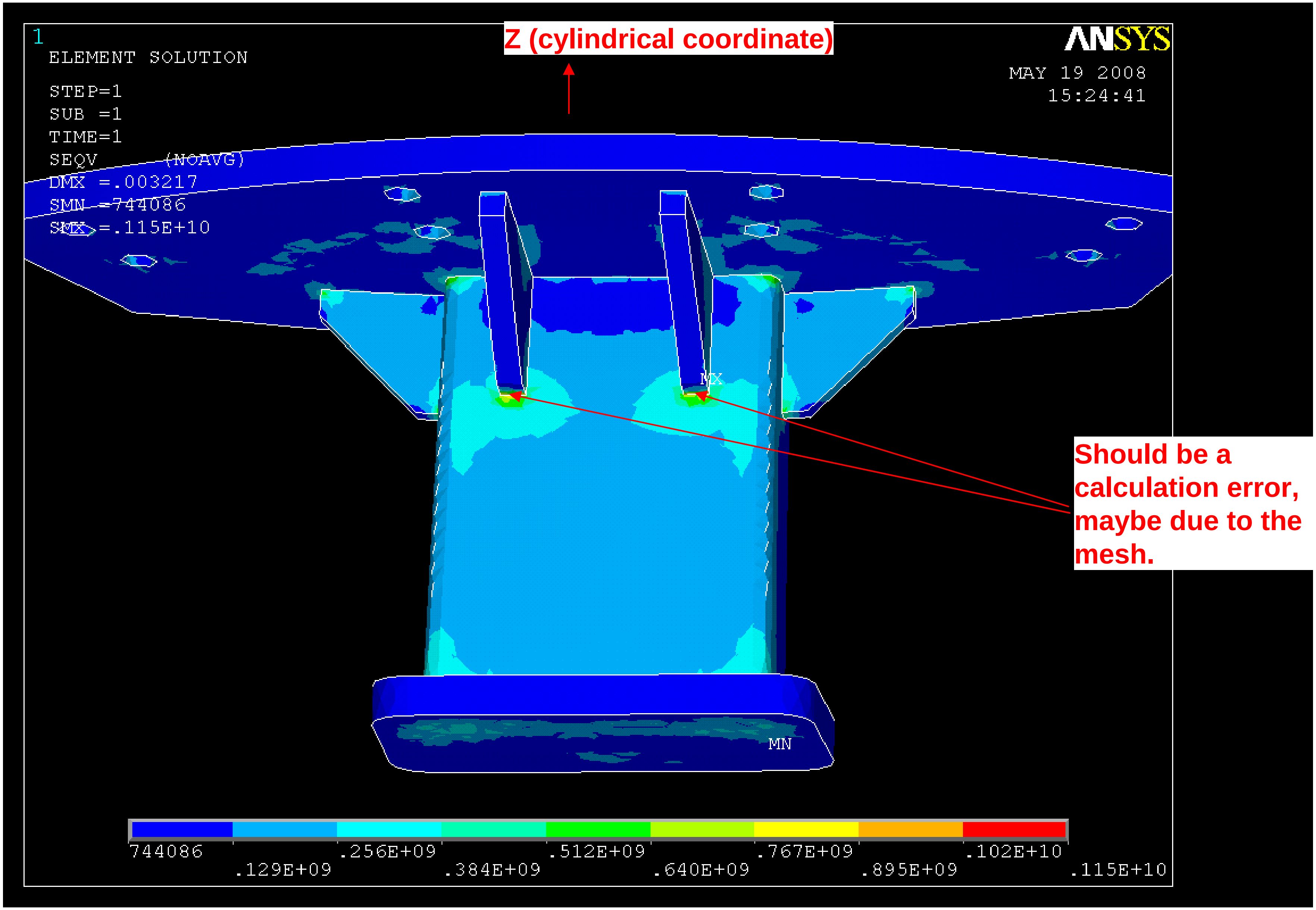
1 MPa=0.145 ksi



Max 239MPa (2.76 ksi) only happened in 1 point, should be a calculation error. In the remaining areas, max stress is ~100MPa (14.5ksi), should not make G10 broken.

Inboard supt thermal stress (Pa)

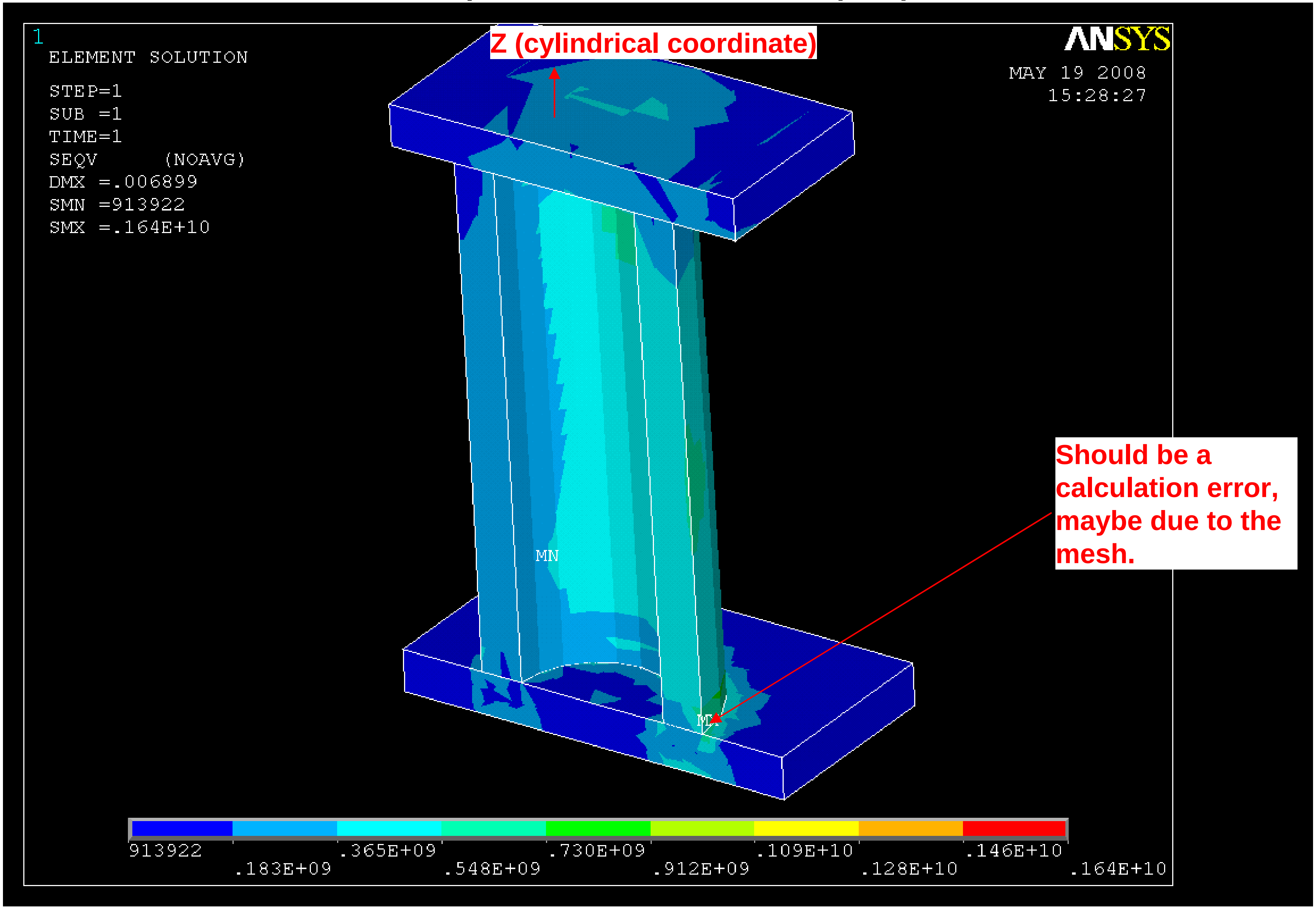
1 MPa=0.145 ksi



Max 1150MPa (167 ksi) only happened in 2 points, should be a calculation error. In the remaining areas, max stress is ~256~384MPa (37~56 ksi).

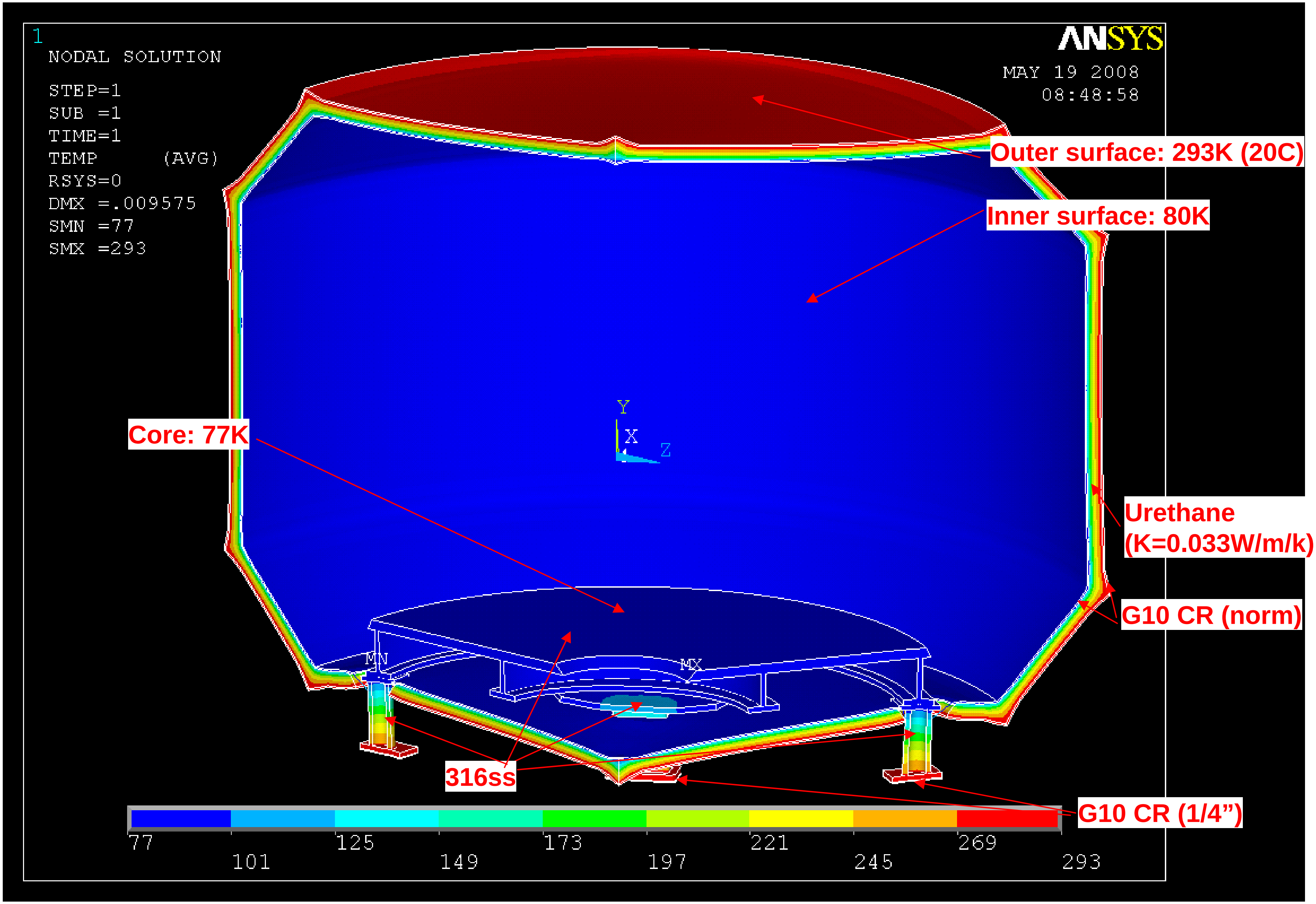
Outboard supt thermal stress (Pa)

1 MPa=0.145 ksi

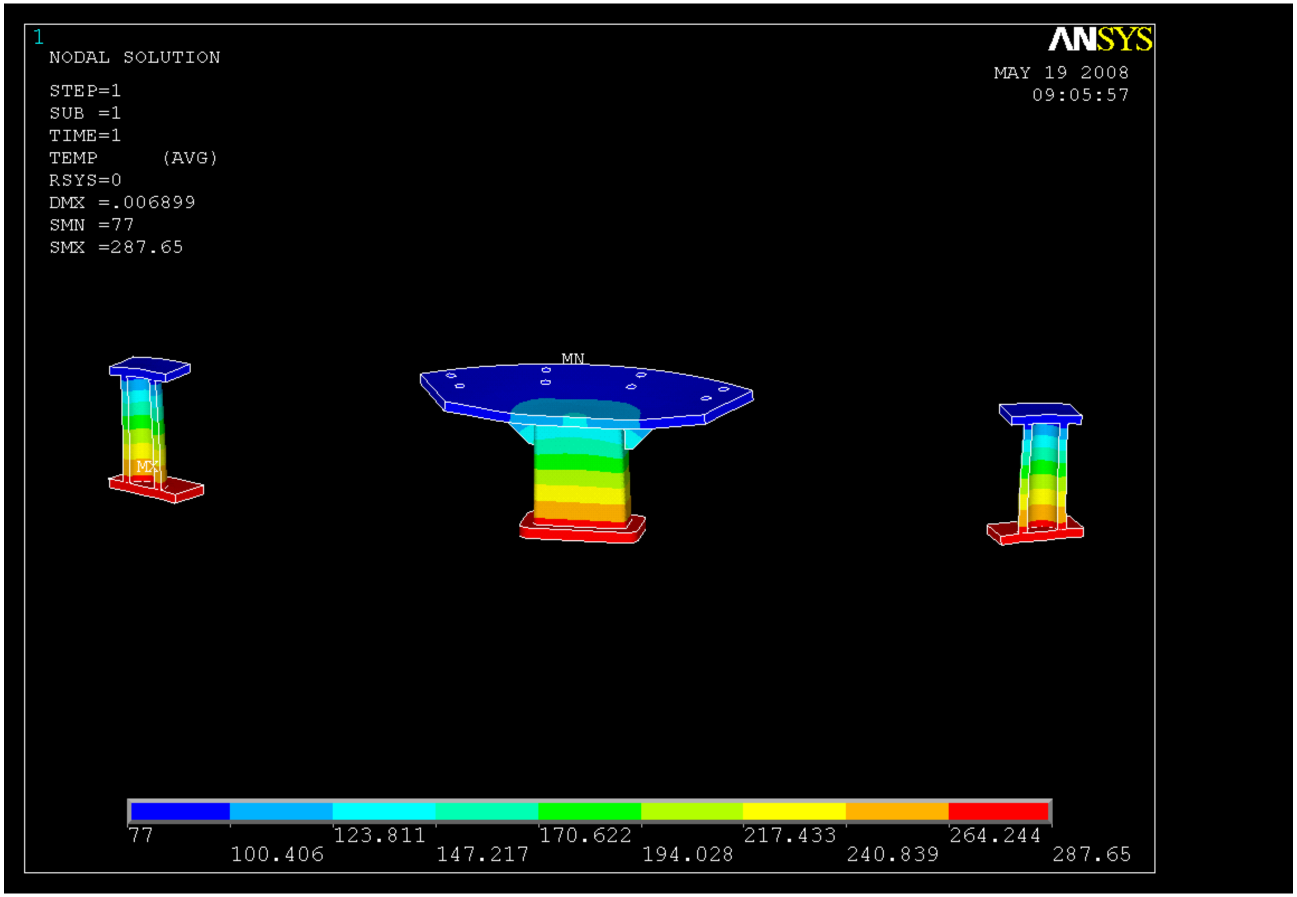


Max 1640MPa (238 ksi) only happened in 1 point, should be a calculation error. In the remaining areas, max stress is ~365~500MPa (53~72 ksi).

Temp distribution (K)



Heat load (W)



1. Heat from the 3 inboard (A-A) supports: 316 W

2. Heat from the 3 outboard (B-B) supports: 251 W

3. Heat from the wall: 5319 W

4. Total heat load requires the boiling rate of LN2 of ~30g/s. Using 645x volume expansion during vaporization (from LN2 at 77K to GN2 at 293K), ~20 liter/s (5.1 gallon/s) GN2 produced.