NCSX Cryostat
WBS171

Preliminary Design Review

Charge from NCSX Engineering

1. Requirements. Do the requirements provide an adequate basis for proceeding with final design?
2. Design. Does the design address and meet the requirements?
3. Analysis. Does the analysis indicate the design satisfies the design criteria and is robust in regard to engineering uncertainties?
4. R&D. Is additional R&D warranted to reduce engineering uncertainties?
5. Manufacturability. Can the design be readily manufactured?
6. Design Integration

   a. Is the design compatible with the integrated model of the stellarator core?

   b. Do adequate clearances exist for final assembly and operation?
7. Interfaces. Have the physical and functional interfaces been adequately established to proceed with final design?

Charge from NCSX Engineering

8. Procurement. Is the procurement plan (e.g., make versus buy, bundling of procurements) appropriate?
9. Cost and Schedule. Are the cost and schedule baselines (and cost basis documentation) consistent with the technical baseline and procurement plan? Do the cost and schedule baselines appear reasonable?
10. ES&H. Have potential environmental, health, and safety issues been identified and addressed?
11. Risk management. Have technical, cost, and schedule risks been identified and appropriately mitigated?
12. Chits. Have all chits from previous design reviews been adequately addressed?

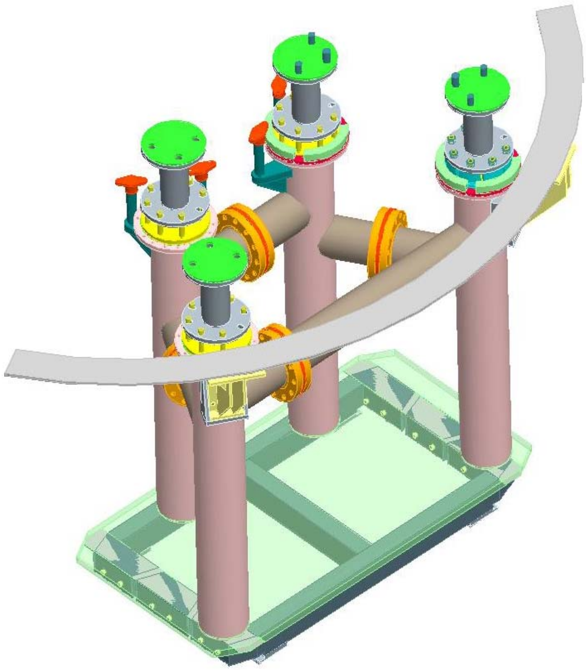
Good Work

- Credit where due: At least Joe Rushinski, Mike Messineo, and Fred Dahlgren steered the evolution of the cryostat design.
- Many thanks to them – this review showcases their work

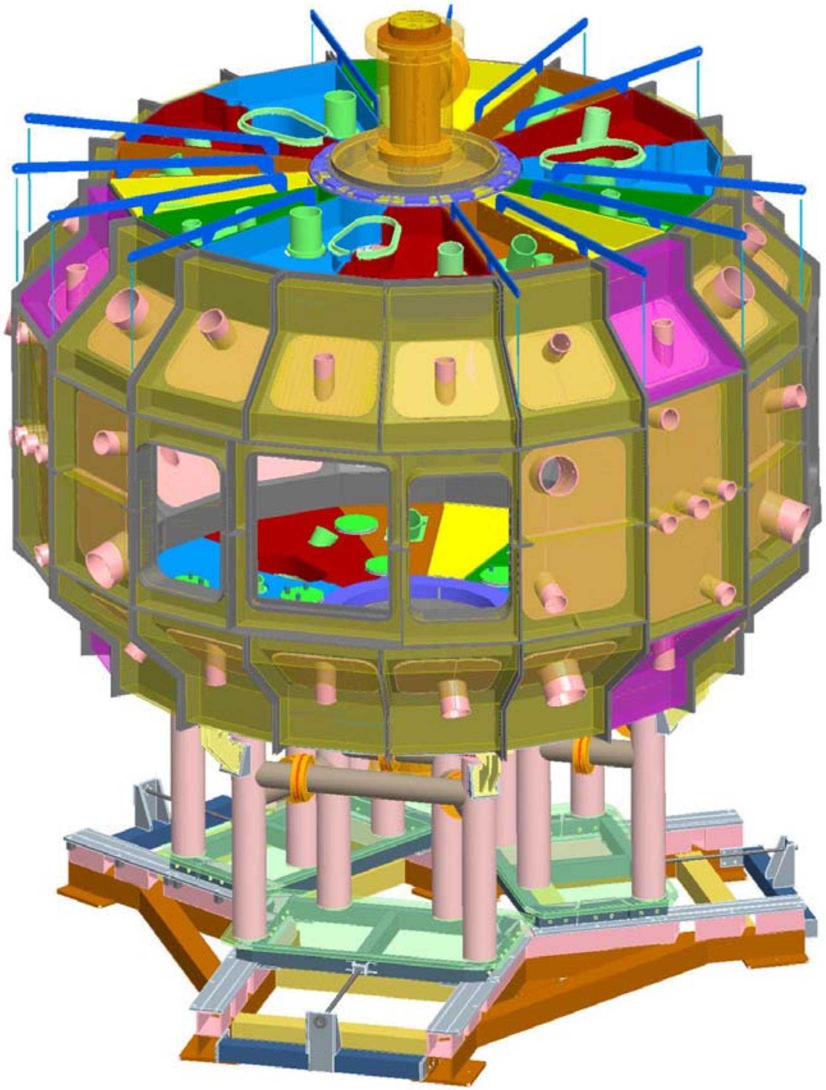
Introduction: What is the Cryostat?

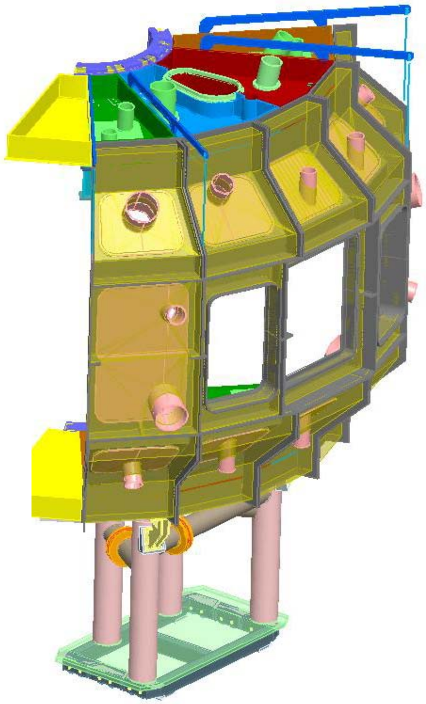
The cryostat (WBS 171) is an insulating, semi-hermetic barrier that will allow the surrounding of the stellarator core with a cold, dry nitrogen atmosphere down to a temperature of 77K.

The semi-hermetic nature of the cryostat excludes the components of atmosphere from approaching the stellarator core in the design temperature range (77K to 311K).



Cryostat and
machine base





Note: Panel covers and insulation are typically not shown

Integration of cryostat wit current vintage facilities in the NCSX Test Cell (looking South)

Cryostat Requirements

1. Must be gas-tight to 7 kPa internal positive pressure
2. Must provide penetrations for vessel extensions, electrical & hydraulic lines, stellarator supports, etc.
3. Shall be of demountable design
4. Shall withstand vacuum boundary displacements due to thermal expansion/contraction and major disruptions
5. The cryostat design, including penetrations and joint sealing, shall limit the influx of ambient heat to about 13.9 kW (includes WBS 172, machine base)

Cryostat Requirements, cont.

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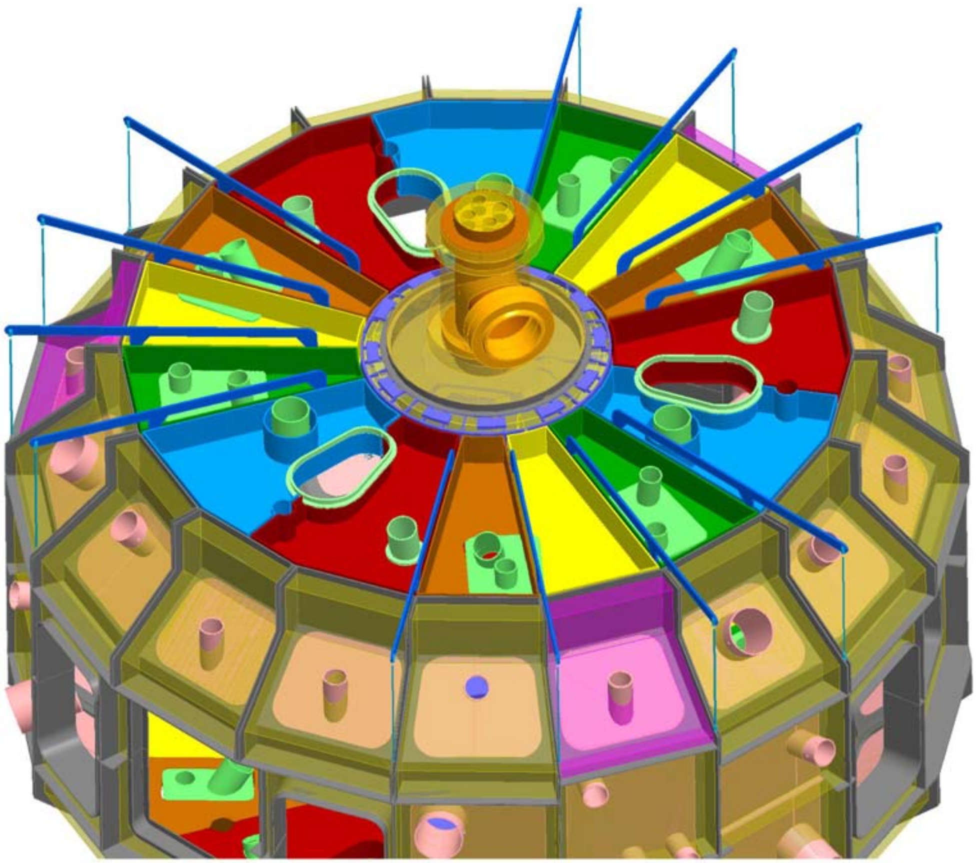
1. Shall accommodate two gas inlet/discharge points located at the bottom/center and top/center of the cryostat
2. Basic cryostat panels shall be have provisions for custom configuration
3. Cryostat panels shall contain a feature allowing the admission of ambient temperature nitrogen gas
4. Shall be able to support TBD kg/m2 of additional load
5. Shall be compatible with all indentified ES&H requirements and best practices

Design Approach

- The conceptual-level NCSX cryostat had a composite space frame onto which closed cell urethane foam would be sprayed

- The preliminary-level NCSX cryostat is somewhat analagous to a prefabricated, modular walk-in freezer for a restaurant
  - It arrives at the Test Cell in finished sub assemblies
  - The subs have gas seals at their joining edges

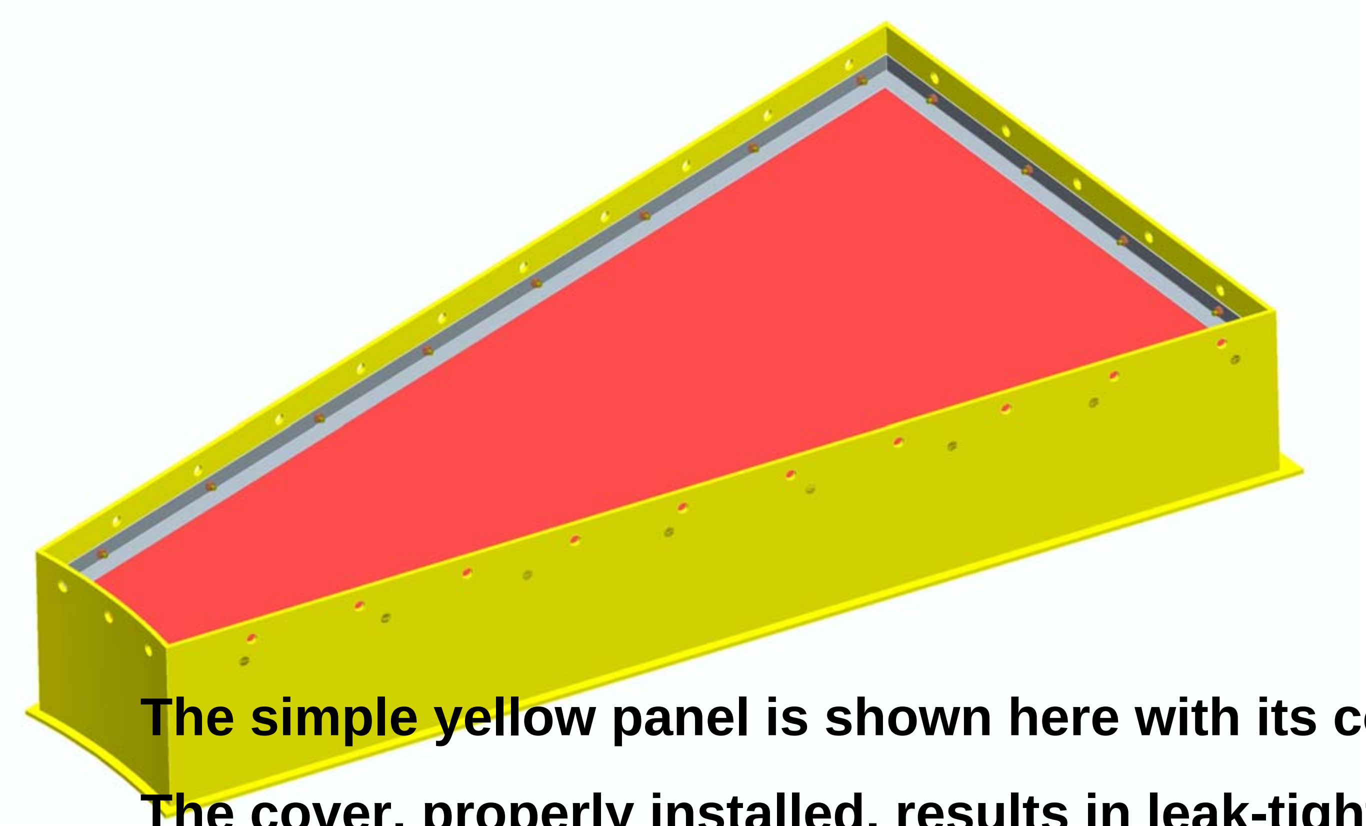
Design Approach



Keeping with the modular concept, the cryostat is an array of panels edge-bolted together.

The next slide will consider one of the simple yellow panels on the top plane.

Panel Design

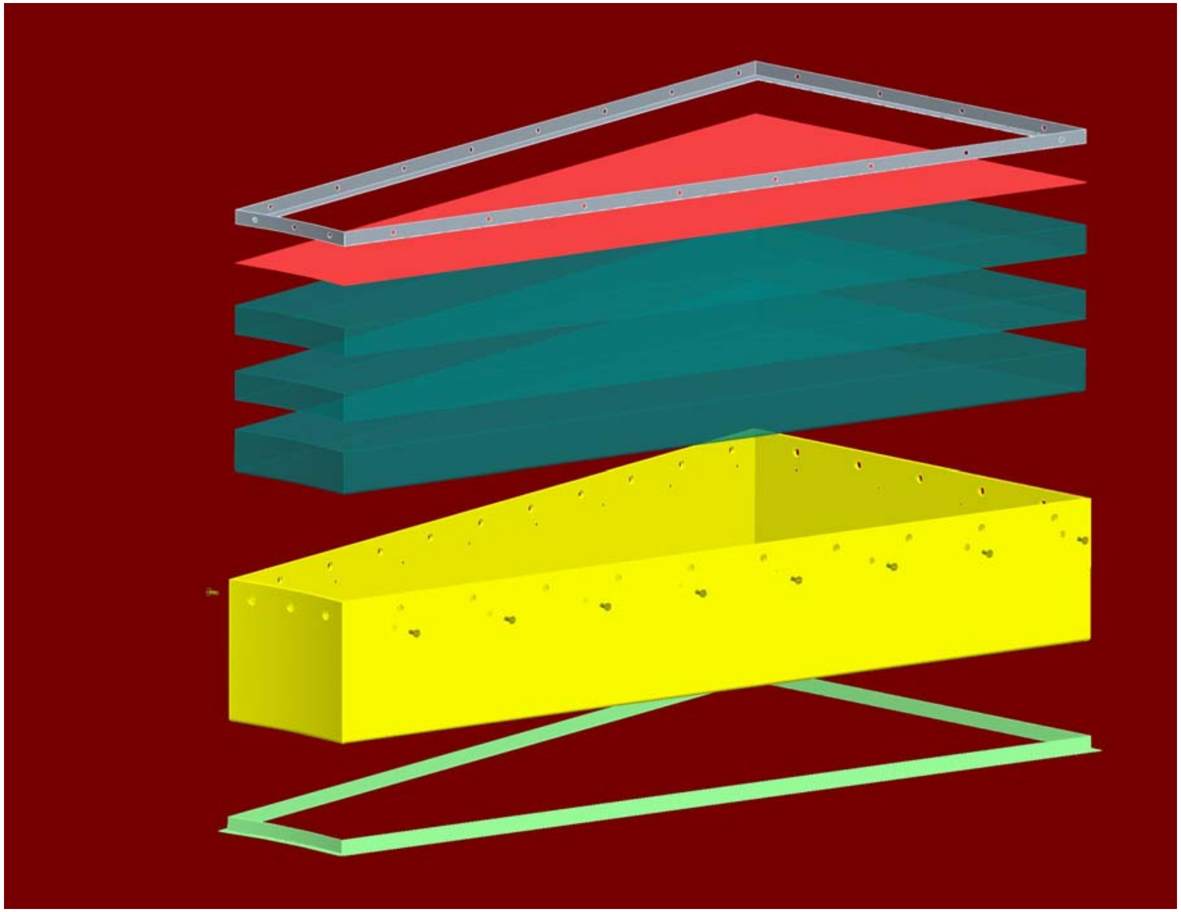


The simple yellow panel is shown here with its cover in place.

The cover, properly installed, results in leak-tight (1 inWater, bubble check) module.

The module will be provided with a purge fitting for 1 inWater N2 gas to keep moisture out.

Panel Design



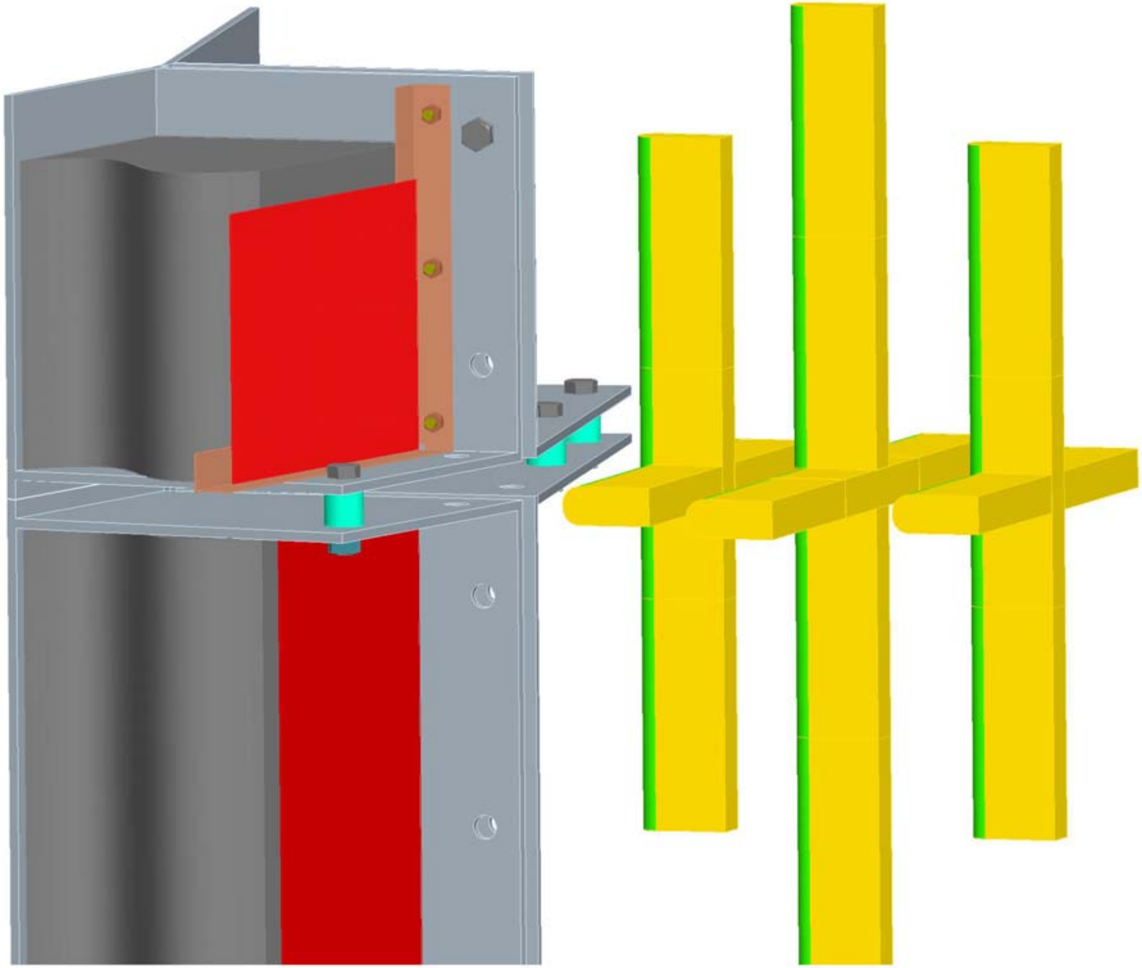
The panel is loaded with 17 cm of closed cell polyisocyanurate board stock in layers. Any joints in the layers are staggered by several inches.

The green 2 x 1 cm unequal leg angle is bonded in place to serve as a seal limiter for the inter-panel packing.

The flat-head screws for the cover are insulating material (for accidental drops).

- Fundamental Panel Objective: Avoid flaws or channels in insulation system that allow gas conduction/convection between ambient and cold areas
  – Increased cooling required for same operating point (read "$$$$")
  – Potential for frost and ice balls on the exterior (read "embarrassed engineer")

Joint Design

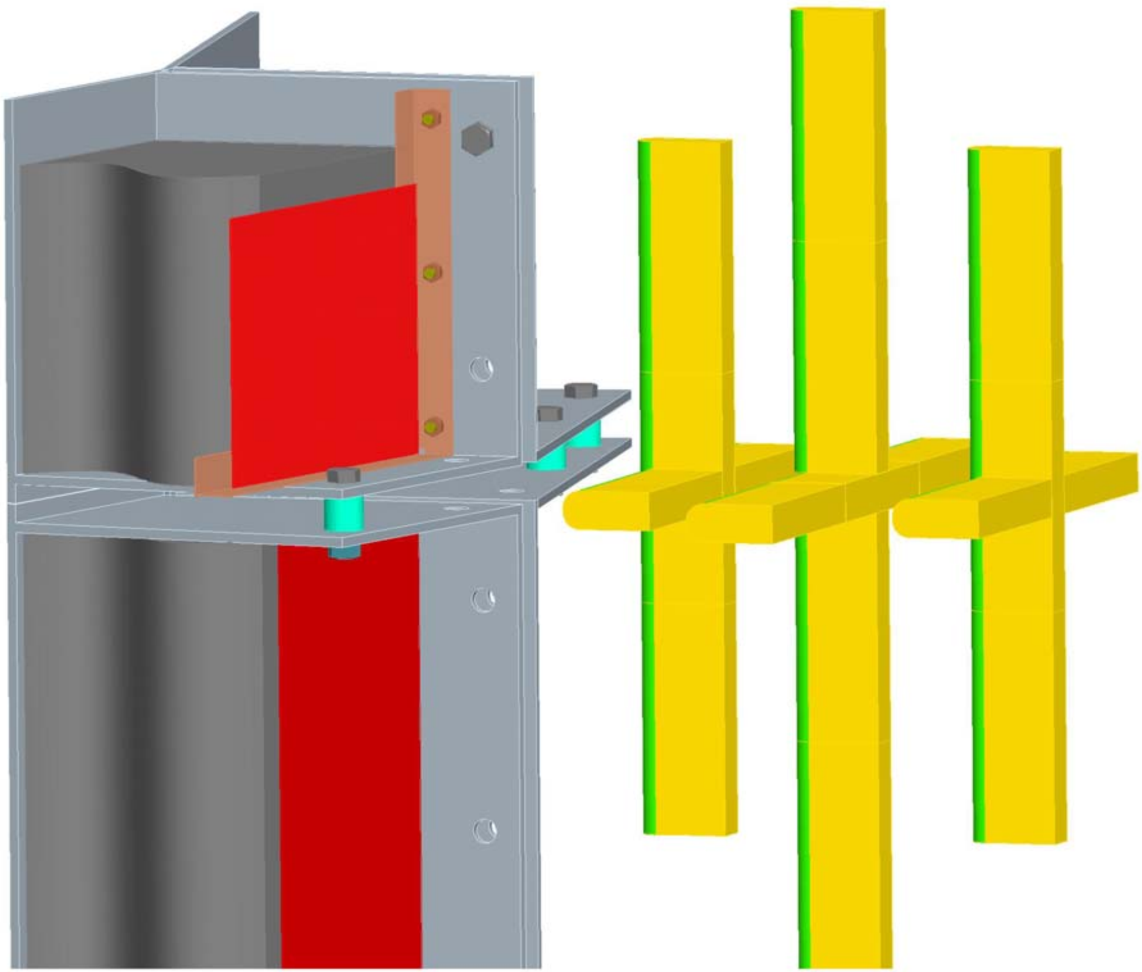


Adjacent panels are joined with screw-bushing-nylok nut combinations.

The bushings will be of insulating materials in case of accidental drop-in.

This method of lacing the warm edges of the panels together along with a gap between adjacent seal limiters will tolerate much dimensional change in the cryostat during cool-down and warm-up cycles.

Joint Design



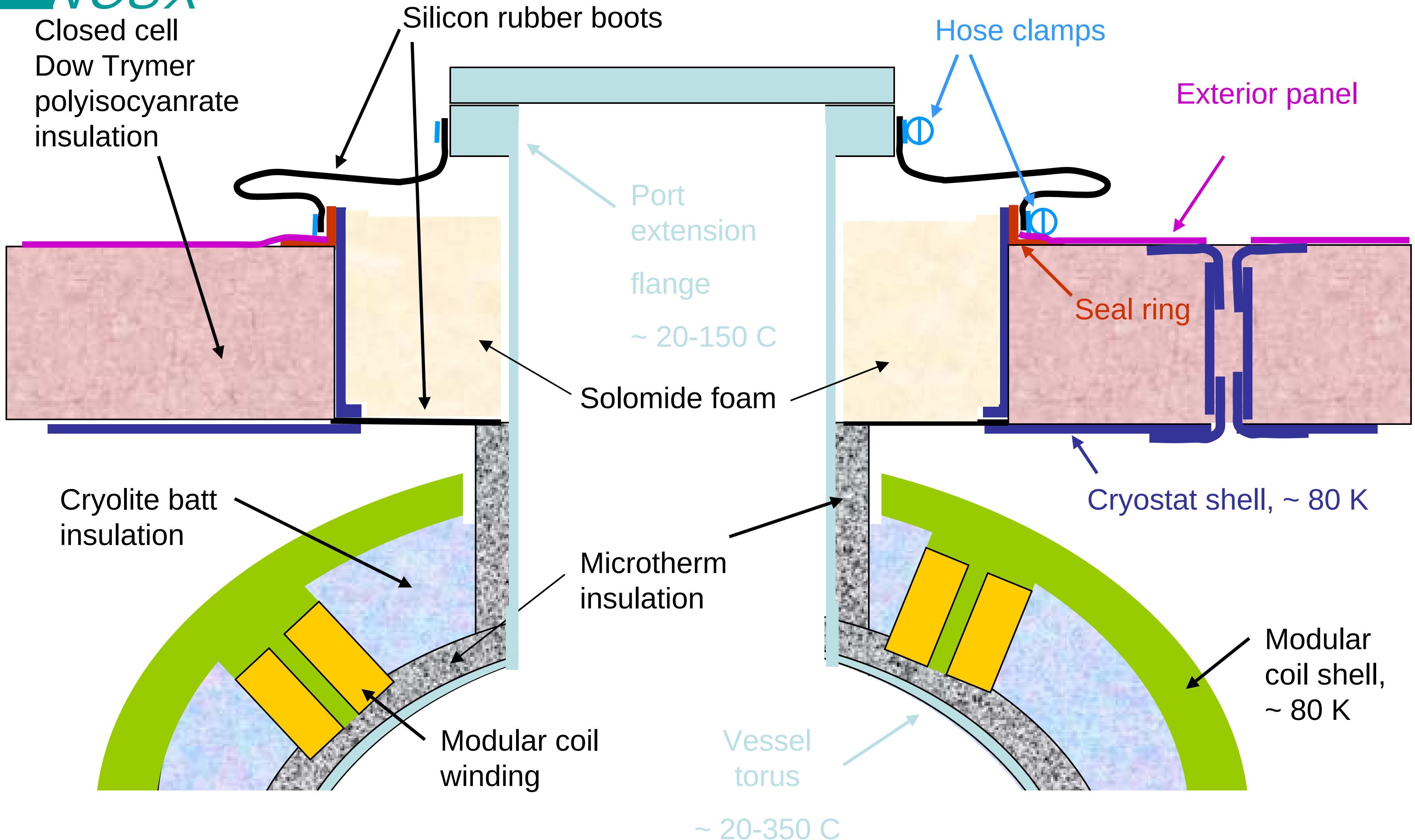
Layers of over-thick resilient foam with PTFE tape on the edges serve as the packing for joints and for MOST penetrations

Multiple PTFE membranes end reliance on a single inboard seal

This scheme is fully serviceable from the outside of the cryostat.

A final circular bead (not shown) seals the joint from atmosphere

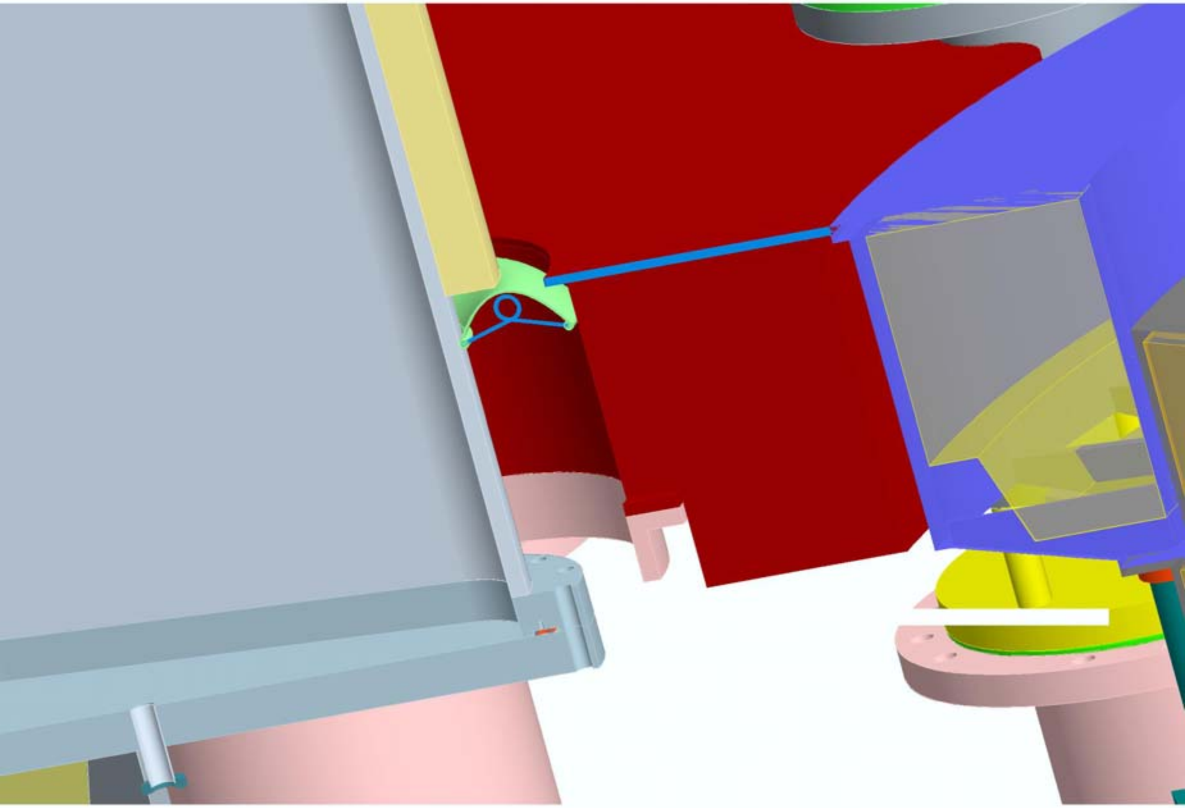
Incumbent Penetration Sealing Schematic



Penetration Basics

- Inner boot is historically fiberglass cloth impregnated with Dow silicone compound
- The penetrations be entirely serviceable from the exterior of the machine
  - Our ever-growing concern about confined spaces AND time-for-rescue tends to call for exterior serviceability
- Inboard travel limiter to prevent packed joint seals from falling in
  - Limiter included in basic tub would be expensive
  - A value-minded engineer might glue non-conductive angle on the tub

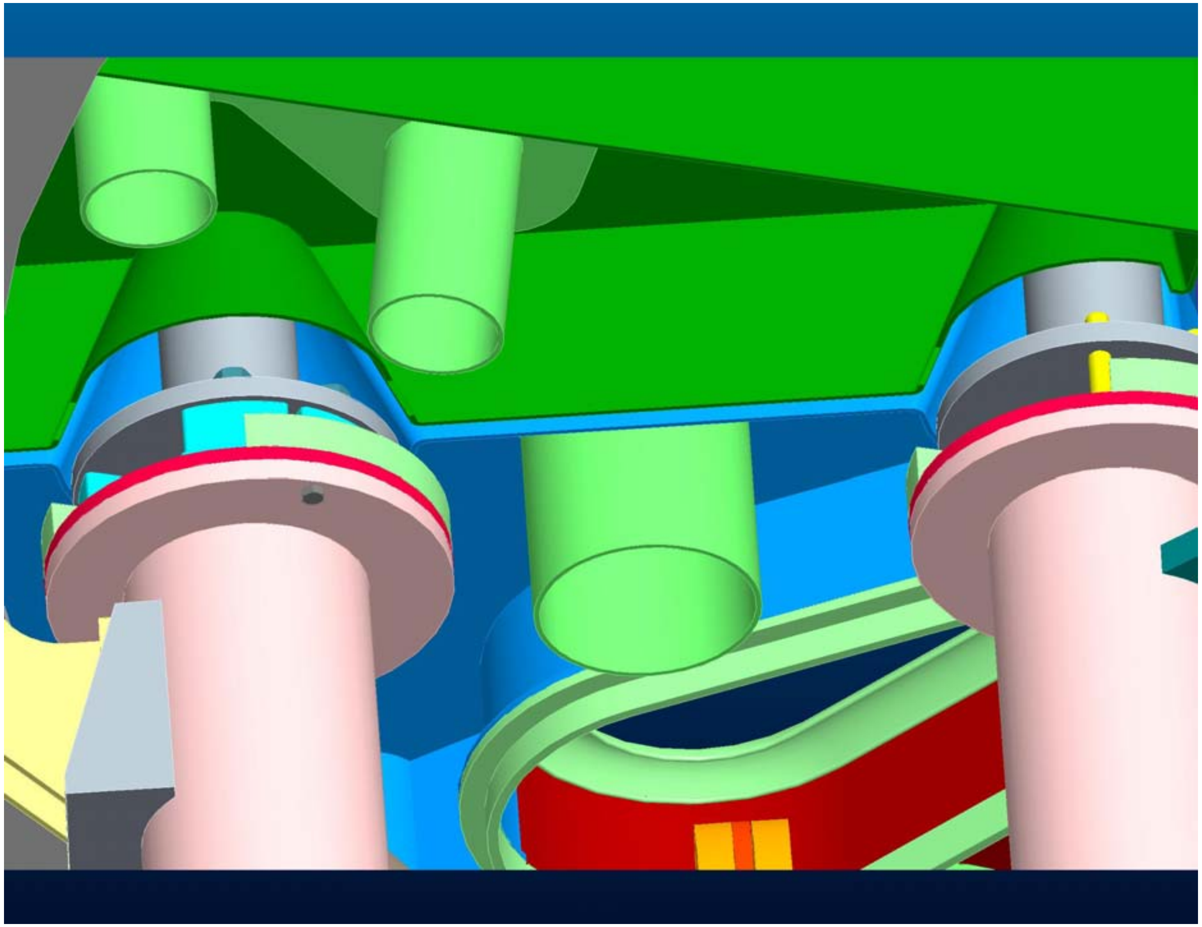
Complex Inner, Cold Seal



Spring-loaded inner seal

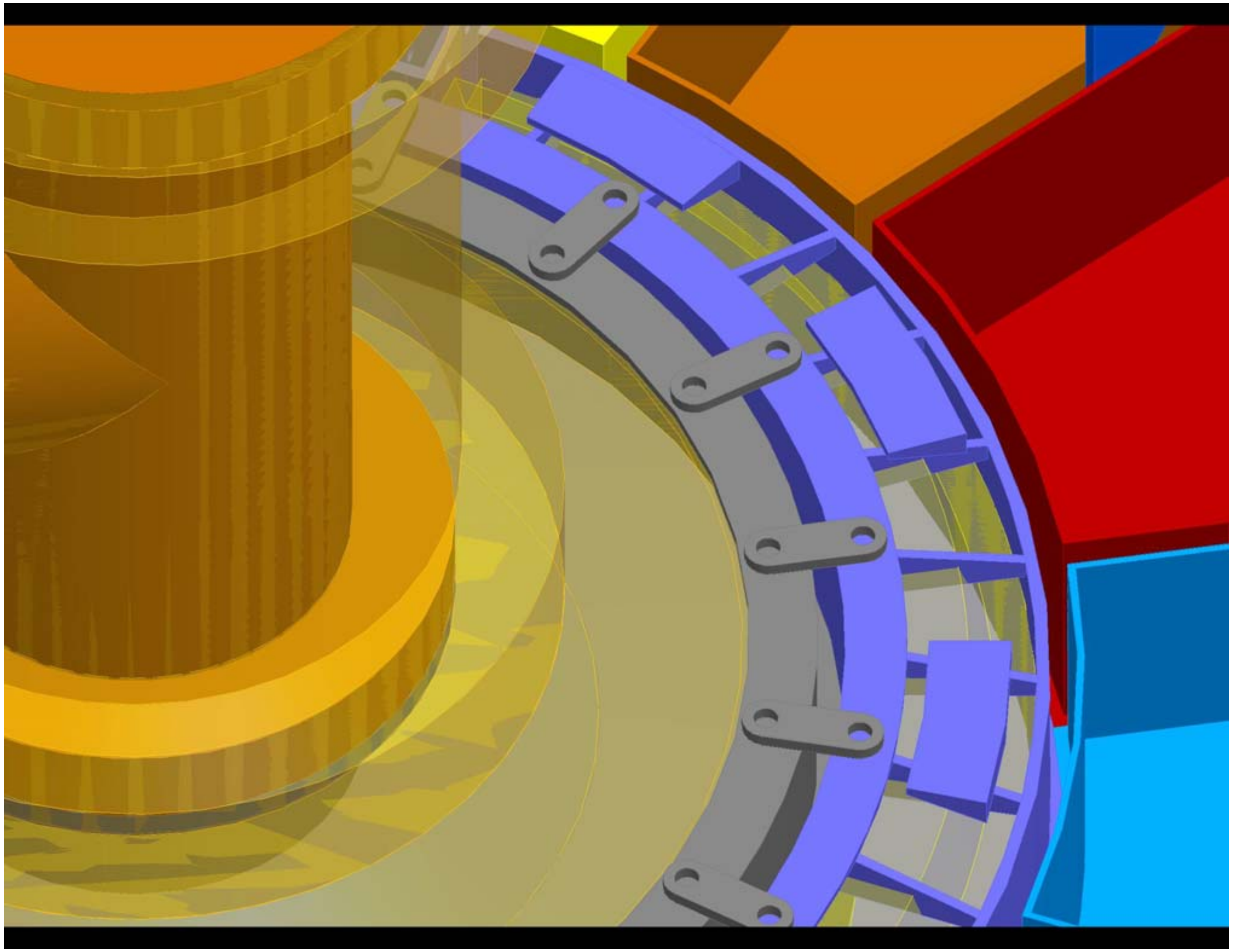
- **Insertable from the outside**
- **Useful for variable-annulus penetration/extension combinations**

Design Points



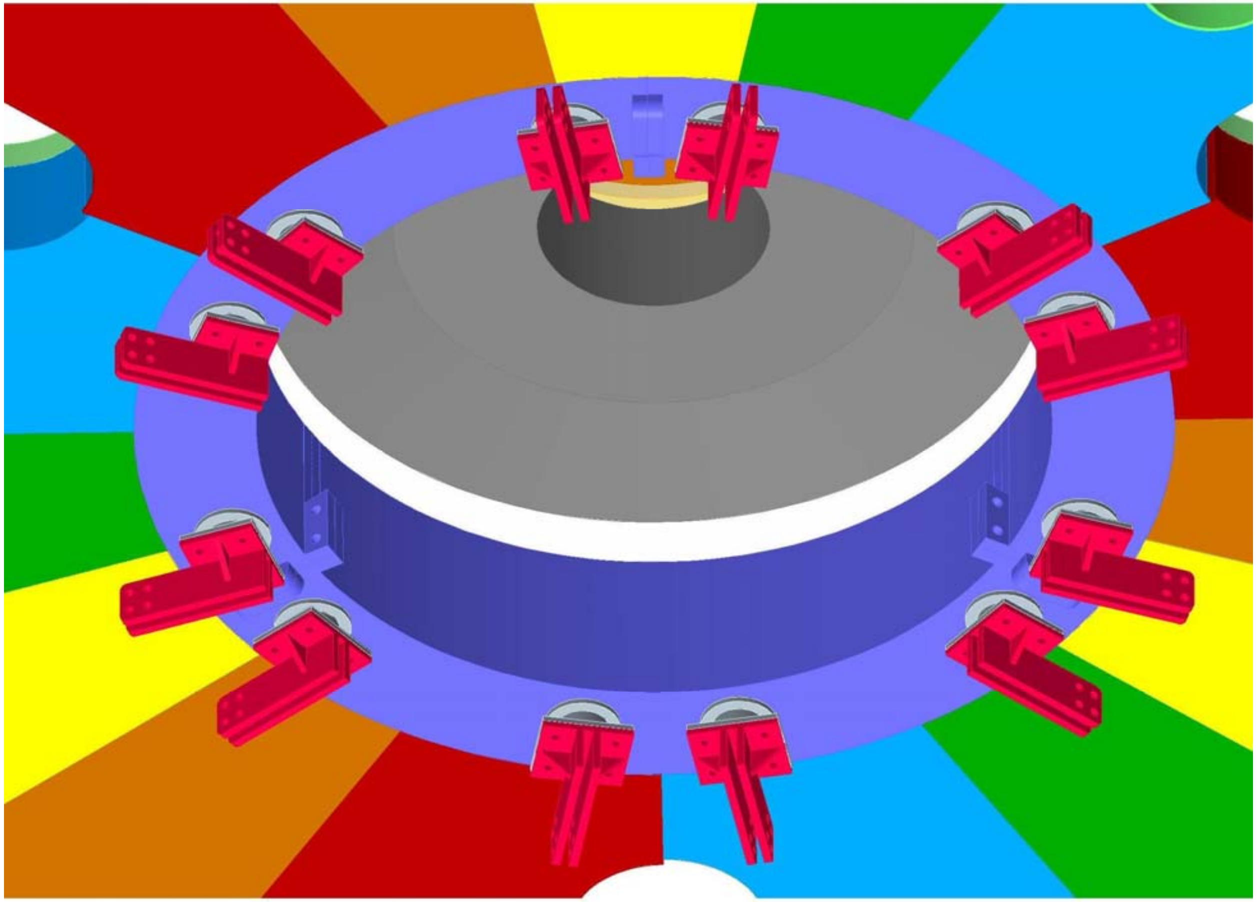
The panel penetrations for the machine base posts have a conical shape to facilitate panel installation and removal in the crowded under-machine area.

Design Points



An array of clips supports the upper inner plug from the intermediate ring

Design Points

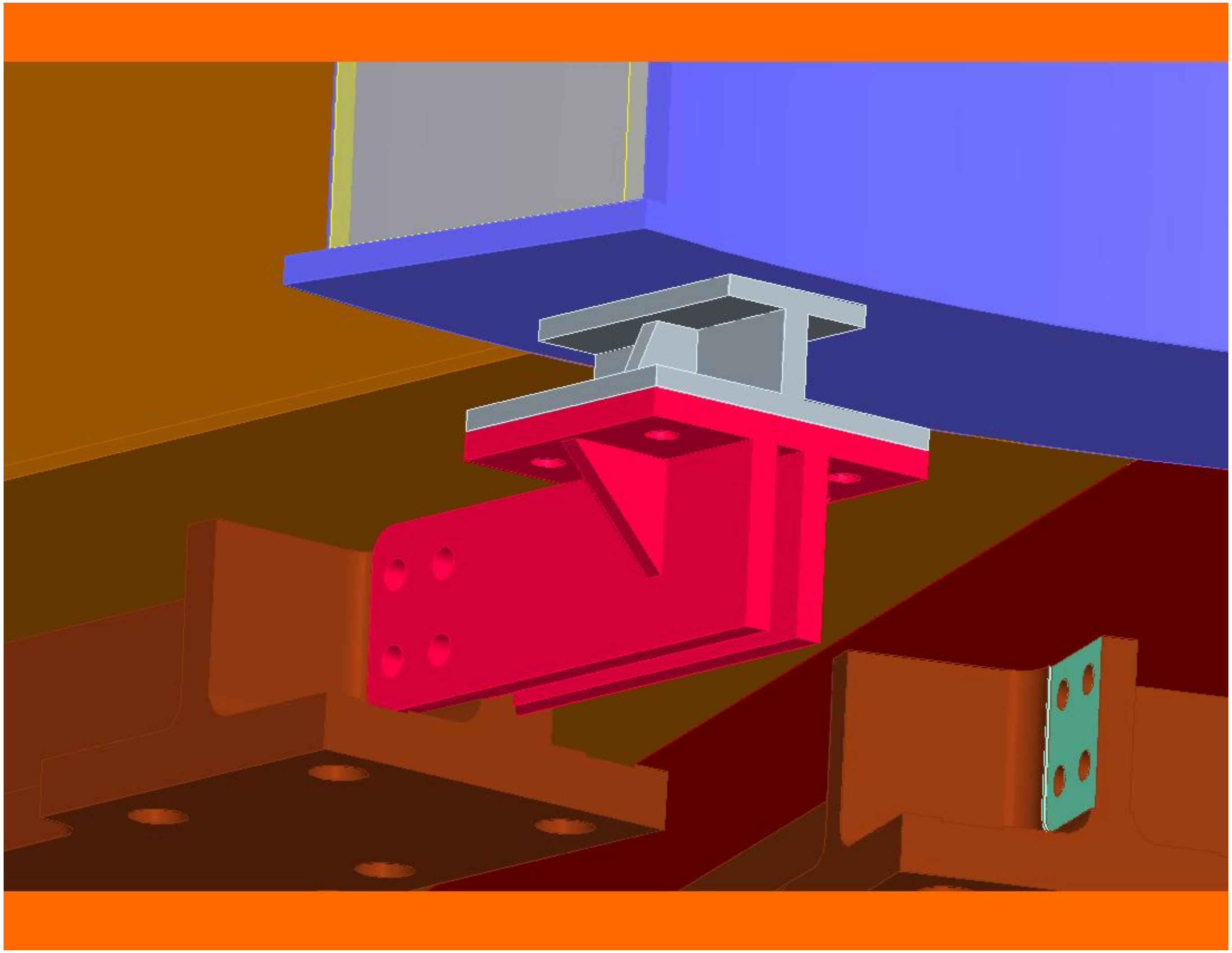


An array of weldments support the upper plug, upper intermediate ring, and the inboard end of the upper (pie slice) panels.

These weldments attach to the upper radial tie beams (WBS 15)

Design Points

Value Engineering – The designer caught this one! This very functional support may be expensive to produce. It has been redone.



Design Points

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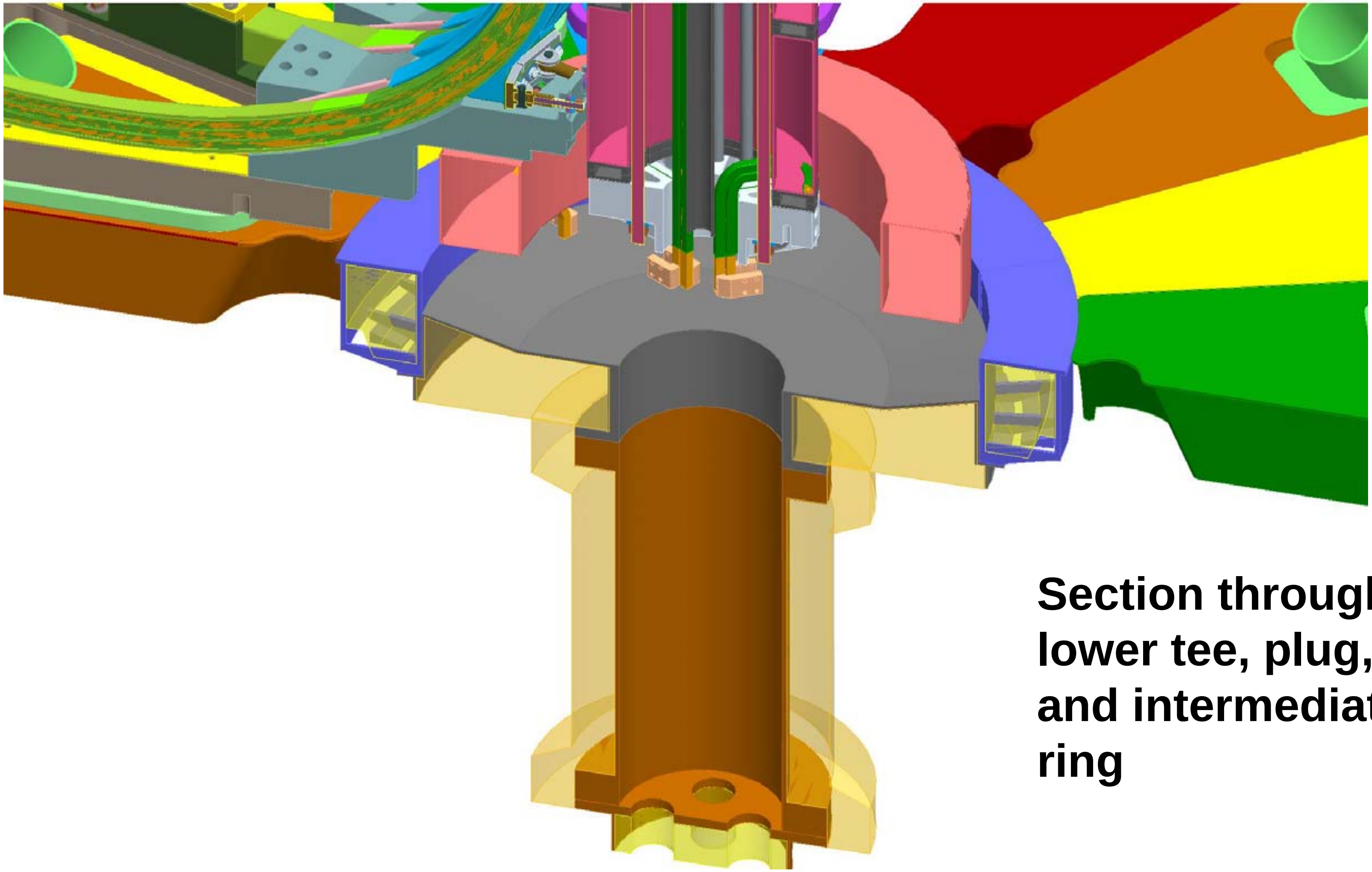
Plan view of cryostat

Note bus feedthroughs in run of FRP Tee on the axis of the cryostat (similar on bottom)

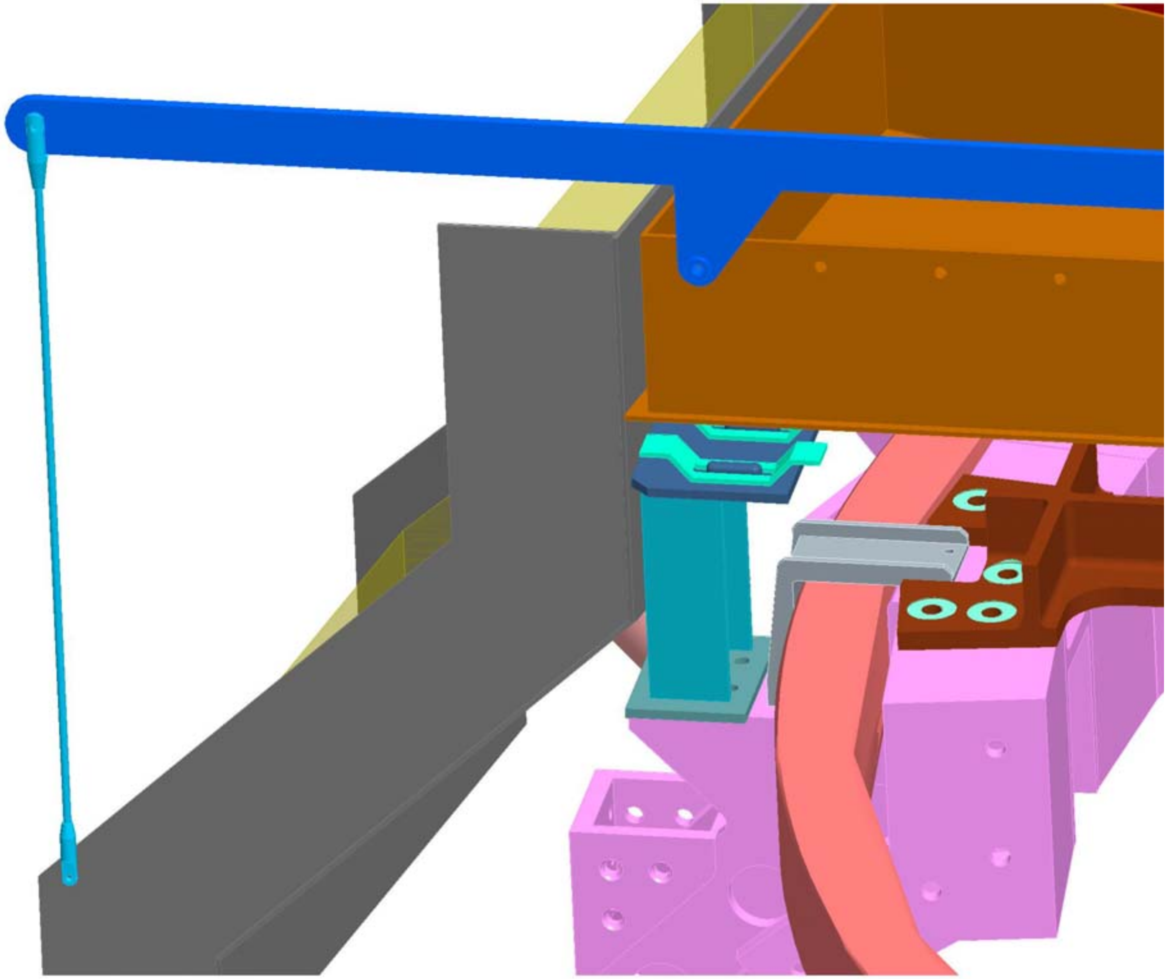
Branch of FRP Tees are available for interface with WBS 623, GN2 Cooling

Design Points



Section through lower tee, plug, and intermediate ring

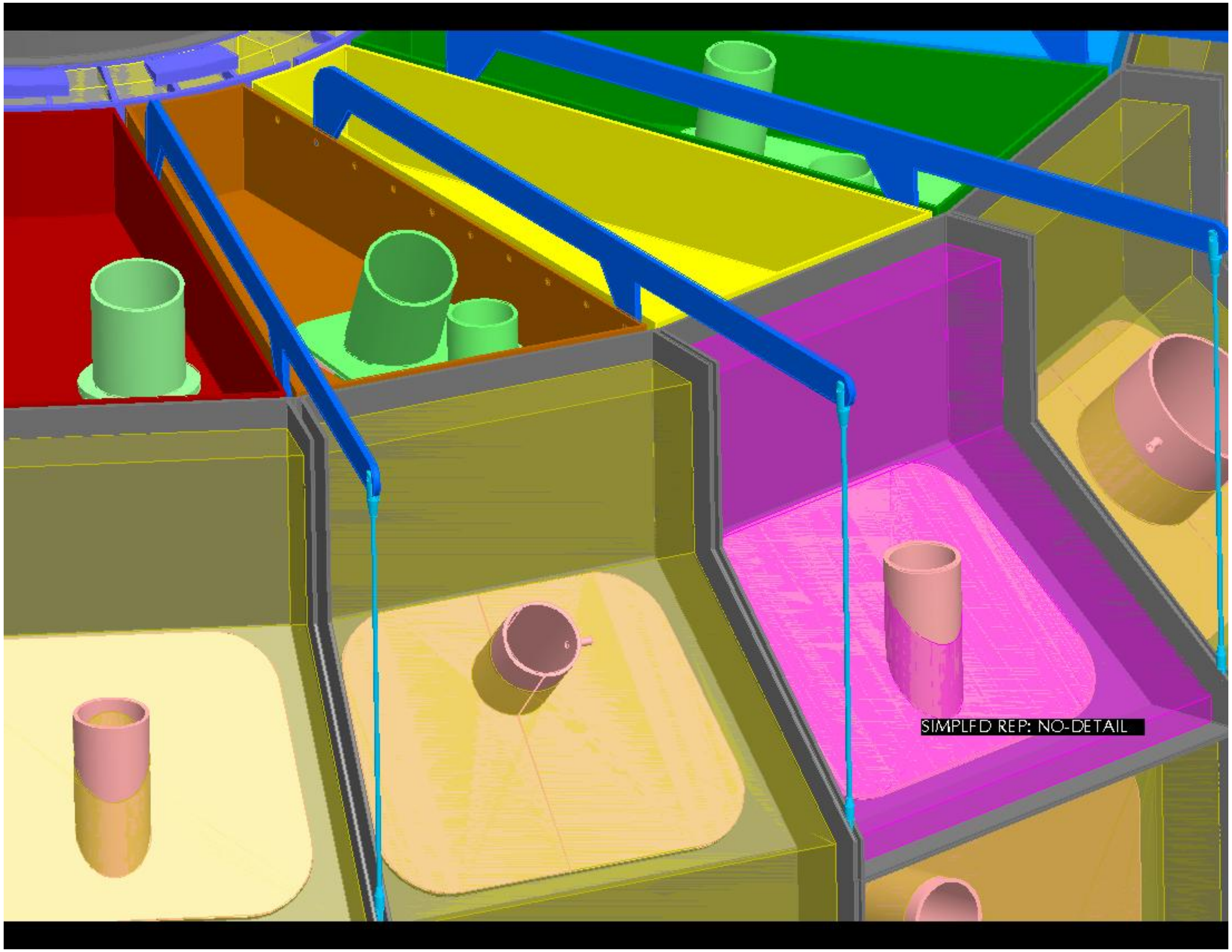
Design Points



Sliding support reacts cryostat load into WBS 15 coil supports.

Conceptual outrigger prevents currently un-investigated creep of epoxy/glass structures.

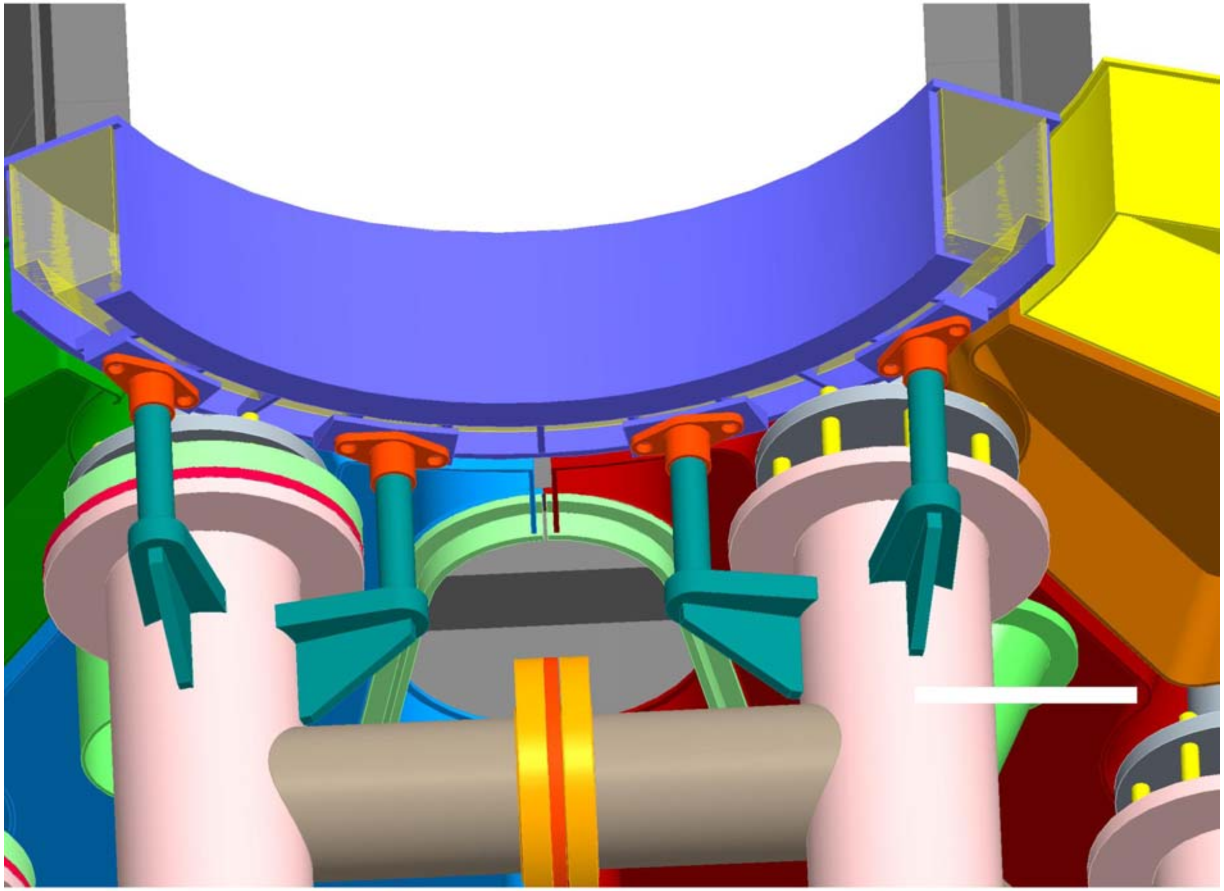
Design Points



View of upper angled panels with location-specific inserts allowing economies of scale in production (36 units)

Outrigger links are in line with midplane load.

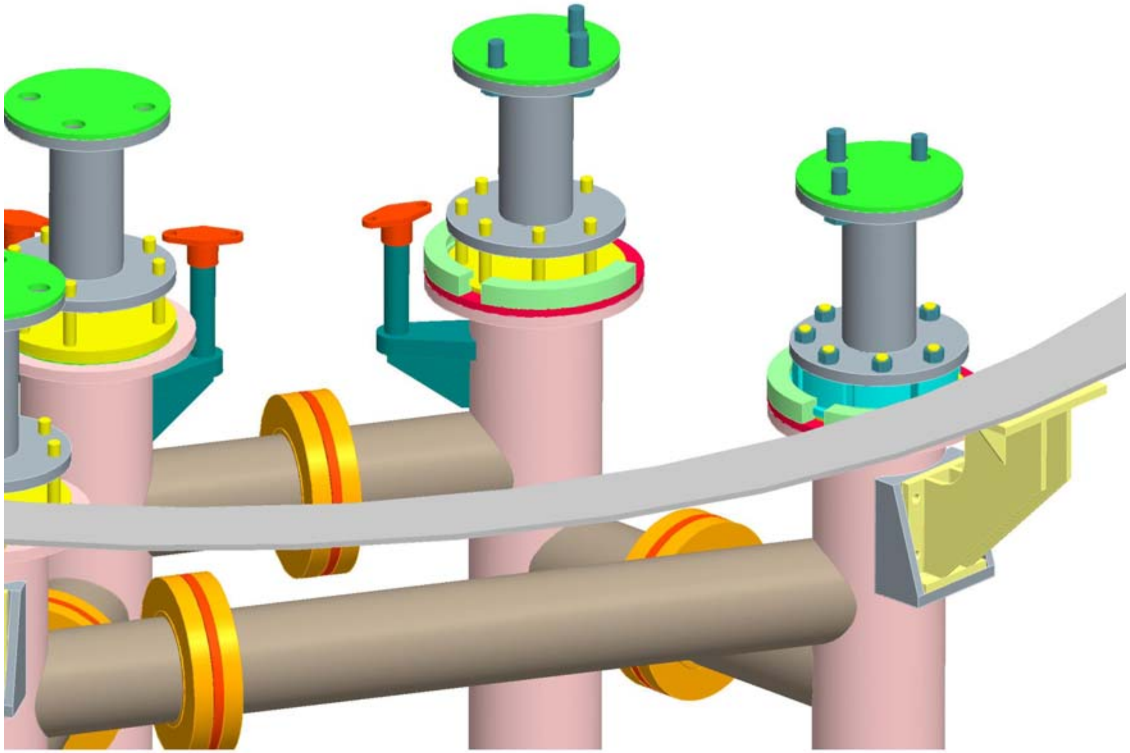
Design Points



Lower intermediate ring supported from machine base

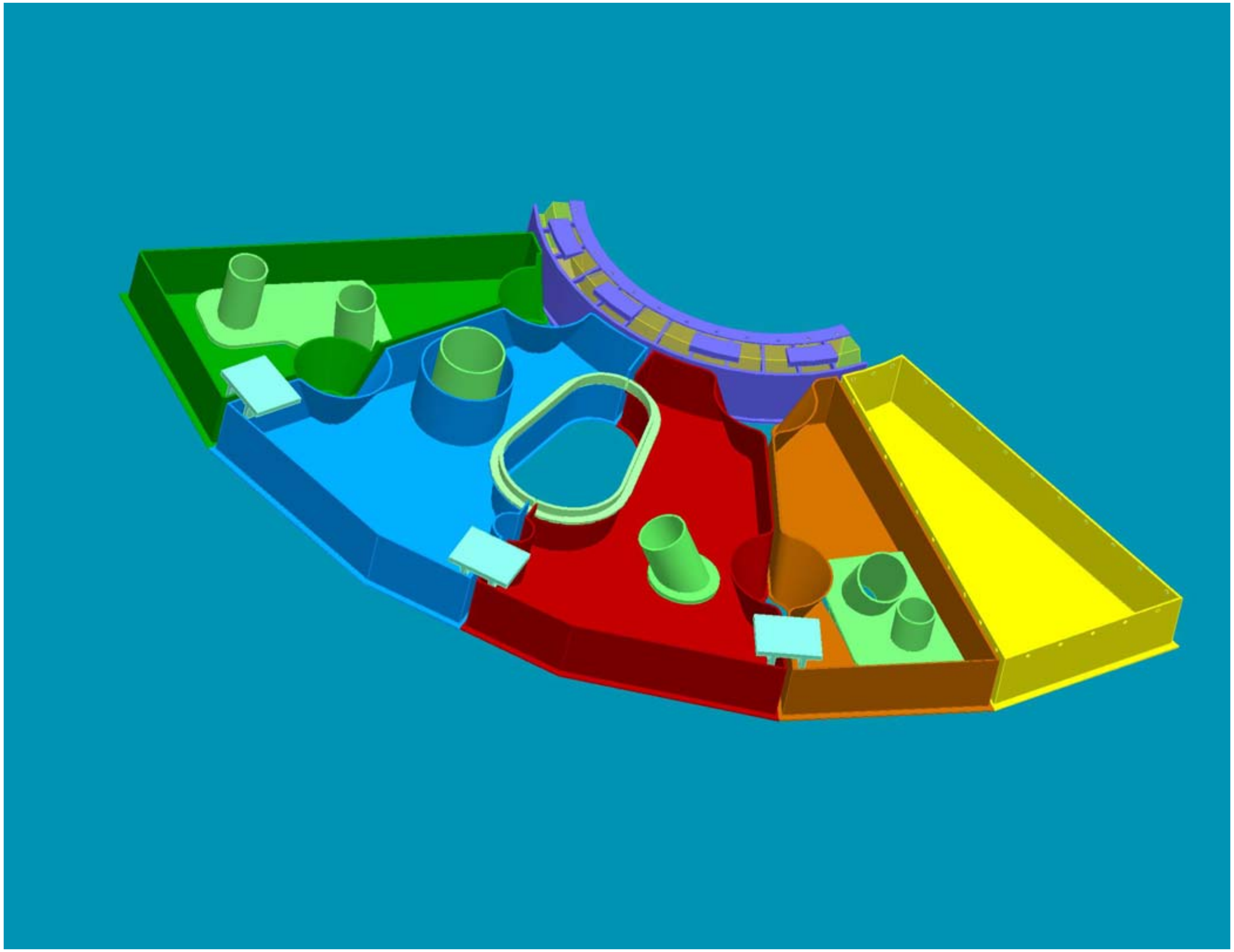
Design Points

NCSX



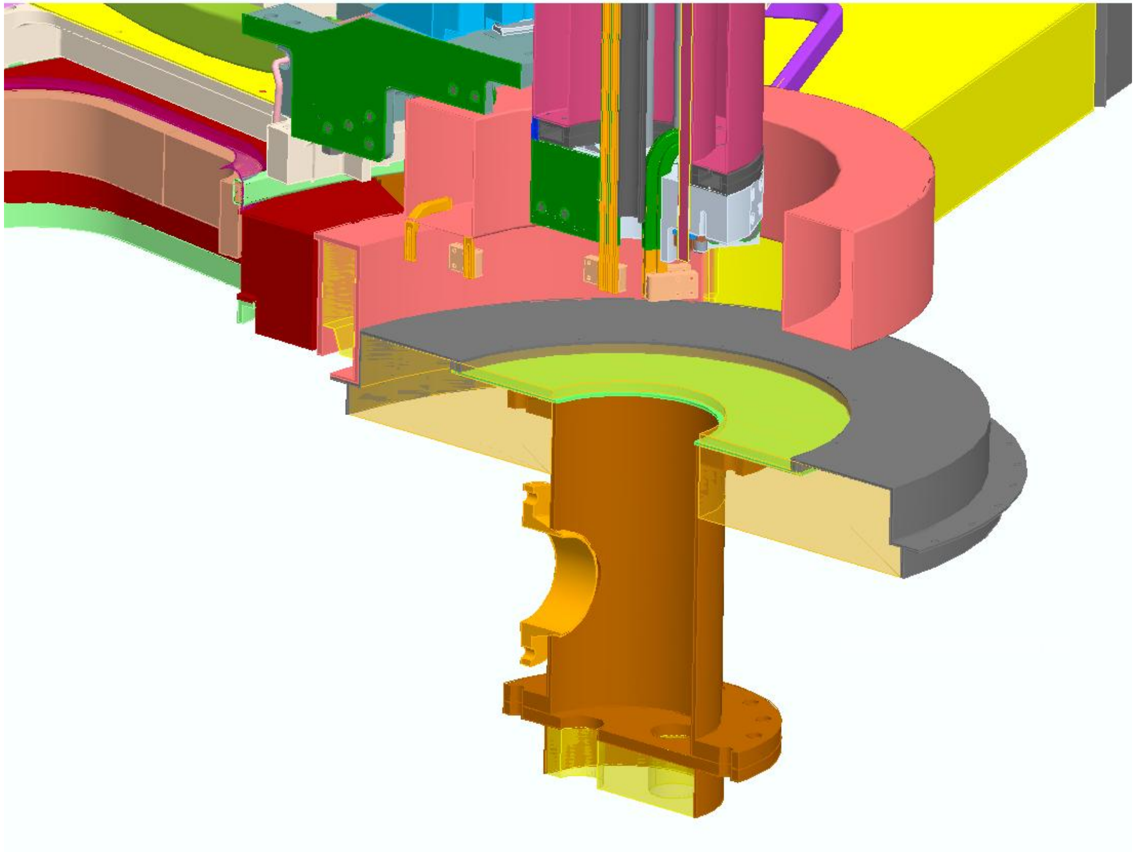
Outer support ring mounted on machine base

Design Points



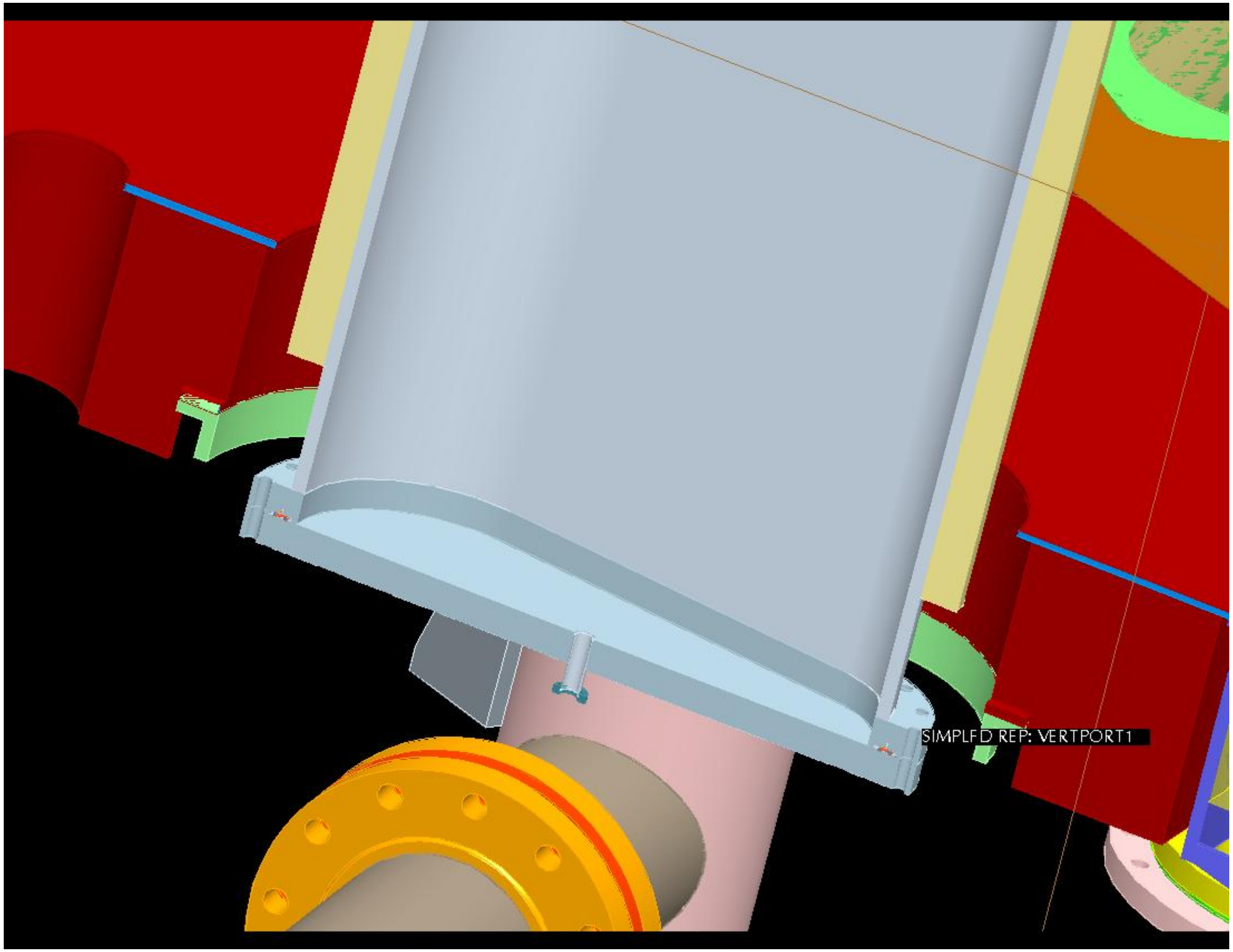
Underside showing conical penetrations for machine base

Design Points



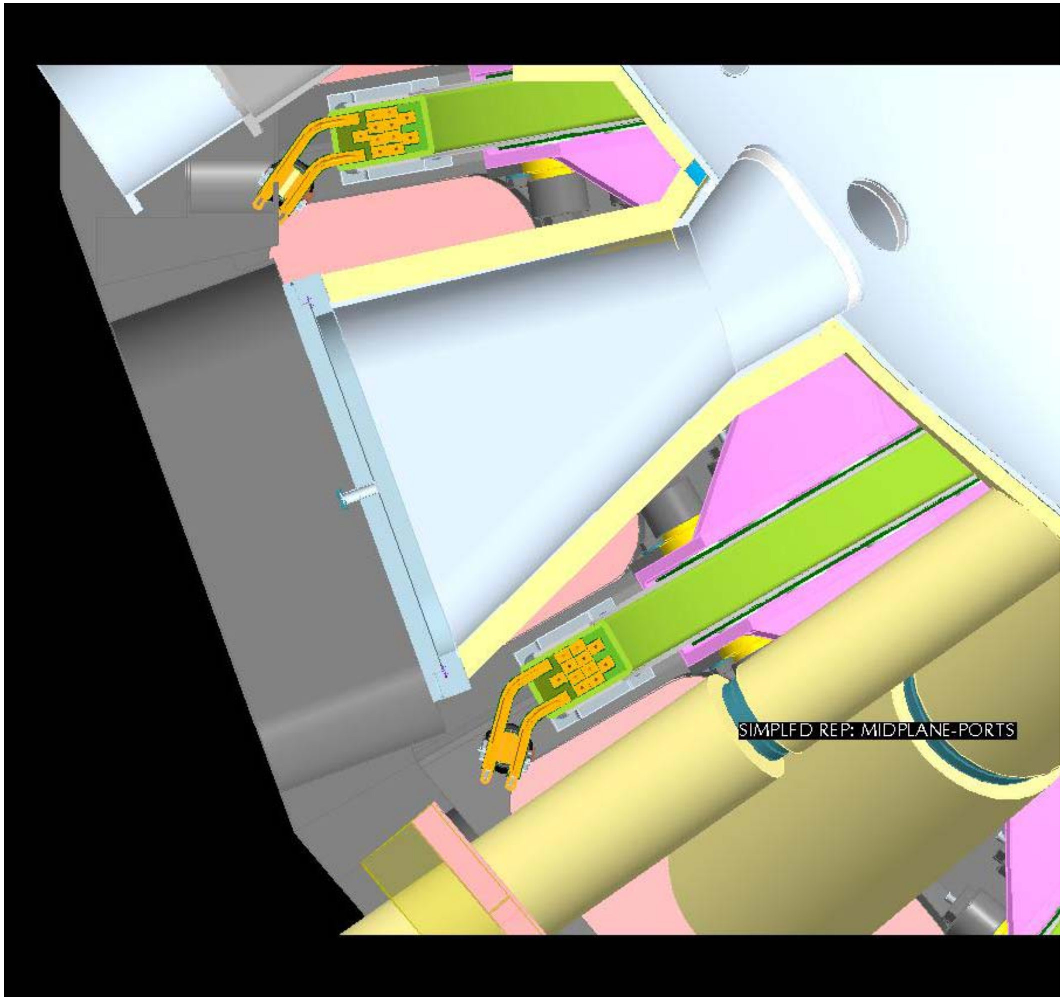
Lower center plug and FRP Tee showing branch outlet and run configured for kickless cable

Design Points



Basic penetration of vertical port

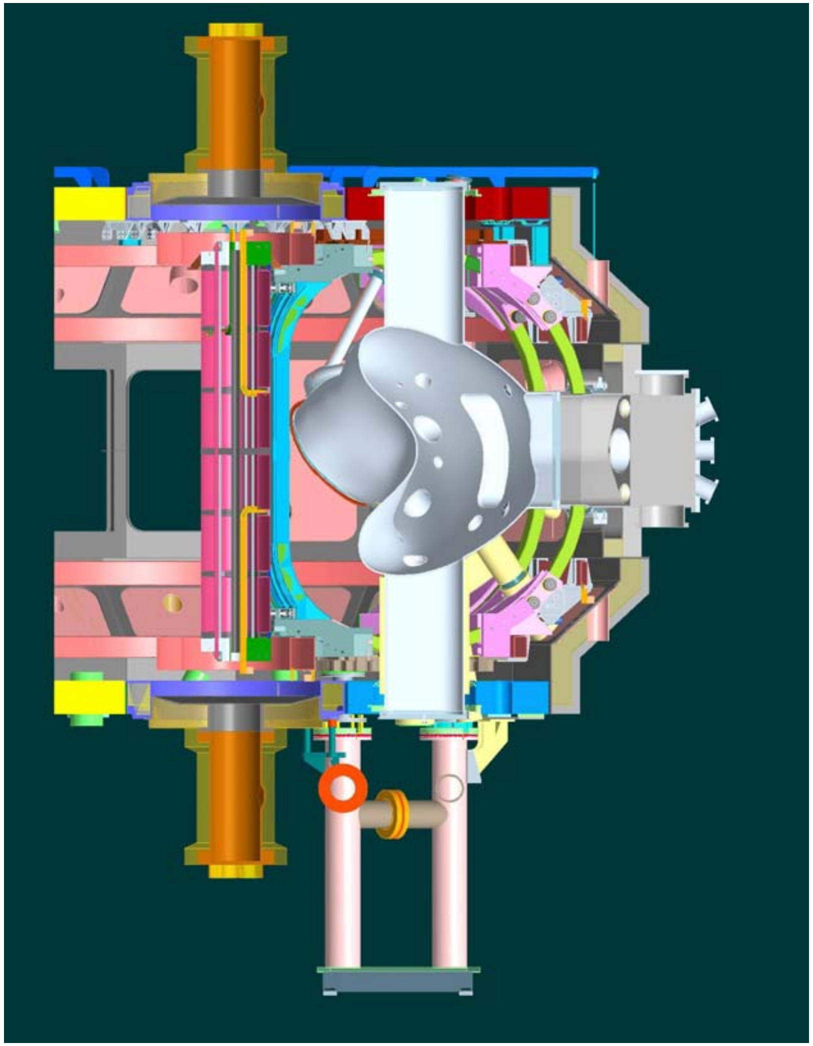
Interface Control (Scope Sheets)



- The cryostat is a secondary or tertiary system – Things happen and drive the design (TF leads pushed the cyrostat outward)

Interface Control, cont.

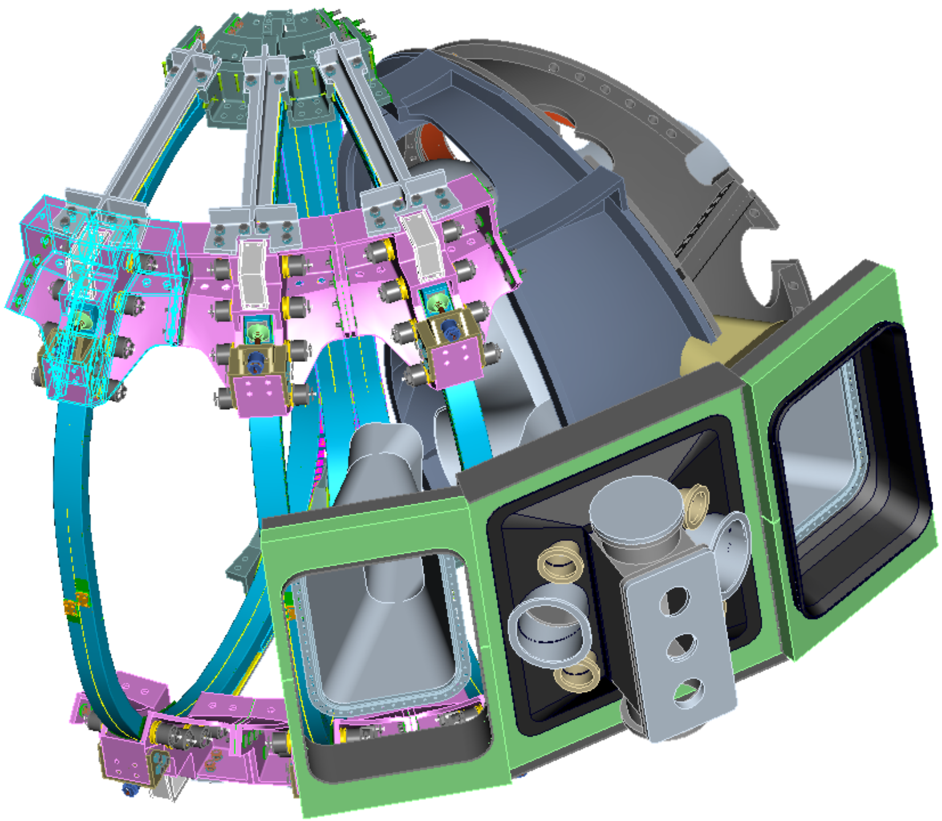
NCSX



- LN2 piping and kickless cable runs may become the next drivers
  - No room for piping and bus at this time
- WBS 16 will embark on this per scope sheet

Interface Control, cont.

- NB and large diag port seals need further development
- Should be undertaken after final cryostat size is understood (scope sheets)



Thermal Characteristics of Materials

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Material	Thermal Conductivity	Coeff of Thermal Expansion
Dow Trymer 2000 Closed Cell Foam	0.027 W/mK @ 293K	9e-5 /K @ 300K Unknown @ 77K
Inspec Solimide Open Cell Foam	0.040 @ 293K	Resilient at all temperatures of interest
G-10 Warp Direction (Inconel 718 is similar)	0.85 W/mK @ 300K 0.30 W/mK @77K	1.16e-5 /K @ 300K 5.5e-6 /K @ 77K
Teflon	0.26 W/mK @ 300K 0.23 W/mK @77K	4.2e-5 /K @ 300K 3.4e-5 /K @ 77K
304 SS	14.9 W/mK @ 300K 8.2 W/mK @77K	1.6e-5 /K @ 300K 7.5e-6 /K @ 77K

Partial Parasitic Heat Load

- The 0.027 W/mK associated with the candidate closed cell foam suggest a constant heat load of about 5 kW through the panels only.
- 5 kW suggests the vaporization of
  - 4900 gallons of LN2 or
  - ¾ trailers per week

- The GRD offers a non-bakeout parasitic load of 2.12 trailers per week
  - The panels claim 36% of this number

Differential Thermal Expansion

	R = 152 cm Vertical Port	R = 193 cm Outboard Leg	R = 320 cm Midpland Diag Cover
Cryostat, G-10 300K to 80K	-0.35cm	-0.44 cm	-0.74 cm
Vessel and Graded Extensions, Inconel 300K to 650K	0.65 cm		~0.8 cm (assuming some gradients in ports & ext.)
Machine Base, 300 Series SS 300K to 80K		-0.56cm	

Differential expansion between the vessel and the penetrations is not trivial at 1 cm & 1.5 cm!

The cold inboard seal must tolerate this displacement AND this assumes no asymmetric vessel constraints (NB tugging vs. diags)

Main Insulation

- Dow Trymer 2000 (or equivalent)
  - Closed cell polyisocyanurate foam available for $0.72 per board foot

  Why closed cell? Avoids condensation of moisture in bulk with consequent increase of k-factor
- This demonstration is already underway in the CTF!
  - Low QC'd polyisocyanurate board (6" worth) should nicely represent the Trymer board stock
  - The 2" wall pipe insulation *is* Trymer 2000

Main Insulation, cont.

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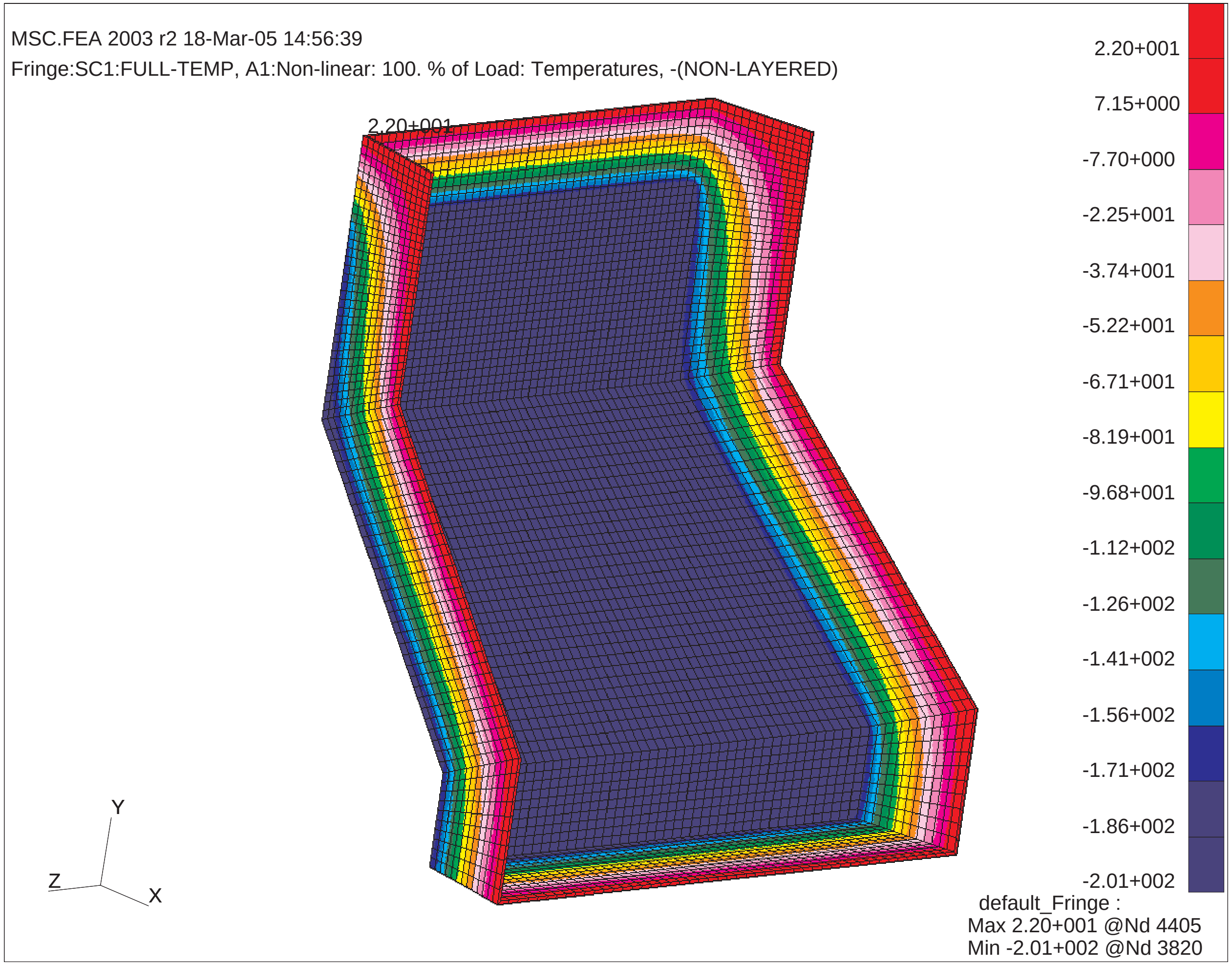
- Coil Test Facility's pump skid with 17 cm of Super Tuff-R
- This will be a great condensation qualifier

Flexible Insulation

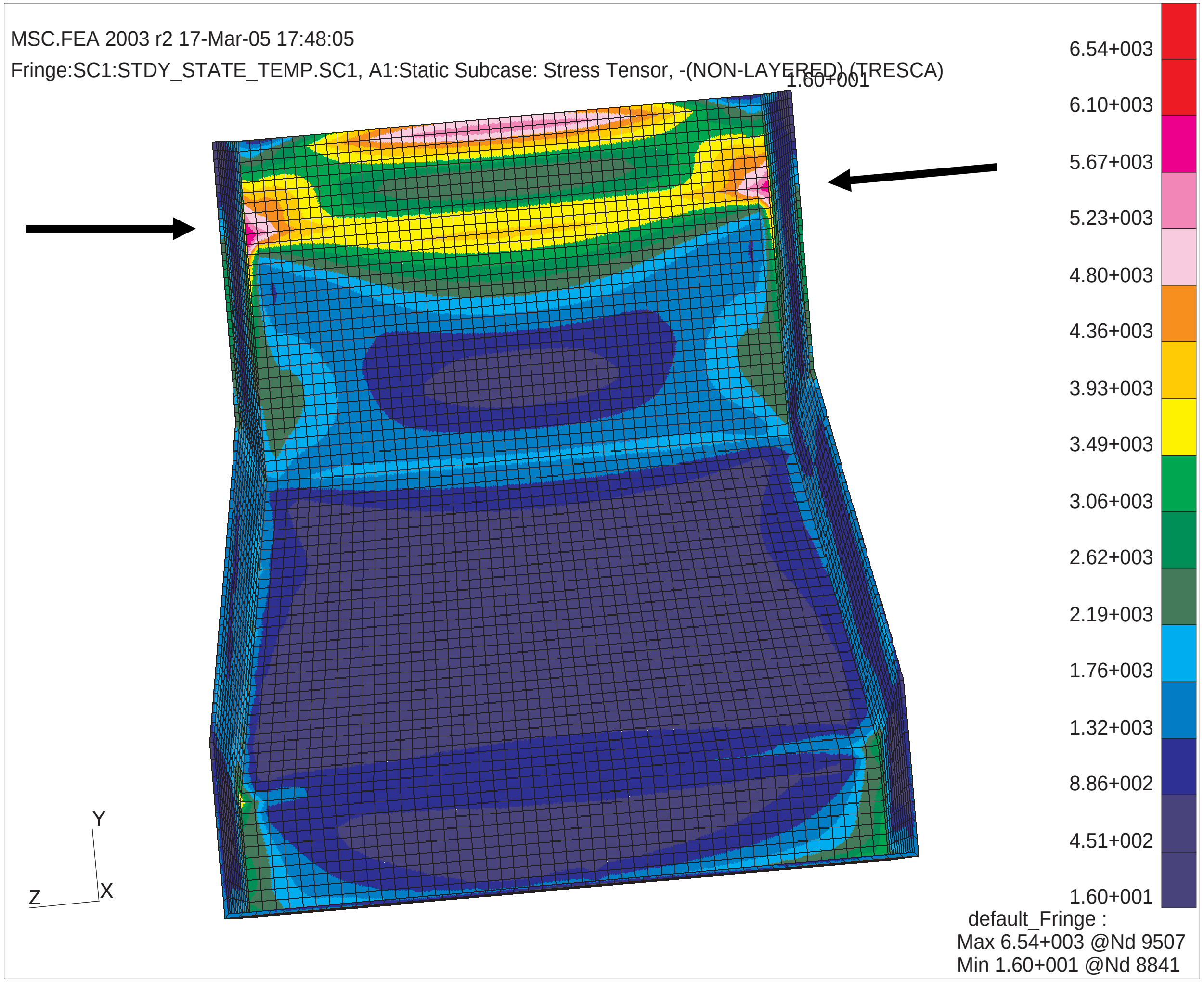
- Inspec's Solomide polyimide open-cell foam has a k-factor of .040 W/mK and retains its resiliency at 77K.
  - Open cell nature is undesirable
  - $6.50/bd ft

Analysis



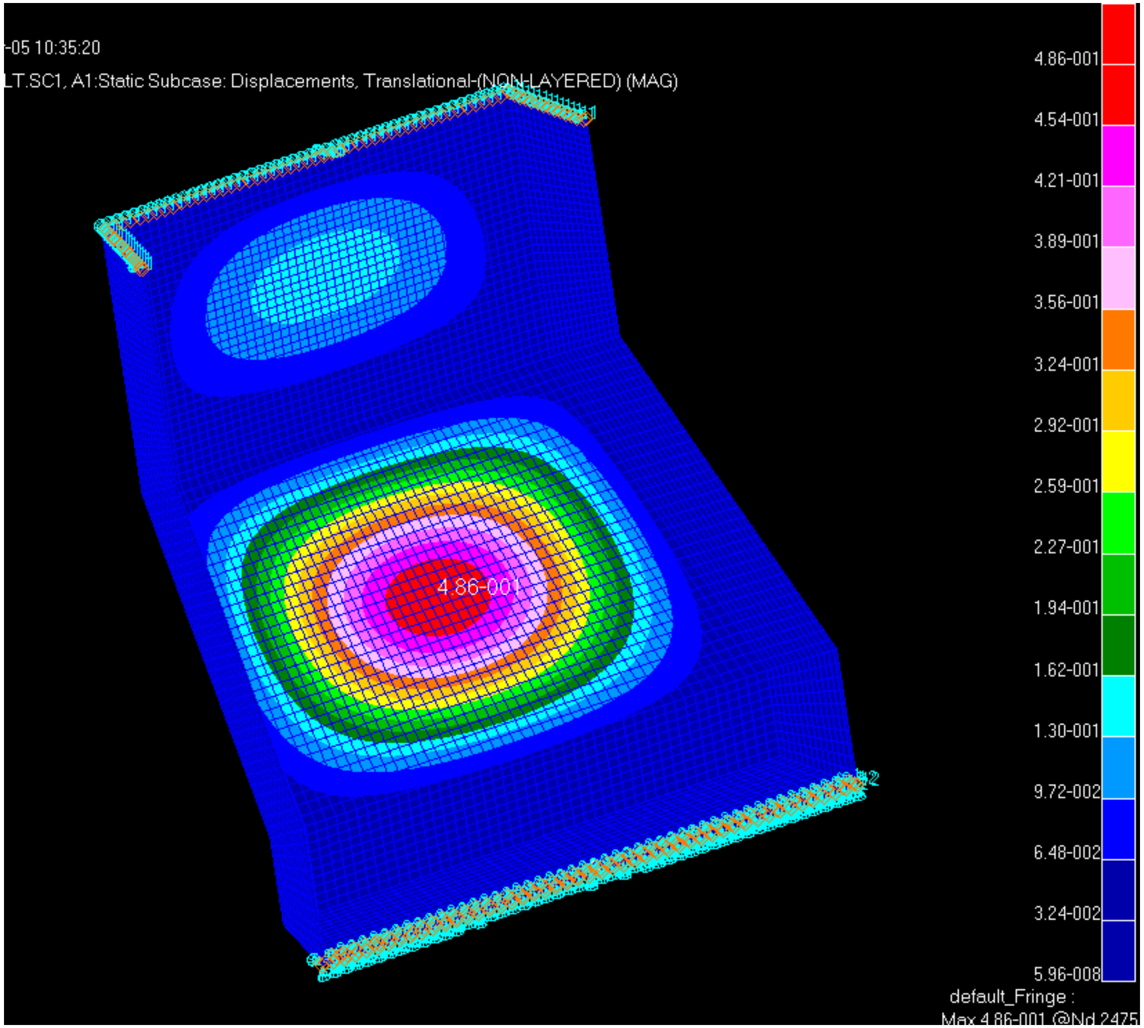
This image shows the thermal gradients generated in an angled (full) panel with the pan clamped at 77K and the edges clamped at 295K

Analysis



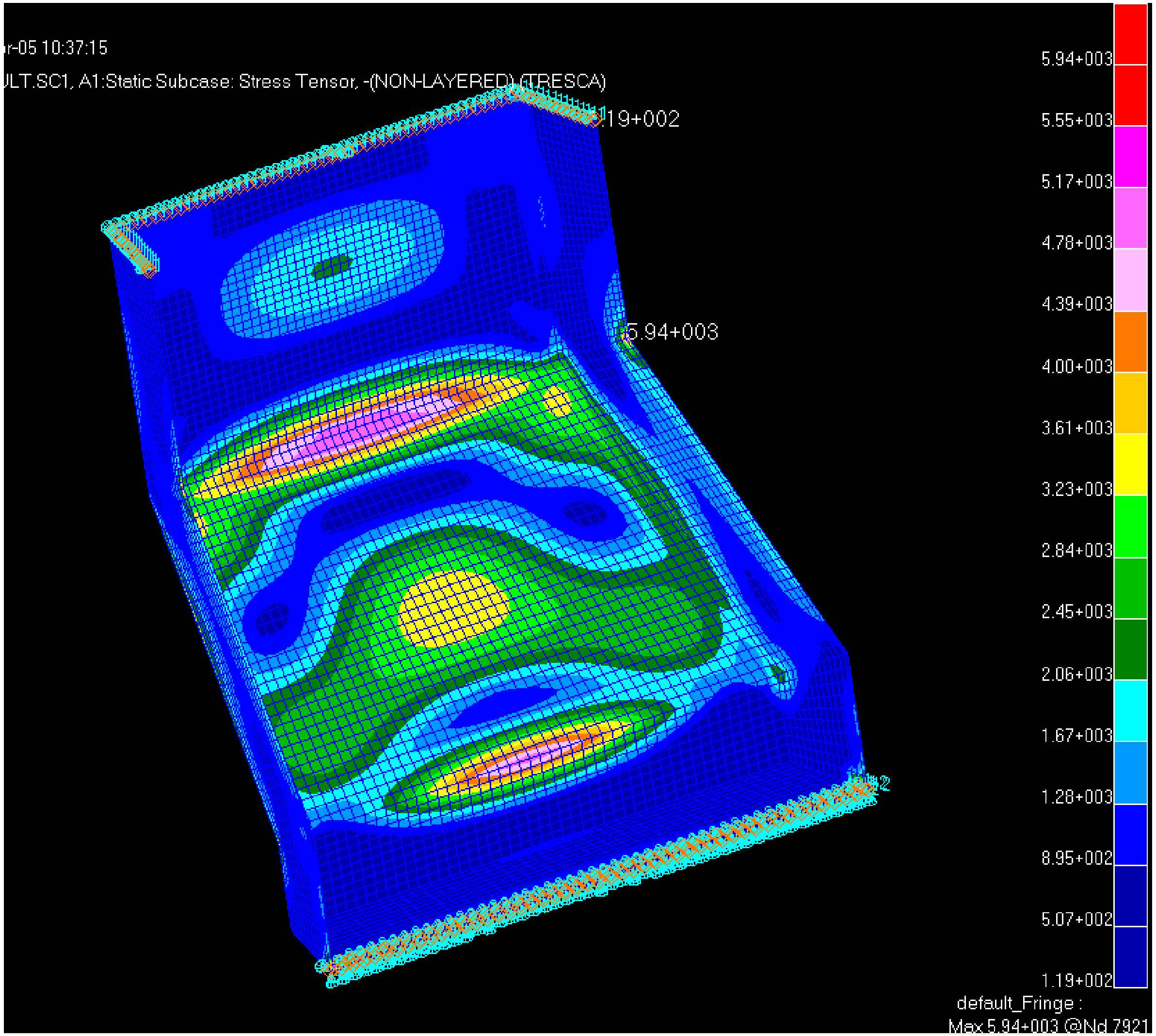
The peak Tresca stresses occur at the upper three-plane corners at 40-45 MPa (5-6 ksi)

An allowable criterion is 1/3 SigUlt (80K) in the warp direction or 248 MPA (36 ksi)



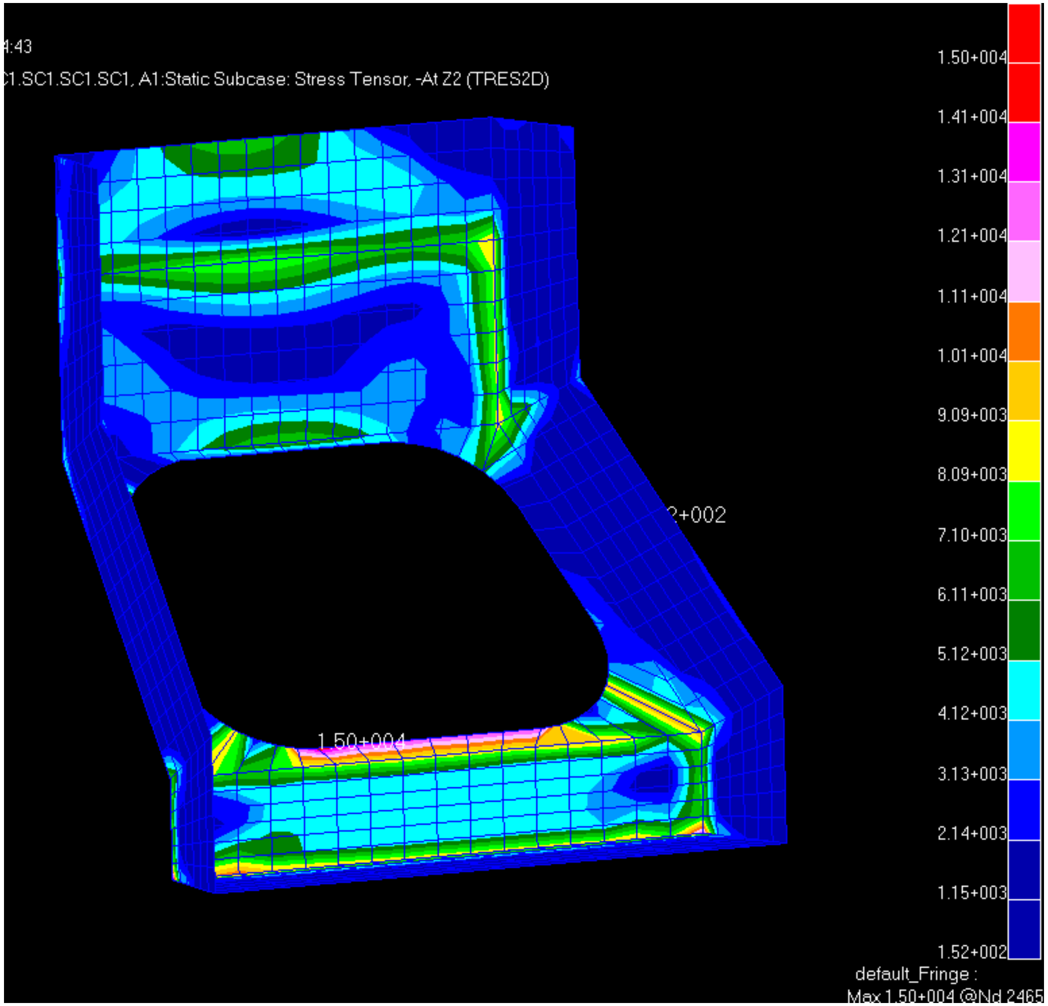
A 6.0 kPa (1 psi) accidental overpressure displaces the center of the panel about 1.2 cm

Analysis



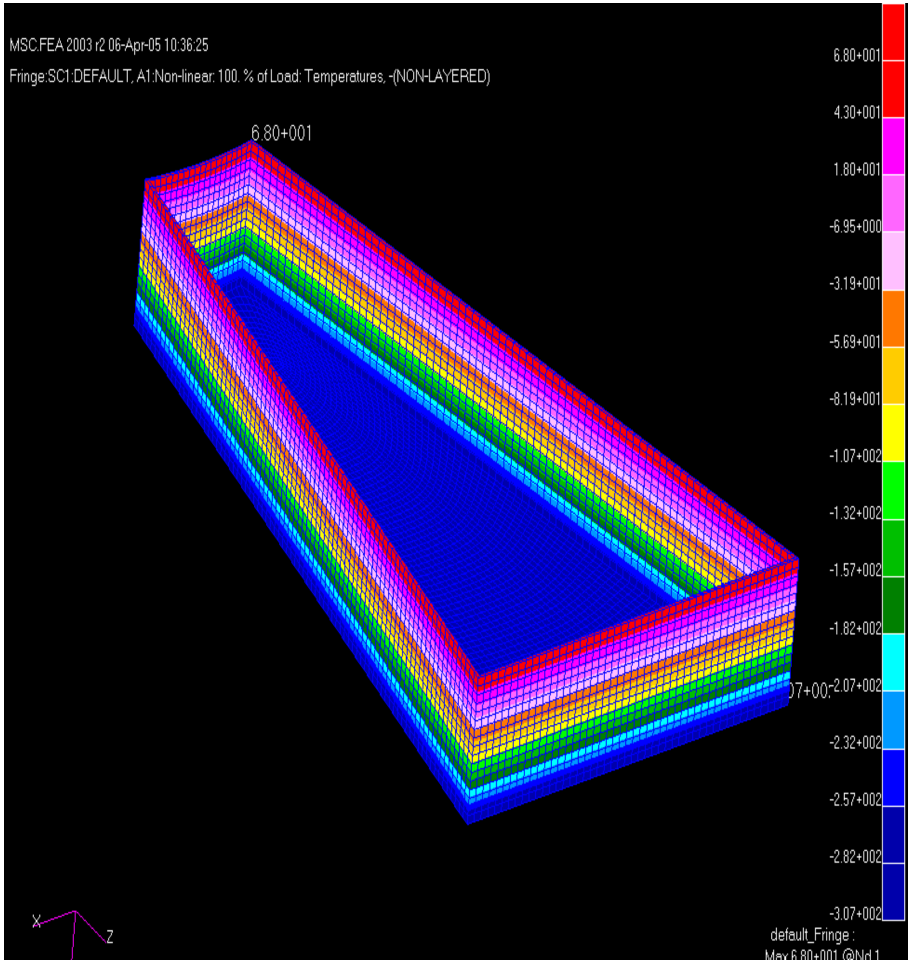
The previous overpressure displacement induces a Tresca stress of about 35.8 MPa (5.2 ksi) in the pan and 41.3 MPa (5.9 ksi) at the upper and lower edge constraints

Analysis



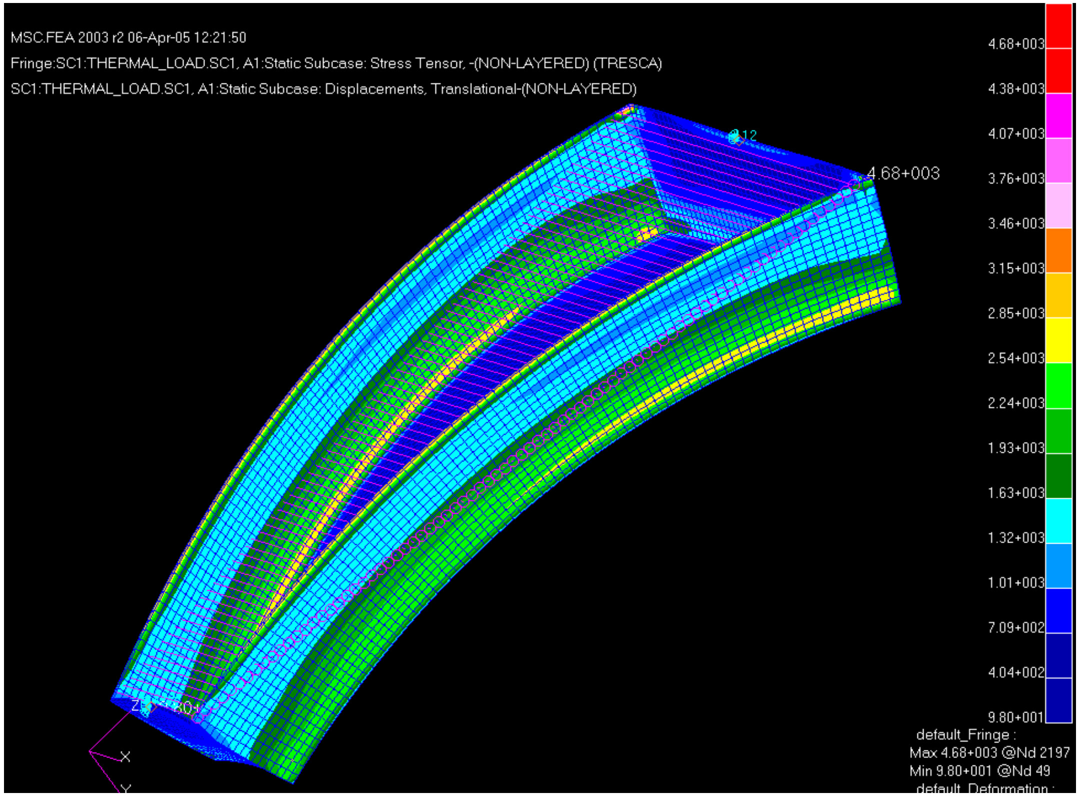
An angled panel taking no credit for the insert has a peak Tresca stress of 103 MPa (15 ksi) at the lower edge of the opening

Analysis



Thermal gradients in an upper simple panel ranging from 80K to 298K

Analysis

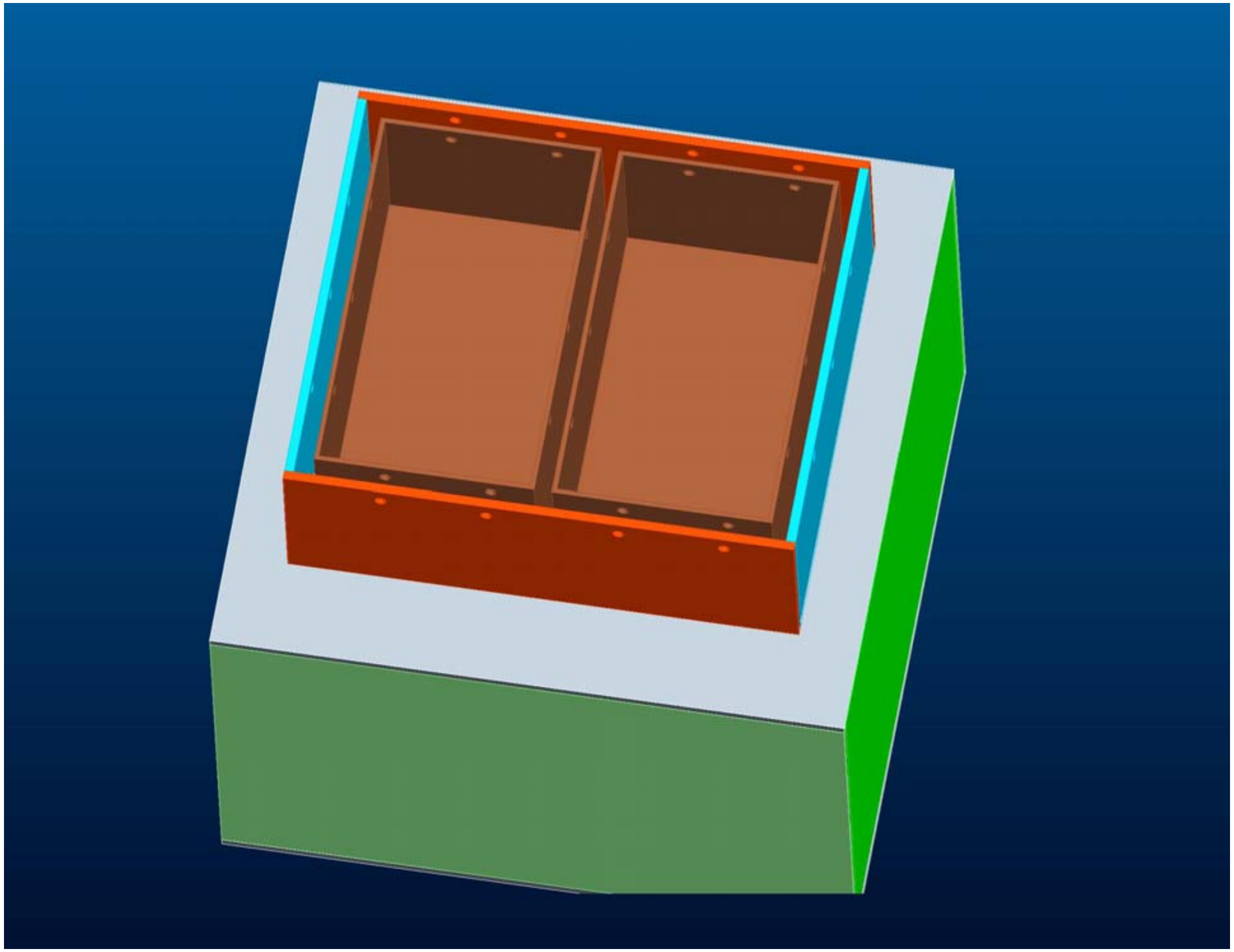


With the inner and outer edges constrained and the long edges able to "ride" with adjacent panels, a peak thermally-induced displacement of ~1 cm is realized.

The peak Tresca stresses of 32.4 MPa (4.7 ksi) occur at the outer corners of the pan

- Development jobs
  - Edge seal test fixture
  - Penetration seal test fixture
    - Purchase a complete unit from Picken's Plastic or competing fabricator
    - Load it, cool it
    - Remake it with a faux diagnostic and test the inter-panel and penetration gas sealing designs

Development, cont.

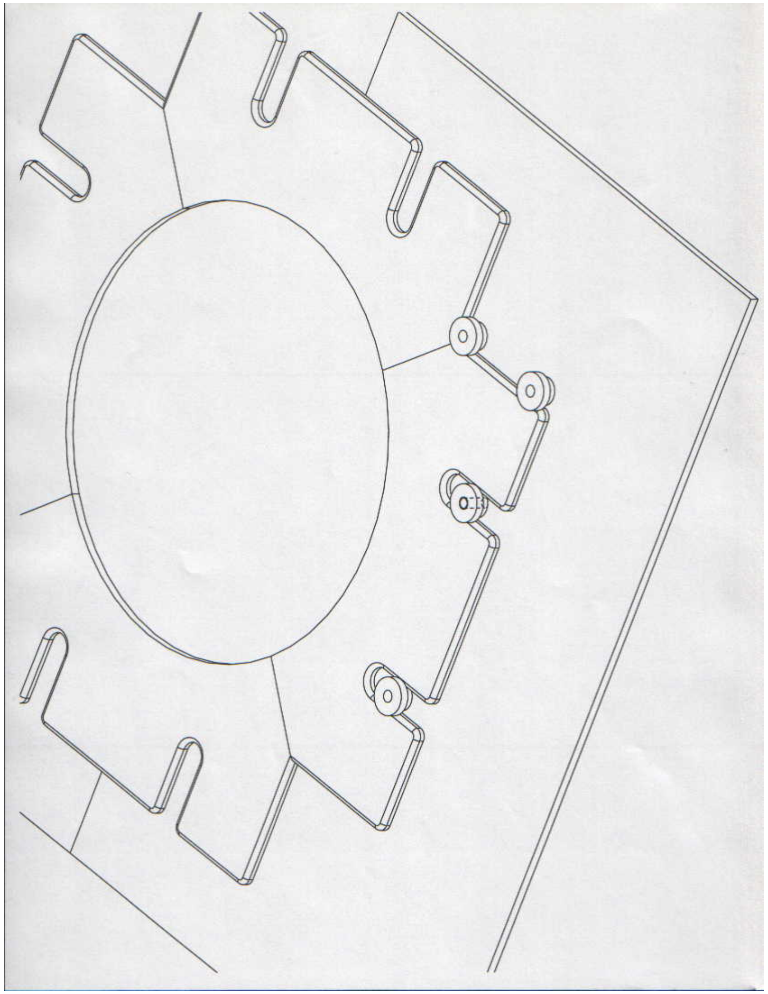


A thermal cycle test fixture is proposed to validate and exercise the joint and penetration sealing design.

Development, cont.

A displaceable seal limiter for diagnostic tubes has been described.

Demonstrating this choice has merit



ES&H Themes

- Oxygen deficiency in Test Cell is a major concern
  - WBS 62 has funding for O2 monitors
- Fire suppression issues
  - The insulation and G-10 have known (low) fire risk numbers.
  - Does the cryostat need an internal suppression system (the existing sprinklers will not help)
    - Document decision, basis

ES&H Themes, cont.

- Many IH issues have been worked out on WBS 1409's coil test facility
  - Much positive interaction between participating staffs

Procurement/Logistics Approach

- Identify and qualify bulk epoxy suppliers
- Identify and qualify molders/machining houses
- Identify contract assembly houses
- Let fab contract
- Procure staples (foams, bushings, etc.)
- Let ass'y contract
- Queue subassy's for WBS 7

Budget, April '05

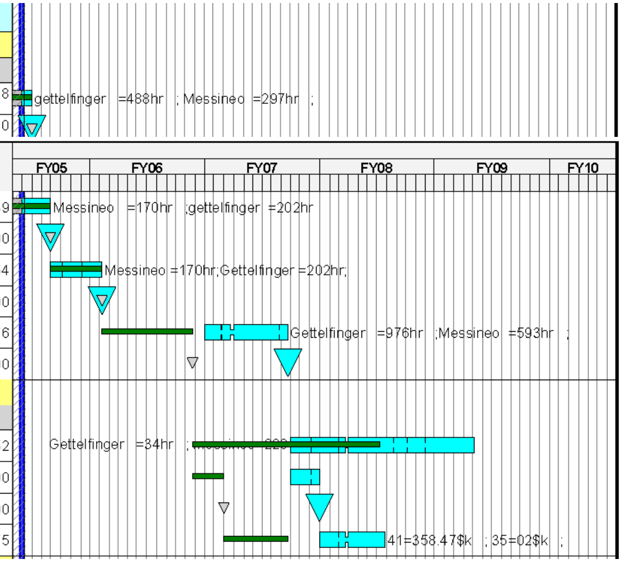
Cost Catergory, WBS 171	Expense Class	
Title I & II	Labor/Other	388.4
Fabrication/Assembly (incl Title III)	Labor/Other	36
Fabrication/Assembly (incl Title III)	M&S	509.6
Total		**$934k**

Trouble Here: The only responding supplier may ask $510k for panels before insulating. Current M&S is $540k forecast, total.

Time for paring back on detail.

NCSX

Activity ID	Activity Description	Forecast Start	Orig Dur	Forecast Finish	Total Float	PCTC	Earned value cost (BCWP)	RE-BASELINE BUDGET	ECP24 Budget
17 - Cryostat and Base Support Structure									
Job:1701-Cryost&Base Sprt Strct Dsn-GETTLEFINGER									
151-001	Title I design WBS 171 cryostat	01APR04A	248*	30MAR05	553	75	94,287.26	125,716.34	128,987.58
151-002	Cryostat PDR		0	30MAR05	553		0.00	0.00	0.00
161-001	Title I design WBS 172 base support struct	01APR04A	291*	31MAY05	396	85	42,273.30	49,733.30	51,132.39
151-003	Base Support Struct PDR		0	31MAY05	396		0.00	0.00	0.00
161-011	Final Design Base Support Structure WBS 172	01JUN05	114	09NOV05	396		0.00	62,224.79	62,677.54
172-199	Base Support Structure FDR		0	09NOV05	396		0.00	0.00	0.00
151-011	Final Design Cryostat WBS 171	02OCT06*	181	22JUN07	175		0.00	248,548.17	229,985.76
171-199	Cryostat FDR		0	22JUN07	175		0.00	0.00	0.00
Job: 1751 - Cryostat Procurement									
171 - Cryostat									
151-031	Title III engr	02JUL07	405	04FEB09	170		0.00	33,083.13	30,998.52
151-036.8	Prep Spec, Solicit bids, and Select Vendor	02JUL07*	65	02OCT07	170		0.00	0.00	0.00
151-036.9	Award Cryostat Procurement		0	02OCT07	241		0.00	0.00	0.00
151-037	Cryostat Procurement [A/1]	03OCT07	141	28APR08	241		0.00	508,421.76	478,642.75



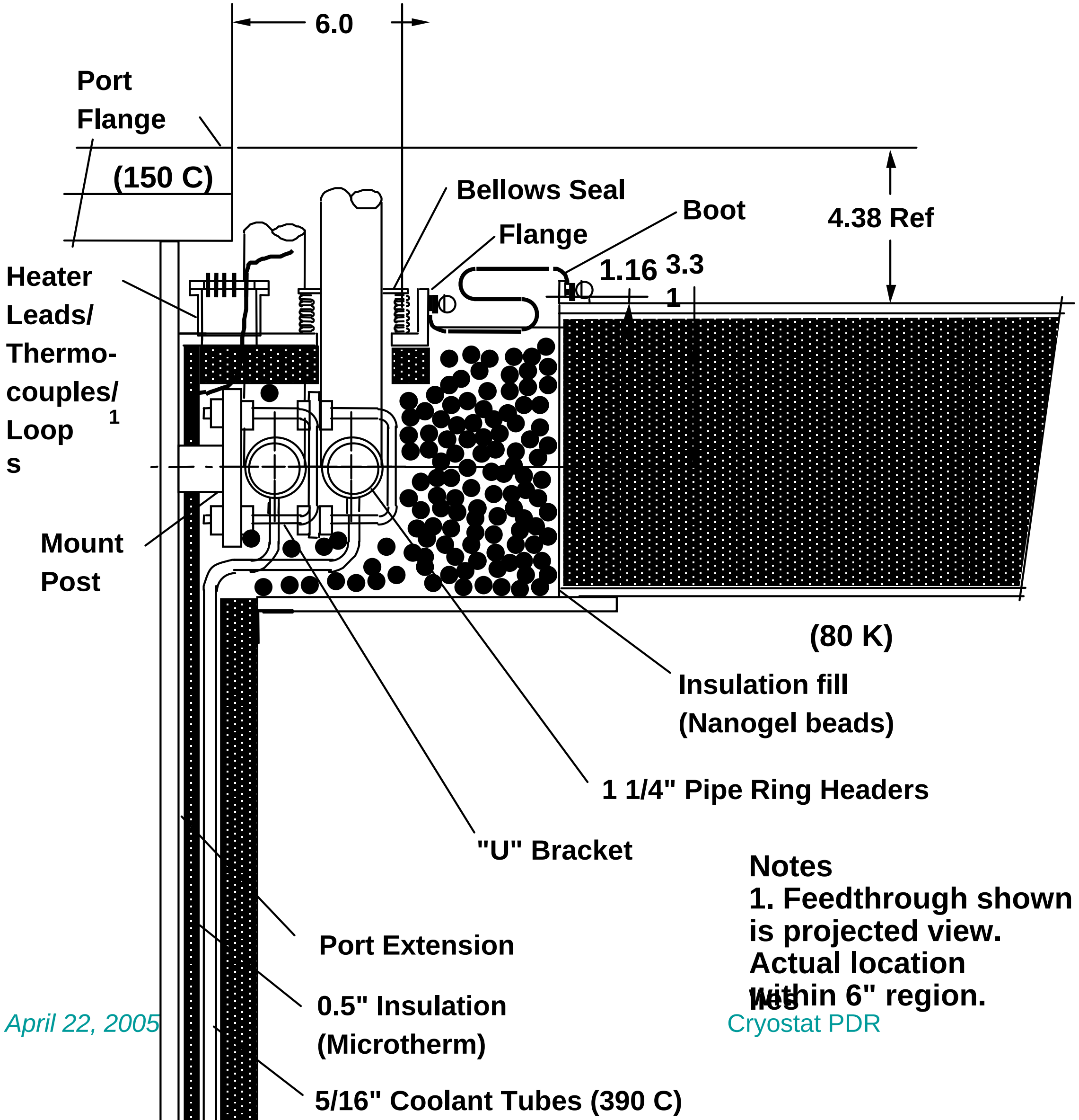
Final Design Interval: October ’06 – June ’07

Procurement Interval: July ’07 – April ‘08

Alternatives – The Devil You Know

- 26 October '04 – NCSX Engineering contacts James Fesmire of the Kennedy Space Center's Cryogenics Testbed
  - NASA continues to work to develop alternatives to the high-button shoe standard of rigid foam
    - It cracks
  - The Shuttle(s) still fly with rigid foam and Solimide flexible foam
- He did suggest we consider Cabot's "Nanogel"
  - Fesmire, J.E., Augustynowicz, S.D., and Rouanet, S., "Aerogel Beads as Cryogenic Thermal Insulation System," in Advances in Cryogenic Engineering, Vol. 47, American Institute of Physics, New York, 2002, pp. 1541-1548.

Alternatives – The One You Don't



Notes
1. Feedthrough shown is projected view. Actual location lies within 6" region.

WBS-12'ers seem to favor aerogel insulation.

Its use in horizontal penetrations may nullify the settling issue.

Keeping control of the "sand" may be a design challenge.

A fairly small flaw in the containment might allow serious leakage.

Development here may pay big dividends (0.011 W/mK vs. 0.027 for Trymer AND easy to pour)

- Resistive heaters were included in the conceptual plan to control condensation
  - hold off until development demonstrations are complete
  - C-Mod local heater/blowers are likely appropriate for the odd trouble spot
- Cost control is key here
  - Every neat feature drives the price up

Conclusion

NCSX

1. Requirements - Adequate
2. Design – Requirements Met
3. Analysis – Design Criteria OK
4. R&D – Some D is Needed
5. Manufacturability – No Problem
6. Design Integration
   a. Design is Compatible
   b. Adequate Clearances Exist
7. Interfaces. MORE WORK NEEDED! Primary systems are still getting their wings

Conclusion

8. Procurement. PPPL must investigate the use of a contract assembly house. Our lone brave quoting supplier for the panel pans did not want the insulation work.
9. Cost and Schedule. OK Here. Cost Control Paramount
10. ES&H. Fire Suppression Basis Needed
11. Risk management. OK
12. Chits. No Previous Chits