Lecture 8
Thermal Insulation & Cryostat Design (Part I)

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Goals

- Complete description of systems to reduce radiation heat transfer
- Discuss design requirements for cryostats
- Describe options for cryostat supports

Thermal Radiation Shields

- Uncooled thermal radiation shields placed in a vacuum space between the warm & cold surfaces also help reduce the thermal radiation heat leak
- It can be shown (with the grey approximation and equal emissivities) that with N shields thermal radiation heat transfer is given by:

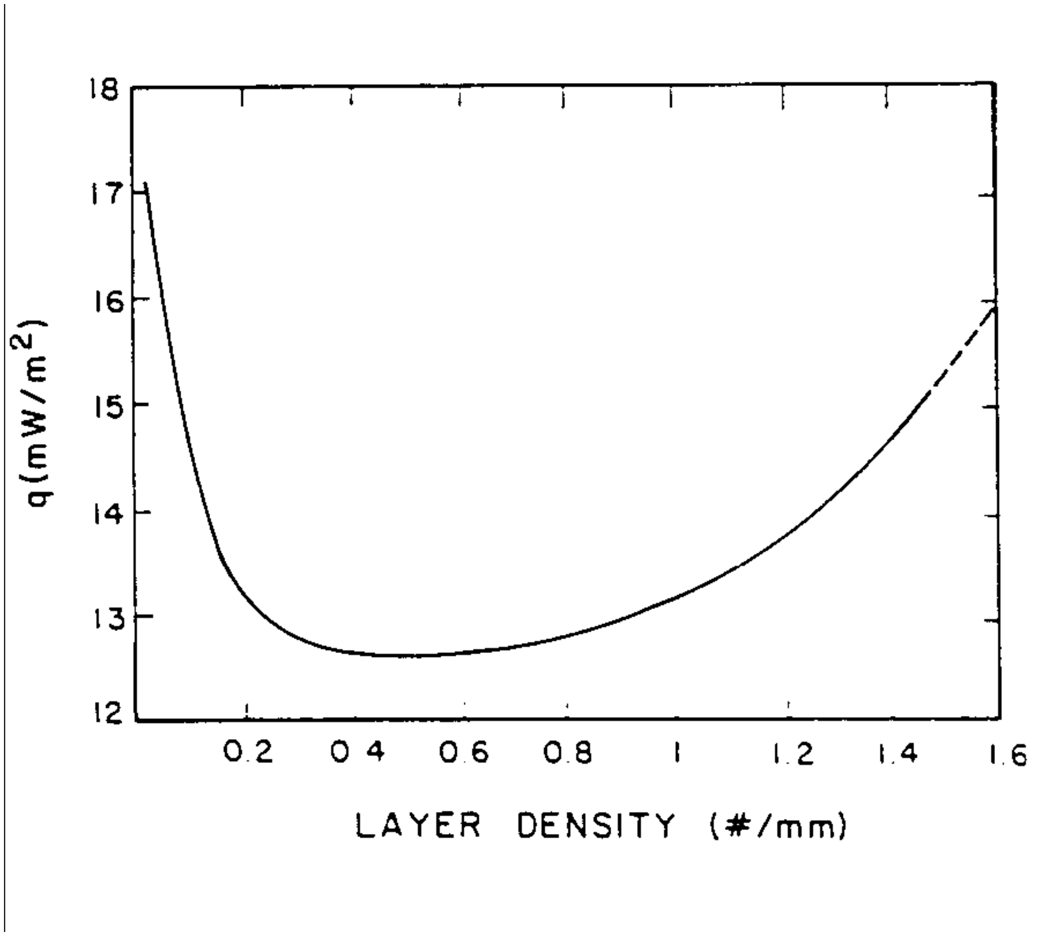
$$q = \frac{\varepsilon}{(N+1)2}\sigma\left(T_H^4 - T_L^4\right)$$

This is the motivation behind Multilayer Insulation

MultiLayer Insulation

- Also referred to as superinsulation
- Used in the vacuum space of many cryostats (10^{-5} torr or better for best performance)
- Consists of highly reflective thin sheets with poor thermal contact between sheets.
  - Made of aluminized Mylar (or less frequently Kapton)
  - May include separate non conducting mesh
  - May use Mylar aluminized on only one side and crinkled to allow only point contacts between sheets
  - Frequently perforated to allow for better pumping
- Can be made up into blankets for ease of installation
- Don't pack MLI too tightly. Optimal value is ~ 20 layers / inch
- Great care must be taken with seams, penetrations and ends.
  - Problems with these can dominate the heat leak

MLI



MLI Example from LHC cryostats

"SERIES-PRODUCED HELIUM II CRYOSTATS FOR THE LHC MAGNETS: TECHNICAL CHOICES, INDUSTRIALISATION, COSTS"
A. Poncet and V. Parma
Adv. Cryo. Engr. Vol 53

Porous Insulation

- Radiation heat transfer may also be reduced by filling the vacuum space between 300 K and cryogenic temperatures with other materials that are low conductivity and block line of sight
- Such materials include:
  - Glass beads or microspheres
  - Perlite powder (made from a volcanic rock)
  - Opaciated powders – copper or other metallic flakes mixed in with other powders to further reduce radiant heat transfer
  - Aerogel
- Advantages:
  - Cheaper
  - Easier to install in complex shapes
  - Better performance than MLI in poor or no vacuum
- Frequently used in large storage and transport dewars

Porous Insulation

The total heat transfer through porous insulation between 2 spheres may be estimated by:

$$W = \frac{\bar{k}\left(T_2 - T_1\right)}{t}\sqrt{A_1 A_2}$$

- Where
  - t = thickness of Insulation
  - $\bar{k}$ = the mean thermal conductivity
  - 1 = inner vessel and 2 = outer vessel

- Mean thermal conductivities may be found in references such as

Cryogenic Engineering by Flynn

Comparison of Thermal Insulation Approaches (6 inch thick insulation in all cases)

	Total Heat Flux (W/m²)	
Type of Insulation	**300 K to 77 K**	**77 K to 20 K**
Polystyrene Foam (2 lb/ft³)	48.3	5.6
Gas Filled Perlite powder (5 – 6 lb/ft³ filled with He)	184.3	21.8
Perlite powder in vacuum (5 – 6 lb/ft³)	1.6	0.07
High Vacuum (10^{-6} torr $\varepsilon = 0.02$)	9	0.04
Opacified powder (Cu flakes in Santocel)	0.3	-
MLI	0.03	0.007

Increasing Cost & Complexity

Note better performance of evacuated Perlite over high vacuum between 300 K & 77 K

From Cryogenic Systems – Barron
For rough estimates only

Cryostat Design

- What is a cryostat?
  - A device or system for maintaining objects at cryogenic temperatures.

- Cryostats whose principal function is to store cryogenic fluids are frequently called Dewars. Named after the inventor of the vacuum flask and the first person to liquefy hydrogen

Which Brings Us to a Limerick

"Sir James Dewar is a better man

than you are

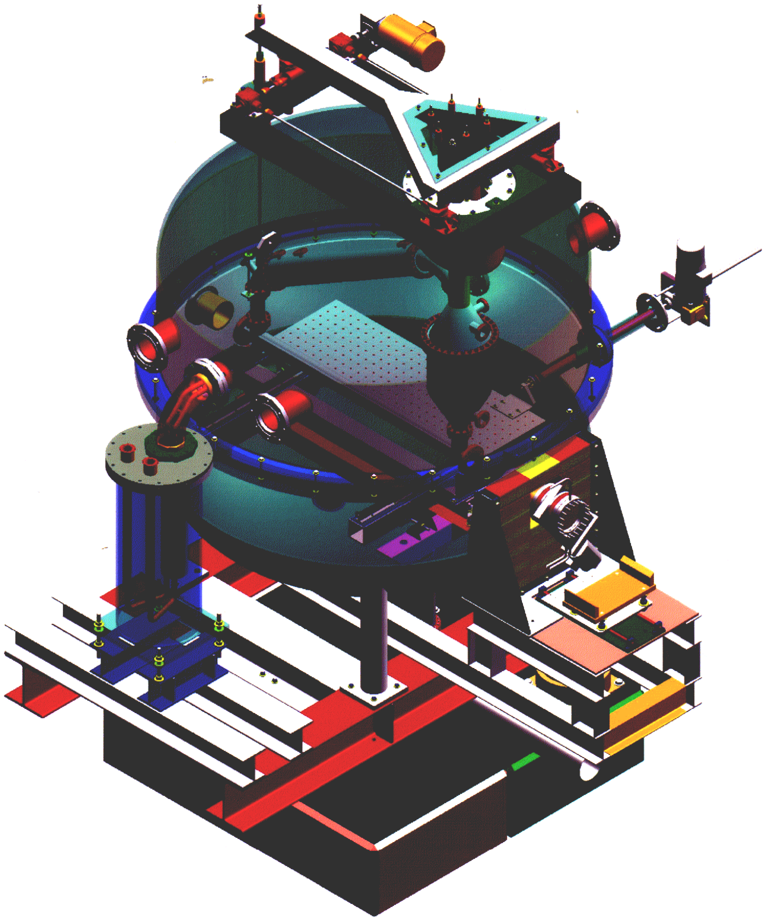
None of you asses can liquefy gasses"

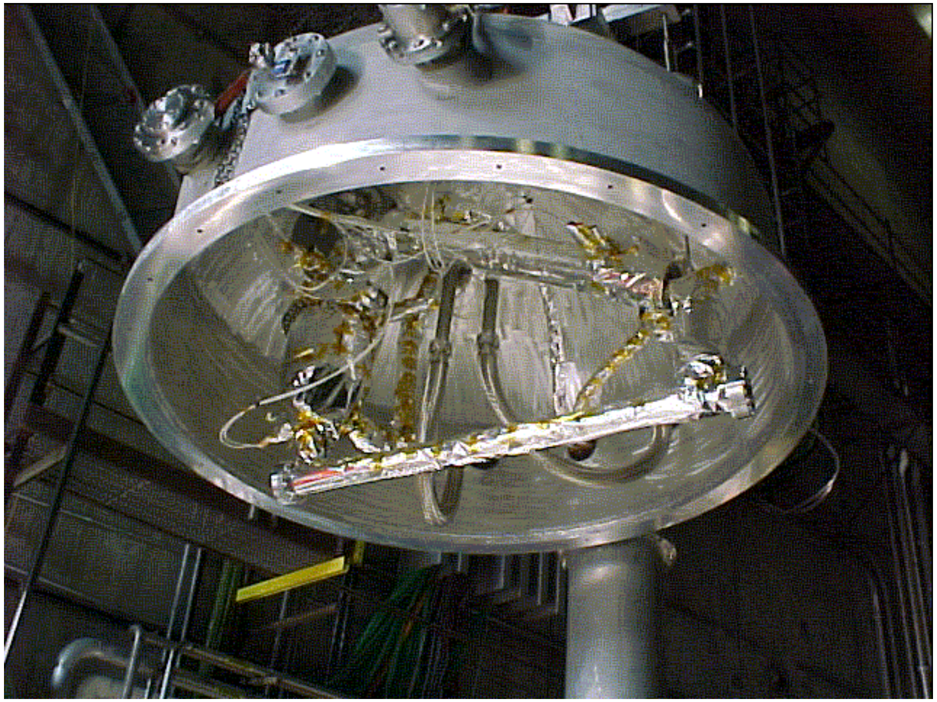
Anon.

Cryostat Design

- Cryostats are one of the technical building blocks of cryogenics
- Cryostat design involves many subtopics:
  - Development of requirements – covered here
  - Materials selection – already covered
  - Thermal insulation - already covered
  - Support systems – covered here
  - Safety – covered in a future lecture
  - Instrumentation – covered in a future lecture
- One of the best ways to learn about cryostat design is through examples
- There are many different types of cryostats with differing requirements
  - The basic principles of cryostat design remain the same
  - Before we can do anything else we have to define our requirements

E158 LH_2 Target Cryostat





Cryostat Requirements

- Maximum allowable heat leak at various temperature levels
  - This may be driven by the number of cryostats to be built as well as by the impact of large dynamic heat loads (SCRF or target cryostats)
- Alignment and vibration requirements
  - Impact of thermal cycles
  - Need to adjust alignment when cold or under vacuum?
  - Alignment tolerances can be quite tight (TESLA : +/- 0.5 mm for cavities and +/- 0.3 mm for SC magnets)
- Number of feed throughs for power, instrumentation, cryogenic fluid flows, external manipulators

Cryostat Requirements

- Safety requirements (relief valves/burst discs)
  - Design safety in from the start. Not as an add on
- Size and weight
  - Particularly important in space systems
- Instrumentation required
  - Difference between prototype and mass production
- Ease of access to cryostat components
- Existing code requirements (e.g. TUV or ASME)
- Need, if any, for optical windows
- Presence of ionizing radiation

Cryostat Requirements

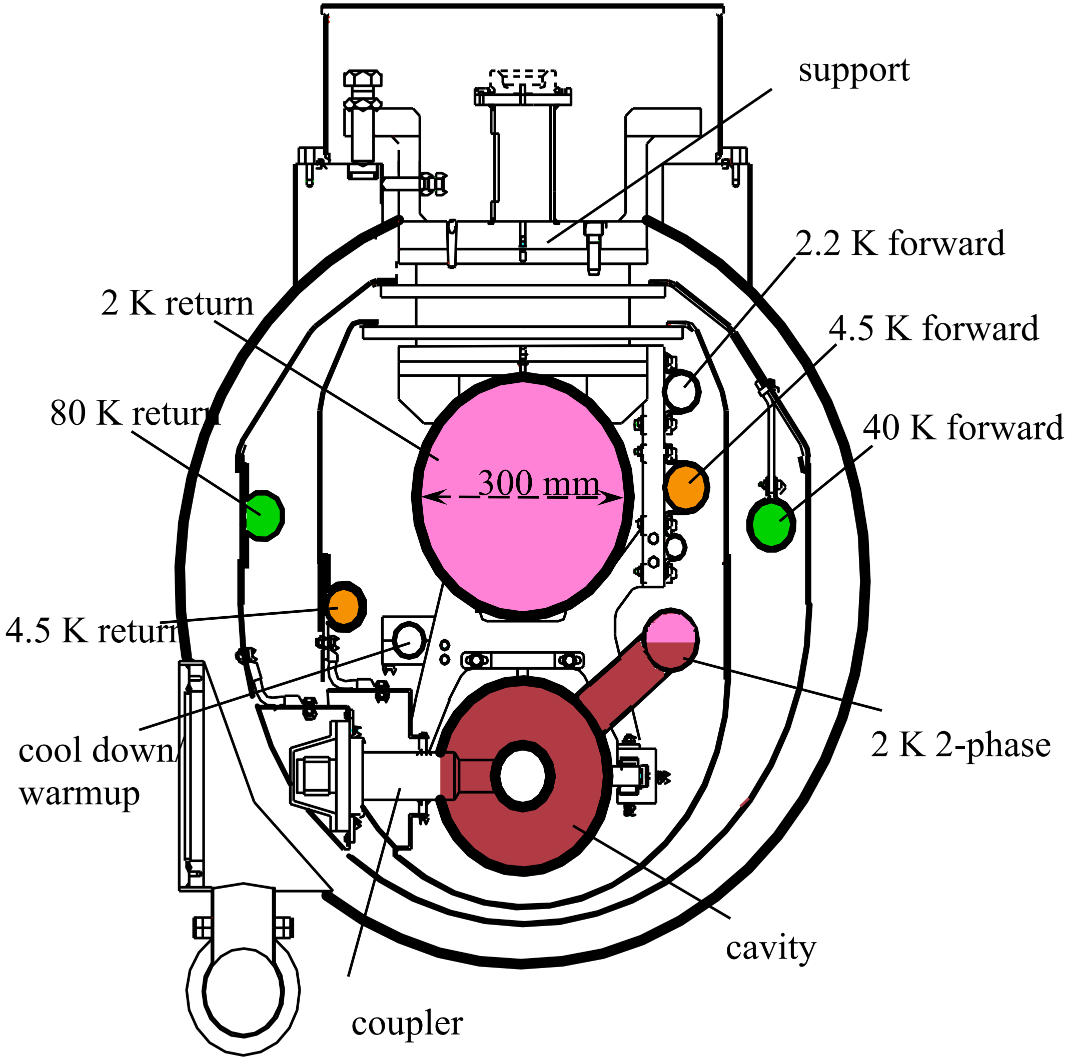
- Expected cryostat life time
- Will this be a one of a kind device or something to be mass produced?
- Schedule and Cost
  - This should be considered from the beginning

All Design is Compromise

Structural Supports

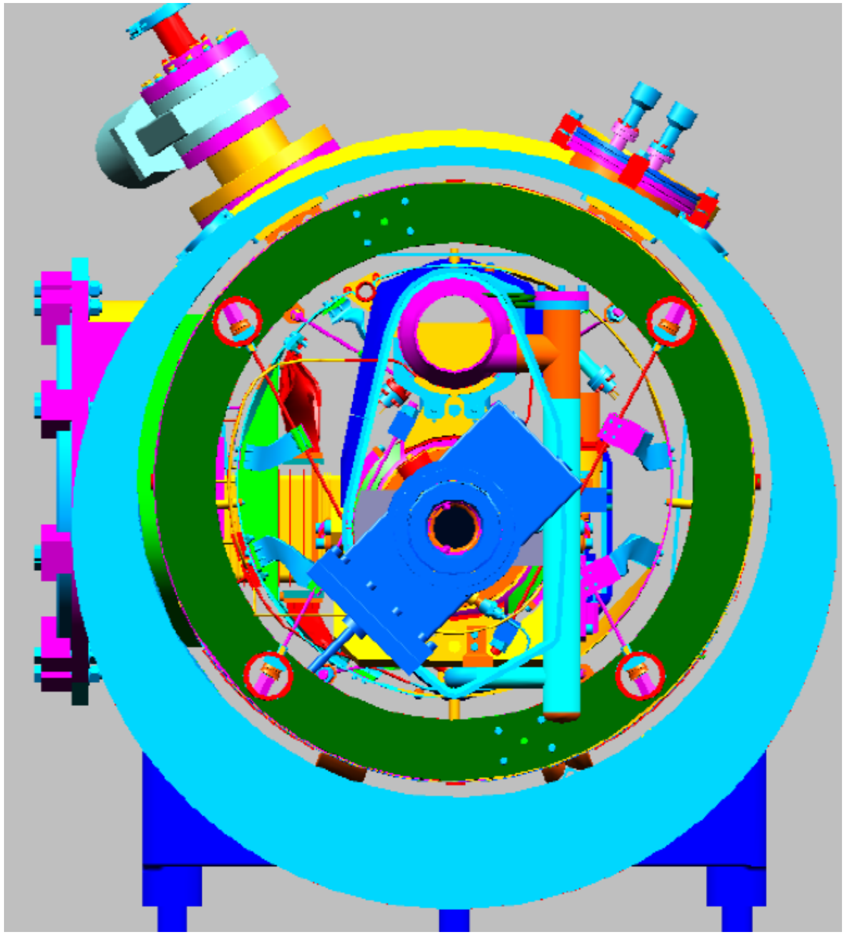
- Solution is highly dependent on cryostat requirements
- Choose materials carefully
  - Acceptable for cryogenic temperatures
  - Low heat leak
- Don’t over constrain supports: allow for thermal contraction
- Does solution meet alignment and vibration requirements?
- Must alignment be changed while cold?

Structural Support Example #1 ILC Cryostat



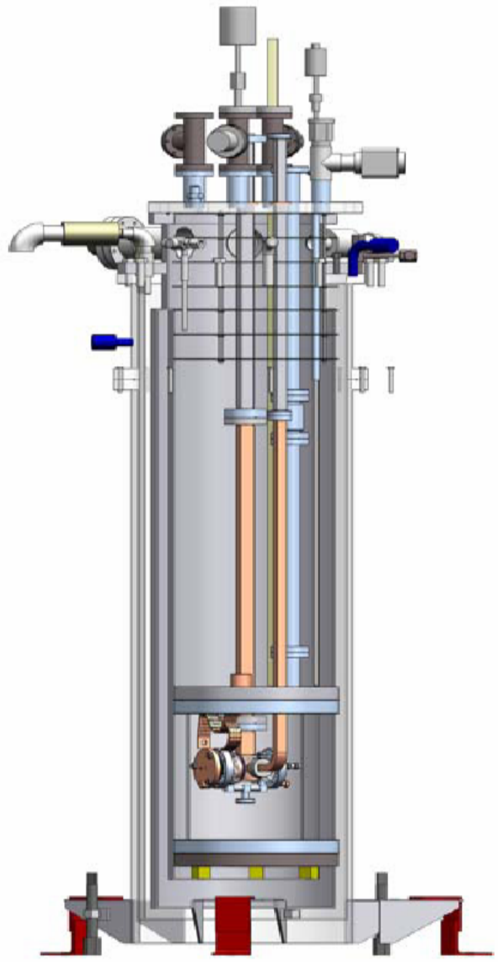
- FRP support between 300 K and Cryo temps
- Cavity assemblies tied to 300 mm pipe backbone
- All other connections to 300 K have flex line or bellows in line
- Meets alignment specs

Structural Support Example #2 JLab 12 GeV Upgrade Cryomodule



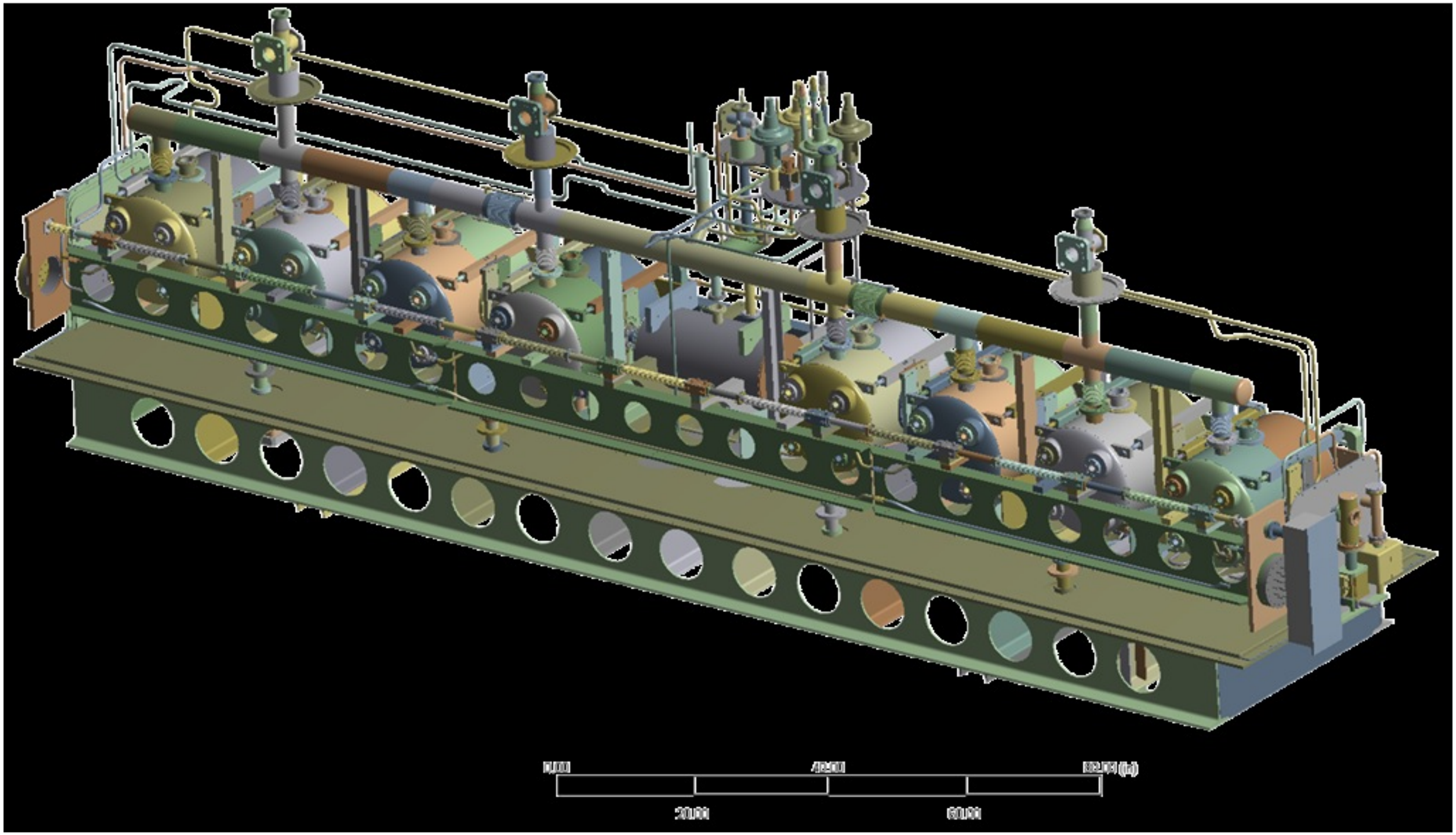
- All components are tied to space frame which rolls into vacuum vessel
- Connections to 300 K done via flex lines and bellows

Structural Support Example #3
Simple Top Load Cryostat



- Very common for test cryostats
- Everything hangs from 300 K top flange
- Connections made via low conductivity piping and supports
- Everything "contracts up"
- Allows easy removal and change of cryostat components
- Useful when precise alignment not an issue

Structural Support Example #4
FRIB Cryomodules



Courtesy M. Johnson et al. - FRIB