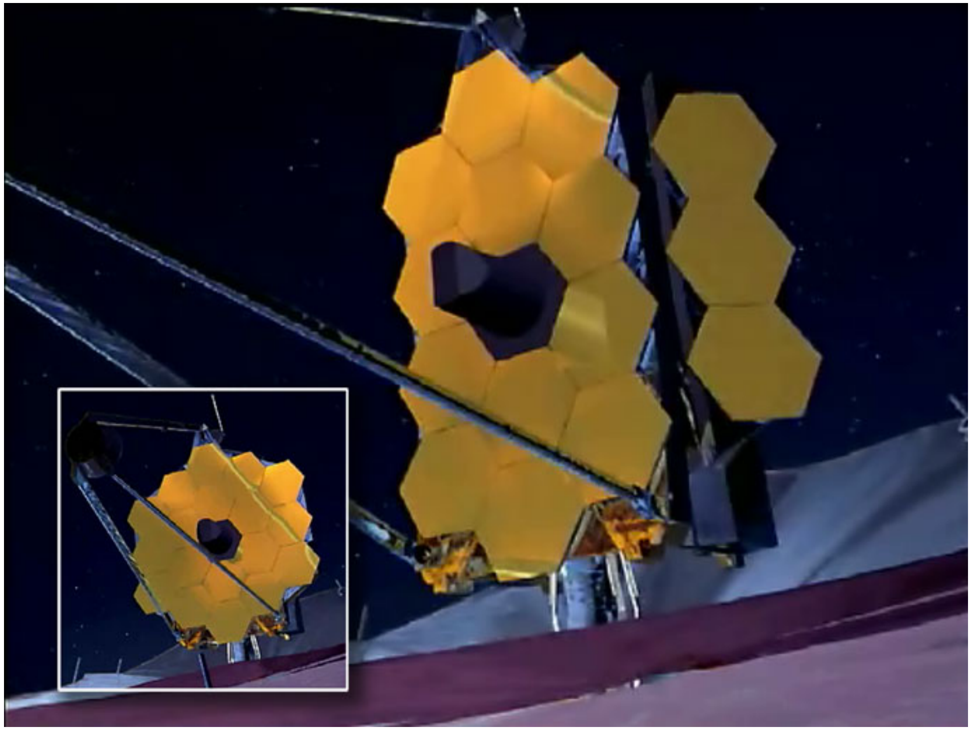
The James Webb Space Telescope: Thermal Testing Considerations



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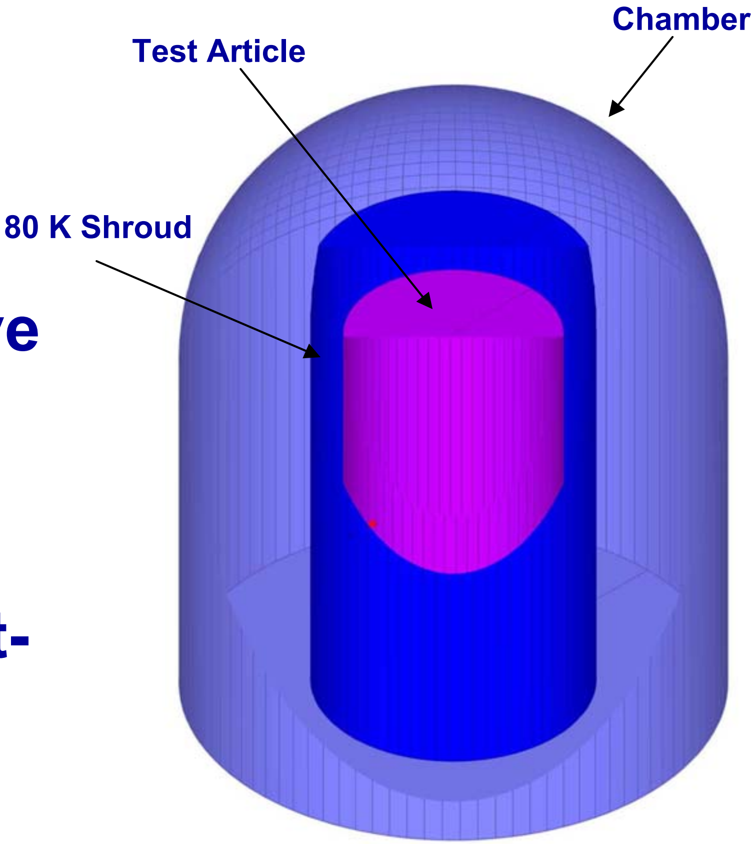
The conventional Thermal Vacuum Chamber thermal control system (TCS) operates down to 80 K

Provide uniform 80 K temperature background

Provide an thermally absorbtive background surface – black paint

Shroud assembly is only “light-tight”

Chamber operation at 1x10^{-5} torr



JWST ground testing requires an additional “20 K” shroud to simulate space flight conditions at L2

Cool test article at 35 K to qualify the design

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Provide uniform testing temperature background

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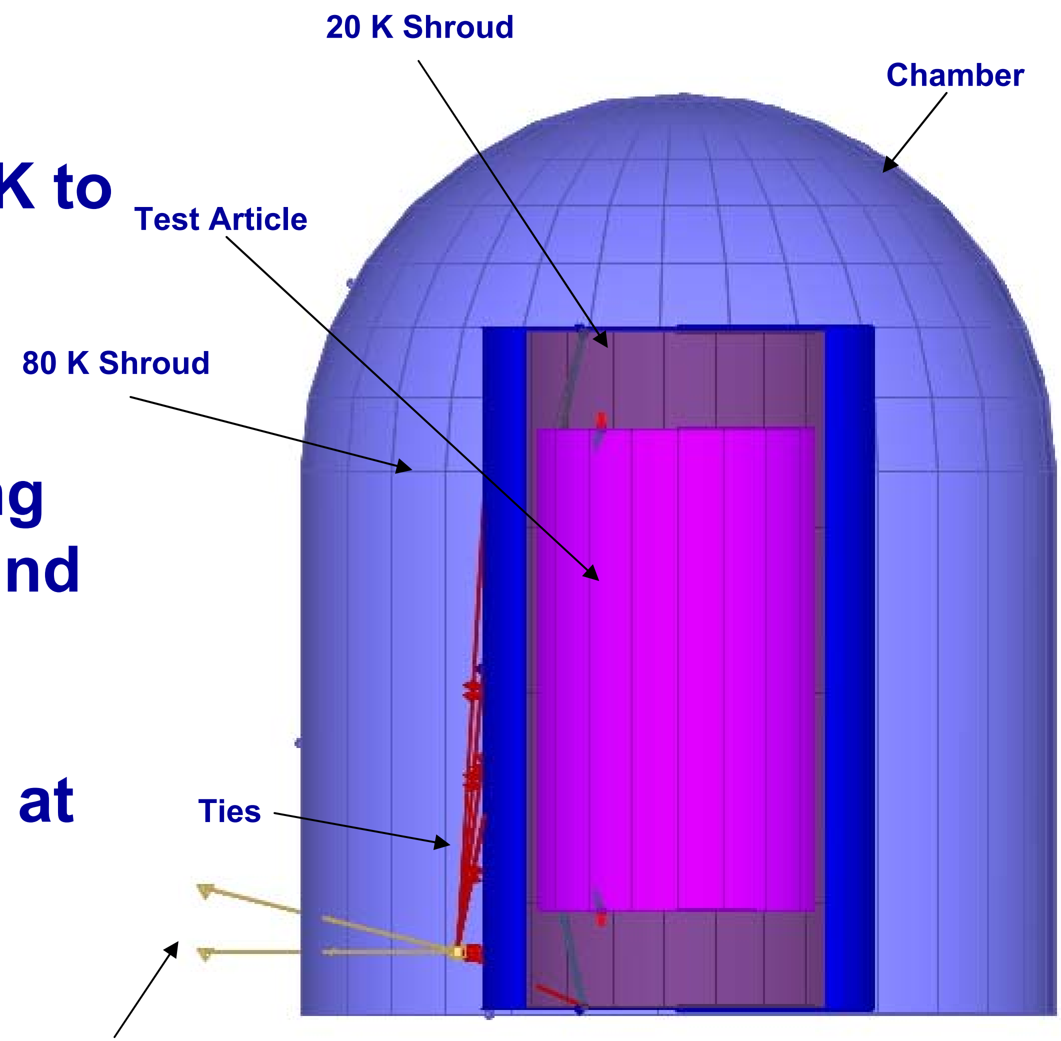
Refrigeration capacity at 20 K for heat load



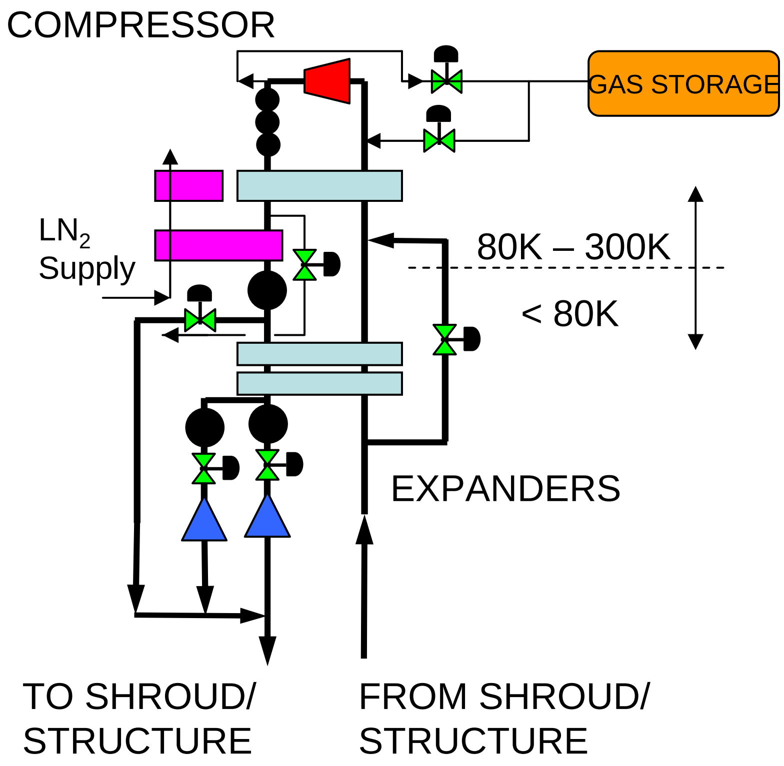
Thermal Conditioning System design parameters

Provide for controlled cool-down, soak, and warm-up of JWST Test Assembly

Hold to a set point temperature, within ± 1 K, during steady state conditions at any temperature from 340 K to 20 K.

Be capable of taking the Test Assembly from 300 K, and under vacuum, to 35 K and steady state within 10 days.

Helium Plant PFD



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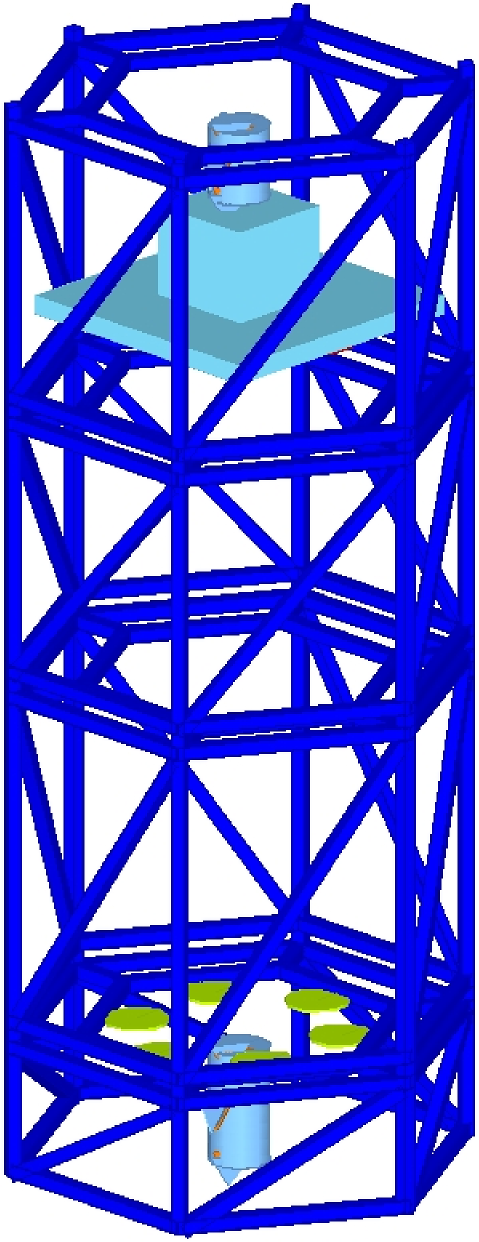
Additional test equipment modeling detail

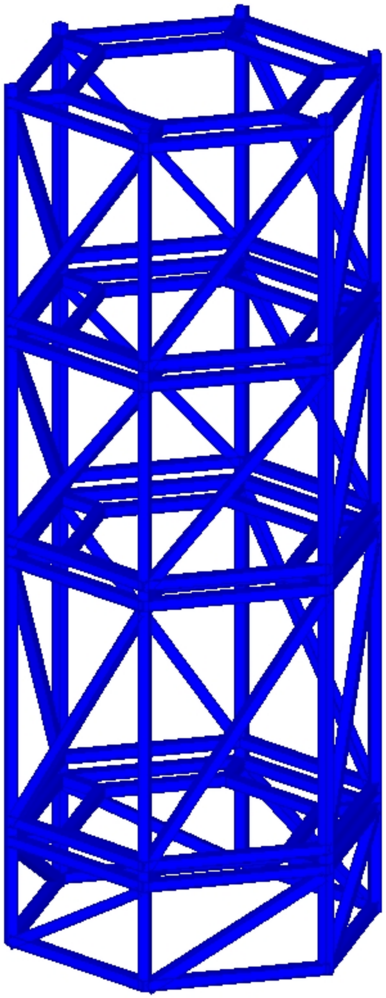
Test Article in various configurations - JWST, Pathfinder, etc. This is assumed to weigh 8000 lbs, have a surface area of 1000 m2 (emissivity = 0.7), and a heat load of 1000 watts. These figures include all test equipment - flats, interferometers, etc

Test Support structure, including heated isolators. The inner structure is assumed to weigh 190,000 lbs and the outer structure is assumed to weigh 60,000 lbs. Both structures are constructed from stainless steel

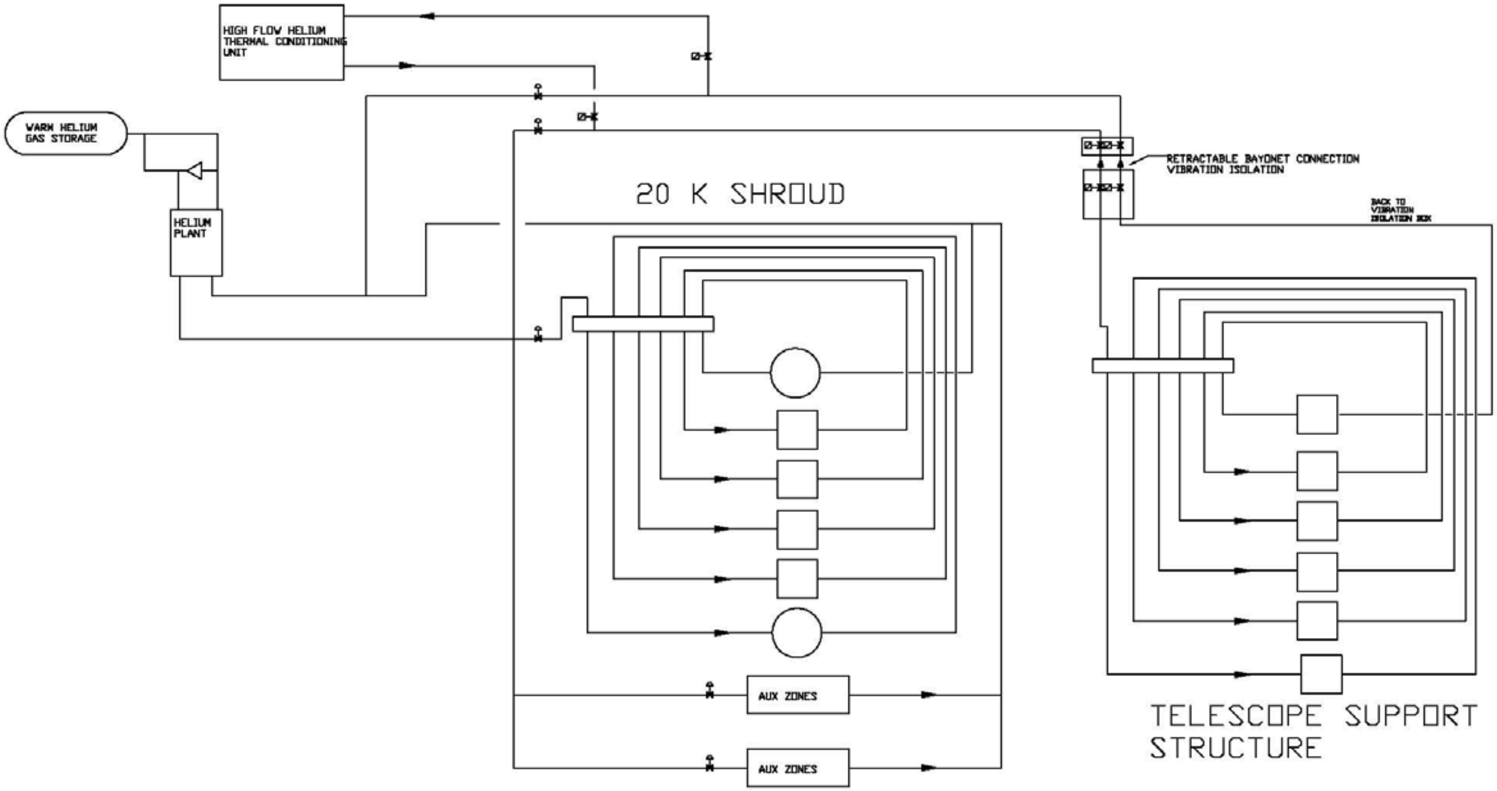


The Test Support Structure is conditioned with He gas mass flow

The Helium gas mass flow is pumped through tracing tubes bonded to the structure or directly through the structural tubing

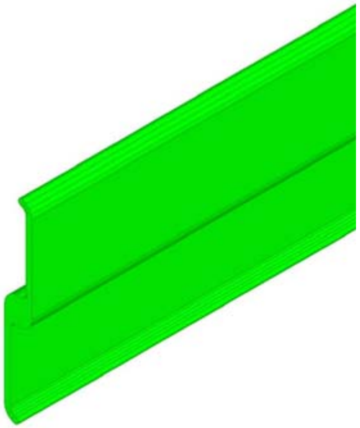


The Helium Flow Diagram

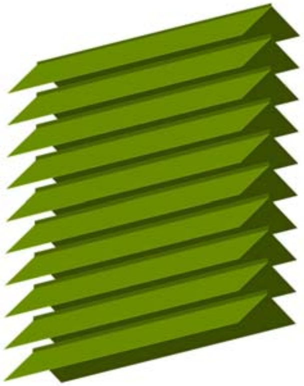


This is one possible concept for the Helium Conditioning System

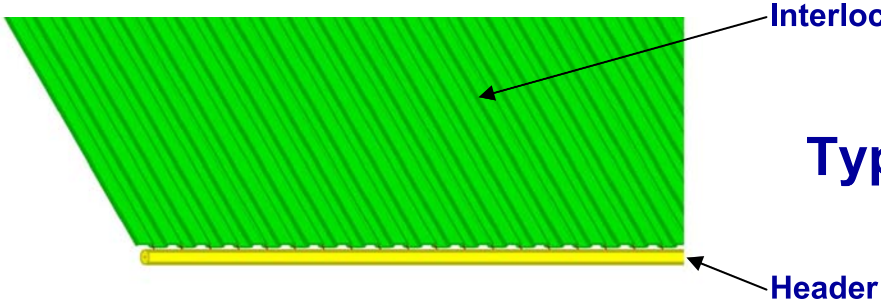
A “light-tight” shroud is typically constructed of “batwings” and “chevrons”



Aluminum “batwing” extrusion



Aluminum “chevron” extrusion assembly – good for vacuum pumping



Typical shroud assembly

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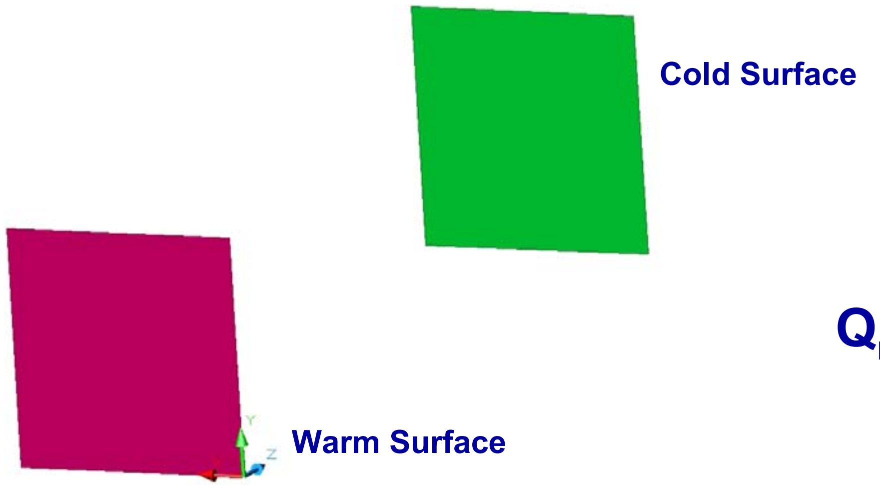
The conventional T/V TCS provides for thermal conditioning by radiation and conduction

$Q = ak/l(\Delta t)$ Conduction



$Q_r = \sigma FA(T_h^4 - T_c^4)$ - Radiation

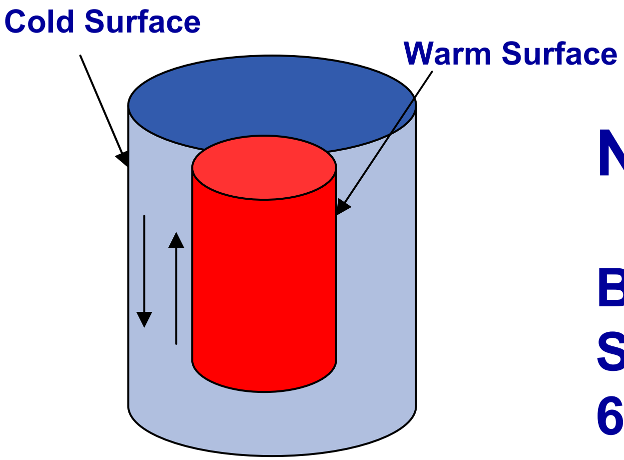
For a given surfaces and constant ε & α, 30 K to 20 K radiation heat flow is 1/38th of 90 K to 80 K radiation heat flow

It may not be possible to reach 35 K relying on radiative heat transfer at these temperatures

What other heat transfer options are there?

Molecular and Continuum Conduction

Sutherlin, S., The X-Ray Calibration Facility (XRCF) Thermal Characterization Test Cycle 3 Data Correlation, 12/20/2002



Natural Convection at reduced pressure

Bell, W., Kudirka, F., Young, P-W, James Webb Space Telescope Thermal Conditioning Study, 6/29/2004

These options are available within Thermal Desktop

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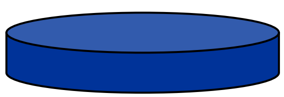
The Sutherlin study shows test results at 30 K

Gaseous heat transfer and flow regimes are defined in terms of the Knudsen number, Kn

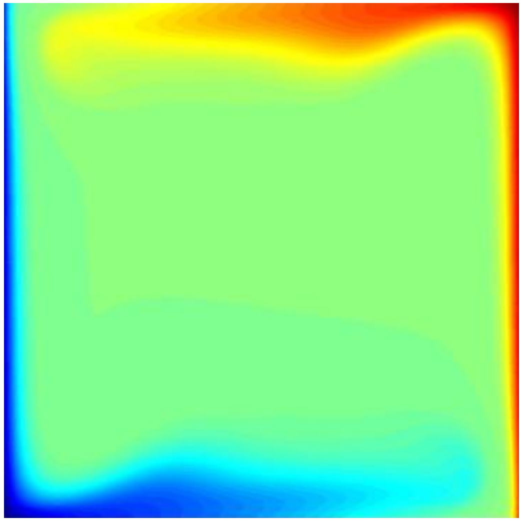
Continuum	**Kn <** ***0.01***
Mixed	***0.01*** **< Kn <** ***0.30***
Free-molecular	**Kn >** ***0.30***



Test Article temperature went from 60 K to 31 K by injecting He gas into the T/V Chamber, increasing Chamber pressure from 3e-06 torr to 5e-04 torr

Bell, et al, built on the Sutherlin study and considered natural convection at reduced pressure

$Nu_p = C(Gr_p Pr)^n$ - Natural Convection (enhanced conduction)

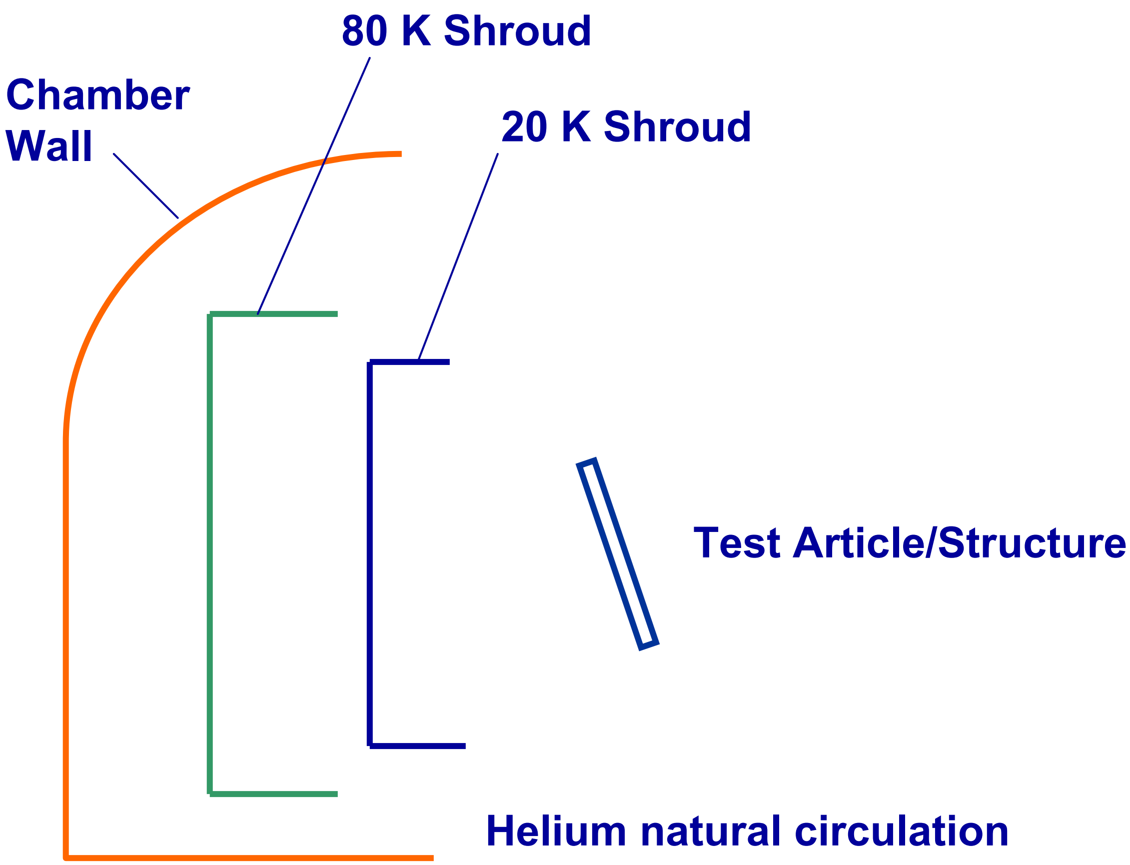


Basis of correlations and values of C are typically derived from data with air at atmospheric pressure
Natural Convection relies on density differences.

The density difference for a 10 C difference in air temperature is 290/300, or 0.967

For Helium gas inside the 20 K shroud this ratio is 25/35, or 0.714

Natural convection works on all surfaces



Some components of the Test Article cannot be traced or tied to a cold surface with a conductive strap

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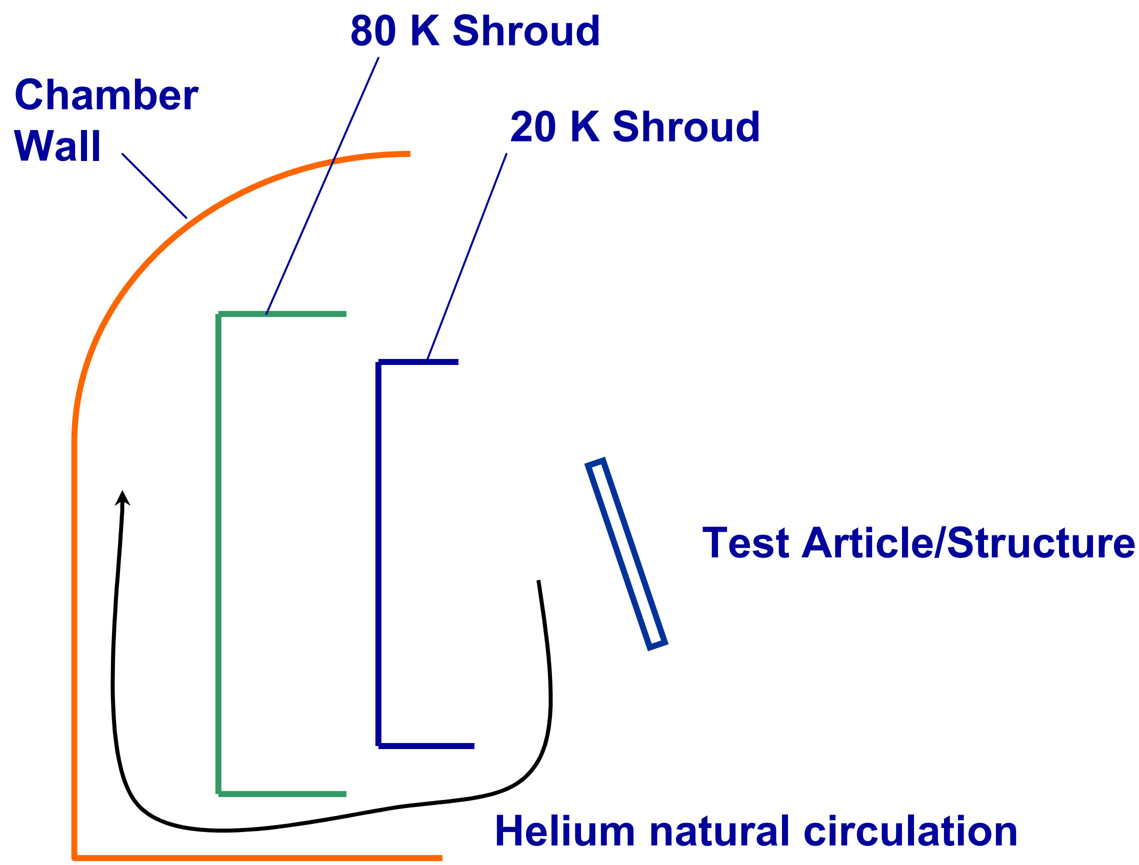
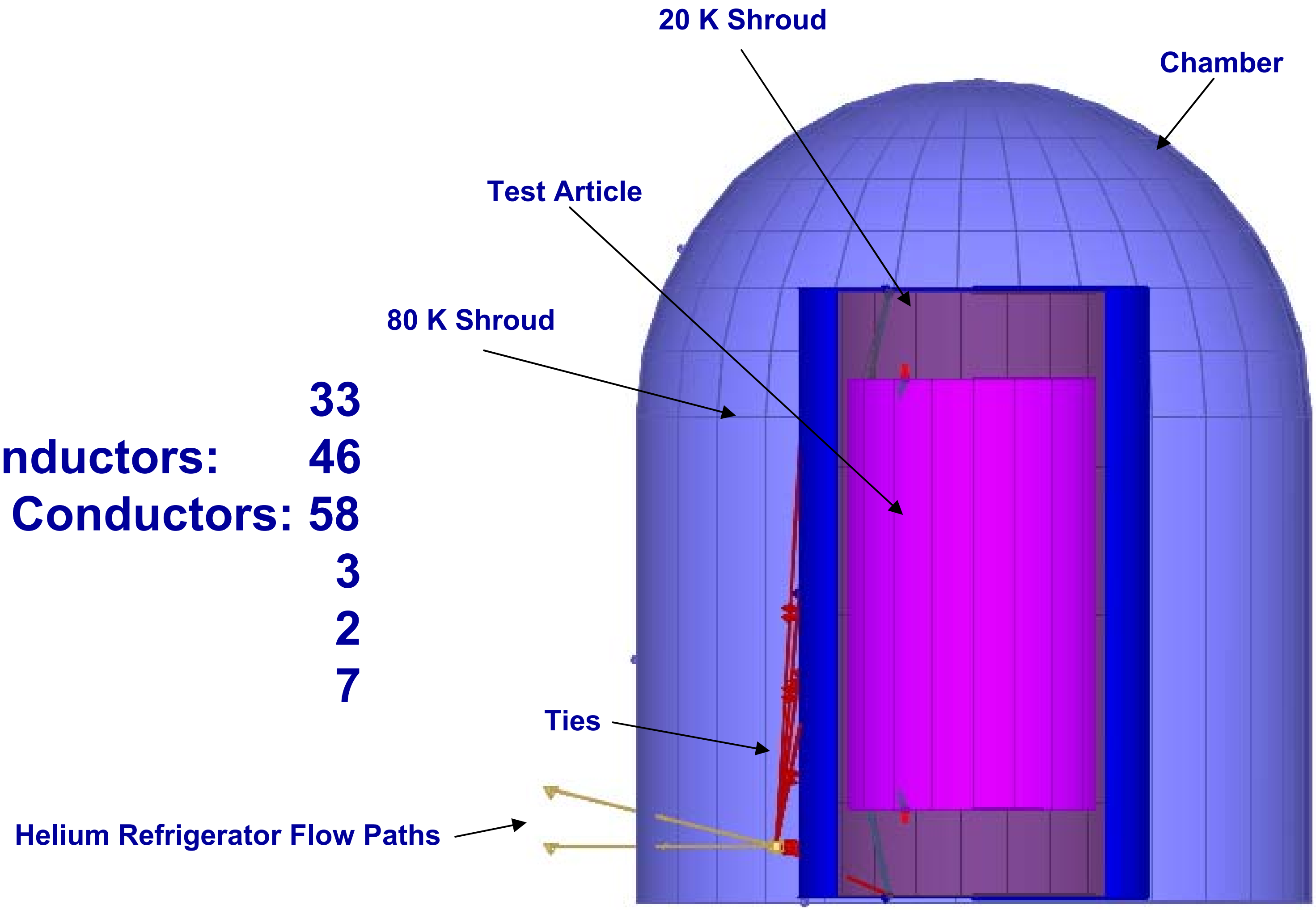
Major difference in thermal control system design



The cold Helium gas within the 20 K & 80 K shrouds must be prevented from flowing over the Chamber surfaces

Simplified Thermal Desktop Model

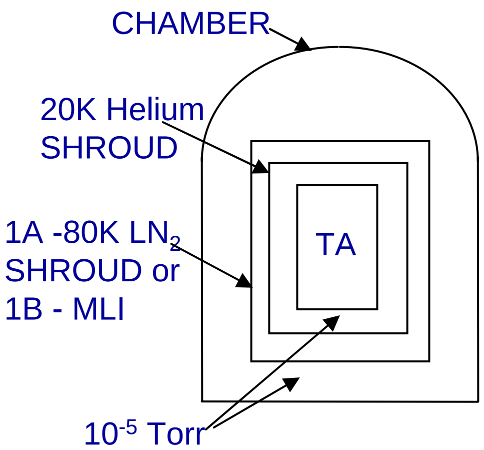
Nodes: 33
Linear Conductors: 46
Radiation Conductors: 58
Lumps: 3
Paths: 2
Ties: 7

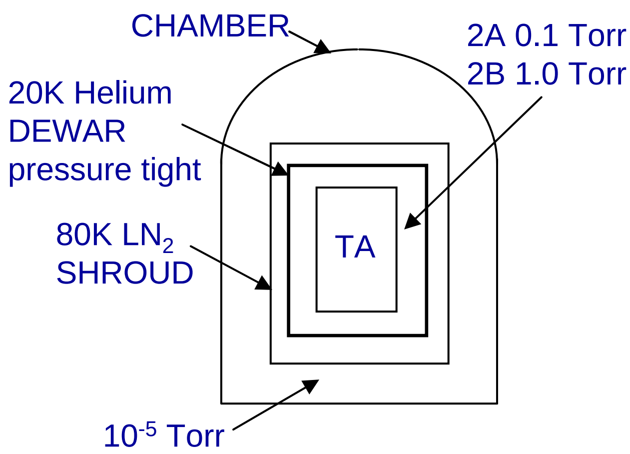


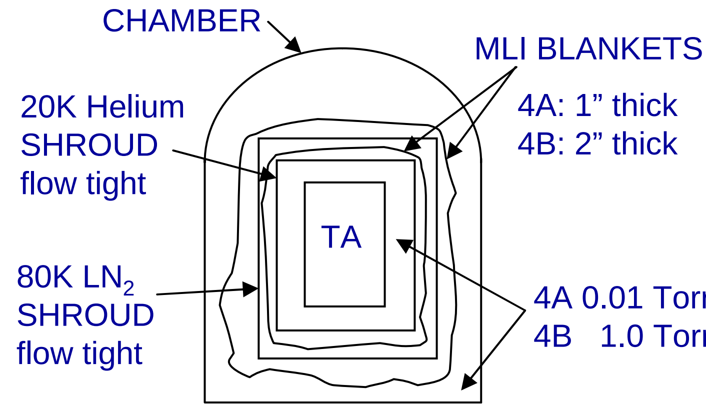
The Test Article is modelled as a cylinder and a node represents the Test Support thermal mass and area

Alternative Cool-Down options modeled

Radiation only - 1



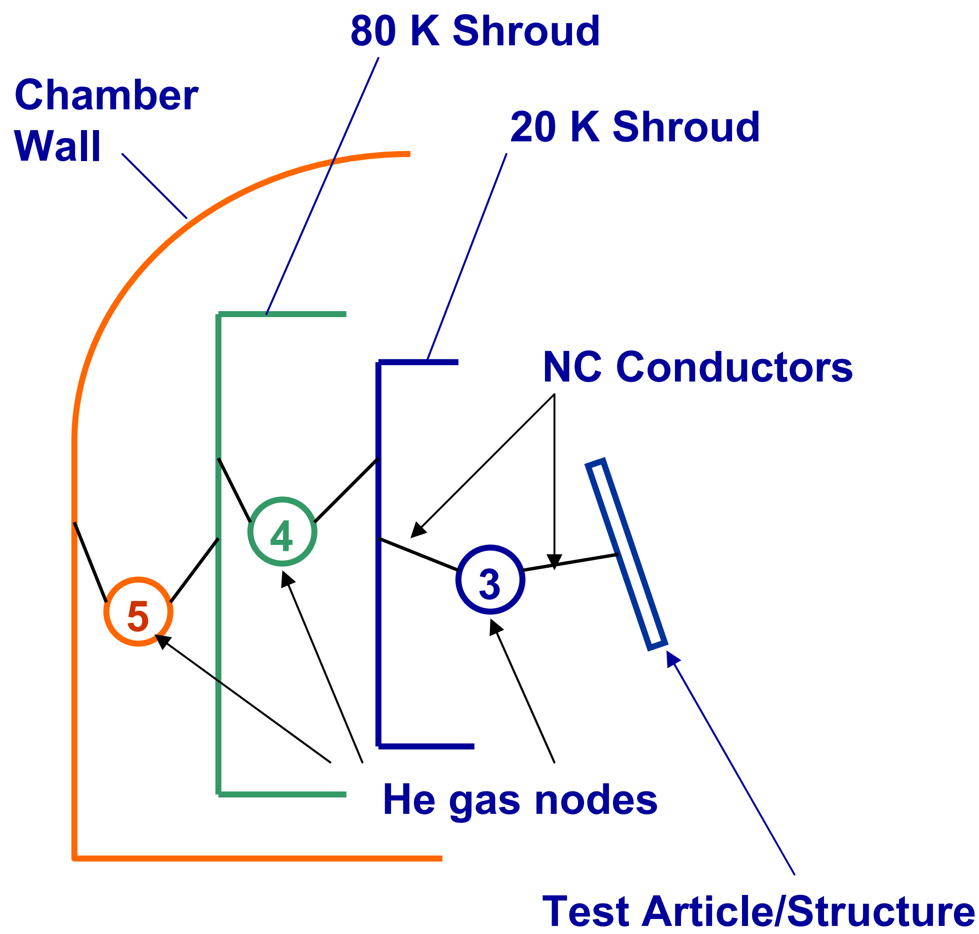


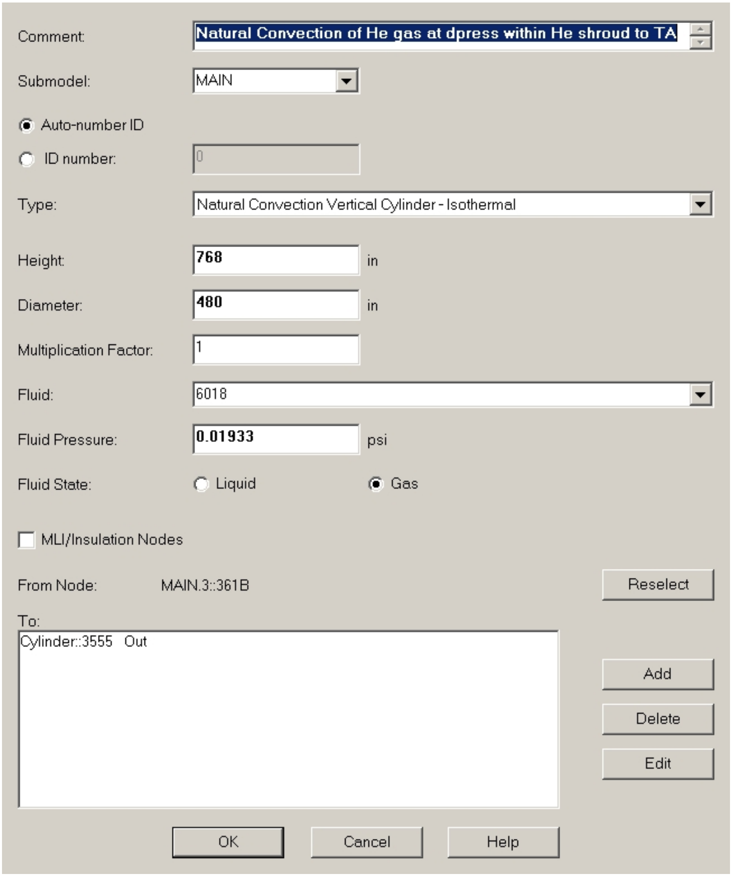


Radiation and Natural Convection – 2 and 4

Thermal Desktop provides means to include molecular conduction and natural convection

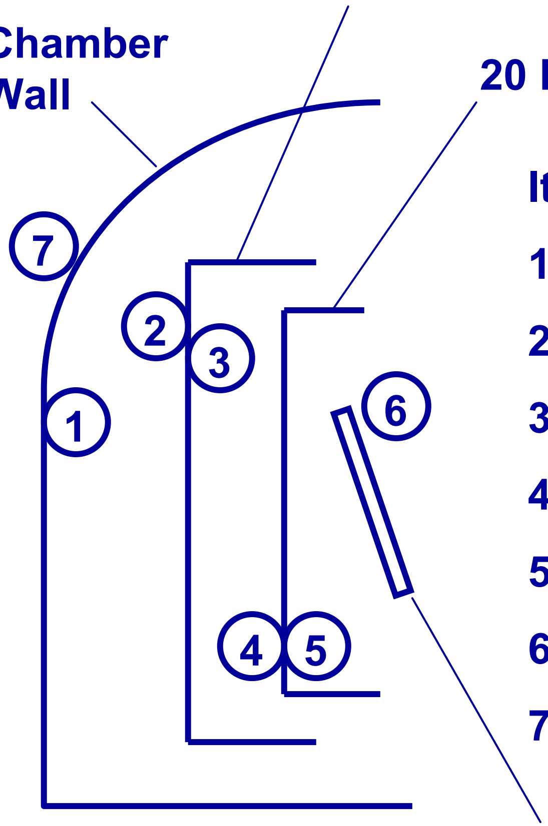
Modeling natural convection at reduced pressure





Thermal Desktop simplifies this once laborious task

Thermal Model Surface Finish/Emissivity



Item	Description	Surface	Emissivity i/o
1.	SPF Chamber Inner	Bare Aluminum	0.10
2.	80 K Shroud Outer	Bare Aluminum	0.10
3.	80 K Shroud Inner	Z307	0.87
4.	20 K Shroud Outer	Bare Aluminum	0.10
5.	20 K Shroud Inner	Z307	0.87
6.	Test Article/Structure	SS304L/Z307	0.15/.7
7.	SPF Chamber Outer	Bare Aluminum	0.10

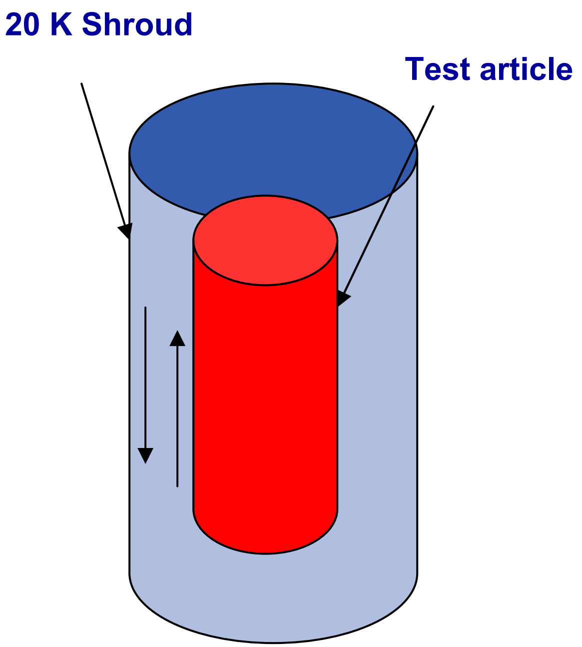
Temperature varying emissivity was not used in this analysis, however, Thermal Desktop can now do this

Modeling results for h_{nc} are reasonable and should be confirmed by testing

A typical natural convection h is 3.2 w/m^2 K for air and a ΔT of 8 K – T_{air} = 290 K, P = 760 torr, & l = 12 in

From Model 4b results, the h is 0.22 w/m^2 K – T_{he} = 30 K, P = 1 torr, & l = 768 in

For l = 12 in, the h goes to 0.65 w/m^2 K



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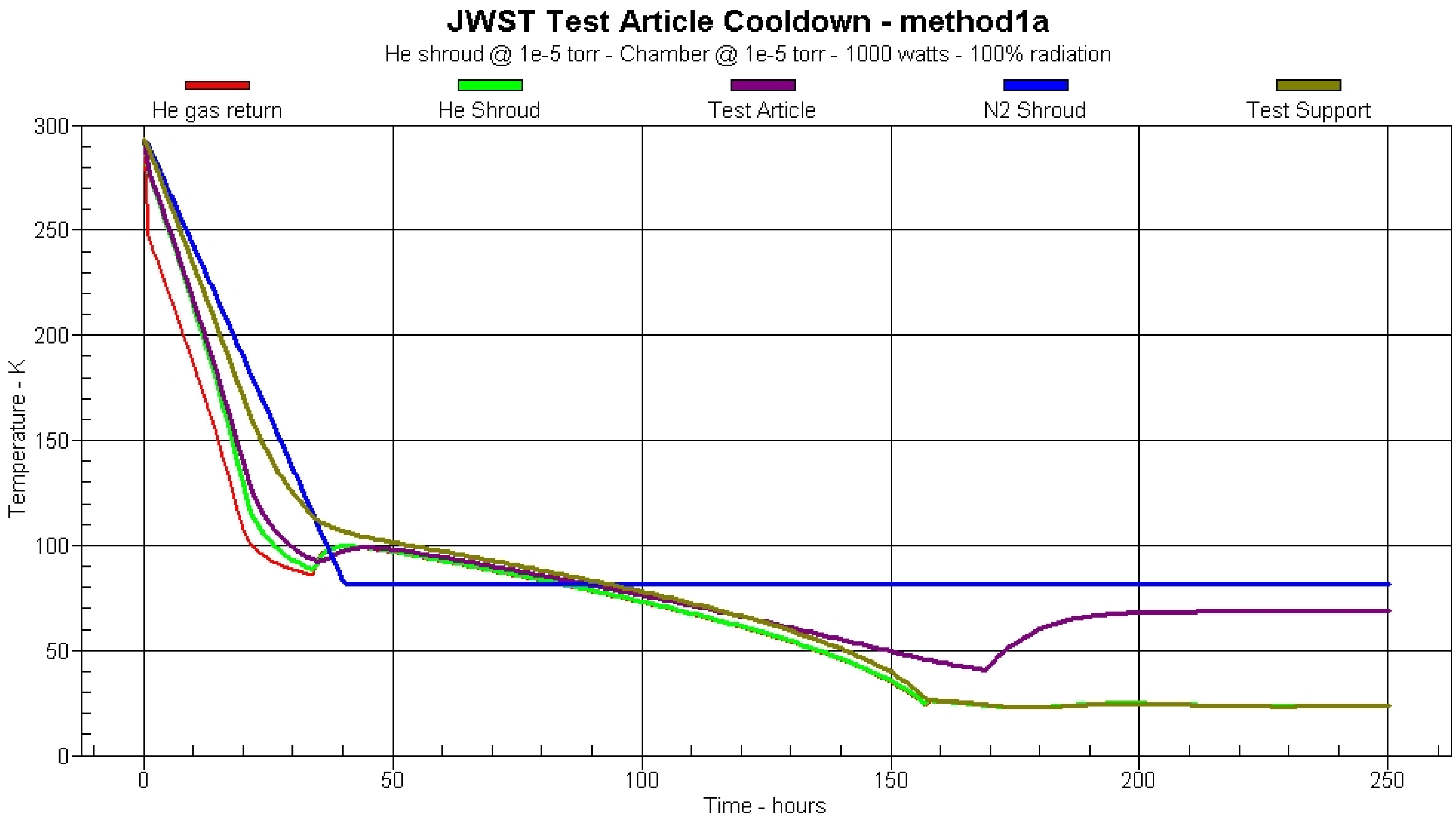
Method 1a Cool-down results



After cooling to 43 K in 170 hours, the test article heats up to 69 K after the 1000 watt radiative load is applied

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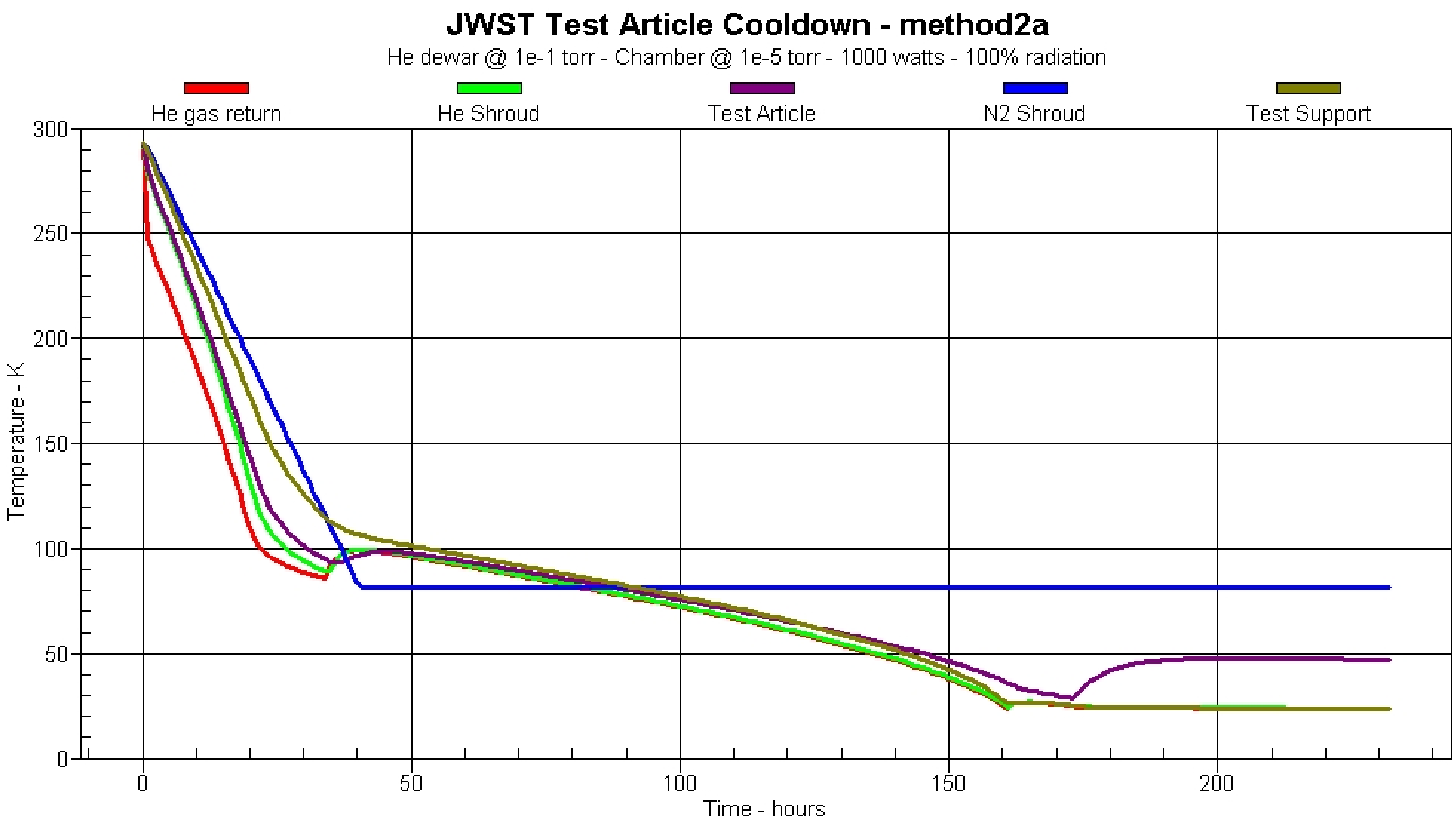
Method 2a Cool-down results



After cooling to 28 K in 173 hours, the test article heats up to 47 K after the 1000 watt radiative load is applied

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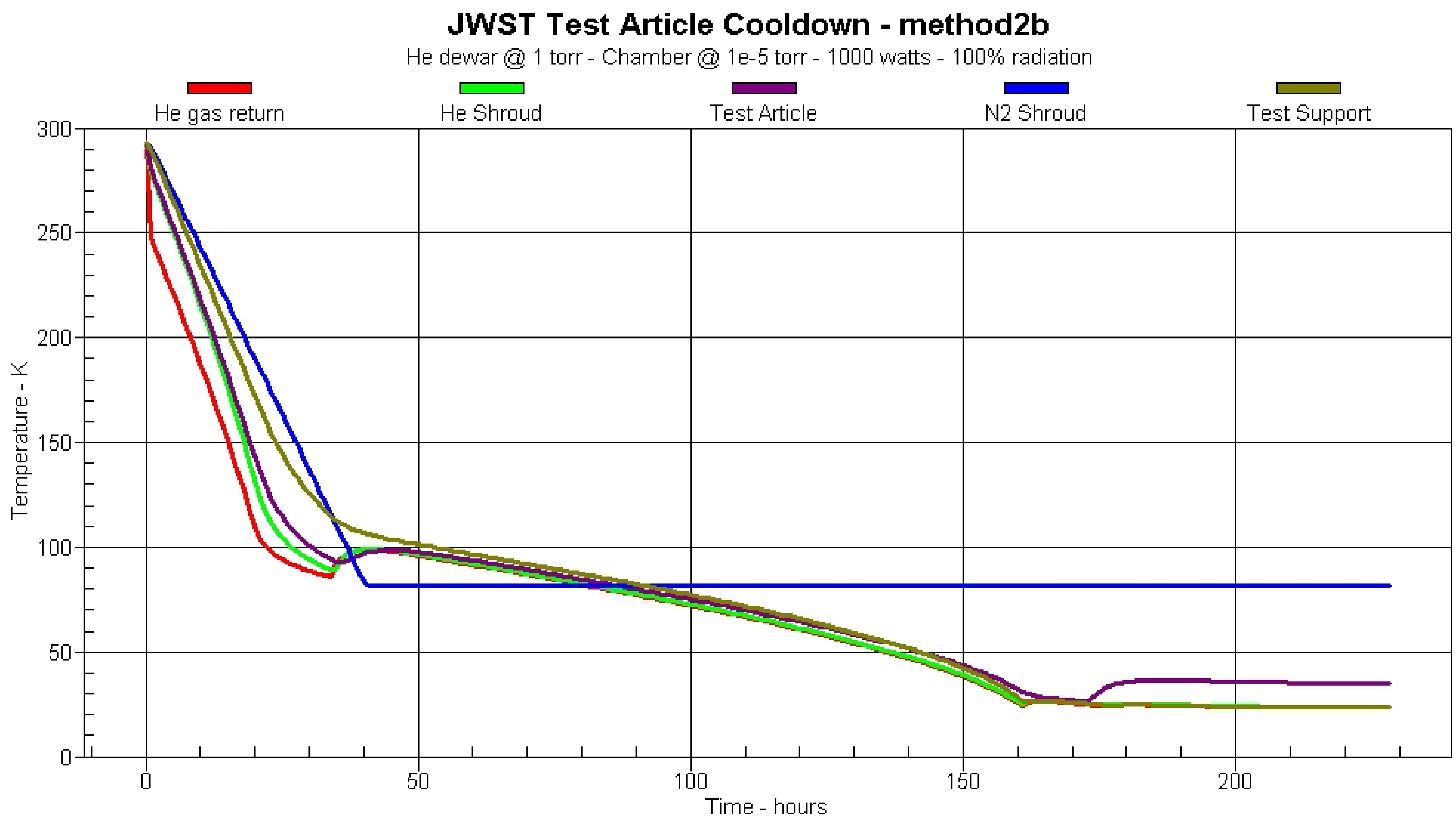
Method 2b Cool-down results



After cooling to 25 K in 173 hours, the test article heats up to 35 K after the 1000 watt radiative load is applied

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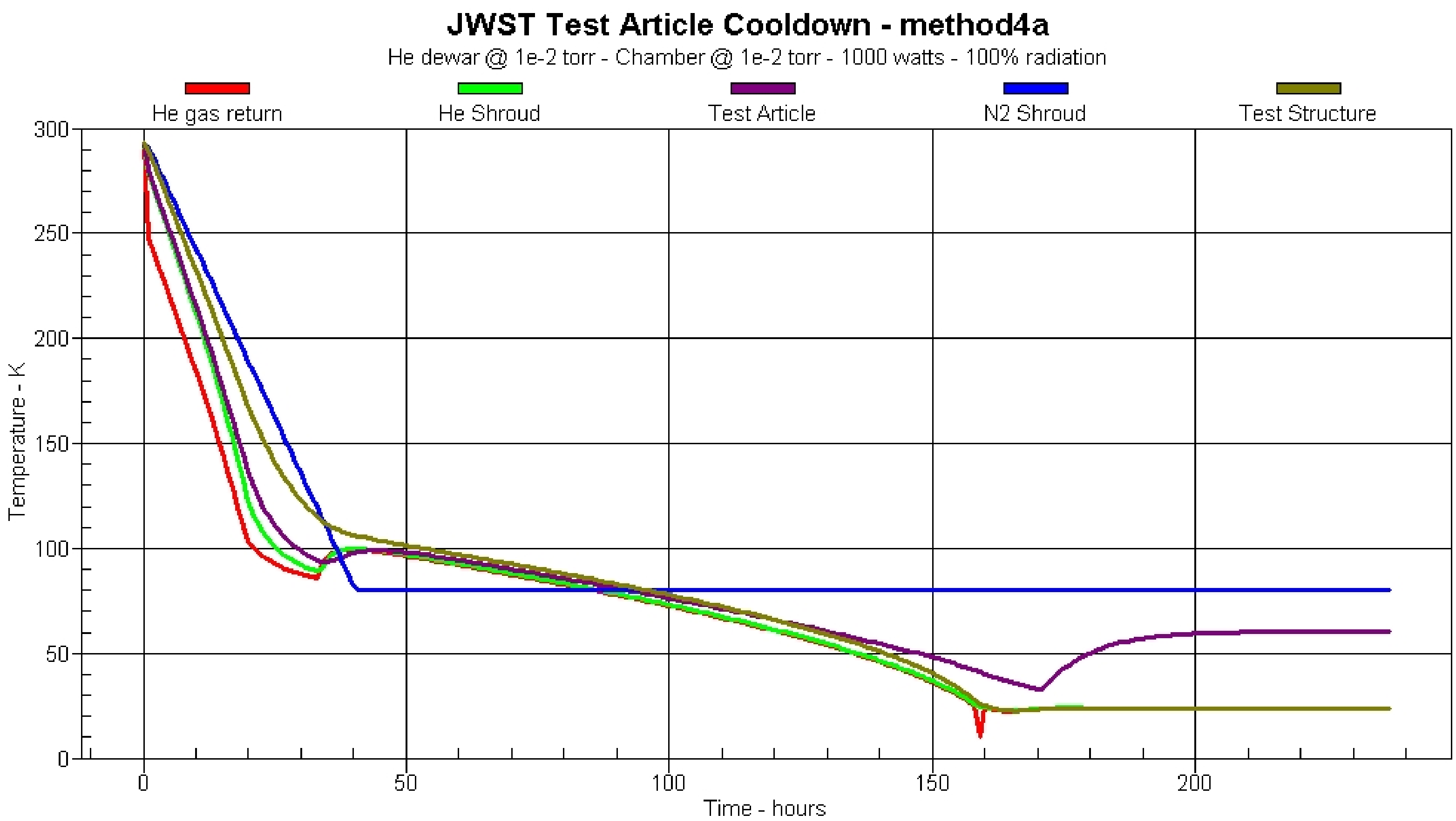
Method 4a Cool-down results



After cooling to 33 K in 170 hours, the test article heats up to 60 K after the 1000 watt radiative load is applied

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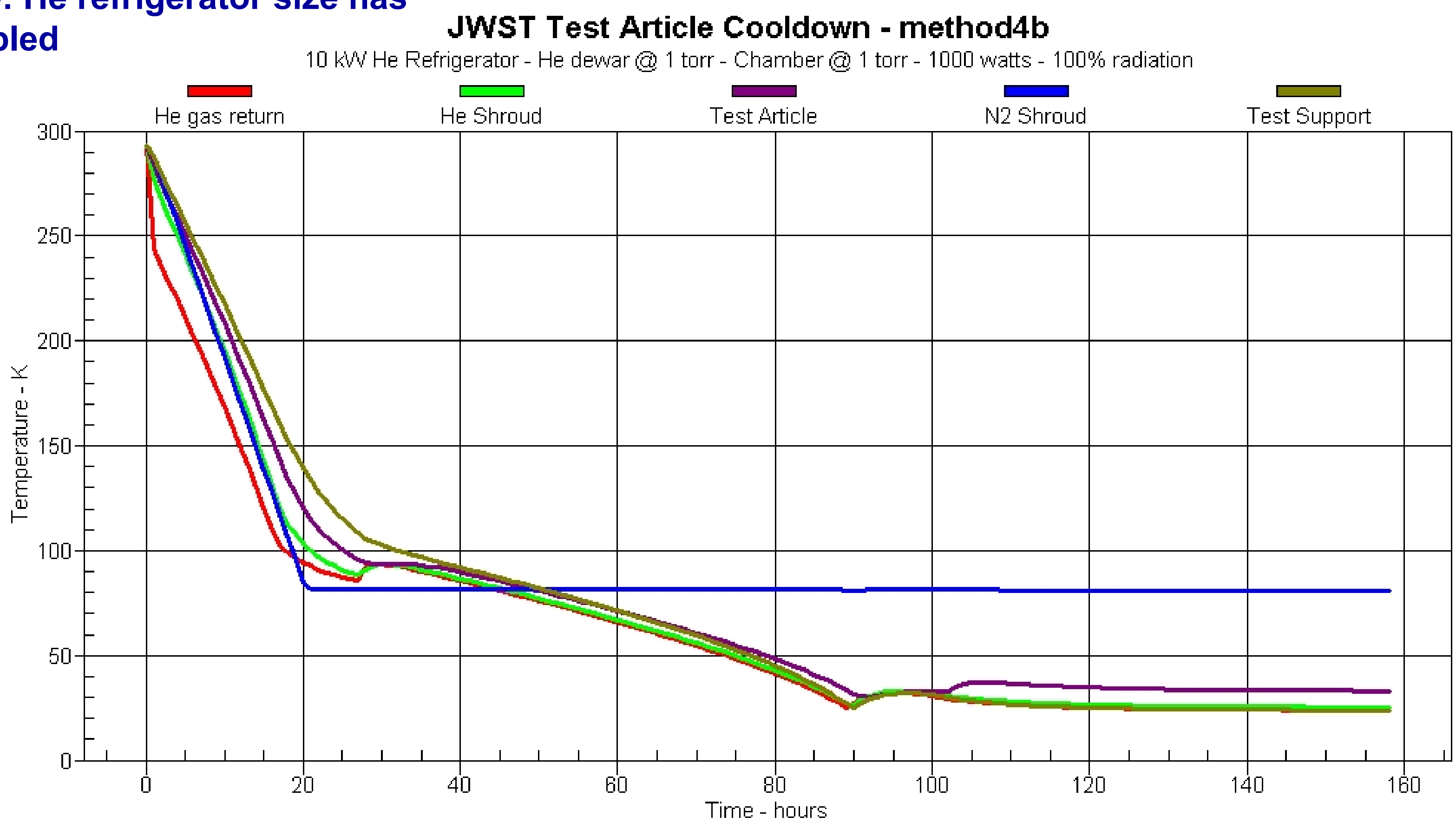
Method 4b Cool-down results

Note: He refrigerator size has doubled



After cooling to 33 K in 90 hours, the test article heats up to 37 K after the 1000 watt radiative load is applied

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The Thermal Control System design must include:

Clean Room Conditions

Vacuum Pumping System

Support Thermal & Vibration Isolation

Material Properties

Optical Test Requirements

Electrical – corona effect

In summary, natural convection is a viable mode of heat transfer for thermal conditioning

Application of natural convection must be consistent with testing goals

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There are important differences in the design of thermal control systems

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Works on all surfaces and reduces thermal gradients

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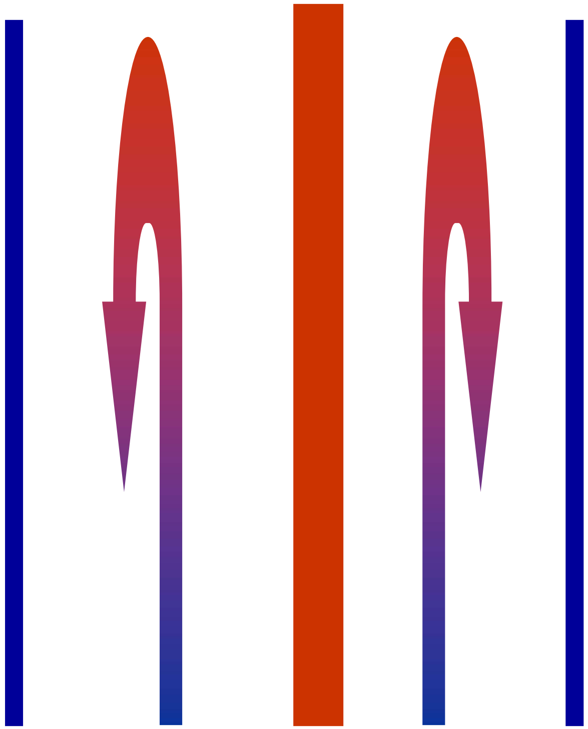
Testing is needed to verify that correlations work under reduced pressure and temperature conditions



Questions?

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