Fermilab

Particle Physics Division

Mechanical Department Engineering Note

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Title: Lab A 200L Vessel Thermal Loads

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Reviewer(s):

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Abstract/Summary:

The thermal loads for the entire imager cooling system need to be characterized. One part of the imager cooling system is the 200L vessel. The vessel and its components are described. The thermal loads are calculated for each of the components. The calculated thermal loads are compared to measurements.

Applicable Codes: N/A

200L Vessel Description

The 200L Vessel is the source for the Imager Vessel liquid nitrogen cooling system. It is the reservoir of nitrogen for the cooling system, has a LN2 pump for circulation, a crycooler and a copper fin condenser for gas condensation. The thermal loads on the vessel due to each of these components are described. A drawing of the vessel and its internal components is shown in Figure 1. The top flange carries all of the vessel feed-thru ports and is not insulated. The first 4.5 inches of the vessel neck is also not insulated. The top of the copper fin condenser is 9.6 inches from the top flange. When the 200L vessel is filled to the fill try-cock level, the liquid is 24.1 inches from the top flange. Conduction in the system is dominated by the stainless steel vessel walls and internal piping. The vessel wall is 18 inch sch. 10 pipe. A 6 inch diameter, 0.120" wall stainless tube supports the circulation pump. The supply and return lines are 1 inch sch. 40 pipe. The supply and return pipes are insulated from the vessel top flange using 12 inch bayonets.

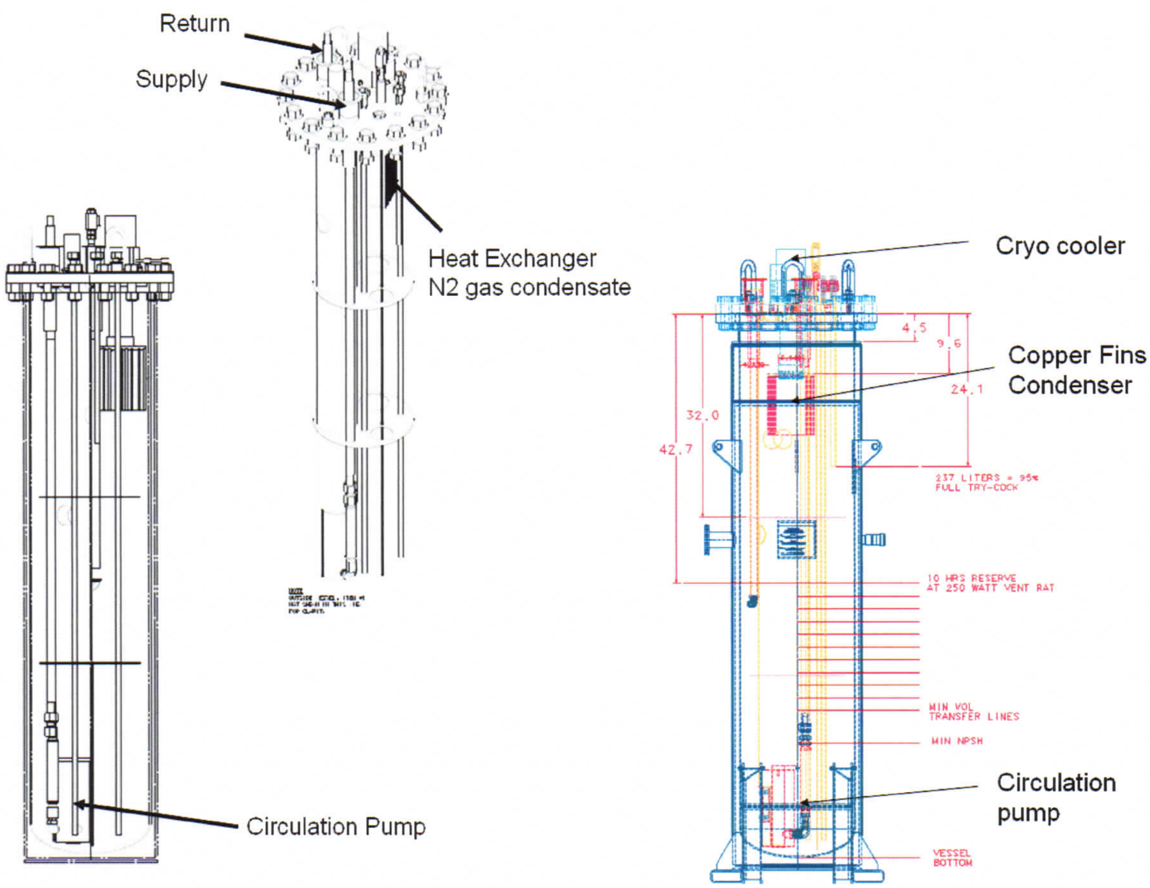


Figure 1, 200L Vessel Assembly, Drawing 436426
(Dimensions in inches)

Thermal Calculations

200L Vessel Finite Element Analysis

The portion of the 200L vessel between the liquid level and the top of the flange is modeled using SDRC-Ideas Finite Element Analysis. Included in the model is the cryocooler with copper fin condenser, the 6 inch stainless tube pump support, and the supply and return liquid lines. Two cases are studied. Case I is with the 200L vessel filled and the remainder of the cryo system is turned OFF. Case II is with the vessel filled and all cryo system components turned ON. Case III is the same as Case II with added insulation on the outside of the vessel neck.

Cryostat Geometry for the FEA

The basic cryostat geometry used in each of the FEA cases is shown in Figure 2. The top 24.1 inches of the cryostat are modeled. Below this elevation it is assumed that the cryostat is filled with LN2 at an operating pressure of 100 psig and a temperature of 100K. (-173°C). Thermal convection to atmosphere is 10 $W/m^2.K$ and is applied to the exterior surfaces. The surrounding atmospheric temperature is 20°C. The cryostat is constructed of 304 stainless steel material. The flanges are class 150 ASME raised face flanges. The inner vessel is constructed of 18 inch sch. 10 pipe. The first 4.5 inches of the cryostat neck are not insulated. A 6 inch diameter, 0.120" wall stainless steel tube is suspended off the top flange and is used to support the LN2 circulation pump at the bottom of the reservoir. The supply and return lines run from the liquid surface to the top flange and are constructed of 1 inch sch 40 pipe. The top 9 inches of the supply and return lines are isolated from the inner vessel gas space by a bayonet style connection. A cryocooler is used to condense nitrogen gas. It is suspended from the top flange. A copper fin heat exchanger is attached to the bottom of the cryocooler. When the cryocooler is operating, the temperature of the copper fin heat exchanger is the same as the saturated liquid, or 100 K (-173° C).

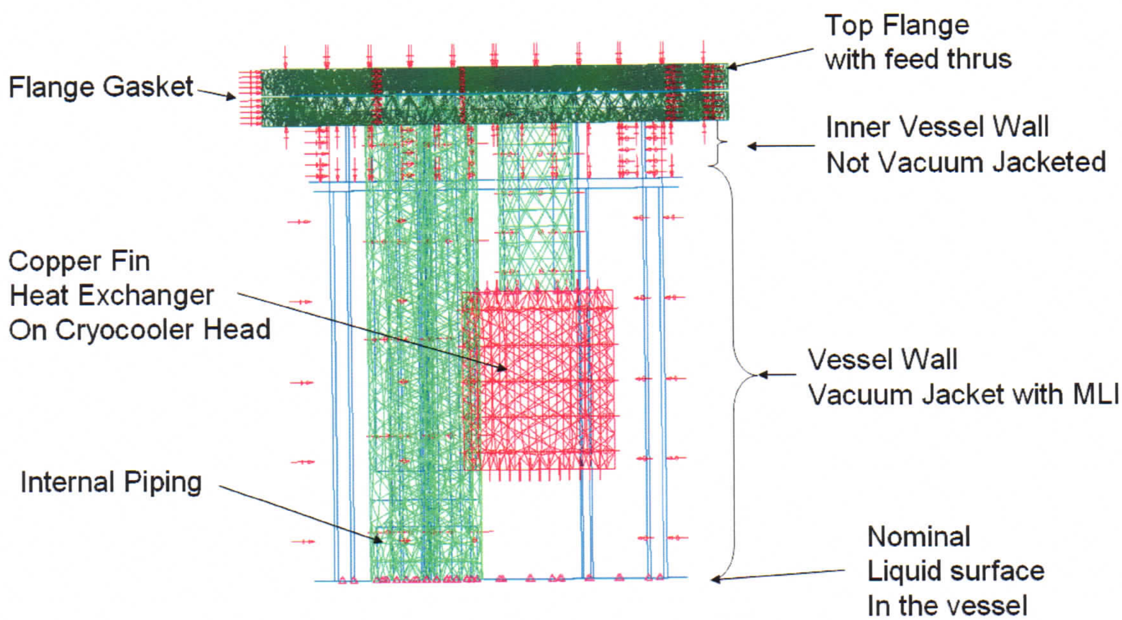


Figure 2, Cryostat Geometry

Case I , Cryostat filled with LN2, cryosystem OFF

Case I is with the 200L vessel filled to the fill try-cock level. At this level, the liquid is 24.1 inches from the top flange. The cryocooler is OFF and the liquid is not circulating. The thermal load on the vessel is dominated by conduction through the stainless steel vessel walls and internal piping. The operating pressure is 100 psig. The LN2 temperature at this pressure is 100K. The outside vessel surfaces are exposed to ambient temperatures. Convection to ambient air is applied to all outer exposed surfaces. The ambient temperature is 20ºC and the convection coefficient is 10 W/m^2.K. Case I boundary conditions are shown in Figure 3.

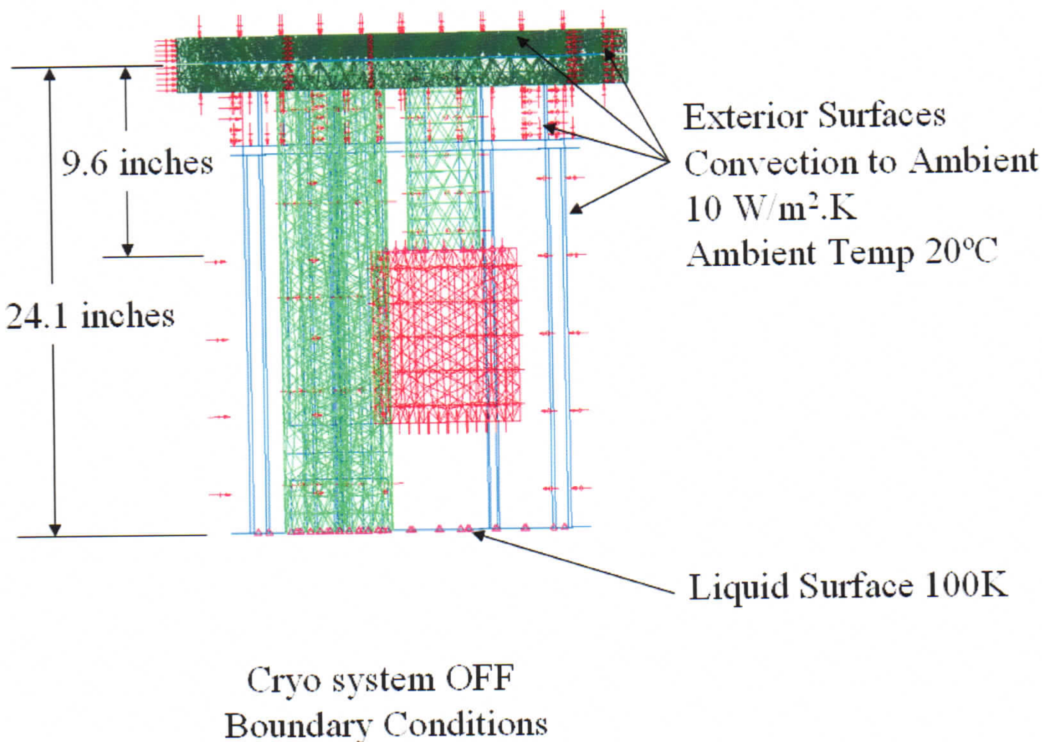
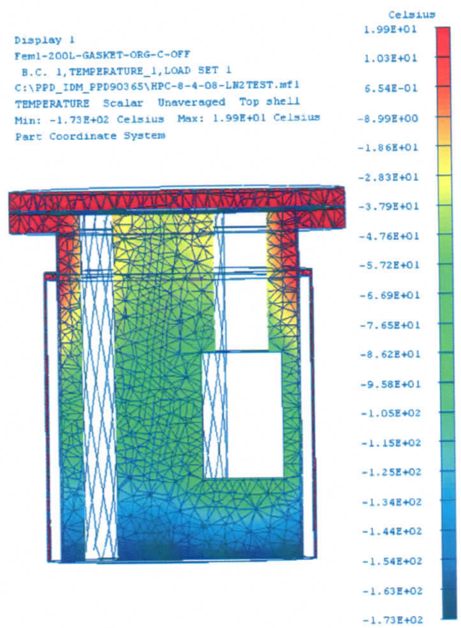


Figure 3, Boundary Conditions, Cryo System Off

The FEA thermal result for Case I is shown in Figure 4. Red, the warmest temperature is 20ºC and blue, the coldest temperature, is -173ºC. The thermal load can be calculated knowing the temperature difference between the external vessel surface and ambient air, the surface area of the vessel, and the convection coefficient. Since the vessel exterior surface has a temperature gradient on it, the thermal load needs to be integrated over the surface.

Watts = surface area * Convection Coef. * delta Temperature.

Calculating this term for Case I gives 42 Watts.



Cryo-Cooler OFF (42 Watts)

Figure 4, FEA Temperature Results, Cryo System Off

Case II, Cryostat filled with LN2, cryosystem ON

Case II simulates the operating condition with the cryo cooler ON. The temperature of the fins is the same as the saturated liquid -173 °C (100K), and the surface of the supply and return lines is -173°C on surfaces below the bayonet. The liquid lines have a 12 inch bayonet for isolation to the top flange. Assuming that the gas mixes, the temperature of the gas is -173°C to a level just below the top of the condenser fins. All of the other Case I boundary conditions are applied. Case II boundary conditions are shown in Figure 5.

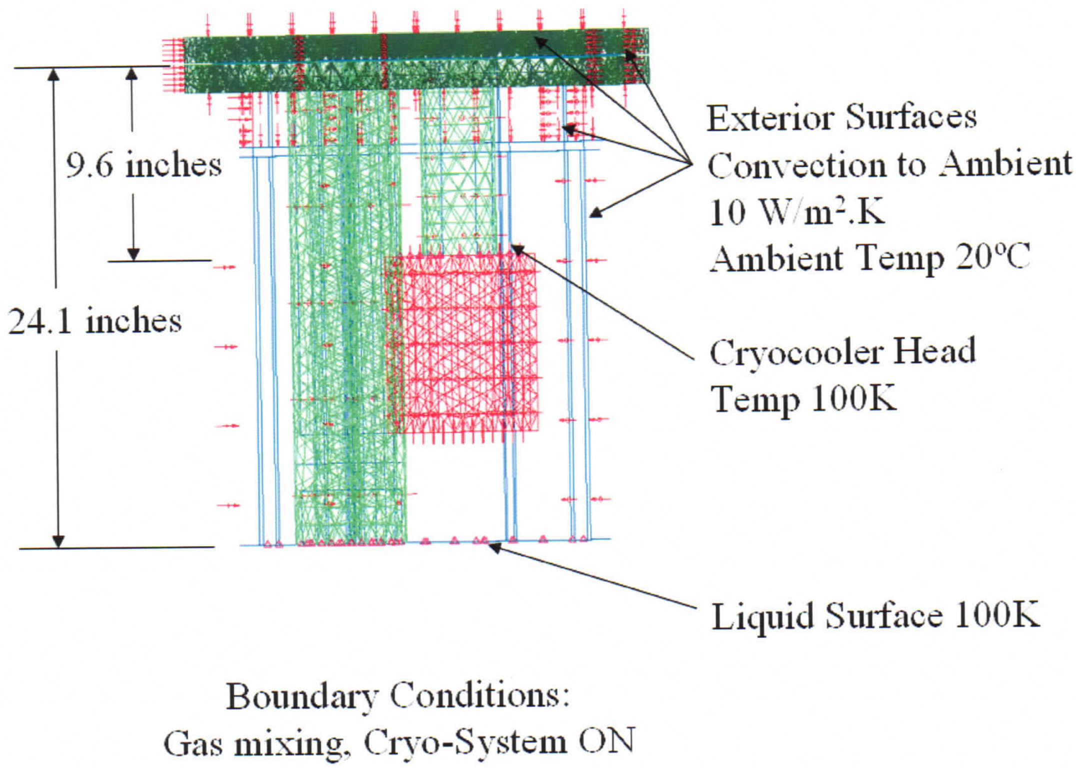
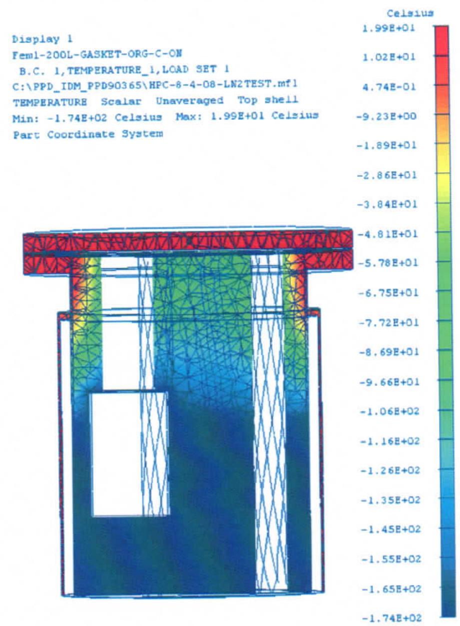


Figure 5, Boundary Conditions, Cryo System ON

The FEA thermal result for Case II is shown in Figure 6. Red, the warmest temperature is 20°C and blue is the coldest temperature -173°C. The thermal load can be calculated knowing the temperature difference between the external vessel surface and ambient air, the surface area of the vessel, and the convection coefficient.

Watts = surface area * Convection Coeff. * delta Temperature.

Calculating this term for Case II gives 109 Watts.



Cryo ON, Gas Mixing
109 Watts

Figure 6, FEA Temperature Results, Cryo System ON

Case III , Cryostat filled with LN2, cryosystem ON, Foam on Vessel Neck

Case III has all of the same boundary conditions as Case II with the addition of a 1 inch layer of insulating foam added to the bare portion of the vessel neck. Case III boundary conditions are shown in Figure 7.

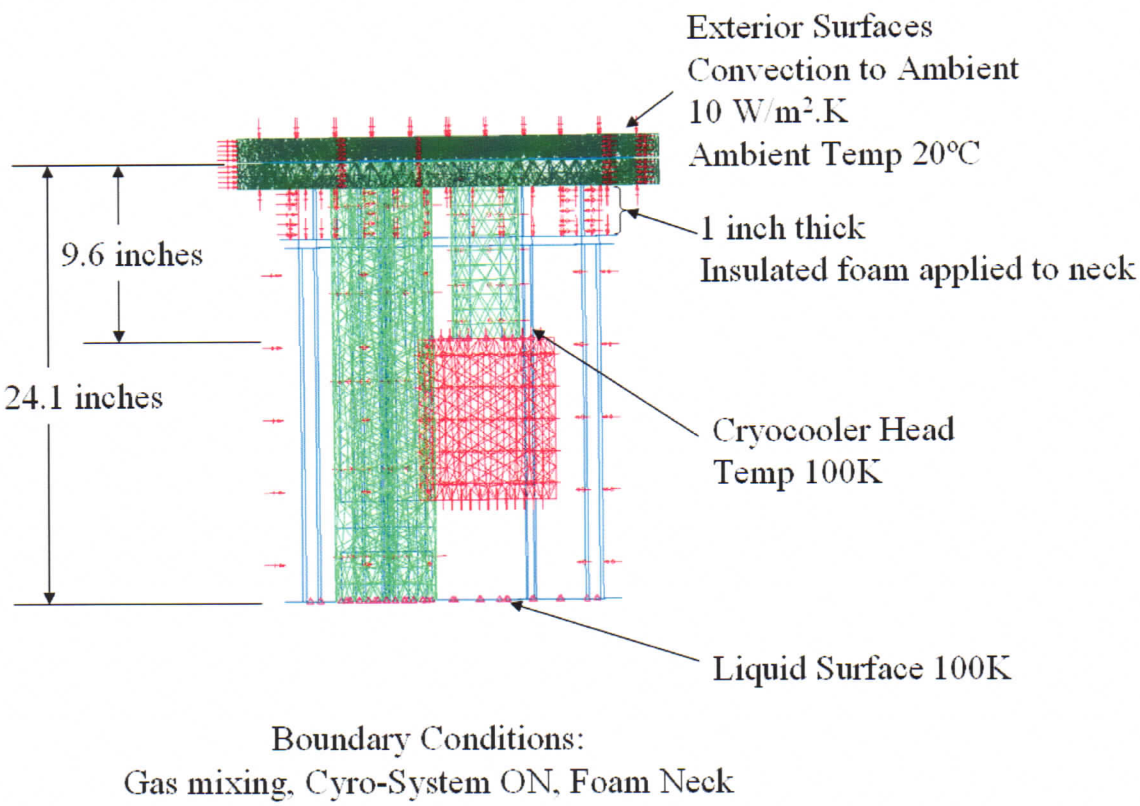
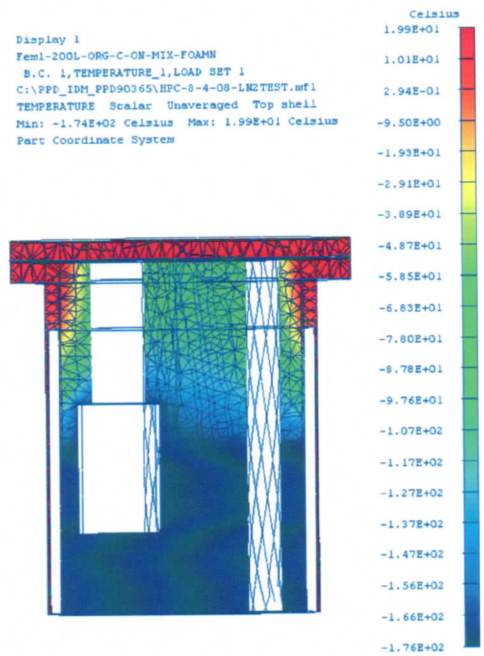


Figure 7, Boundary Conditions, Cryo System ON, Foam on Vessel Neck

The FEA thermal result for Case III is shown in Figure 8. Red, the warmest temperature is 20°C and blue is the coldest temperature -173°C. The thermal load can be calculated knowing the temperature difference between the external vessel surface and ambient air, the surface area of the vessel, and the convection coefficient.

Watts = surface area * Convection Coeff. * delta Temperature.

Calculating this term for Case III gives 95 Watts.



Cryo ON, Gas Mixing, Foam Neck
95 Watts

Figure 8, FEA Temperature Results, Cryo System ON

FEA Hand Calculation, Checks

The majority of the thermal load is due to conduction through the stainless vessel walls and internal plumbing.

Watts = Cross Section Area * SS Conduction * dT / Length

Where,

Cross Section Area for 18 inch sch 10 pipe
(PLUS INTERNALS) = 13.8 inch^2 = (0.0089 m^2)

Stainless steel integrated thermal conductivity = 11 W/m.K

dT = 298K -100K = 198K

Length from top flange to liquid surface = 9 inches and greater

A plot of thermal load due to conduction through the stainless steel as a function of distance from the top flange to the liquid level is shown in Figure 9. With the cryo system operating, the temperature in the vessel is -173 °C at a distance of about 10 inches from the top flange as shown in Case II, Figure 6. In this operating condition the hand calculation shows that the thermal load due to conduction through the stainless steel pipes is 74 Watts. With the cryo system OFF and the 200L vessel filled with LN2, the distance from the top flange to liquid level is about 24 inches. This corresponds to a thermal load due to conduction of 33 Watts.

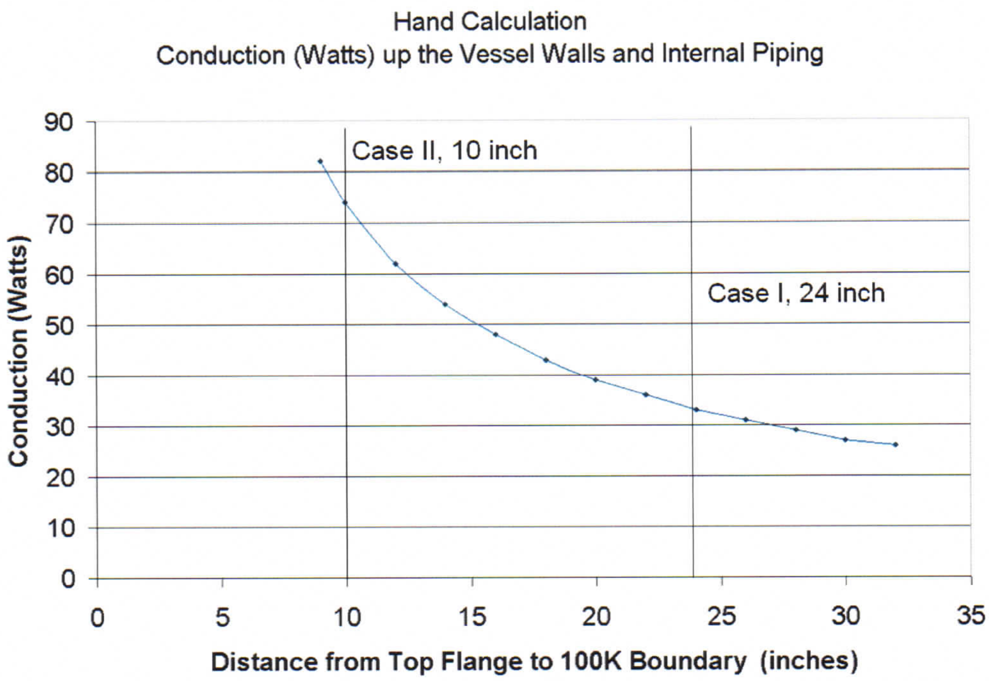


Figure 9. Conduction up stainless steel vessel walls and piping.

Conduction through the stainless steel vessel walls and piping accounts for 74 out of the 109 watts in Case II and 33 watts out of 42 watts in Case 1.

Cryostat Vacuum Jacket

The vacuum jacket on the vessel is a thermal load. The load is due to a combination of radiation, gas conductivity, and solid conduction through the vacuum jacket. Radiation is minimized by wrapping the liquid vessel with 30 layers of Muli-Layer Insulation (MLI). The thermal load due to conduction is minimized by maintaining a good vacuum.

The heat transfer through the vacuum jacket (assuming 30 layers of multi-layer insulation, and a vacuum of 1x10-5 torr) is 0.52 W/m^2 using FN-423, "An Experimental Study of Heat Transfer in MultiLayer Insulation." The approximate surface area of the cryostat walls is 3.85 m^2. The combined thermal load through the vacuum jacket is less than 2 Watts.

Circulation Pump Measurement

The thermal load due to the pump is broken into two parts: work required to move the liquid, and the energy loss due to the efficiency of the pump. The total load is measured by monitoring the line voltage and current on all 3 phases of the pump. The measurement is 8 Watts running dry in gas (the No Load condition). The gas temperature is about 100K and the pump is operated at 52 Hz. The thermal load is 55 Watts with the pump running in liquid nitrogen (Loaded condition) at 52 Hz and 11 psid across the pump.

The pump controller is configured with parameter uL=220hz. Motor controller full current is 3.3 A. Motor controller full voltage is 230 V.

No Load, cold in gas, 52 Hz power measurement:
C = % full current to the pump = 4%
P = % full voltage to the pump = 16%
0.04 *3.3A * .16*230V *sqrt(3 phases) = 8 Watts

Loaded, cold in liquid, 52 Hz, 11 psid across the pump, power measurement:
C = % full current to the pump = 15%
P = % full voltage to the pump = 28%
0.15 *3.3A * 0.28 *230V *sqrt(3 phases) = 55 Watts

200L Vessel Thermal Load Measurement

The thermal load on the 200L vessel is measured with the cryocooler ON and the circulation pump OFF. The 200L vessel internal pressure is maintained at 45 psig using a heater submersed in the LN2 liquid. The saturated temperature of the nitrogen at 45 psig is about 92K. The system heat load is then the heater power required to maintain pressure subtracted from the cryocooler capacity.

The heater power measured on 4/5/09 is
260 watts with the internal vessel pressure at 45 psig.
The cryocooler capacity at 92K is extrapolated from Figure 10.
The cryocooler capacity is 360 Watts.

200L Vessel thermal load
= Cryocooler capacity – heater power
= 360 Watts – 260 Watts
= 100 Watts.

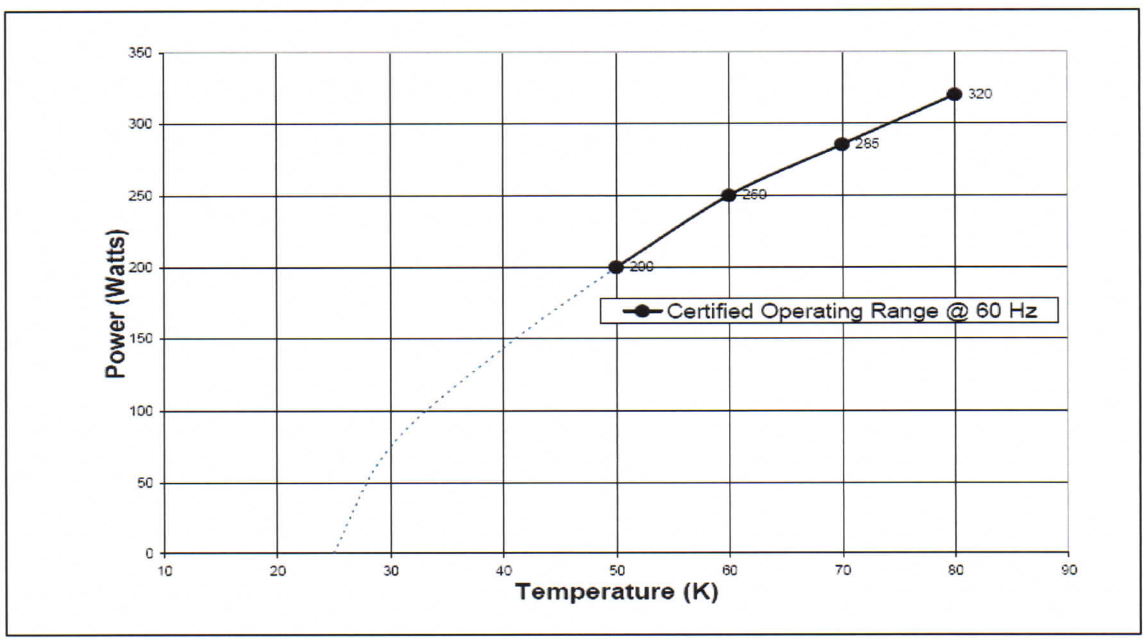


Figure 10, Cryomech capacity curve for the Al-300. Slope is 3.5 W / K

Total 200L Vessel Thermal Load

The total thermal load on the 200L vessel is the sum of the tabulated loads. The thermal load measured at Lab A is higher than the expected design case as shown in the following table.

Table 1. 200L Vessel Thermal Loads

Thermal Load	Design Basis	Measured at Lab A
CryoCooler ON Liquid level 24" from top flange	25 Watts	100 Watts
Circulation Pump – operating at 52 Hz	38 Watts	55 Watts
Total 200L Vessel Assembly Thermal Load	**63 Watts**	**155 Watts**