Fermilab

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Title: SuperCDMS Detector Cooldown Report

Author(s): Glenn Morgan

Reviewer(s):

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Introduction / Abstract

SuperCDMS is a sensitive experiment that requires extremely cold temperatures for superconducting the Geranium in the detectors. Being placed in SNOLAB facility deep below ground, very little background radiation penetrates to the laboratory, but this causes logistic issues with a liquid helium transfer line.

This report looks into the possibility of using helium liquefiers to provide the liquid helium to the detector eliminating the need for the transfer line. There is a concern if the liquefiers can provide enough cooling power to cool the detector down to liquid helium temperatures in a reasonable timeframe.

Description

Due to the complexity of the model, certain simplifications were made so that hand calculations were feasible. Radiation was omitted since cryogenic emissivity data is sparse and the net effect is relatively minor with a heat dissipation of no more than 50W. If emissivity and surface area are known, the spreadsheet is still set up to take radiation into account. With these simplifications, an energy balance equation, Eq. (1), was developed to find the temperature of the system as a function of time:

$$\left(m_s c_{p,s} + m_{cu} c_{p,cu} + \rho_{He} V_{He} c_{p,He}\right)\frac{\partial T}{\partial t} = \frac{q_{@4.2K}}{T_o - 4.2K}(T_o - T) - \dot{m}\left(c_{p,He}(T - 4.2K) + h_{fg}\right) \quad (1)$$

Where:

m_s	mass of 304 SS
$c_{p,s}$	specific heat of 304 SS
m_{cu}	mass of copper
$c_{p,cu}$	specific heat of copper
ρ_{He}	density of helium
V_{He}	volume of helium
$c_{p,He}$	specific heat of helium
$q_{@4.2K}$	heat leak when T = 4.2 K
T_o	outside air temperature
$\dot{m}$	mass flow rate of liquid helium

Because this equation is based on temperature-dependent properties, an analytical solution would not be advisable. Therefore a numerical approach was used called the Runge-Kutta method. This essentially considers it linear over small intervals so caution must be made to ensure the time interval is small enough, thus a default value of 10 minutes was used. This equation gives a good approximation of how each parameter affects the cooldown time so if a faster cooldown time is recommended, then it could be adjusted accordingly.

Since $\dot{m}$ is based on the liquid helium flow rate from a liquefier, a calculation was performed to see if this flow rate gave a reasonable time to reduce the temperature down to the specified cooldown temperature. Boil-off rate also factors into the equation by giving the heat leak when a temperature of 4.2 K is reached. With 0.55 L/hr boil-off rate of liquid helium, the maximum heat leak is not even half a watt.

Analysis

With one helium liquefier, a flow rate of 18 L/day takes the system down to the liquid helium temperature in only 109 hours (4.5 days). If a faster cooldown period is still wanted, a second liquefier can take it down to 53 hours (2.2 days). Figure 1 visually shows the cooldown of the SuperCDMS detector and the difference between one and two liquefiers.

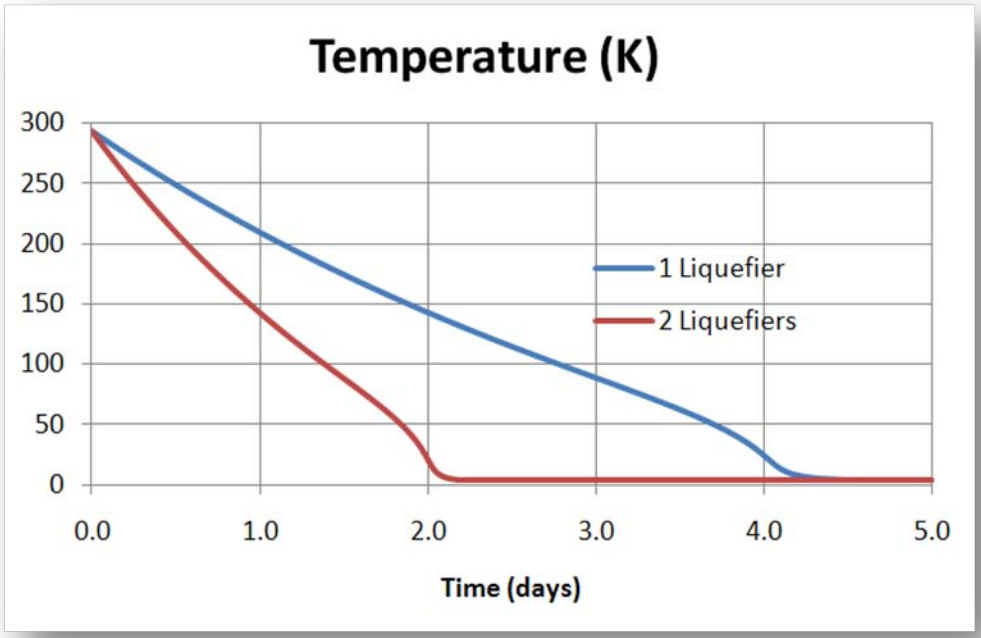

Figure 1: System temperature

Mass of the system takes part in how long the system takes to cooldown. There is a considerable amount of dimensioning inherent the engineering drawing of a detector. So the mass of large components were calculated and multiplied by 200% for a total mass of 82 kg (180 lbs) which is likely overestimating its actual mass. This is a very rough estimation so if a more refined number is essential, more time can be put into refining the actual mass value.

Helium properties such as its density and specific heat were tabulated at 14.6 psia and taken from REFPROP. This allowed the spreadsheet to create temperature-based equations. Helium's properties were then calculated at a film temperature, $\left(T_{film} = \frac{T_f + T_{wall}}{2}\right)$.Specific heat coefficients of stainless steel and copper were pulled from the cryogenics page at NIST.gov.

Conclusion

Results look promising for a cooldown period no longer than 5 days. One helium liquefier provides more than enough cooling power, but another liquefier can be recommended for redundancy and speeding up the cooldown period. They may not work optimally or a larger heat load might be imposed on the system so the second one allows a larger safety net. Since the results are promising, the need for a long liquid helium transfer line can be ruled out and instead the liquefiers can handle the cooling load of the detector.

The spreadsheet for the cooldown calculator will be placed in the same docdb number so that any input value can be changed if further analysis is necessary. Macros should be enabled to use this spreadsheet as well as iterative calculations. It should be noted that the calculator is for estimation purposes only and its results should only supplement engineering judgment by giving a basis and insight into the behavior of the system.