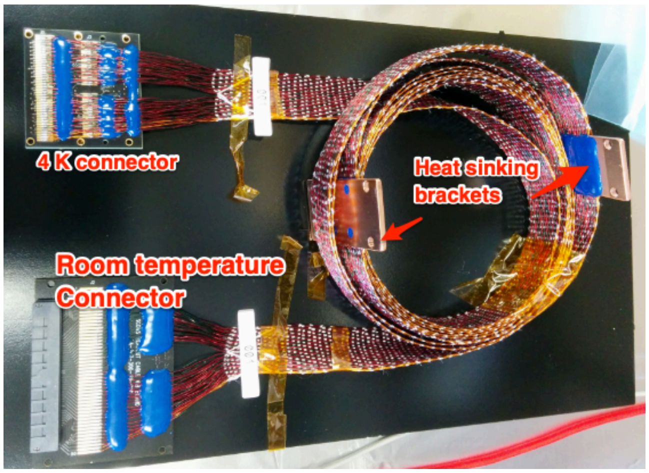
PHY2405, eHEP, Homework 2
(You are expected to look up data when necessary. Sometimes it's also necessary to make assumptions to proceed with the calculations. State them clearly when that happens.)

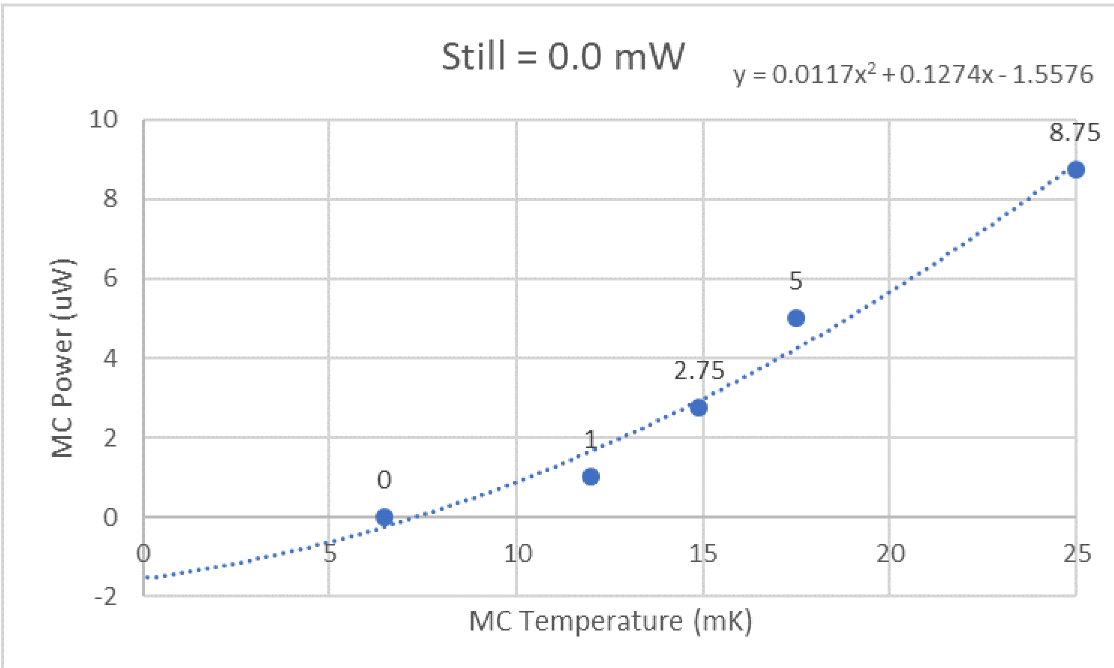
1. For cryogenic experiments, controlling the heat load on various stages is a key aspect of experimental designs. The SuperCDMS experiment plans to operate 24 detectors. Each detector is read out by a loom of 50 twisted-pair wires (100 wires). We focus on the room temperature to 4 Kelvin cable here. A picture is below. All wires are 32-gauge. Among the 50 pairs, 48 of them are made of phosphor bronze, and two pairs are made of copper. The total length of the cable is 3 meters. You can see two copper "heat sinking brackets" glued onto the cable to thermalize part of the cable to a specific temperature of the cryostat.



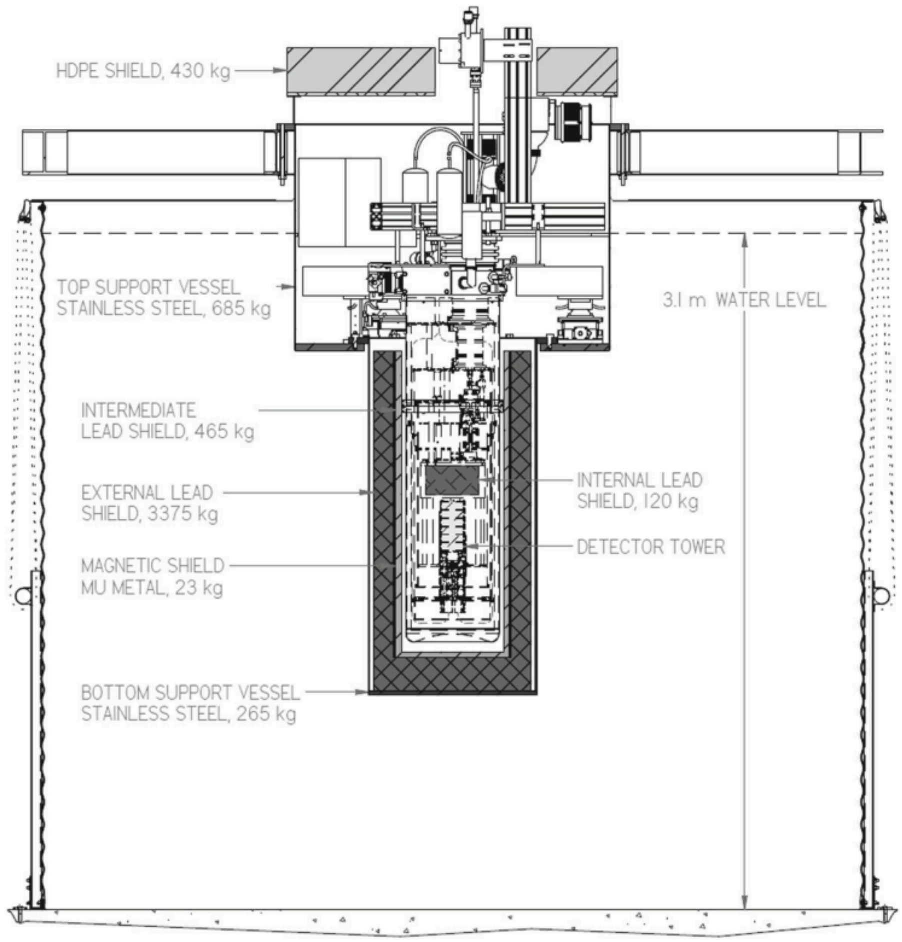
Recall the cryostat (driven by a Pulse Tube CryoCooler followed by a dilution refrigerator) has multiple temperature stages, nominally at 50K (PT 1st stage), 4K (PT 2nd stage), 1K (Still), 100 mK (Cold Plate), 10 mK (Mixing Chamber). The "nominal temperatures" are well-rounded numbers for abbreviations. The actual temperatures are different from the nominal temperatures, driven dynamically by the cooling power available and the heat load present.

Assume the two heat sinking brackets have perfect efficiency (i.e. the cable will be anchored at the temperature where you bolt the bracket to). One of them is to heat sink the cable to the 50K stage, and the other is for the 4K stage. We use one CryoMech PT415 to cool down the 50K and 4K stages, with a certified performance of 40W@45 K for the first stage and 1.35W @ 4.2 K for the second stage (see https://bluefors.com/wp-content/uploads/2023/09/PT415-RM-Capacity-Curve.pdf). What is the minimum distance between the room temperature connector and the first heat sinking bracket, and the minimum distance between the first and second heat sinking bracket? We assume 45 K and 4.2 K are the highest temperatures we would like to operate the cryostat at. Consider the cases for 1 cable, 6 cables, and 24 cables.
In one of the detector testing operations, we needed to plug the 4K connector directly onto a bracket at the Still stage. A typical cooling power at the Still temperature is 2 mW@850 mK. Would this improvisation work? What is the minimum length between the 2nd bracket and the 4K connector for 1 cable, 6 cables, and 24 cables?

2. The cooling profile of the NEXUS dilution refrigerator is measured as below. The qubit folks would like to install a stainless-steel coax cable, which can be approximated as a rod with the dimensions L=0.5 m and diameter of 1.0 mm. It is proposed to mount this cable between the 4.2 K and Mixing Chamber stage. The heat conductivity of stainless steel is dominated by the electronic thermal conductivity of $k = cT$, with $c=0.15$ W(mK^2).
   a) Calculate the heat flow through this coax line that heats the mixing chamber
   b) Determine the temperature of the mixing chamber with the coax line installed, assuming no other heat loads
   c) Determine the minimum temperature of the mixing chamber if you can heat sink the rod at the still temperature (800 mK) 0.2 meters from the 4K end.



3. The SNOLAB background gamma flux is quoted as 0.060 cm^{-2}s^{-1} for the 1.46 MeV gamma from ^{40}K and 0.0075 cm^{-2}s^{-1} for the 2.614 MeV gamma from ^{208}Tl. The friendly neighbour of SuperCDMS at SNOLAB is the Cryogenic Underground TEst facility, with a cross-sectional view below. It is a cryostat with ~1-meter of water shield and ~10 cm of lead, including the “internal lead shield” that is placed inside the cryostat and cooled down to the still temperature. Assume this internal lead shield reduces the uncovered solid angle to ~0.1%.
   Now invoke the “spherical cow floating in vacuum” assumption. Let’s pretend the SNOLAB is a sphere of a 10 meter diameter. All photons are emitted normal to the surface. For a SuperCDMS silicon detector (10 cm diameter, 3 cm thick cylinder, but approximated as a 6 cm diameter sphere) running in this cryostat, ignore multiple scattering, ignore other materials but the lead shield, what is the expected background rate from cavern photons around ~50 keV, in the unit of DRU? How much of a difference would the water tank make for the gamma background? What are the other utilities of the water tank? Given sufficient funding, what are the possible ways to improve this shield?



4. Estimate the energy loss of a 1GeV/c momentum muon and alpha in 1 cm of plastic scintillator, 2 cm of Argon gas, 2 cm of liquid Argon, and 300 μm of silicon.
5. Beryllium, despite being highly toxic in powder form, has excellent properties to be used as “windows” materials for X-ray detections. Often X-ray sources and X-ray detectors are packaged in housings with a Beryllium window to allow low-energy photons to pass through.
   Assume we put a ^{55}Fe radioactive source in front of a NaI detector. Both the source and the detector have a Be window of 0.05 cm thick. What is the expected intensity ratio between the K-alpha and K-beta peaks?
   If we would like to acquire more low-energy calibration points (as many as reasonably achievable) for the NaI detector, with the existing setup and a stingy supervisor (you can safely assume a $20 budget, and your supervisor would highly recommend you to grab whatever you can find in a kitchen), how would you propose to achieve this? Is there a limit to this approach? (hint: look up X-ray fluorescence)