Thermal modeling and cryogenics

DM Radio Collaboration Meeting

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Outline

1. System overview
2. Cooling timescale estimates
3. Wire considerations (for magnet)
4. Simulations capability
5. Next steps

System overview

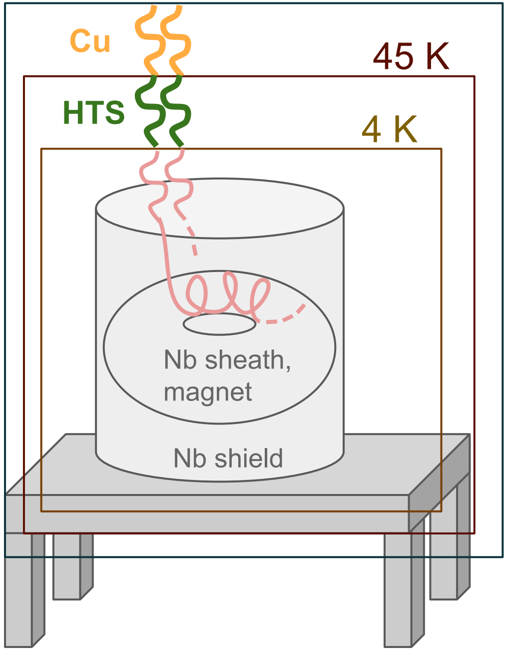
Pulse tube #2
Cools sheath, magnet, shield, etc

+ Exchange gases?
  (H or He options)
+ Pulse tube #3?

Pulse tube #1 + dilution refrigerator
PT420 Cryomech
- ➔ 2.0 W @ 4.2 K with 55 W @ 45 K

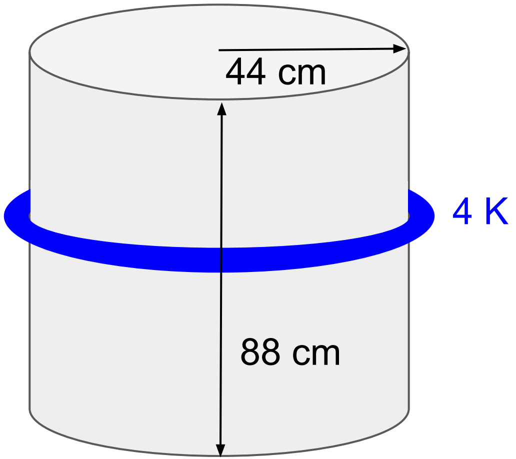
LH400 BlueFors
- ➔ 12 μW @ 20 mK
- ➔ 400 μW @ 100 mK
- ➔ 575 μW @ 120 mK

Cools pick-up

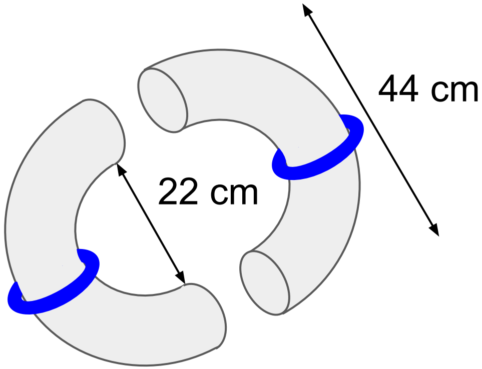


Cooling timescale estimates

1. Nb shield (62.5 kg)



2. Nb sheath (11.7 kg)



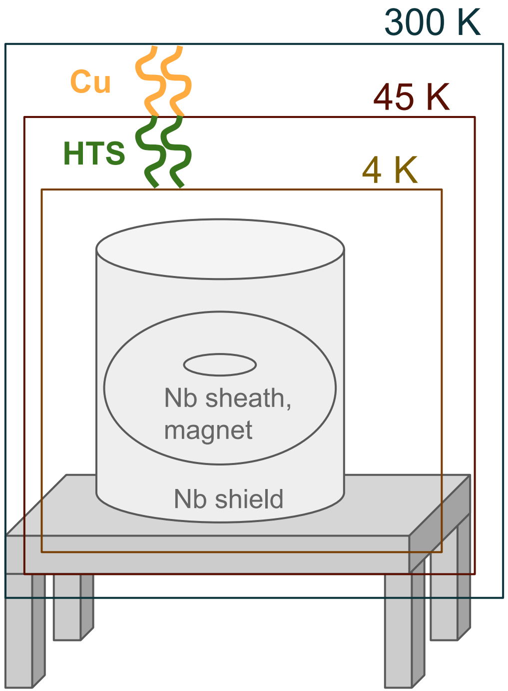
Estimates

- τ = C/G, where C = specific heat*mass and G = thermal conductivity*area/length
- P = G*ΔT

Cooling timescale estimates

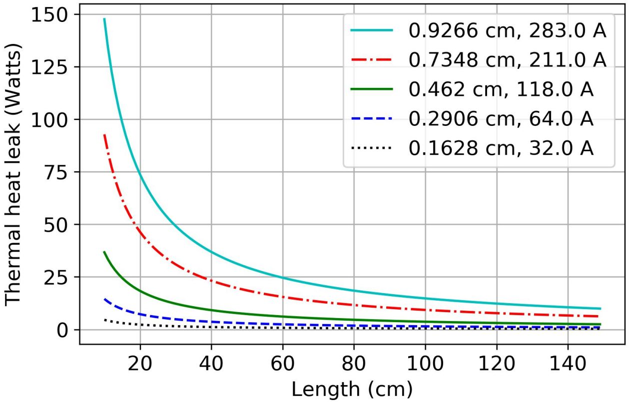
Temp.	Nb thermal conductivity	Nb specific heat	Piece	C/G	G*ΔT
300 K	53.6 W/m*K	266.4 J/kg*K	Shield	4.6 hours	279 W
			Sheath	34 mins	209 W
80 K	58.4 W/m*K	156.3 J/kg*K	Shield	2.5 hours	84 W
			Sheath	18 mins	63 W
40 K	95.2 W/m*K	56.7 J/kg*K	Shield	33 mins	65 W
			Sheath	4 mins	48 W
4 K	7.8 W/m*K	0.27 J/kg*K	Shield	1.9 mins	0 W
			Sheath	0.24 mins	0 W

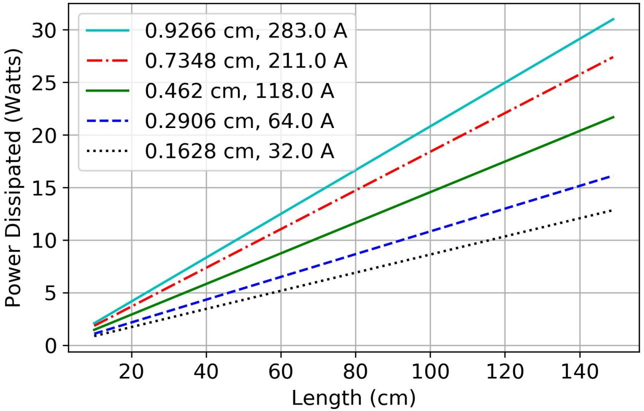
Initial estimates - wires



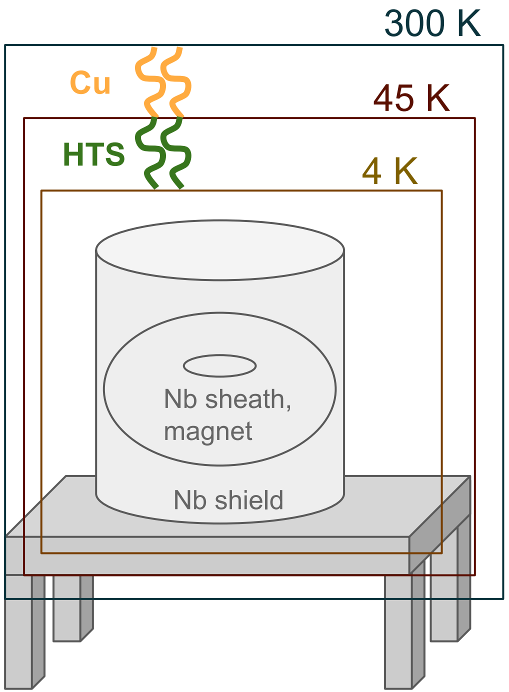
Copper wire is connected to 300 K and 45 K, carries current when the magnet is ramping, so it adds heat:

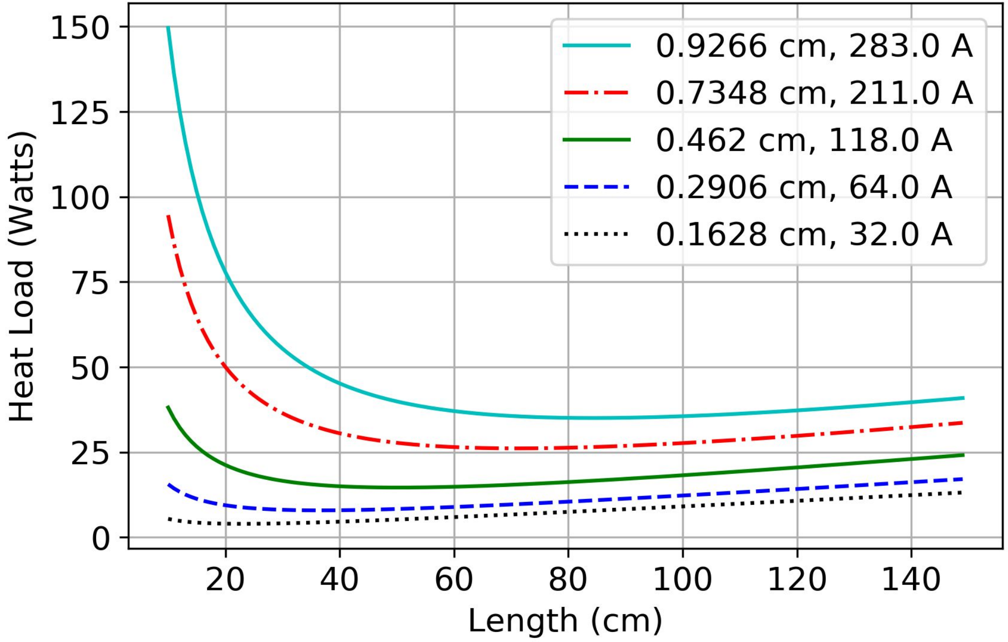
1. Thermal heat leak $Q = (A/L) \int_{T1}^{T2} \sigma(T') \, dT'$
2. Ohmic heating $P = I^2R = I^2\rho L/A$ (ramping magnet)





Initial estimates - wires





Simulation capability

- Time-dependent simulations to approximate cooling times
- Steady-state simulations to analyze thermal gradients
- Tool: ANSYS Mechanical APDL
  - Geometry
  - Realistic temperature-dependent material thermal properties
  - Mesh
  - Initial conditions - temperature, external heat flux, cooling power or set cold spot
  - Thermal contact conductances

Next steps

- Improve rough cooling time estimates
- Connect to Sebastian’s magnet designs
- Simulations:
  - Input realistic temperature-dependent cooling power
  - Simulate cooling time of various elements (magnet, sheath, shield, etc)
  - Study more carefully thermal contact effects on our cooling ability

Thanks for listening!