Use of He Gas Cooled by Liquid Hydrogen with a 15-T Pulsed Copper Solenoid Magnet

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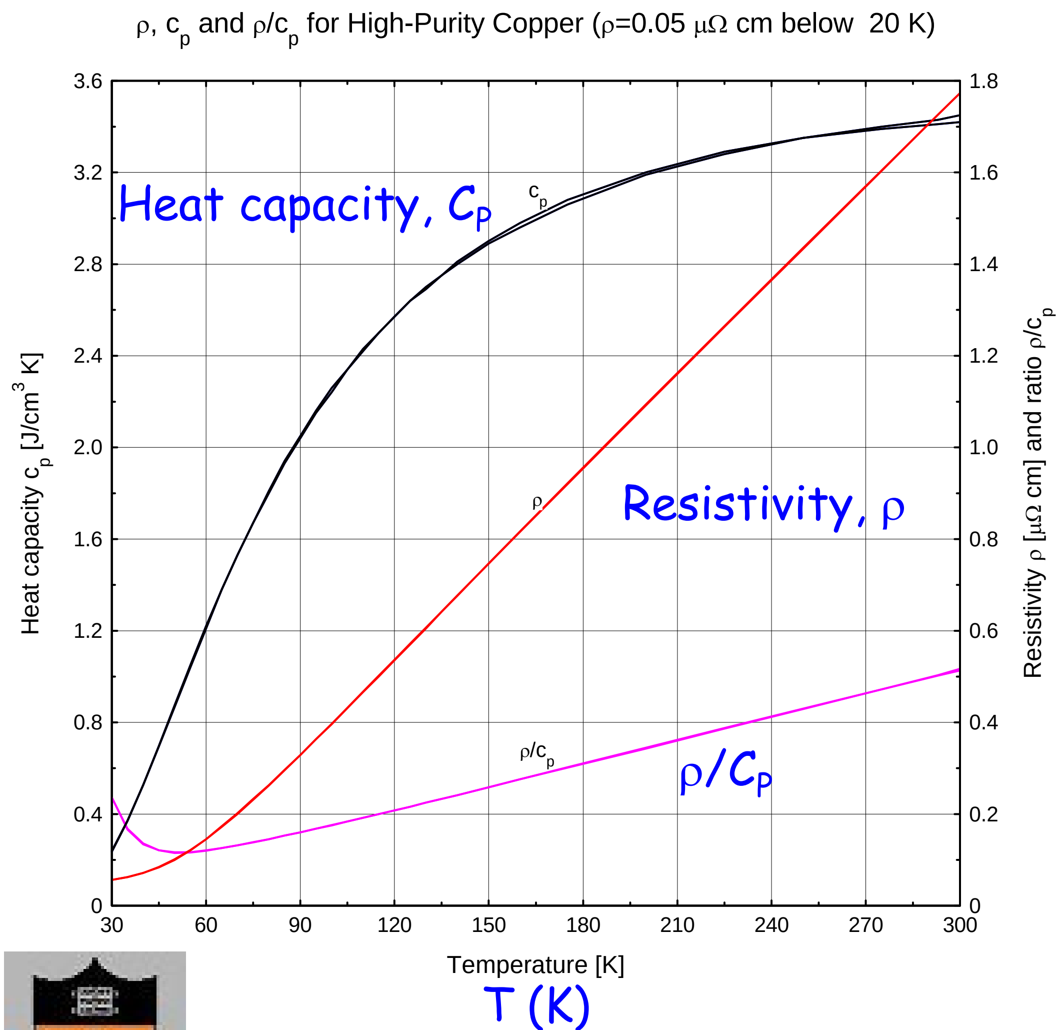
Cool Magnets to Lower Their Resistance – and Their Power Consumption

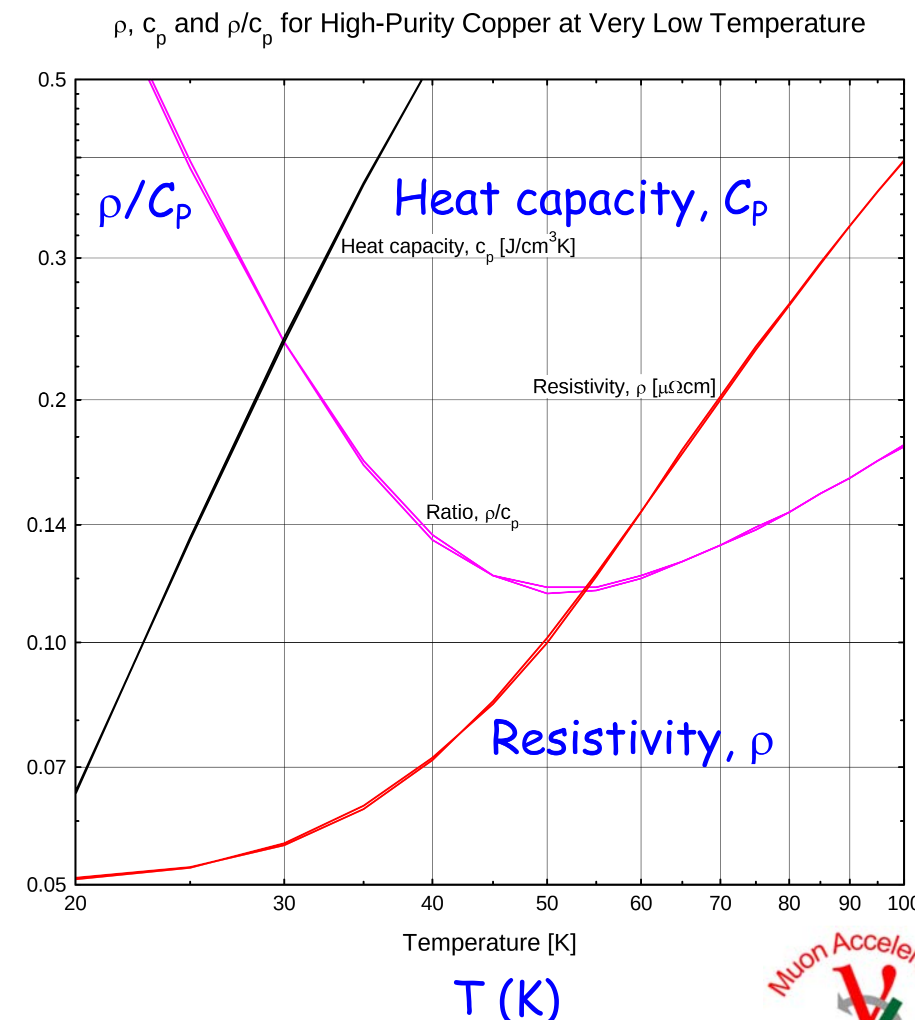
We considered a 15-T, 20-cm-diameter, warm bore, pulse copper solenoid.

Would require 70 MW to operate at room temperature.

Favorable to operate at ~ 30 K, to reduce resistance by a factor of 30.

If go below 30 K, the very low heat capacity of copper leads to rapid temperature rise.



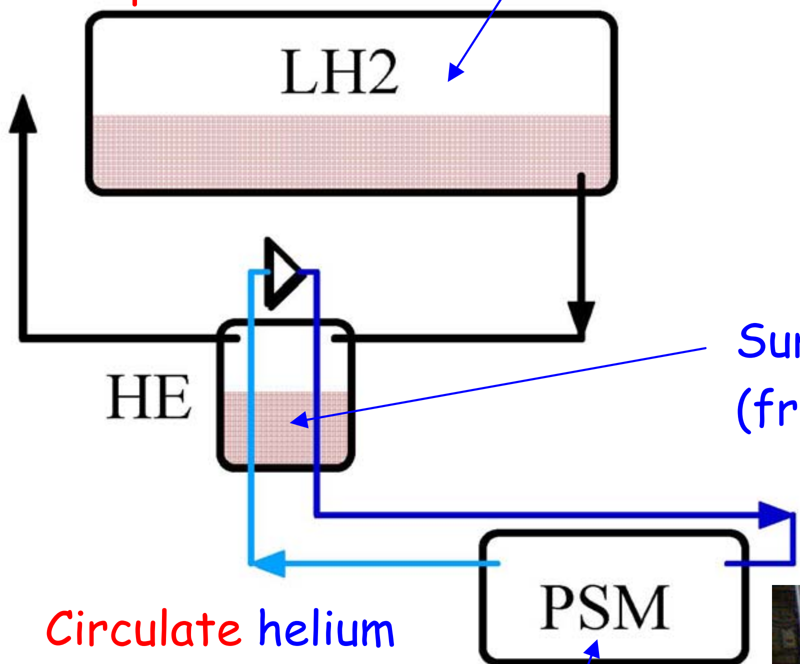


Cooling Concept: He gas + LH_2 Heat Exchanger

The concept is simple – and we foresaw low-cost implementation using recycled components.

Vent H_2 gas to atmosphere

"Weathered" 20,000 liter LH_2 Dewar

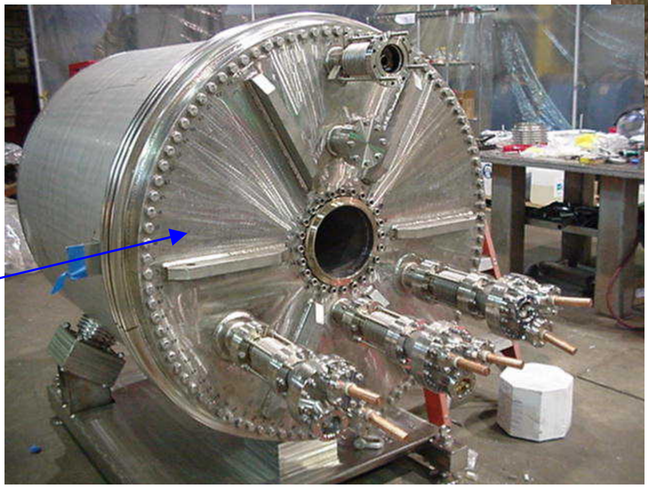


Concept based on direct cooling of aluminum and copper magnet coils by liquid hydrogen and liquid neon in the late 1950's.
Laquer, RSI 28, 875 (1957)

Surplus heat exchanger (from the SSC)

Circulate helium gas thru magnet to cool it

15-T pulsed copper magnet 20-cm-diameter warm bore (new)



After the success of large, high-field superconducting magnets in early 60's, this concept was largely forgotten.

Choice of Cryogens

Only candidates are H_2, He and Ne.

Magnets sometimes catch fire ⇒ don't cool directly with hydrogen.

Heat capacity per liter same for He and Ne gas, so use cheaper He gas.

Quality factor Q for the refrigeration of the circulating gas via liquid cryogen consumption (boiling in the heat exchanger) was defined as

$$Q\ (\text{kJ}/\$\text{US}) = \Delta H_V \cdot \rho_L \cdot (1\ \text{m}^3/1000\ \text{liter}) \cdot (\text{liter}/\$\text{US}).$$

That is, Q is a kiloJoule of heat-of-vaporization/$US at T_{NBP}.

Fluid	T_{NBP}	ΔH_V	ρ_L	Cost	Q
	K	kJ/kg	kg/m^3	$US/liter	kJ/$US
He	4.2	20.3	124.9	3.00	0.85
H_2	20.3	446.0	70.8	0.53	59.58
Ne	27.1	85.8	1207.0	173.00	0.60
N_2	77.3	199.0	808.0	0.07	2297.03

(Costs from 2002)

An operational cycle of the system involved a 10-s-long pulse of the 15-T magnet during which 18 MJ = 18,000 kJ of energy was generated, followed by a 30-min cooldown.

LH_2 Cooling Cost = 18,000 / Q = $300 per pulse.

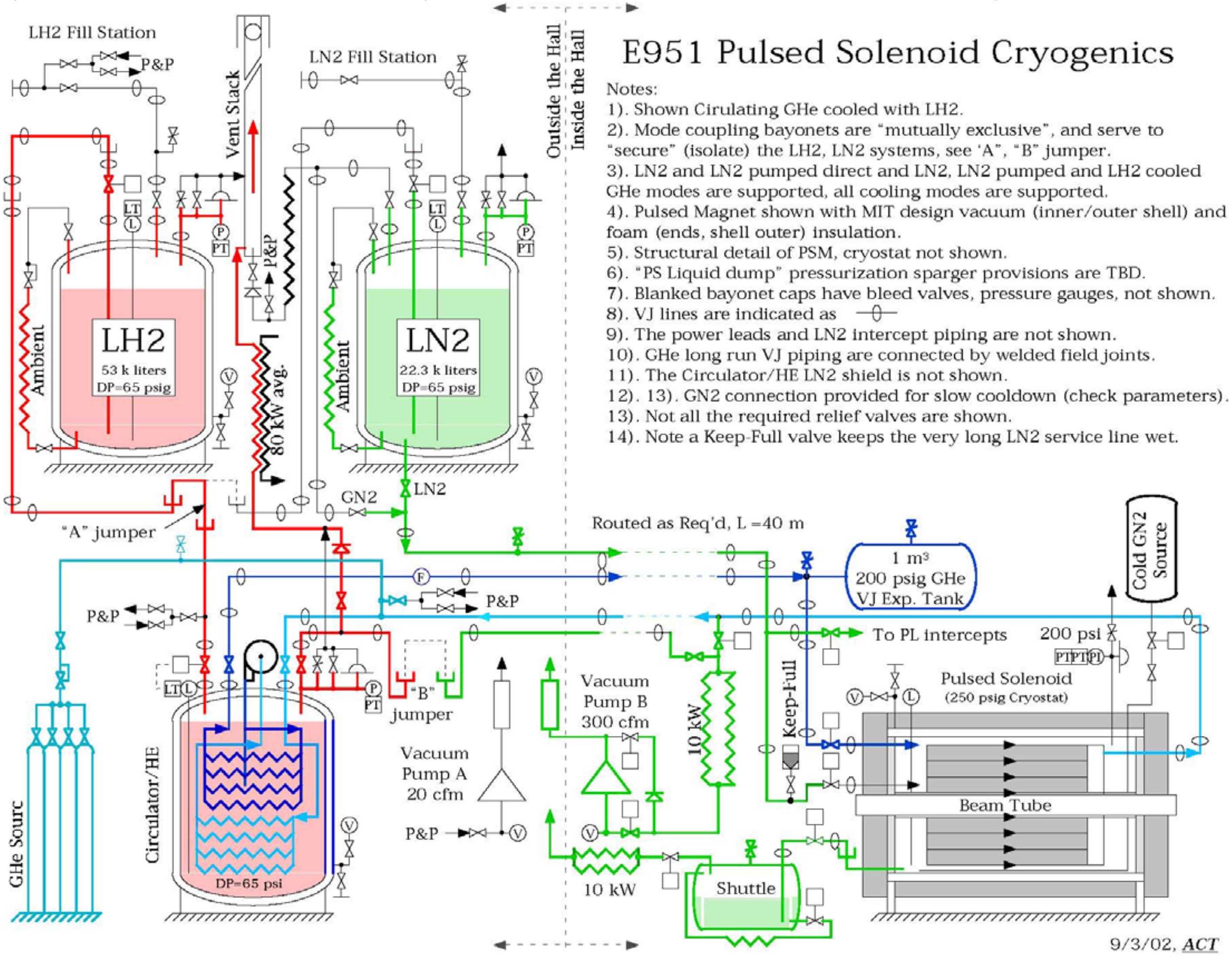
LHe Cooling Cost = (60/0.85) · (LH_2 Cooling Cost) = $21,000 per pulse.

LNe Cooling Cost = (60/0.60) · (LH_2 Cooling Cost) = $30,000 per pulse.

⇒ Clearly, liquid hydrogen is favored economically.

What Came of This?

We developed a PI diagram and presented it to the Lab Safety Committee.



But when an 8-MW power supply became available, we used it, along with liquid nitrogen cooling of the magnet.

(Thanks to F. Haug for the LN_2 cryo system of the CERN MERIT Experiment.)