Cryocooler-based conduction cooling technology development for 1.3 GHz Nb_3Sn superconducting radio frequency cavity

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Innovation Center for Applied Superconducting Accelerators
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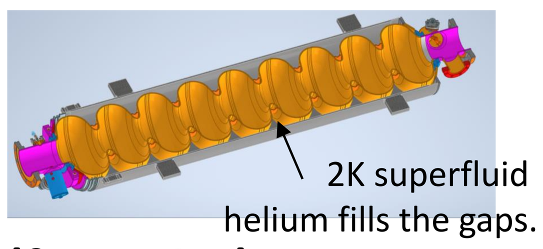
Abstract

The superconducting radio frequency (SRF) cavity is, along with the superconducting magnet, indispensable technology for modern particle accelerators. This research focused on **conduction cooling** of the SRF cavity by **cryocoolers** while current SRF cavities were cooled by immersing in liquid helium. In stead of liquid helium bath, copper rings surrounded the outer surface of cavity equator region for thermal conduction cooling. As for cryocoolers, we have used two types of cryocoolers: **GM-JT** (9 W@4.2 K) and **GM** (1.8 W@4.2 K, 50 Hz) (both Sumitomo Heavy Industries). We were able to see each advantage in the GM-JT and the GM in terms of cooling capacity, temperature stability, and cooling time. To evaluate conduction cooling systems, the cavity performance was compared between immersion cooling with liquid helium and conduction cooling with a cryocooler. Although the cavity performance was degraded due to the cooling capacities of cryocoolers, accelerating gradients of 6 MV/m or more than 6 MV/m were recorded. The current target is 10 MV/m.

1. Background(1): Difficulties with liquid helium

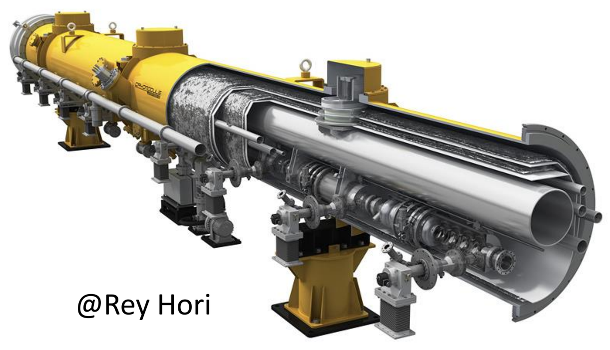
☺ **Liquid helium immersion cooling**

The cavity is covered by a liquid helium jacket. Ideal method.



☹ **Complex cryomodule design**

Many kinds of transfer lines. High cost.



☹ **Large facility (footprint)**

"Building size" facility, gas cardles and gas tanks.

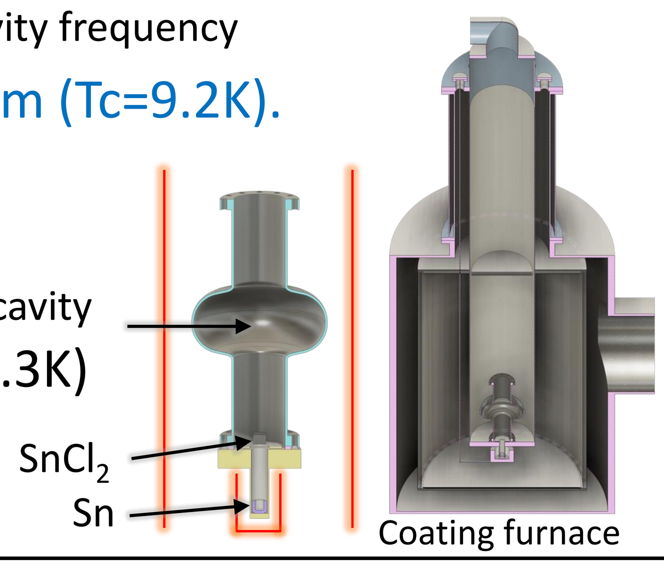
☹ **High pressure gas safety**

The cavity must pass pressure proof test.

☹ **Helium price increase**

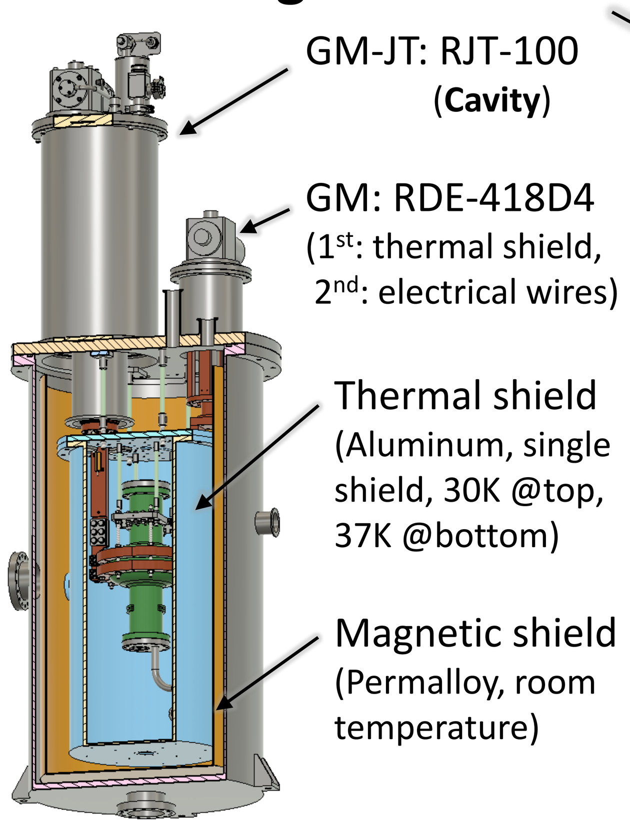
2. Background(2): SRF cavity

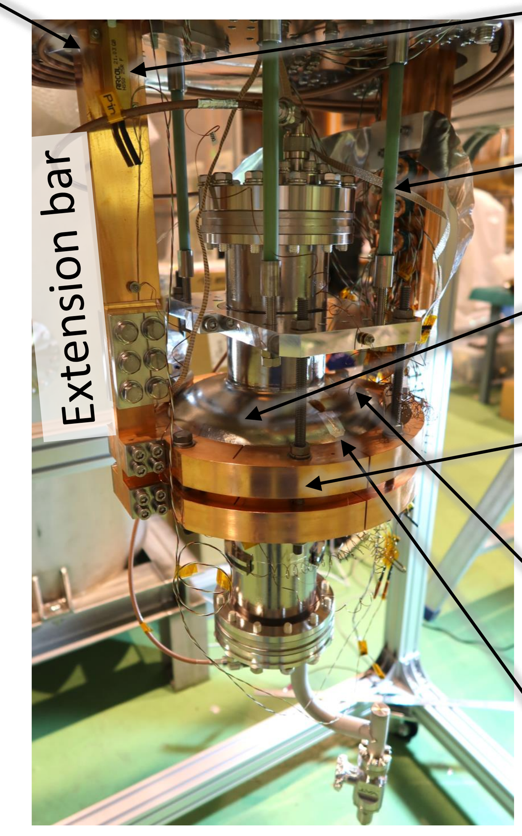
- To operate the SRF cavity by cryocoolers, RF heating (loss) at the cavity wall must be small enough because cryocooler's cooling power is low.
- ➢ RF heating ∝ Surface resistance
- ➢ Surface resistance = BCS resistance + Residual resistance
- ➢ BCS resistance $= A\frac{\omega^2}{T}\exp\left(-\frac{B}{k_B T}\right)$ A, B: Constant depending on material; ω: Cavity frequency
- Conventional SRF cavity was made by Niobium (Tc=9.2K).
  → 2 K is required for 1.3 GHz cavities.
  2 K is too low temperature for cryocoolers.
- Nb_3Sn cavity can be operated at 4.2K. (Tc=18.3K)
- The Nb_3Sn layer is formed by diffusing Tin vaper inside Niobium cavity.



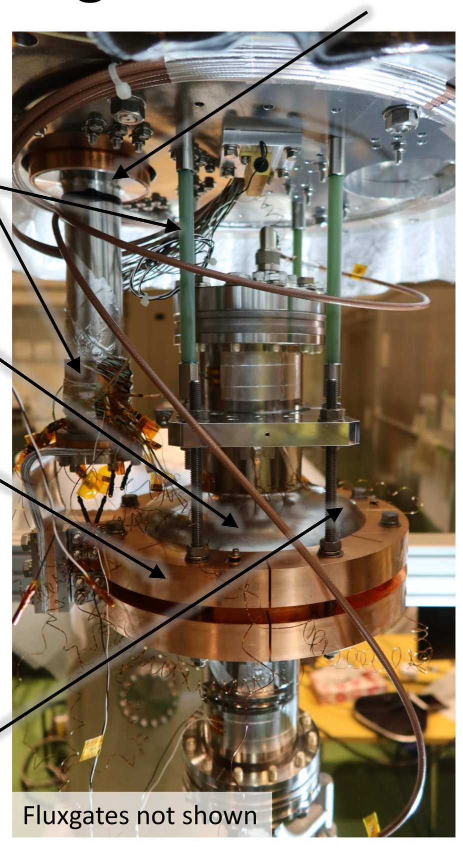
3. Cooling system

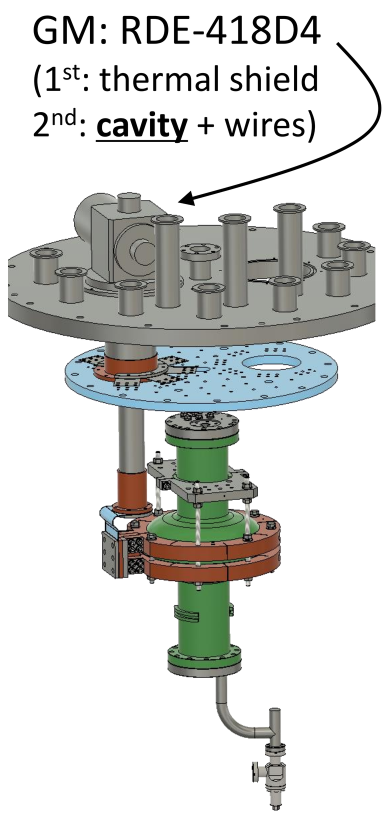
Configuration: GM-JT cryocooler case





Configuration: GM cryocooler case

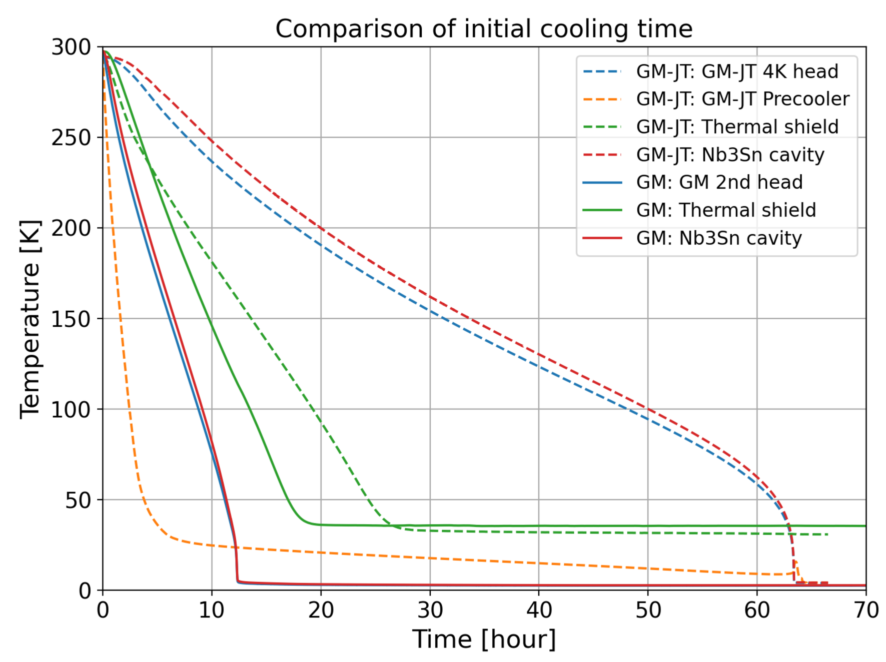




4. Cooling results

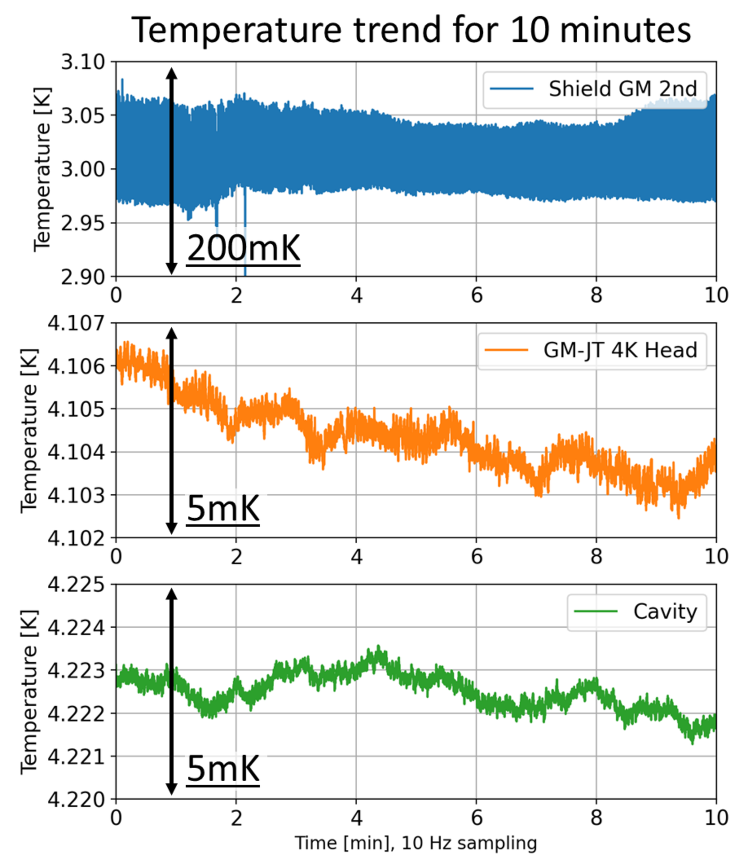
- **Cooling time and temperature**

	GM-JT (RJT-100)	GM (RDE-418D4)
Cooling time	63 hours	12 hours
Cavity min. temp.	4.1 K	2.7 K



- **Temperature stability (for GM-JT)**

Since the GM-JT uses latent heat of liquid helium, temperatures were quite stable.



5. Conduction cooled RF measurements

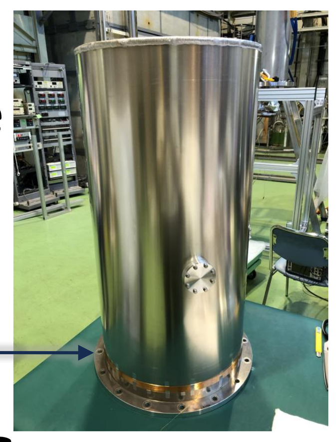
The liquid helium (LHe) and cryocooler measurements were performed at different facilities and therefore in different magnetic field environments.

- **Slow cooling**

Once cavities reached the lowest temperatures, they were **warmed above 20 K and re-cooled at a rate of 3 K/h** between 20 K to 7 K to minimize temperature gradient at superconducting transition.

- **Magnetic field cancellation**

The SRF cavity is quite sensitive to magnetic field, therefore it is covered by a magnetic shield. In the early conduction cooling test, cavity performance deteriorated due to geo-magnetic penetration through opening at the top of the magnetic shield. **A cancelling coil was implemented and magnetic field was reduced from about 20mG to a few mG.**

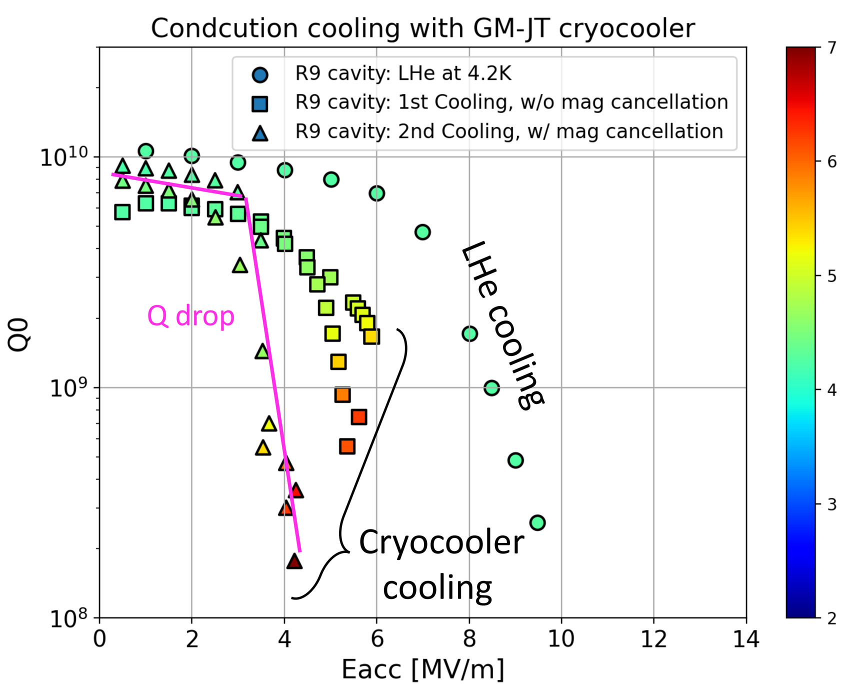


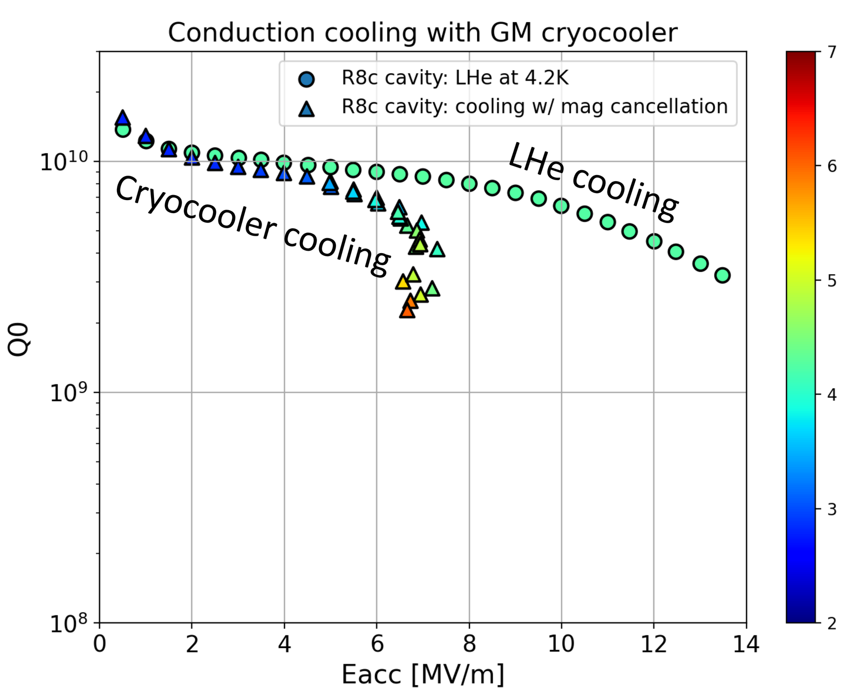
- **Q-E curve**

First of all, since two graphs on the right used two different cavities with different Nb_3Sn coatings, results cannot be simply compared.

Facts are 1) KEK's Nb_3Sn coating technology is rapidly improving, and 2) Eacc reached about **6 MV/m with one GM-JT (9 W@4.2 K)** and now **one GM (1.8 W@4.2 K) can achieve more than 6 MV/m** thanks to 1).

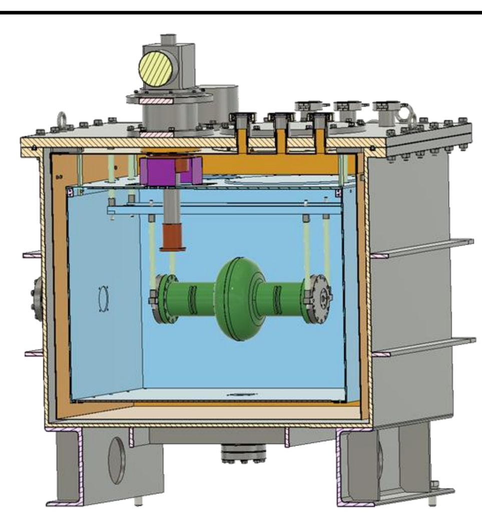
Sudden Q drop occurred at 3.5 MV/m. This was due to breaking of Nb_3Sn film due to strong clamping force. Improvements are required.

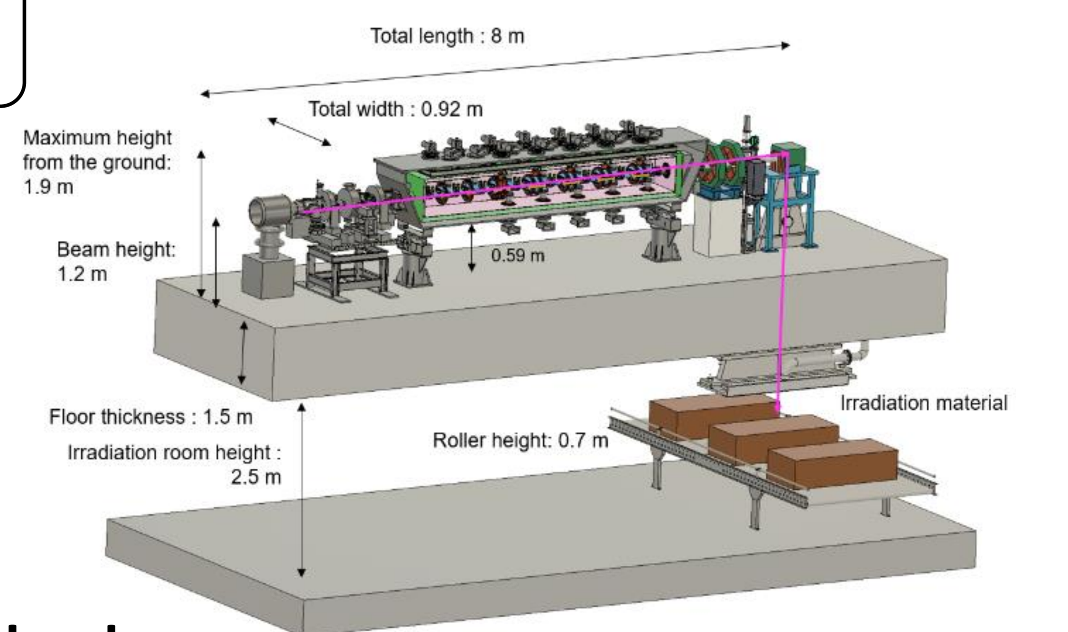




Future application:

Liquid helium free superconducting high-power electron beam irradiator





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6. Summary

- Nb_3Sn coating and cavity conduction cooling researches are conducted in KEK.
- We used the GM-JT and the GM cryocoolers for conduction cooing and achieved Eacc of 6 MV/m or more than 6 MV/m with conduction cooling condition.
- Improvements on cooling jigs are necessary not to damage Nb_3Sn fragile film.
- Horizontal cavity performance tests will be performed as a next step.

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