US-JAPAN HAWAII SYMPOSIUM
Symposium of the US-Japan Science and Technology Cooperation Program

High heat capacity and radiation-resistant organic resins for impregnation of high field superconducting magnets

Fermilab · Argonne National Laboratory · Brookhaven National Laboratory · NIMS · RIMTEC · KEK

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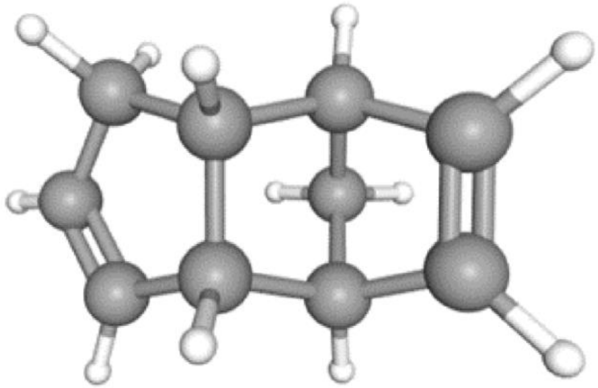
NIMS

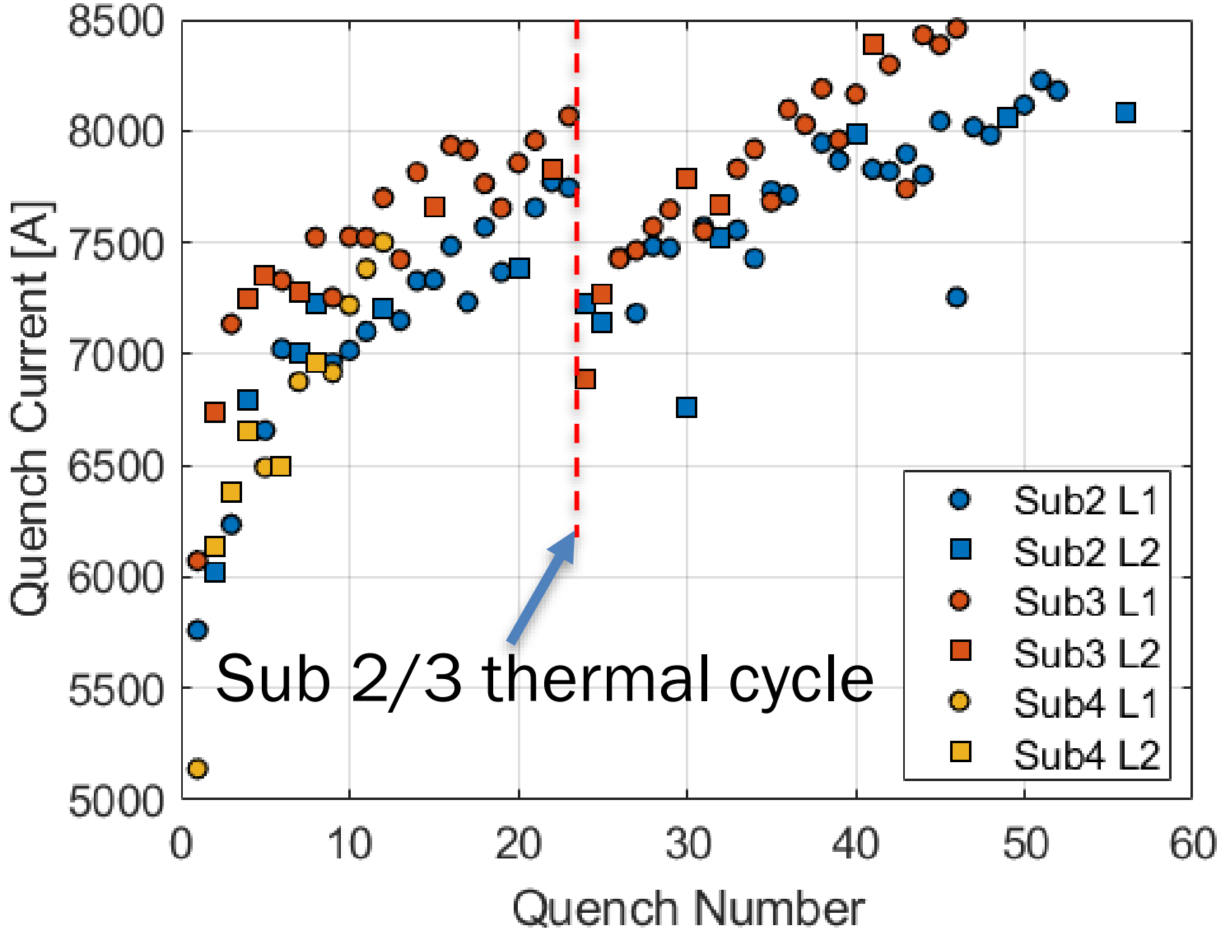
Goal 1

One of the main challenges of high field accelerator magnets for HEP made of superconducting Nb_3Sn is their training due to temperature variations in the coils ➔ Significantly reduce or eliminate training, by using a different impregnation resin than the epoxy currently used. This is a novel <u>organic</u> olefin-based thermosetting dicyclopentadiene (DCP) resin, commercially available as TELENE® at RIMTEC.

Dicyclopentadiene ($C_{10}H_{12}$)



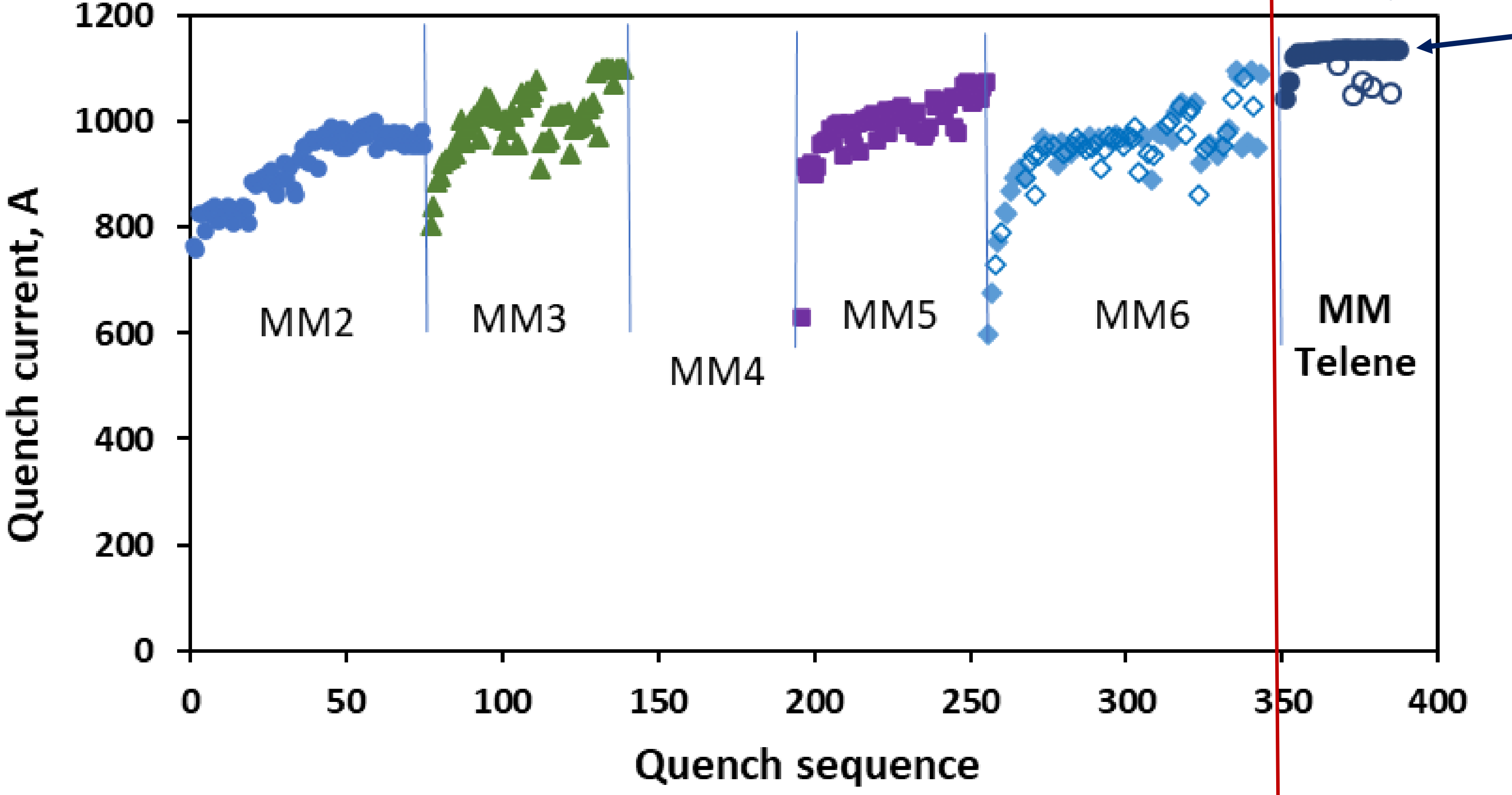
EXAMPLE OF MAGNET TRAINING

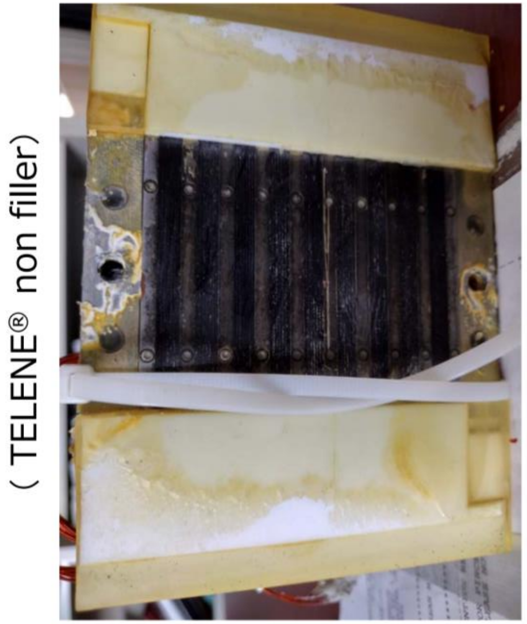


Canted Cosine Theta subscale magnet (D. Arbelaez)

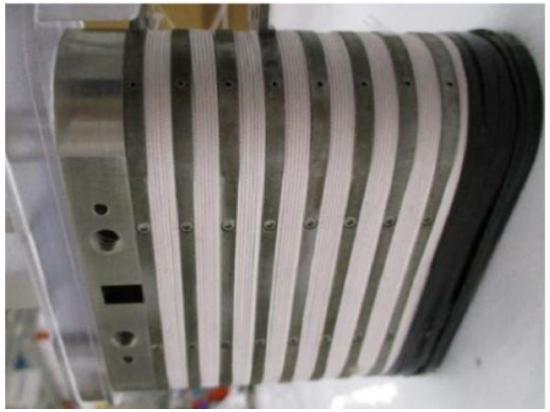
Goal 1 Close to Achievement

THE SMALL ANL UNDULATOR MAGNETS ON THIS SIDE WERE NEARLY IDENTICAL AND IMPREGNATED WITH EPOXY

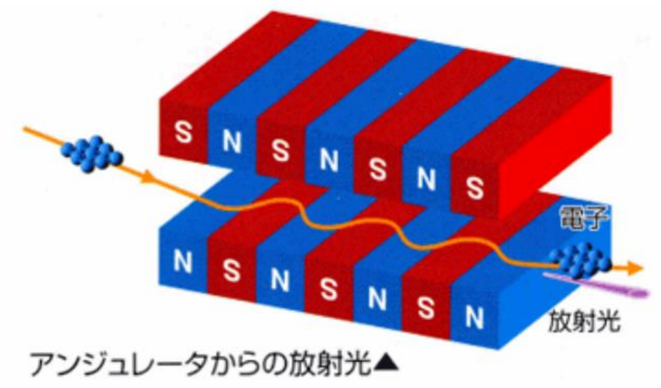


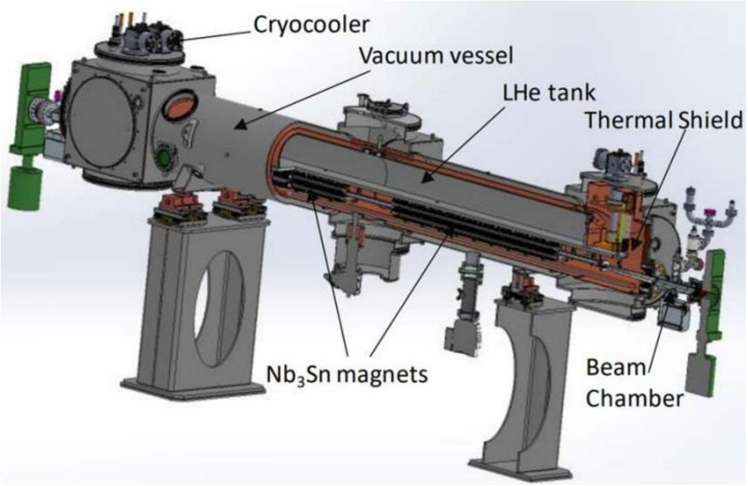


Ibrahim Kesgin – ANL Co-PI



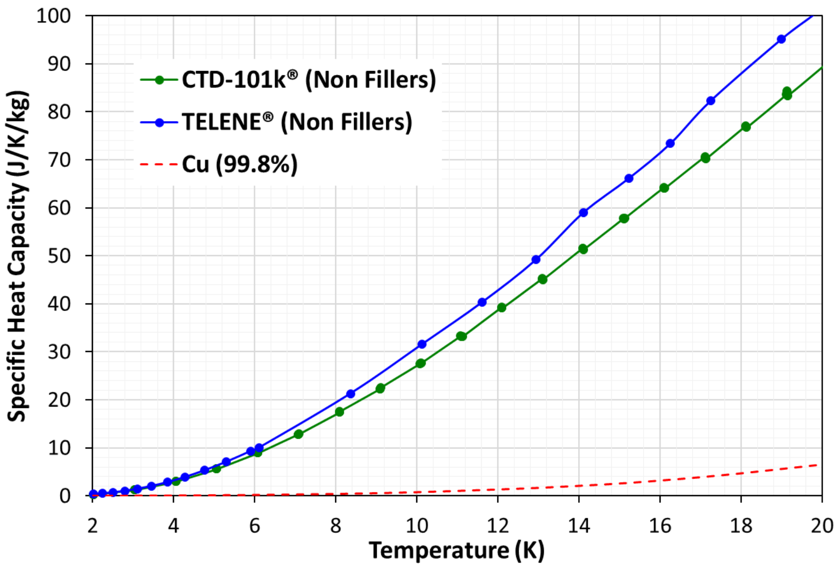
Nb_3Sn Undulator Magnets for Advanced Photon Source (APS)



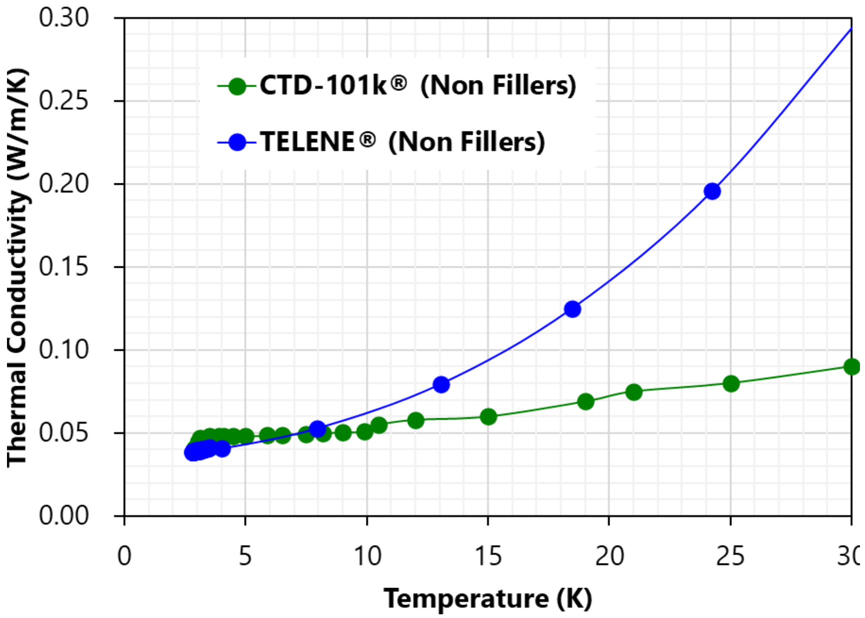


- Each Nb_3Sn undulator short model fabricated at ANL has nine racetrack coils wound in a groove between ten poles with an insulated Nb_3Sn wire. There are 46 turns in each groove. The period length is 18 mm.
- After winding, the magnet was heat treated at FNAL in argon atmosphere using well-established treatment cycles.
- Then it was placed in a leak-tight impregnation mold for vacuum pressure impregnation at ANL.
- Finally it was tested at FNAL in the Superconducting R&D lab, using a new DAQ hardware&software system for quench protection.

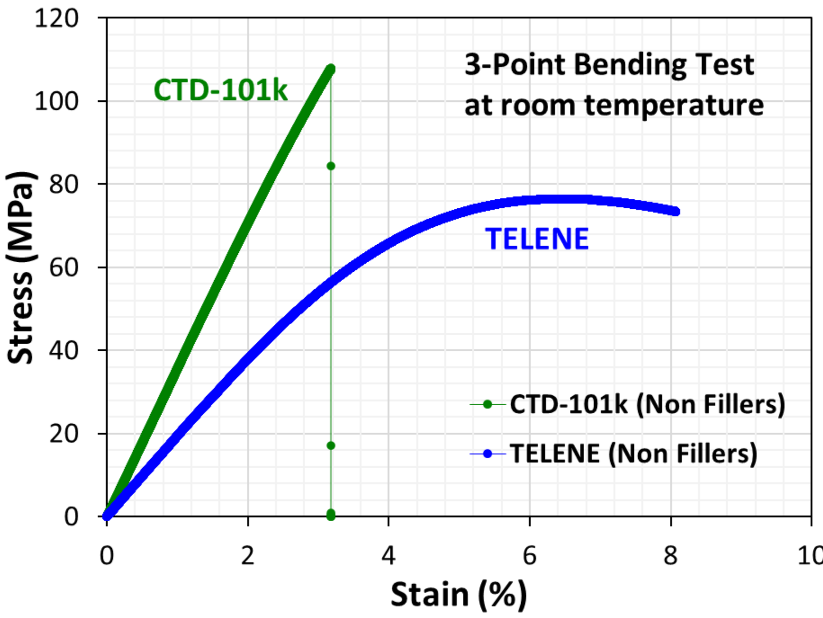
Why TELENE?



Specific heat C_p is somewhat larger than for epoxy

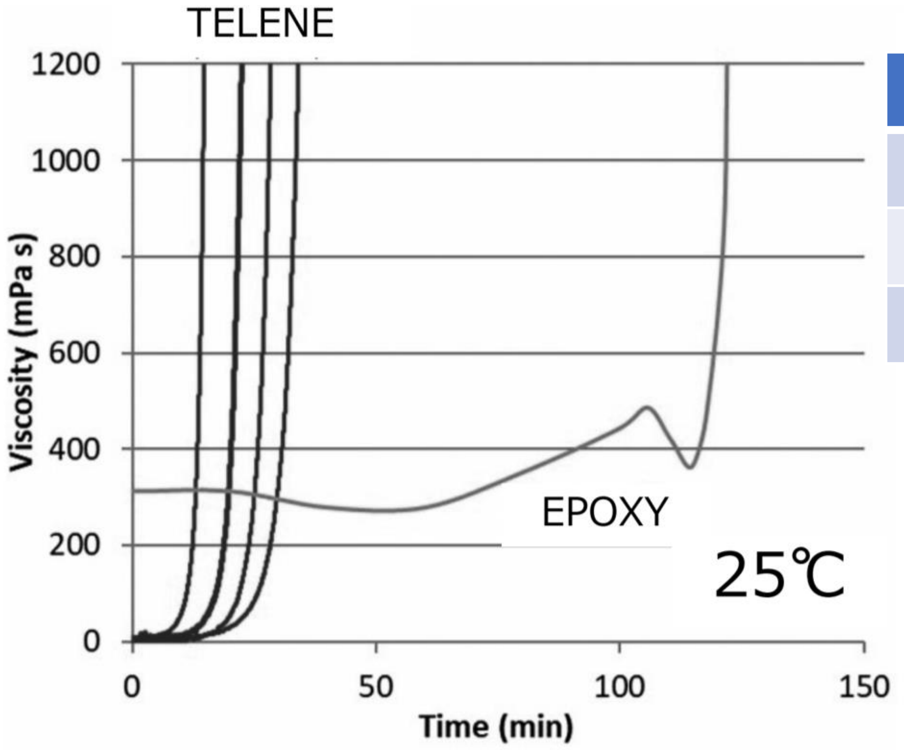


Thermal conductivity is larger than for epoxy



It accepts much larger strains than epoxy

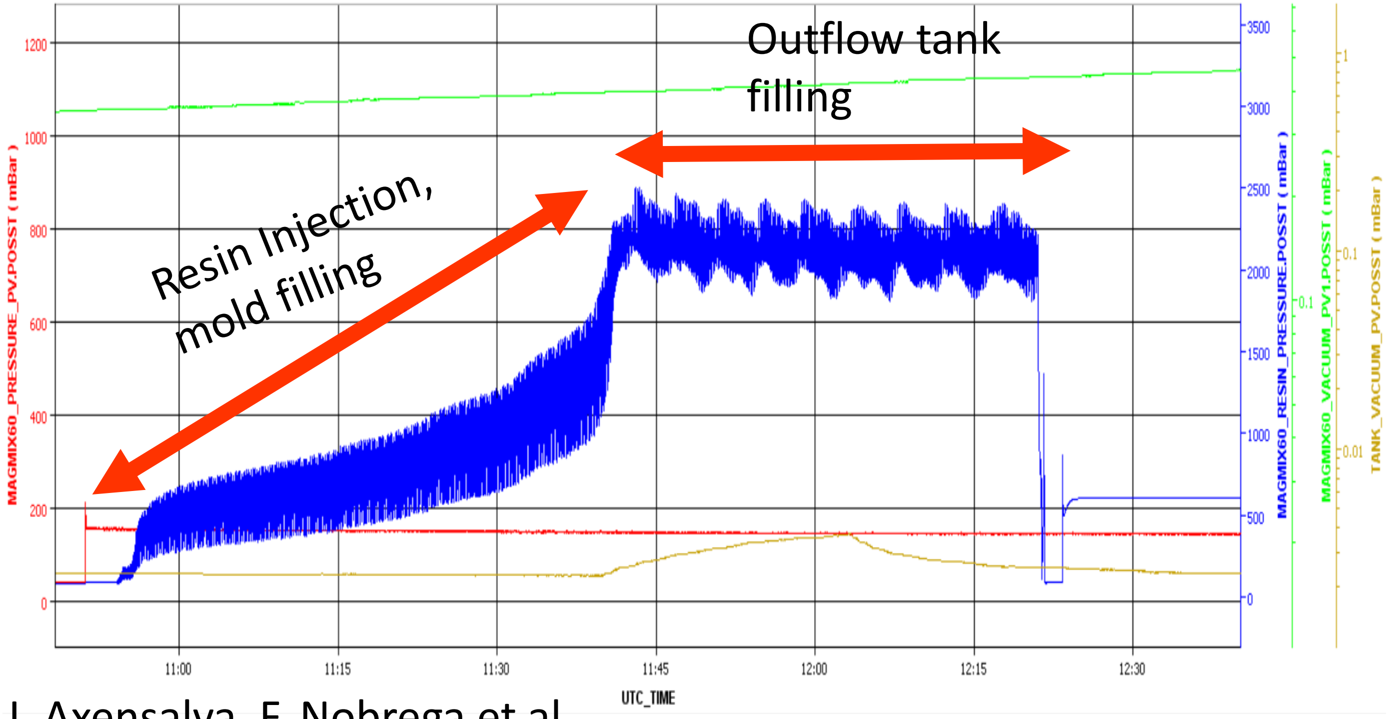
Problems Solved



POT LIFE, min	TEMPERATURE, ºC
30	25
60	15
120	5

Max. time limit for impregnation process with TELENE

By using one epoxy inlet into the tooling with multiple vents and an inlet pressure of 2 Bar, <u>fill times vary from 45 min to 1.5 hrs</u> for CERN accelerator quadrupoles 7.3 m long.

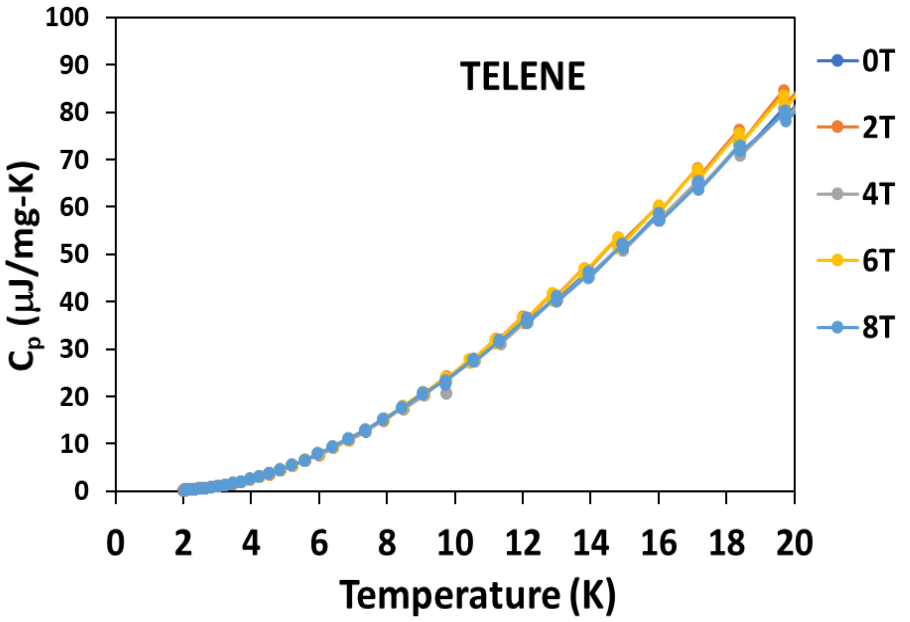


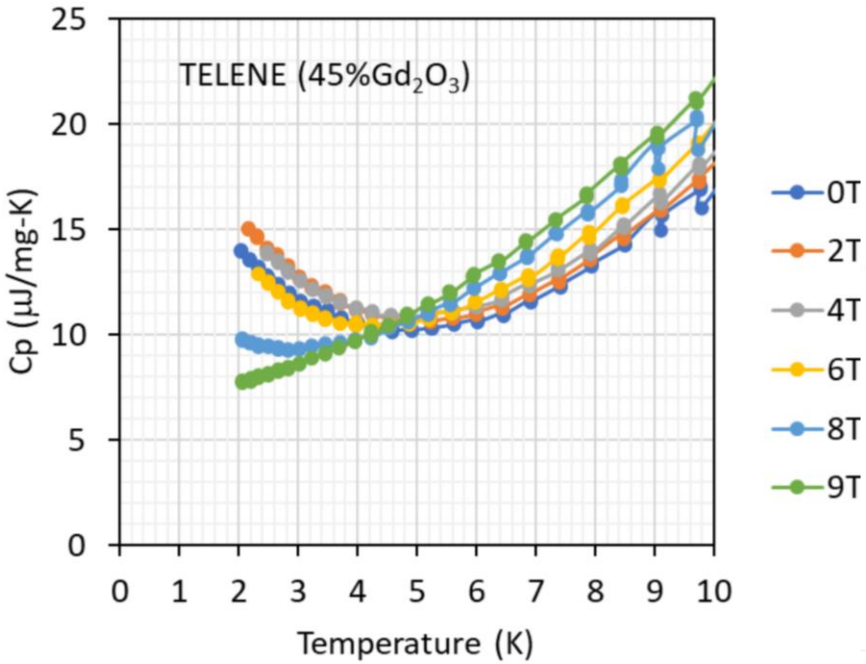
Courtesy of J. Axensalva, F. Nobrega et al.

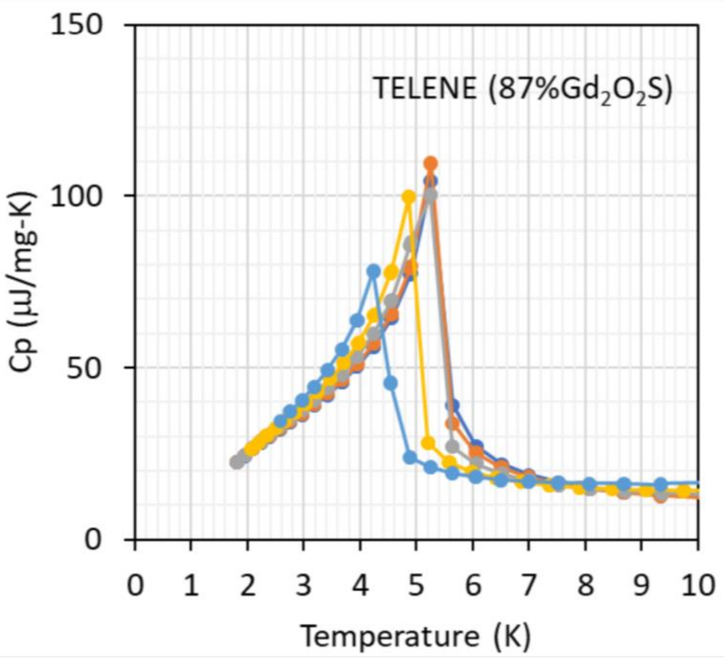
How to Further Improve Stability

- **By mixing TELENE with high-C_p ceramic powders such as Gd_2O_3 and Gd_2O_2S.**
- **This is done with a planetary mixer. The resin is then cured with a ruthenium complex. The curing time is controlled by a retardant.**

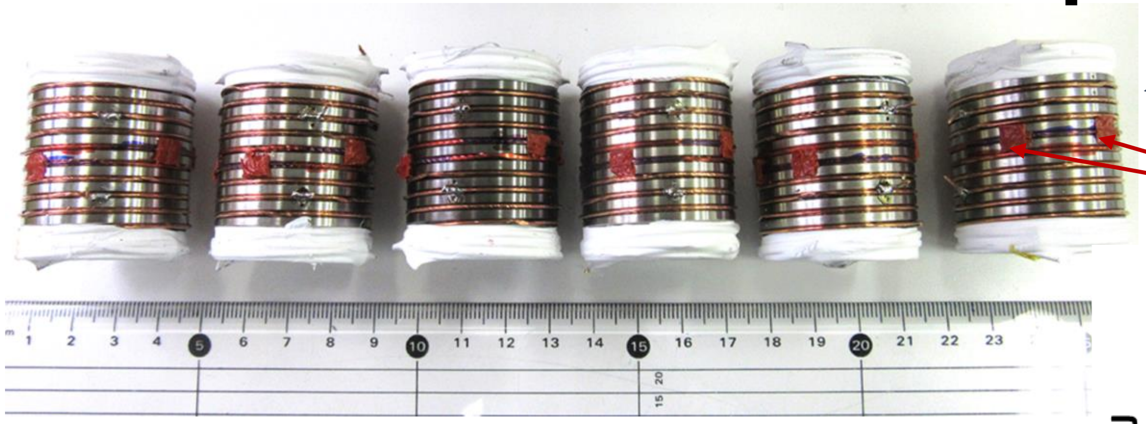
Specific Heat as Function of Magnetic Field of TELENE Resin Mixed with High-C_p Ceramic Powders







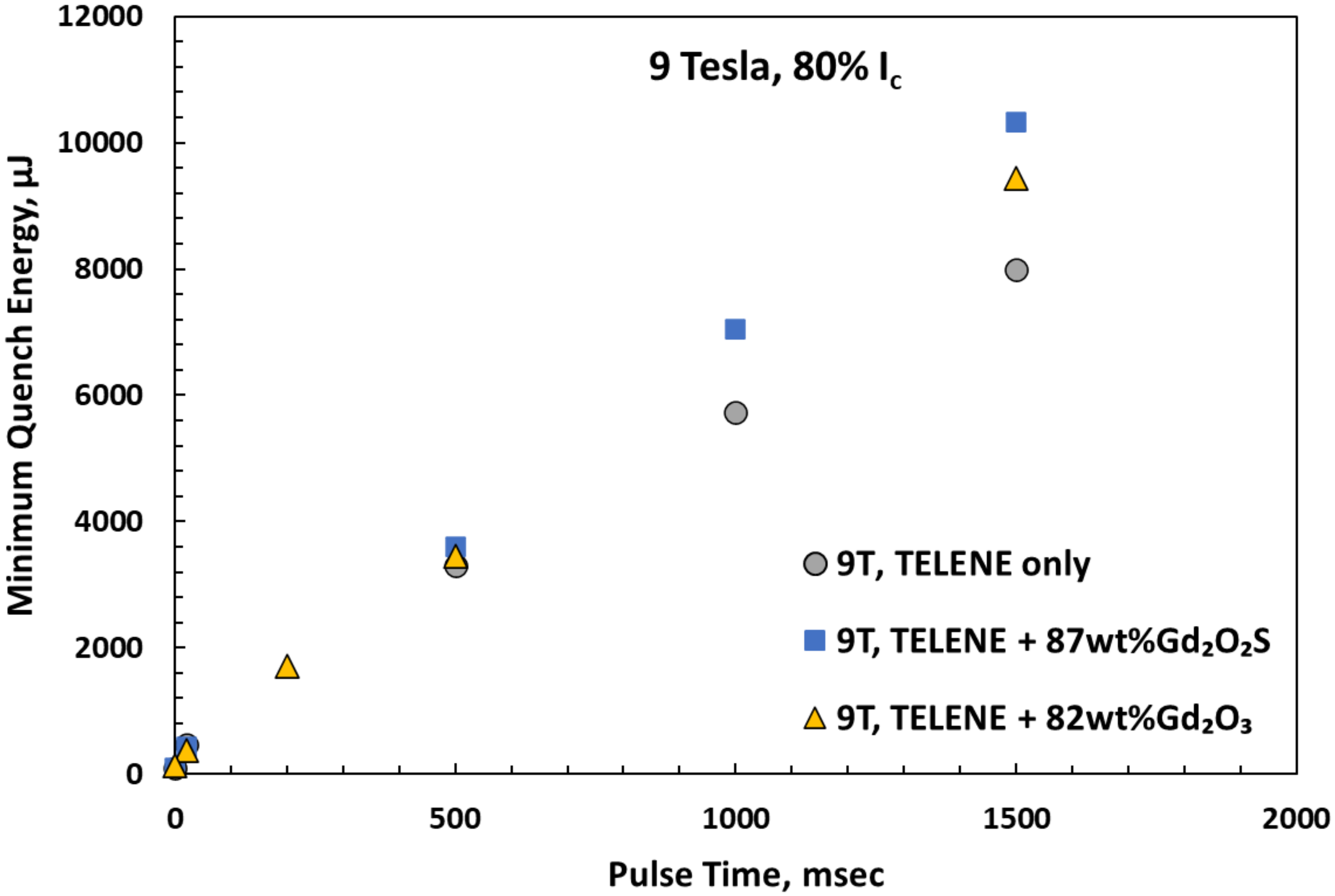
Measurements of Minimum Quench Energy of Impregnated Wire Samples



0.8 mm NbTi wire; $I_c(9T)$ = 114 A; $I_c(8T)$ = 235 A

Locations of heaters

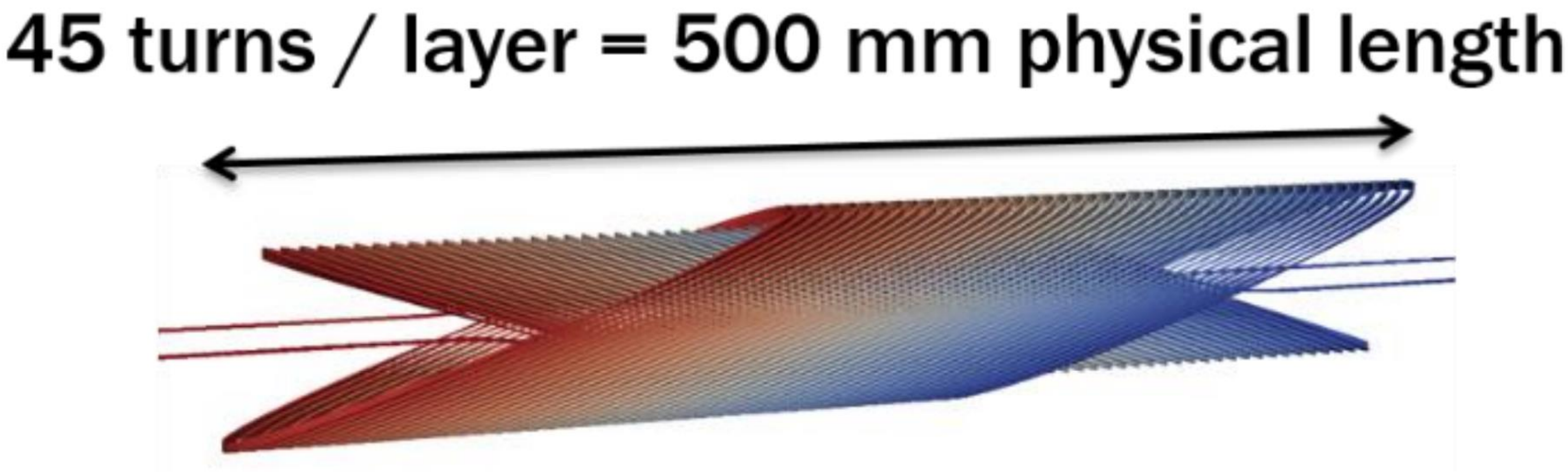
- A dozen 0.8 mm NbTi wire samples were prepared at FNAL and sent to NIMS for impregnation with MIXED resins.
- The Minimum Quench Energy was then measured at FNAL at 80% of the critical current I_c and various magnetic fields, for pulse durations from 200 ms to 2 s.



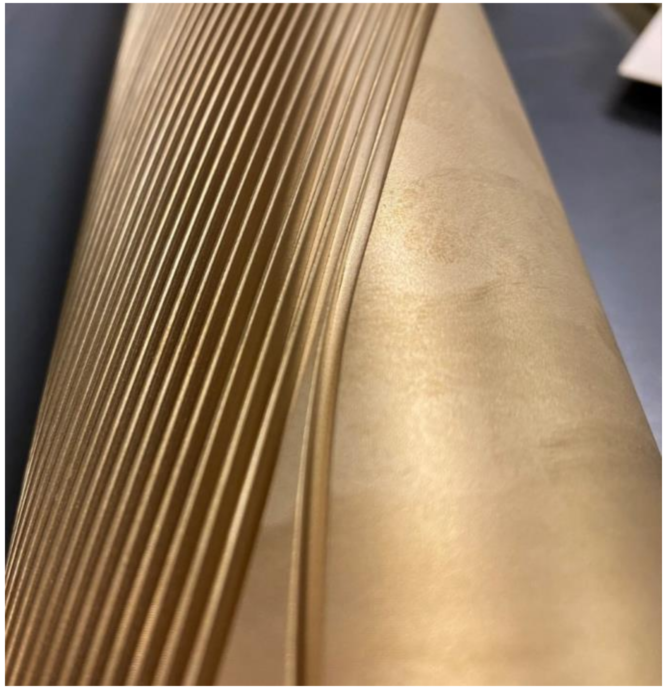
TELENE Application to LBL Canted Cosine Theta

TO CHECK PERFORMANCE UNDER LARGER LORENTZ FORCES

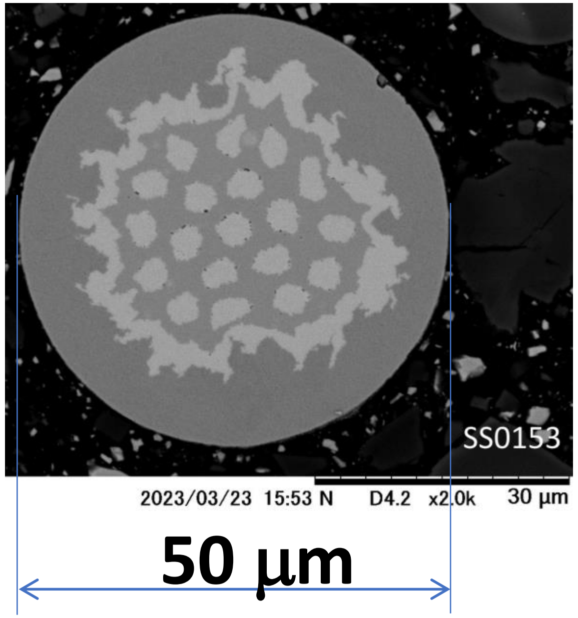
Design developed within the U.S. Magnet Development Program - Synergy

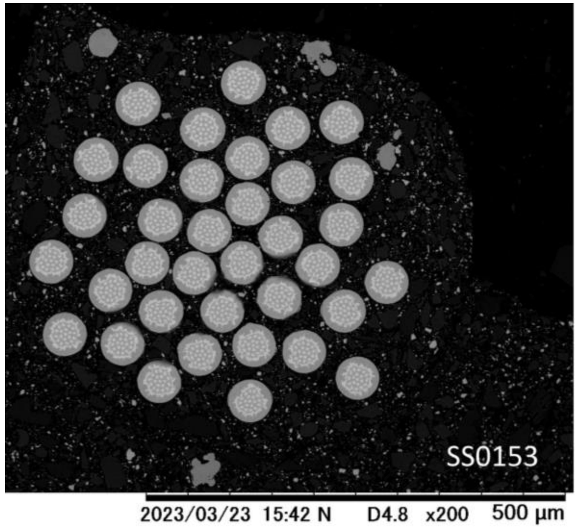


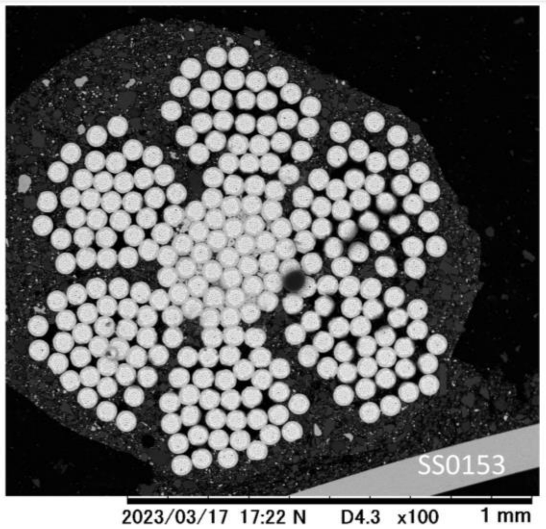
D. Arbelaez, J. L. Rudeiros Fernandez et al.

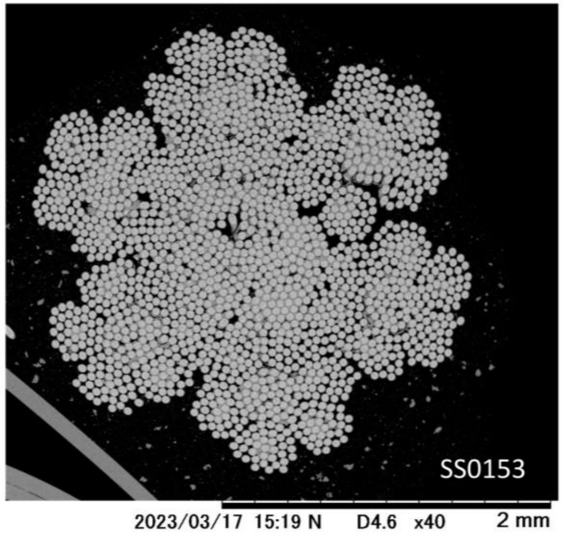


Multi-stage Conductor with Small AC Losses

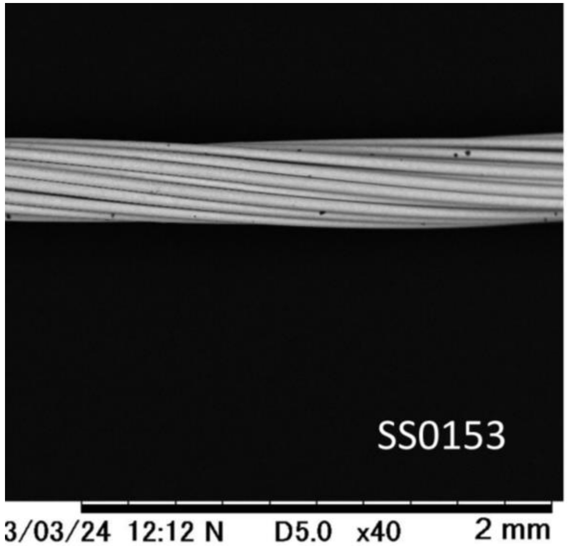




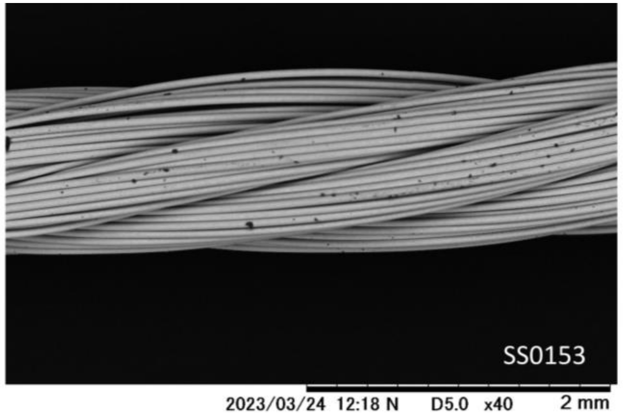




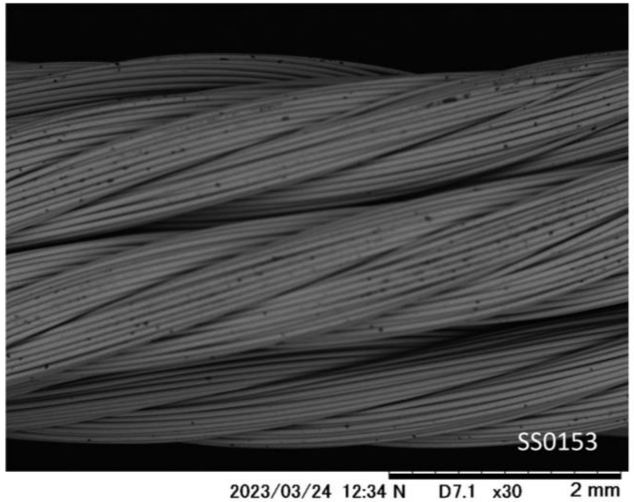
Superfine Nb_3Sn wire separately developed at NIMS - Synergy



36/0.05 Strand Primary Cable (Cable Diameter: 0.33 mm)



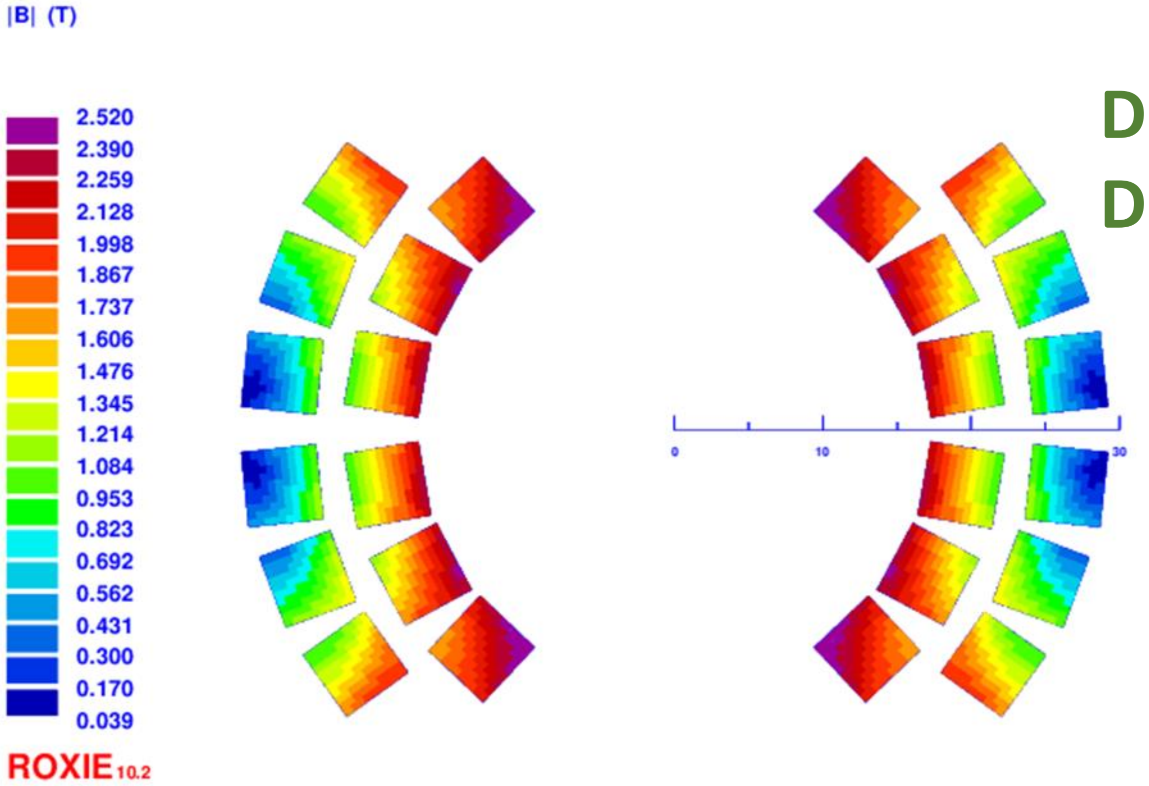
7/36/0.05 Strand Secondary Cable (Cable Diameter: ~1 mm)



7/7/36/0.05 Strand Tertiary Cable (Cable Diameter: ~3.0 mm)

TELENE Application to Fast-Ramping ±2 T Accelerator Magnets

TO CHECK PERFORMANCE UNDER ALTERNATE LOADS



A. Zlobin, I. Novitski et al.

Design developed within the U.S. Magnet Development Program - Synergy

- Target specifications with a cable outer diameter of 3 mm are 3-4 kA for a magnetic field of 2T.
- Cable was tested in Japan and provides 5 kA at 2 T.

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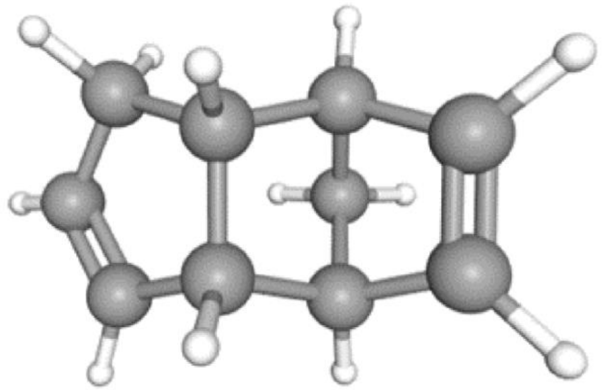
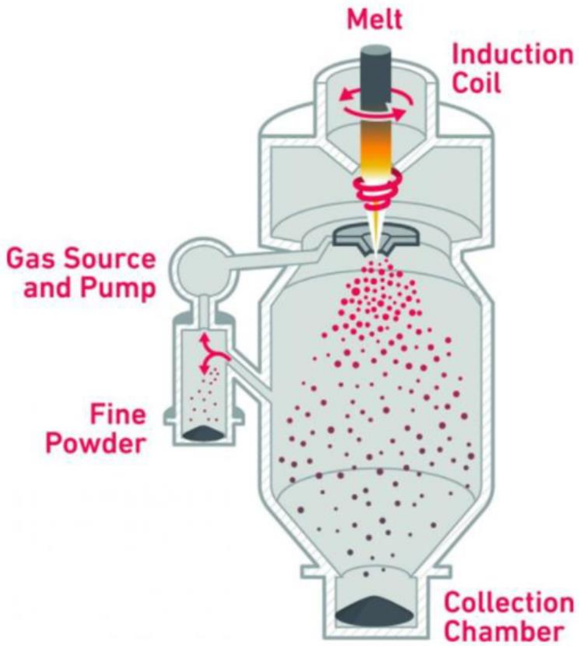
Goal 2

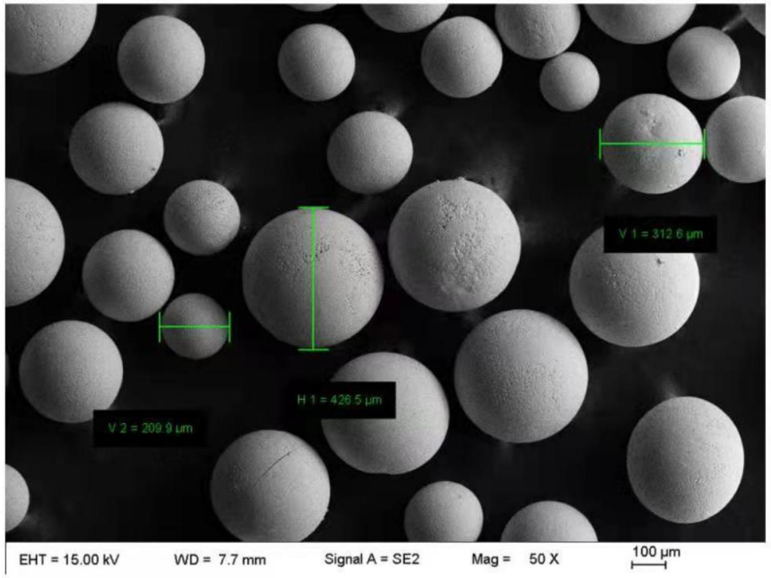
Radiation strength of insulating materials used in superconducting accelerator magnets is another critical parameter. The common limit of HL-LHC type magnets is 25 MGy of proton radiation for the current epoxy. There are indications in literature that DCP could do better → Measure and study resins mechanical and chemical properties before and after irradiation.



Dicyclopentadiene ($C_{10}H_{12}$)

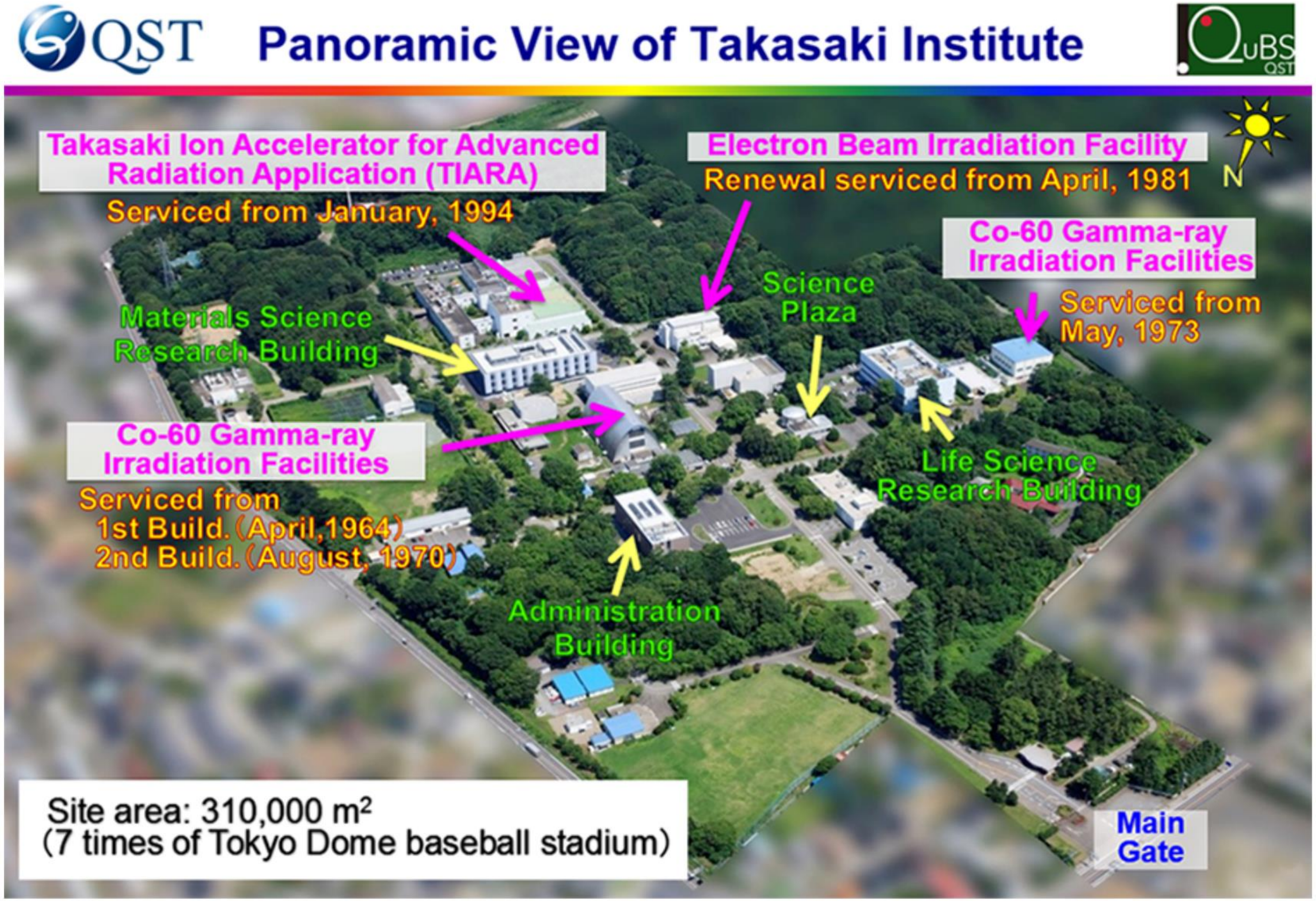
In addition to Gd_2O_3 and Gd_2O_2S, NIMS has been producing ceramic powders of radiation resistant $HoCu_2$ with a gas atomization process.





Gamma Ray Irradiation at the QST

Gamma Ray irradiation can be performed at the Takasaki Advanced Radiation Research Institute, which is part of the National Institutes for Quantum Science and Technology (QST) in Takasaki.



Cobalt-60 Gamma Ray Irradiation Experiment

1. TELENE
2. CTD-101
3. TELENE+82wt% Gd_2O_3
4. TELENE+87wt% Gd_2O_2S
5. TELENE+83wt% $HoCu_2$

- For each resin shown, 6 samples are being irradiated at Takasaki at a dose rate of 8 kGy/hr. The goal is to achieve 10MGy +.
- For nonorganic materials, there is a dependence of material response on the type of beam irradiation. However, such a dependence is modest for organic materials, and the absorbed dose can be used to qualify their radiation resistance.
- At a later stage, this could be confirmed with proton beam irradiation experiments at the BLIP facility at BNL.

Results are going to be presented at CEC/ICMC 2023, July 9-13, here in Honolulu by Prof. A. Kikuchi

Next Plans

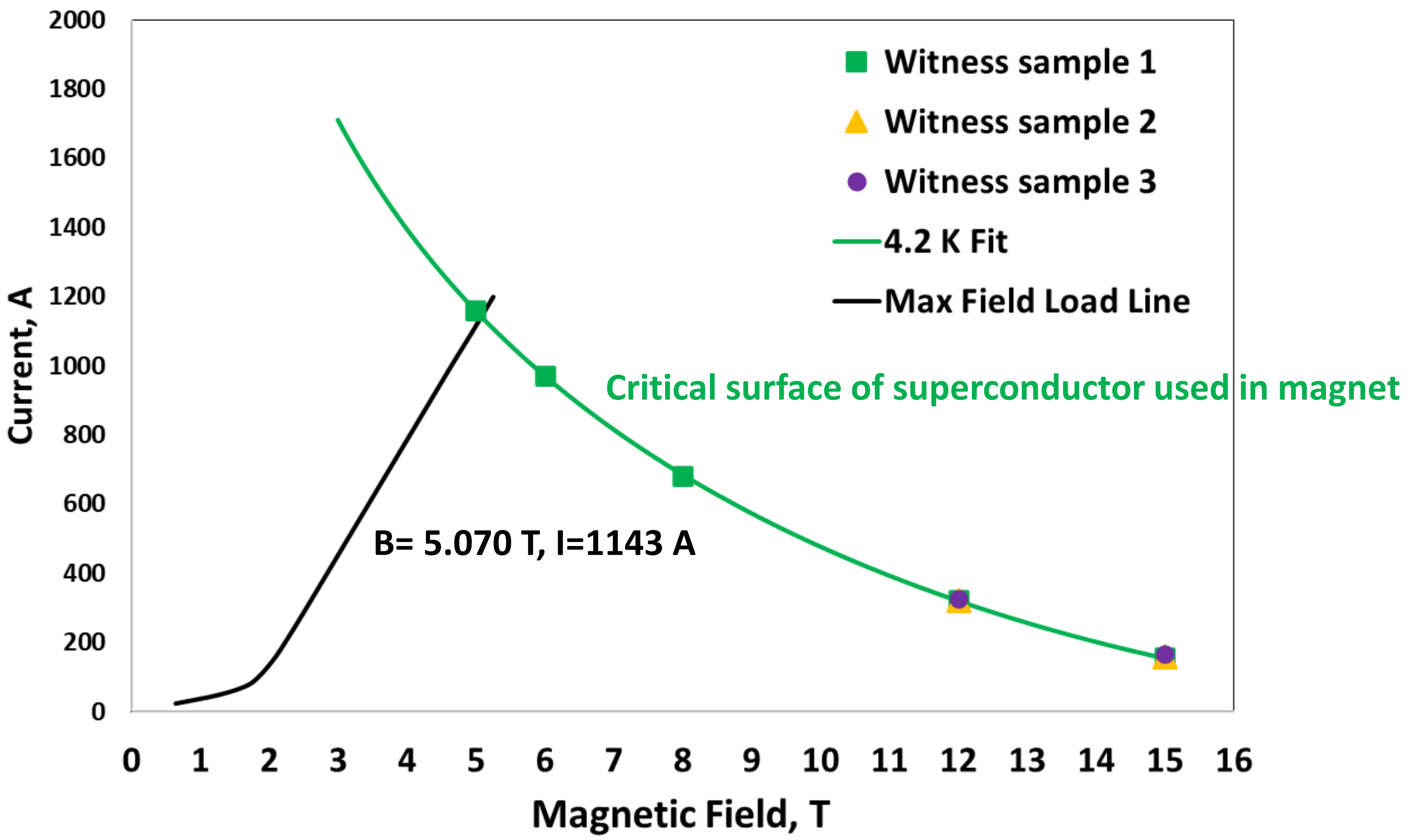
- **Use at least 2 more ANL small undulator coils with mixed resins to measure the effect of the ceramic powders.**
- **By leveraging the U.S. Magnet Development Program, use either pure resin or mixed resin to impregnate LBL Canted Cosine Theta sub-scale magnets to check performance under larger Lorentz forces.**
- **By leveraging the U.S. Magnet Development Program and NIMS own research programs, use either pure resin or mixed resin to impregnate FNAL Cosine Theta coil made of superfine Nb_3Sn to check performance under alternate loads in a fast ramping magnet.**
- **Continue studying irradiation effects.**

BACK-UP

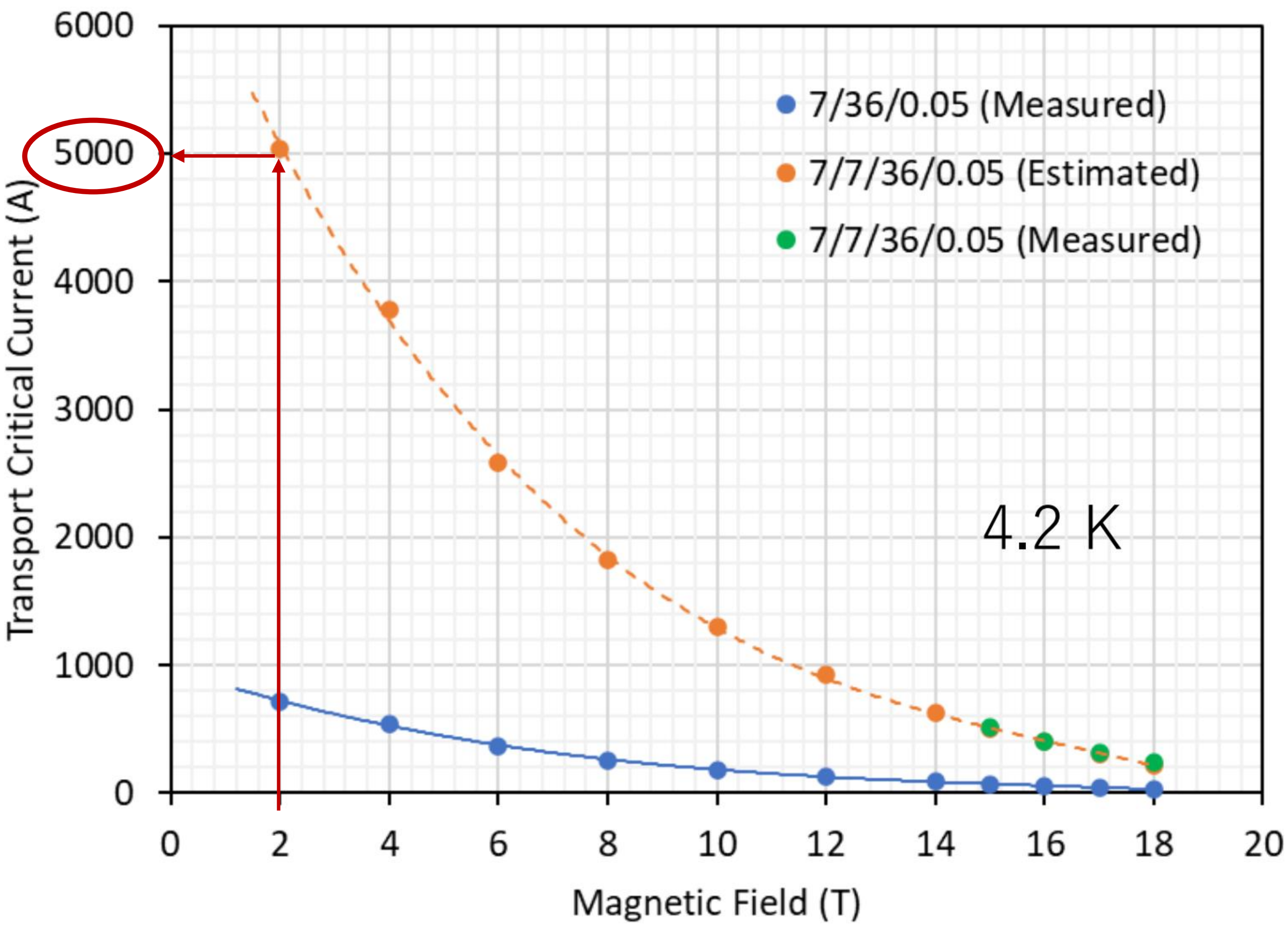
FNAL Testing

The undulator magnets will be tested at FNAL in the Superconducting R&D lab, which is equipped with a cryostat, a power supply, a complete DAQ system and a probe to test superconducting coils up to 25 cm wide and up to 2000 A in transport current. Since the system had been established to test high Temperature Superconducting coils, a quench protection system adequate for Nb_3Sn was installed after procurement of an IGBT (insulated gate bipolar transistor), capacitor, driver board and cooling plate. A quench protection system that makes use of a fast IGBT switch and a NI compact RIO DAQ system was used.

Short Sample Limits for Small Undulator



Test of Multi-Stage Conductor



High heat capacity and radiation-resistant organic resins for impregnation of high field superconducting magnets

- A major focus of Nb_3Sn high field accelerator magnets for HEP is on significantly reducing or eliminating their training.
- ΔT is proportional to Q/C_p ➔ Use high-C_p impregnation.
- Mix organic olefin-based thermosetting dicyclopentadiene (DCP) resin, commercially available as TELENE® by RIMTEC Corporation in Japan, with high heat capacity ceramic powders such as such as Gd_2O_3, Gd_2O_2S.