Development of Superconducting Magnets in KEK

T. Ogitsu on be half of KEK Cryogenics Center and its Collaborators

Development of Superconducting Magnets in KEK

- On going projects
  - HL-LHC D1
  - J-PARC COMMET
- Under development
  - J-PARC g-2/EDM (Muon Storage Ring)
  - J-PARC MLF Second Target (Muon Capture Solenoid)
- Basic R&D
  - Radiation Hard Superconducting Magnet
    - Organic Material gamma ray irradiation test at QST Takasaki (in collaboration with CERN and LBNL)
    - HTS conductor neutron irradiation test at IMR Oarai
    - Inorganic electric insulator development
  - High Field Magnet and Conductor
    - CERN KEK collaboration for High Jc Nb3Sn conductor development with Kobelco/JASTEC and Furukawa Electric

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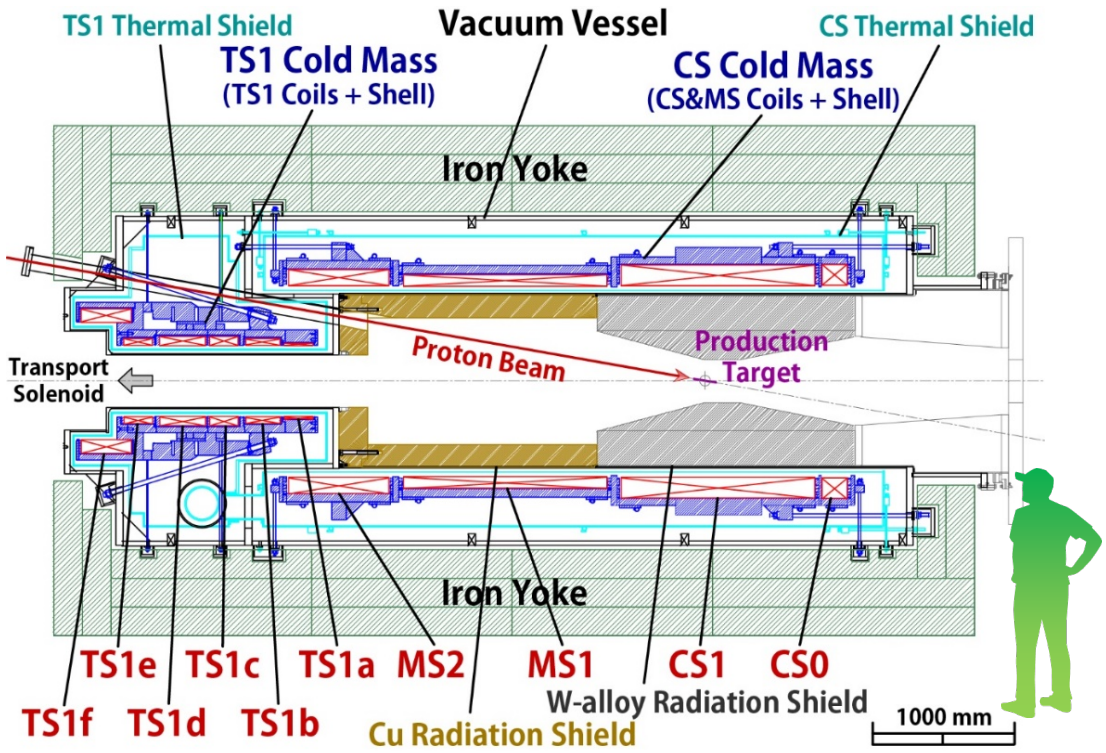
COMET muon source (5 T-class solenoid)

- **In case of the recent muon source,**
  the production target is equipped in a solenoid magnet
  → High radiation resistance is required

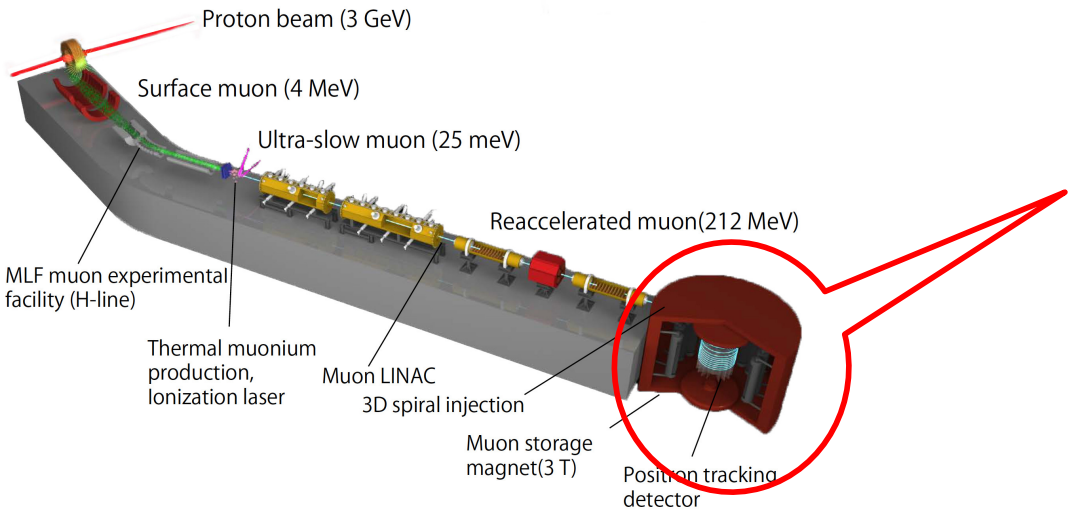


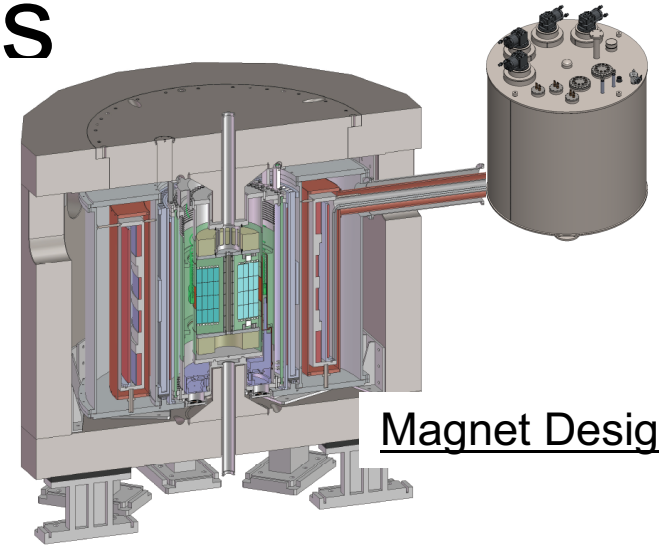
- OD of cryostat: **2.3 m**
- Length of cryostat: **6.5m**
- Weight of cryostat: **45 t**
- Peak field at target: **5 T**
- Proton beam power: **56 kW**
- Weight of Radiation shield
  : **~40 t** (W-alloy + Cu)
- Absorbed dose: **~1 MGy**
- Nuclear Heating: **191 W**





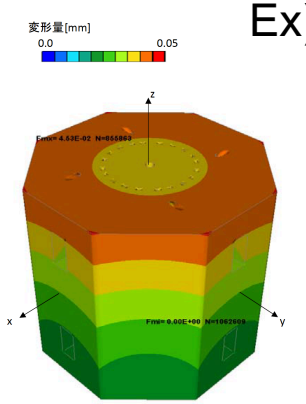

J-PARC g-2/EDM status



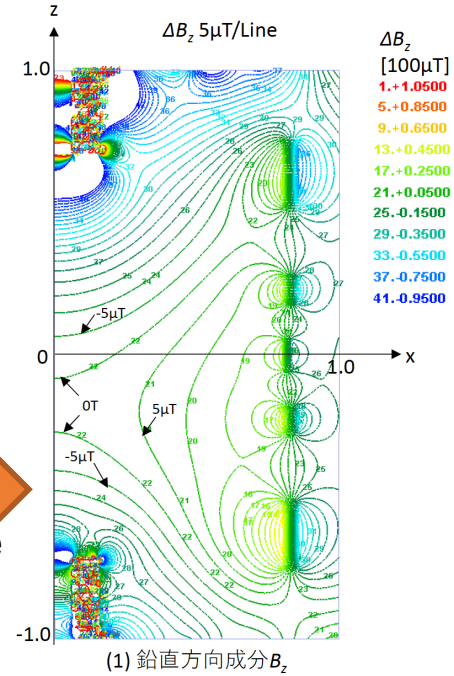


Magnet Design R&D

Ex) temperature effect



Yoke deformation



(1) 鉛直方向成分B_z

Error field
by temp. change

NMR probe system R&D

Cross calibration
btw US and JP probes

- Funding request : in progress

J-PARC Future Muon Source

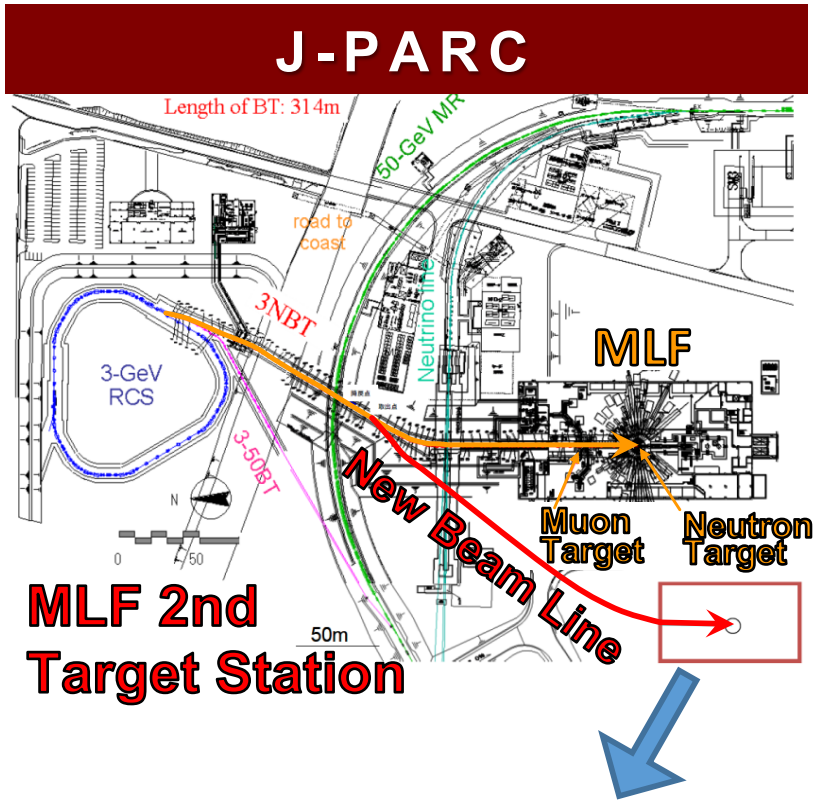
J-PARC MLF 2nd Target station

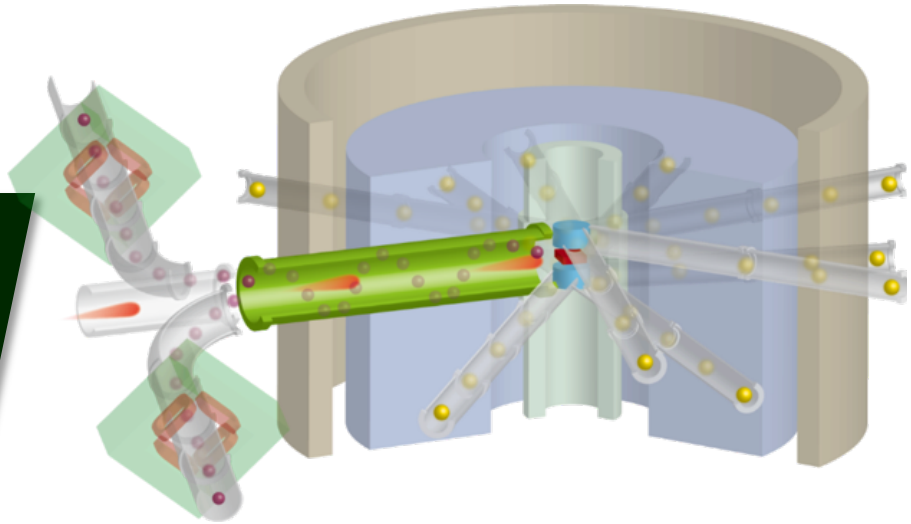
- Solenoid covering production target
  → Absorbed Dose: 130 MGy???

Conventional Magnet Technology

- **NbTi Cable**
  → T=5 K with heat load reaching 650 W? due to nuclear heating
- **Organic Material for Insulation**
  → Degradation of the machine strength from 10 MGy

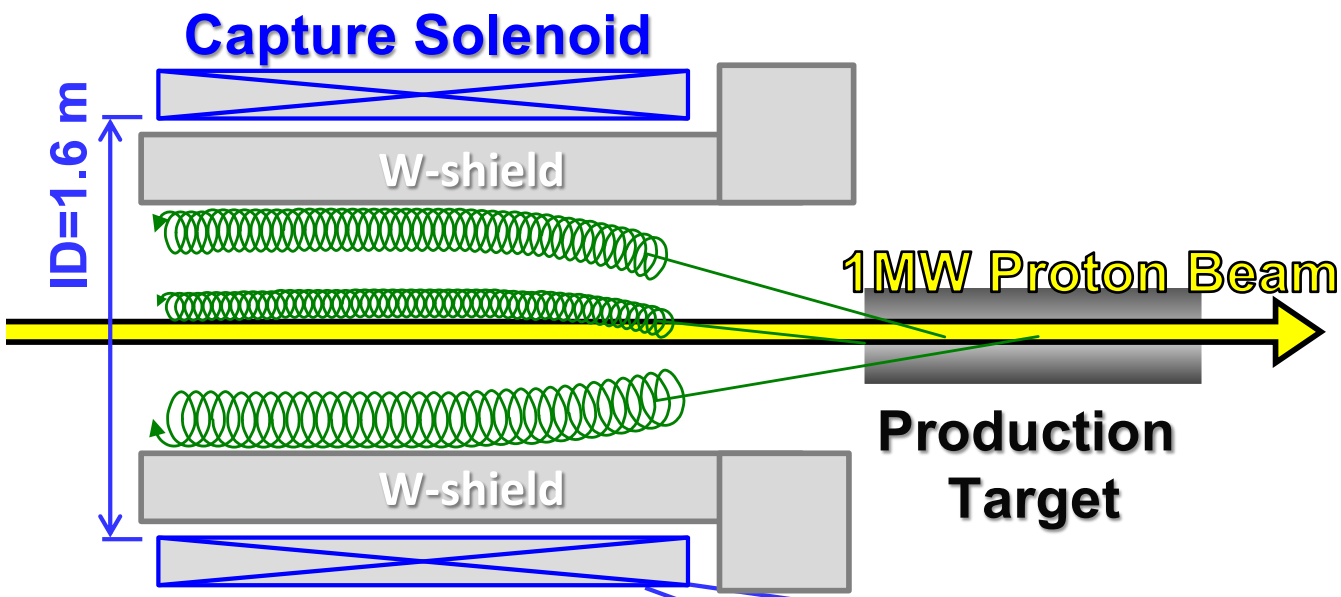
Development of next-generation radiation-resistant superconducting magnet has been awaited

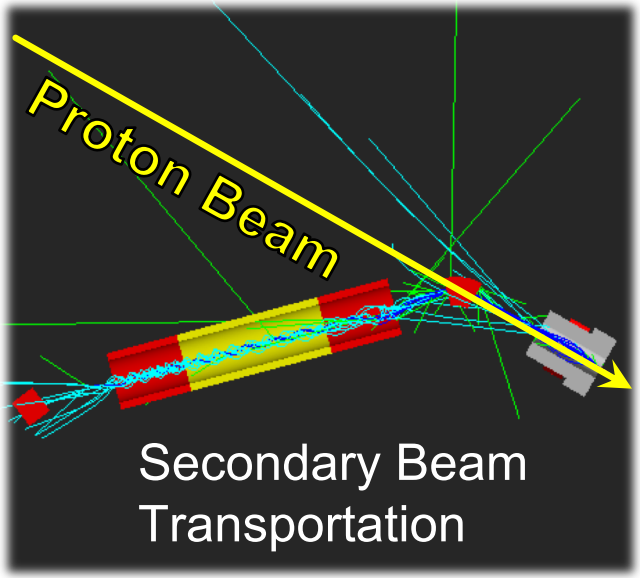


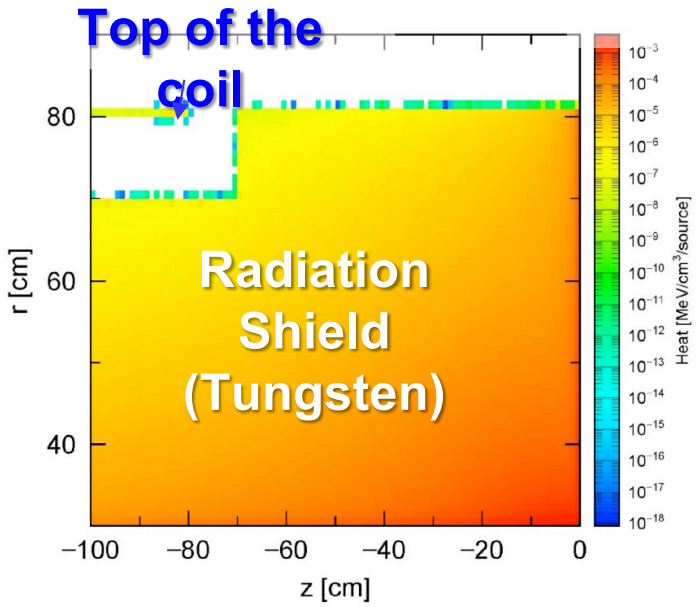


Capture Solenoid for MLF 2nd Target Station

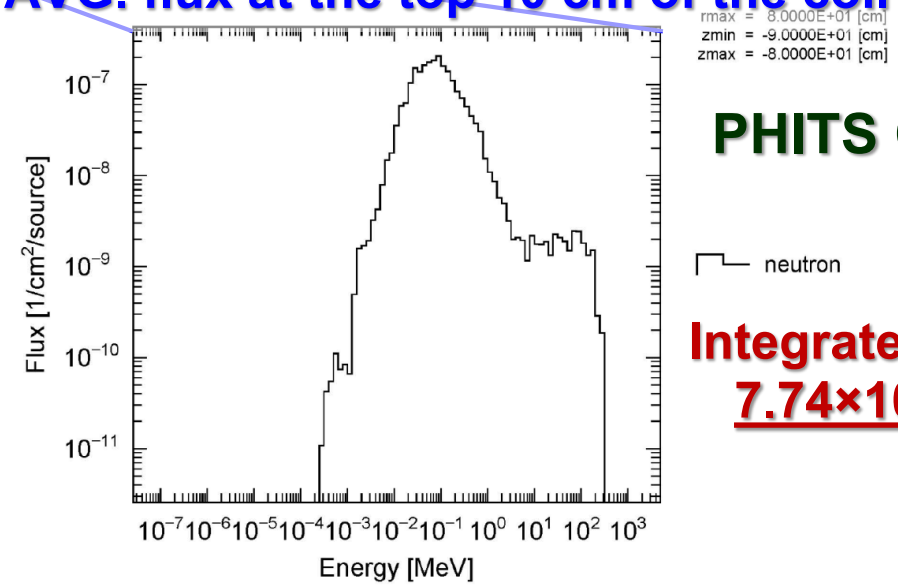
- **Conceptual design of capture solenoid is ongoing**







AVG. flux at the top 10 cm of the coil



PHITS Code

Integrated flux :
7.74×10^{20} n/m²/y
(@1 MW)

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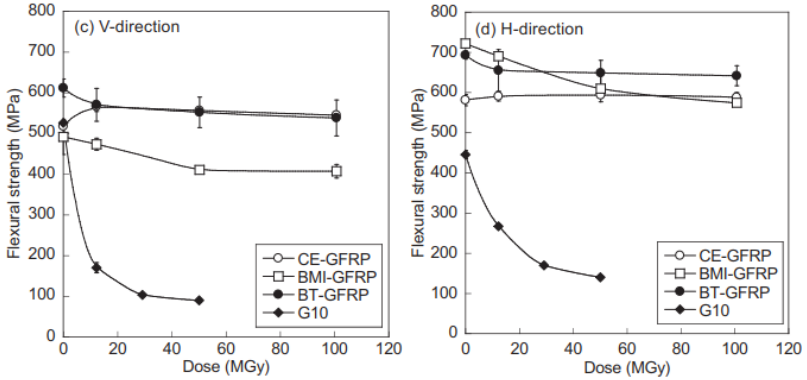
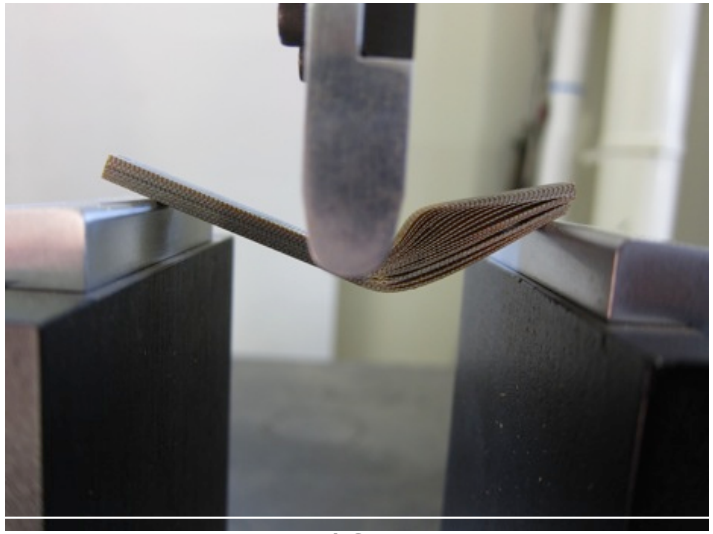
Organic Material Gamma Ray Irradiation Tests

- Performance of BT Based GFRP has been confirmed

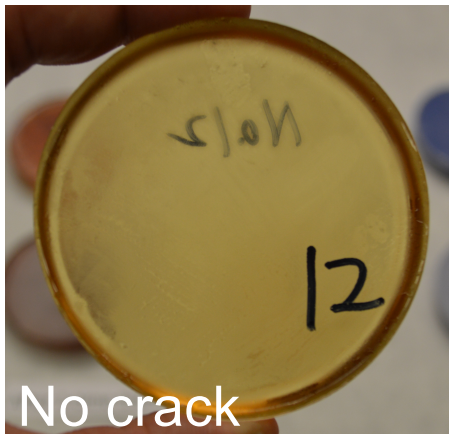


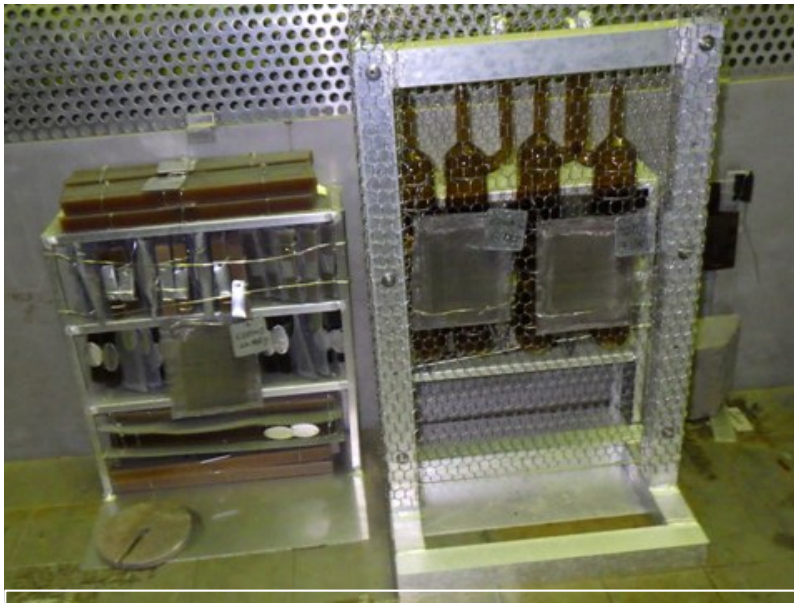


Flexural strength test w/ G10 sample irradiated at 30 MGy. Delamination of glass sheets is observed.

CTD-101 k, used by US LARP, after one thermal cycle to 77 K

NHMFL-mix61, an amine-based epoxy after one thermal cycle to 77 K





GFRP Samples from KEK, CERN and LBNL set at Co60 Gamma Ray Irradiation Facility at QST Takasai.

Shijian Yin, Tengming Shen, LBNL

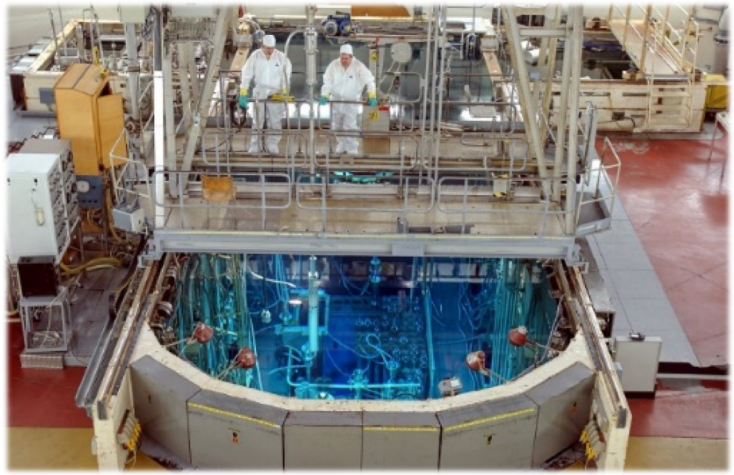
HTS Neutron Irradiation Test

Inter-university cooperative research program

International Research Center for Nuclear Materials Science, Institute for Materials Research, (IMR-Oarai) Tohoku University

Sample (REBCO tape)

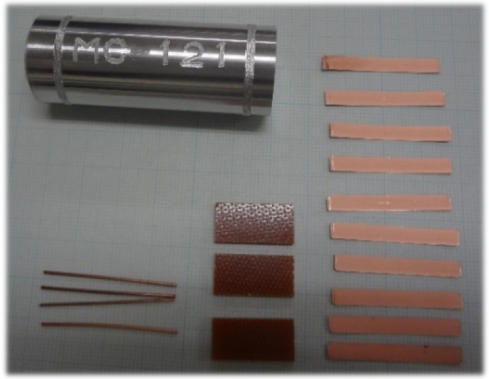
BR2 @Belgian nuclear research center



Superconducting Properties Evaluation System @IMR-Oarai

Temperature Range	4 ~ 80 K
Max. Current	500 A
Max. External Field	15.5 T

Current status of neutron irradiation



Irradiated samples at BR2 in FY2016

2 capsules (It returned in FY2017)

→ HTS (SCS4050-AP) x10, BT-GFRP x3

→ Neutron fluence: 1.80x10^{22}, 8.37x10^{22} n/m^2 (En>0.1 MeV, T< 100 ℃)

→ Equivalent dose of HTS: 150, 650 mSv/h (Distance: 0.5 m)

Irradiated samples at BR2 in FY2017

2 capsules (It will return in FY2018)

→ HTS: SCS4050-AP x5 & FYSC-SCH04 x5, BT-BFRP x3

→ Neutron fluence: 1x10^{22}, 5x10^{22} n/m^2 (En > 0.1 MeV, T< 100 ℃)

Irradiated samples at BR2 in FY2018 (Shipped soon)

2 capsules (It will return in FY2019)

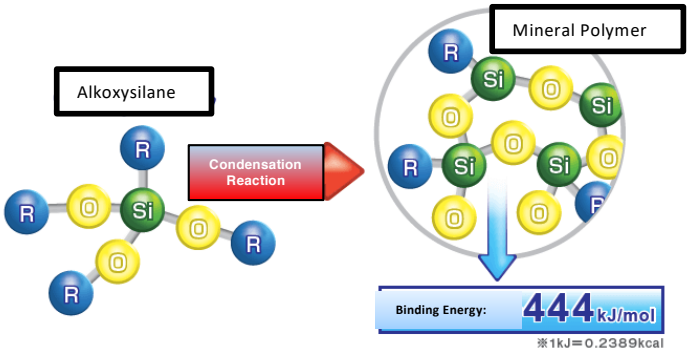
→ HTS: SCS4050-AP x5 & FYSC-SCH04 x5, MgB2 x3, BT-BFRP x3, MI-Cu

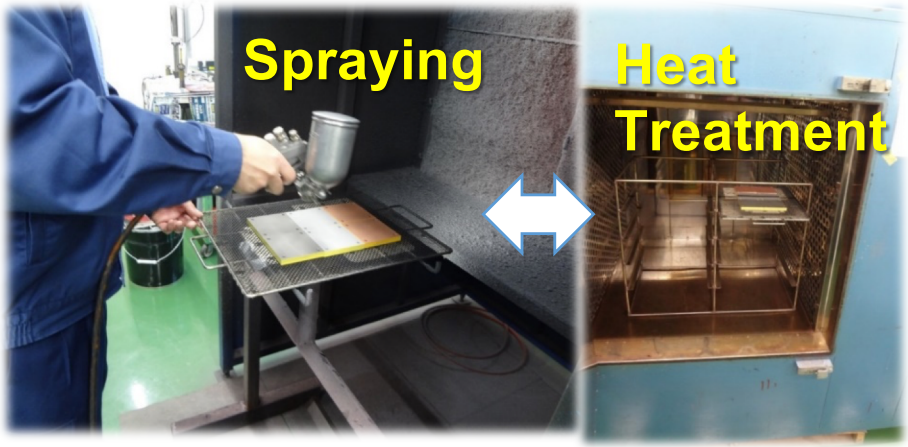
→ Neutron fluence: 1x10^{21}, 5x10^{21} n/m^2 (En > 0.1 MeV, T< 100 ℃)

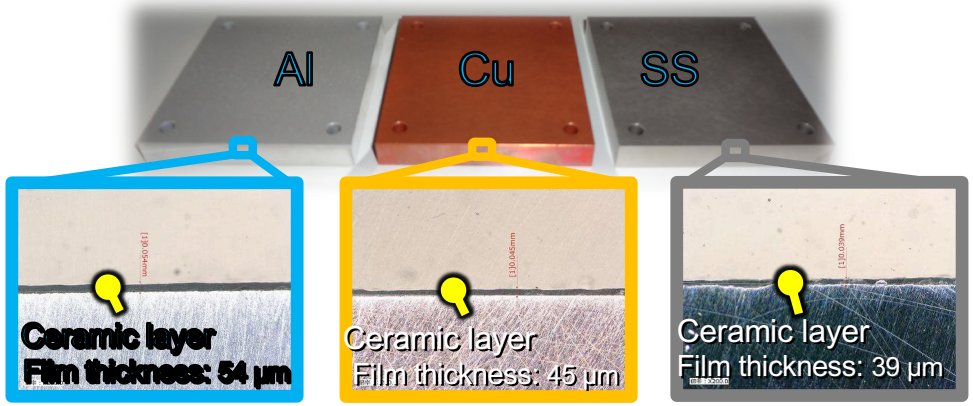
We are preparing for PIE (post irradiation examination)

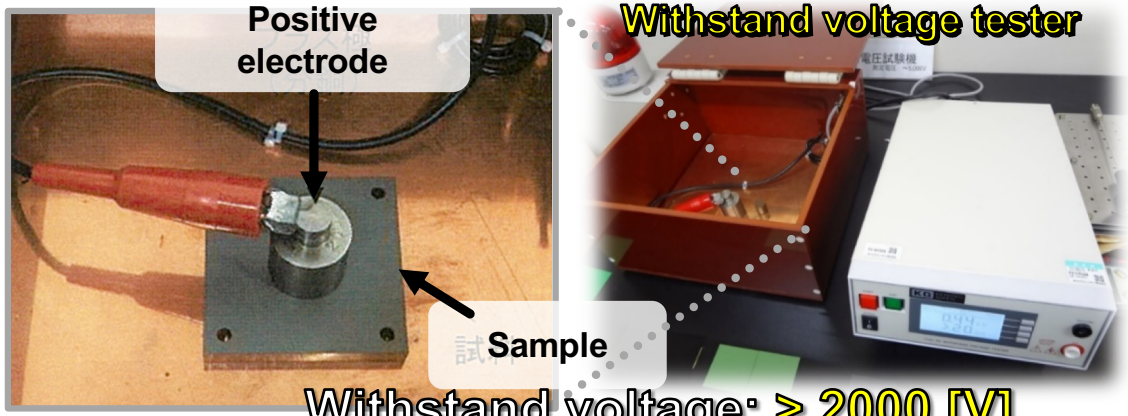
Inorganic Insulation

- SiO_2 polymer with Al_2O_3 mixed



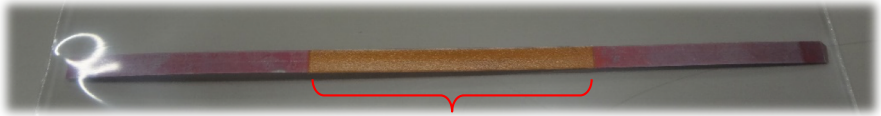




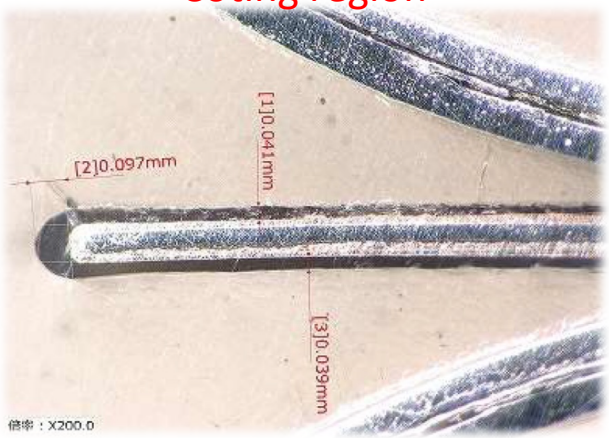


Trial Carting on REBCO Tapes

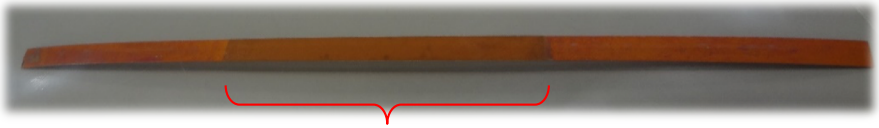
SCS4050-AP (SuperPower)



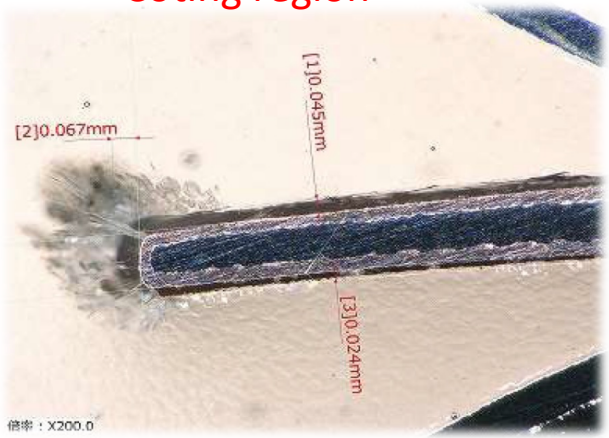
Coting region

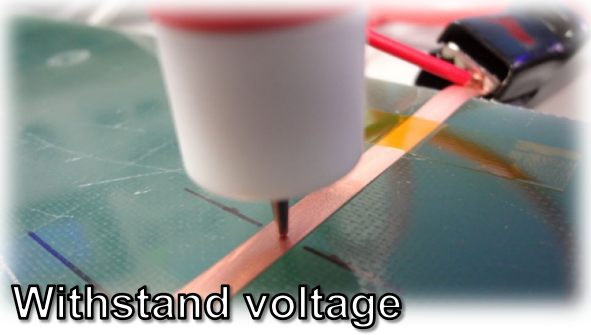


FYSC-SCH04 (Fujikura)



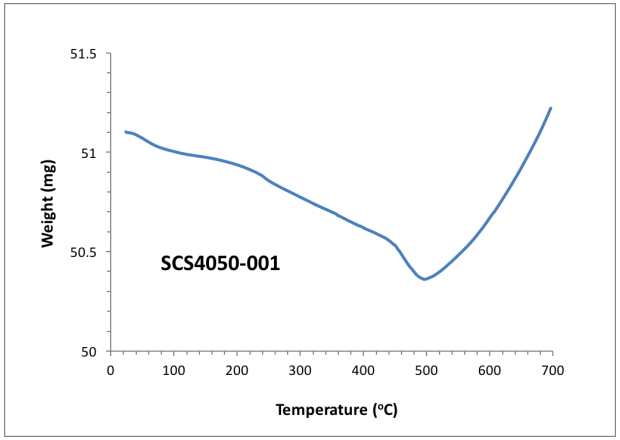
Coting region



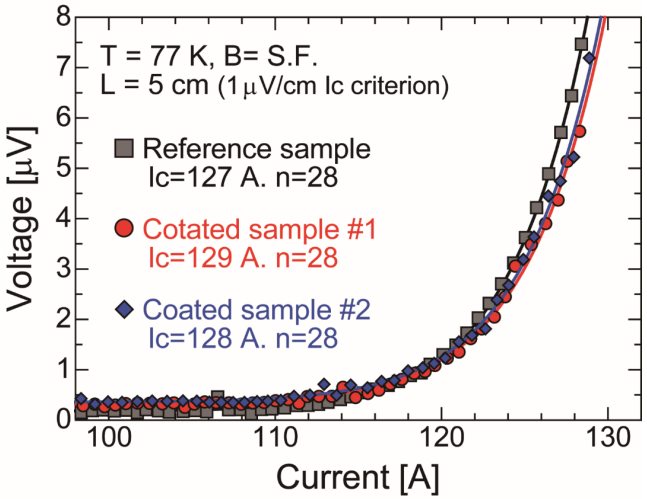


- t=16 μm : 0.679 kV
- **t=24 μm : 2.006 kV**
- **t=38 μm : 2.693 kV**

TGA measurement at LBNL: small weight loss RT-500C



No I_c Degradation



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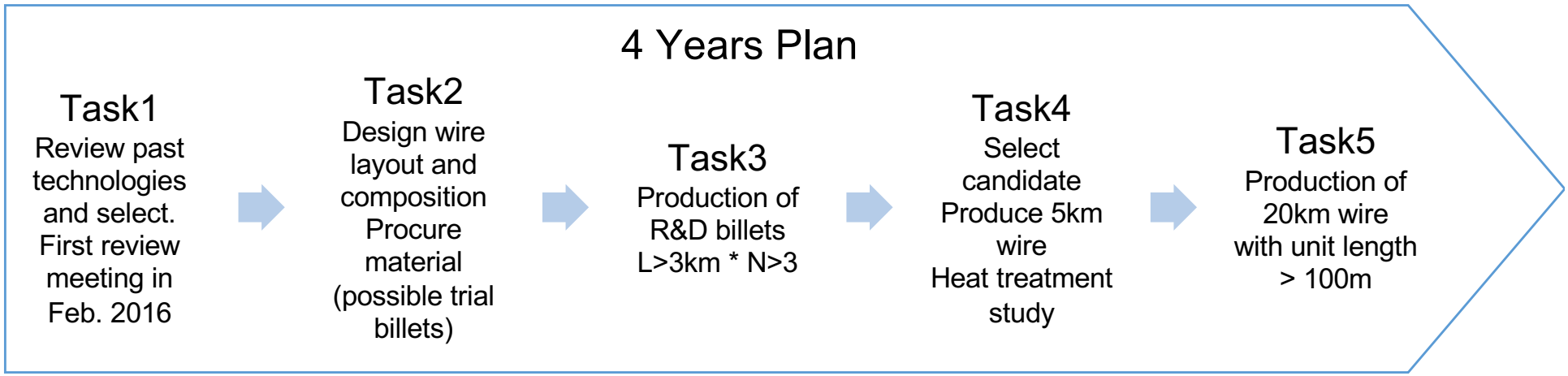
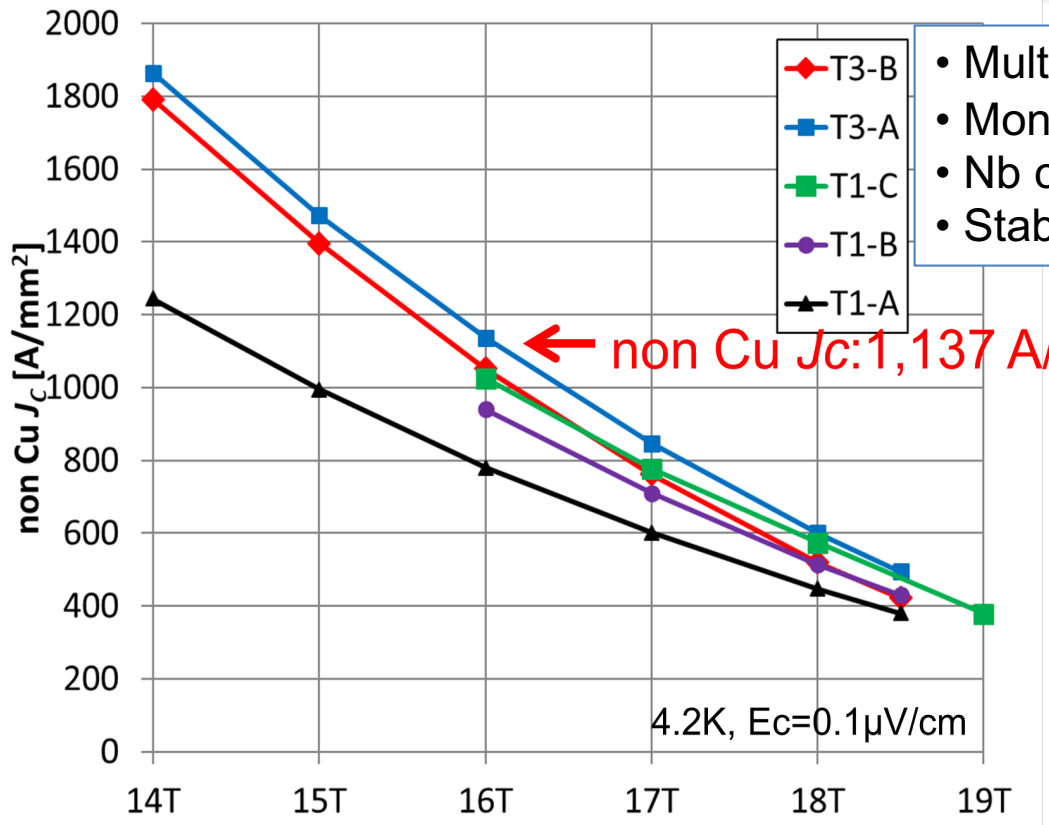
R&D Plan

CERN, KEK and Tohoku & Tokai university have jointly launched a R&D program

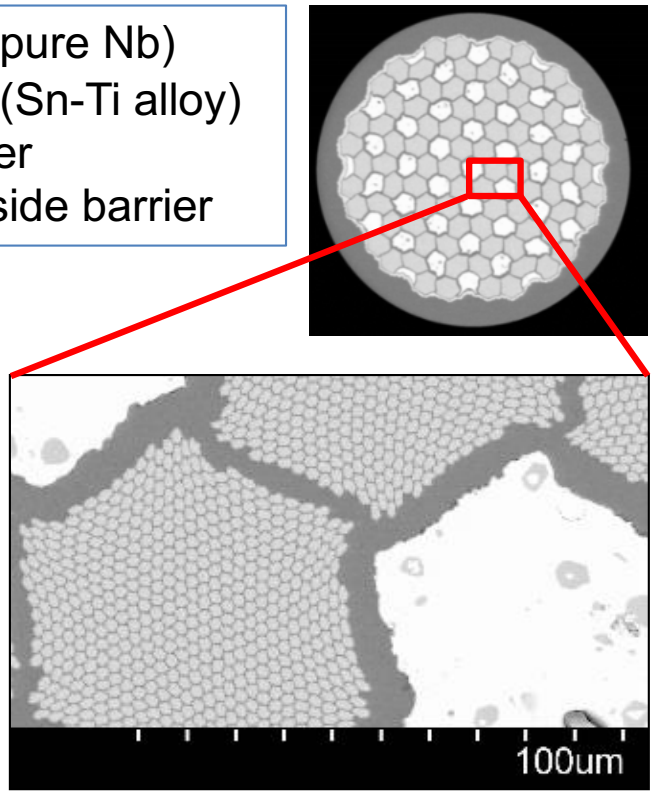
- The scope of the program is to develop, produce in representative lengths and characterize Nb_3Sn wire with enhanced characteristics.
- The final goal is to achieve in representative unit lengths of material the development targets defined, on the basis of magnets performance, for the FCC Nb_3Sn conductor: 1500A/mm^2 @ 16T
- Contract with 2 Japanese companies: Task 3; 4 R&D contracts each
  - JASTEC/Kobelco: Distributed Tin (DT) Method
  - Furukawa Electric: Nb Tube Method



KSL/JASTEC DT wire: Non Cu J_c *v.s.* B



- Multi Nb module (pure Nb)
- Mono Sn module (Sn-Ti alloy)
- Nb common barrier
- Stabilized Cu outside barrier



	T1-A	T1-B	T1-C	T3-A	T3-B
Wire diameter (mm)	0.80	0.74	0.64	0.80	0.80
Sn diffusion distance (μm)	60	58	48	32	32
Ti ratio (wt%)	0.55	0.55	0.55	0.48	0.35
non Cu J_C (A/mm²)@16T	800	930	1025	1137	1032

KOBELCO KOBE STEEL GROUP

Non Cu *Jc* of 1,100 A/mm² at 16 T, 4.2 K has been achieved by improving Sn diffusion and optimizing Ti content.

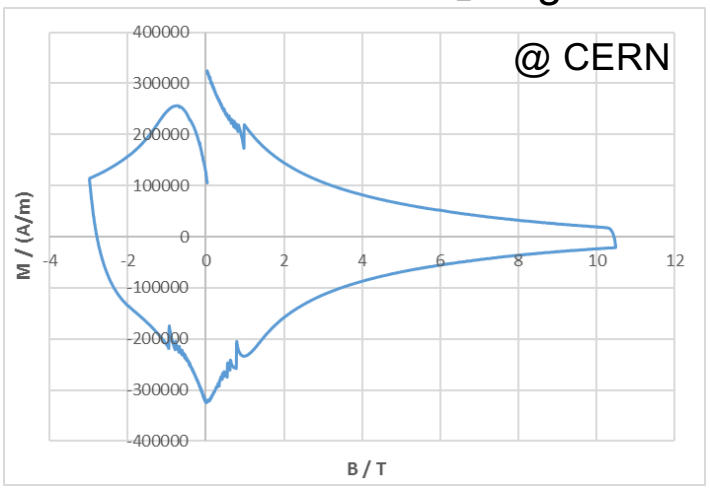
JASTEC SUPERCONDUCTOR

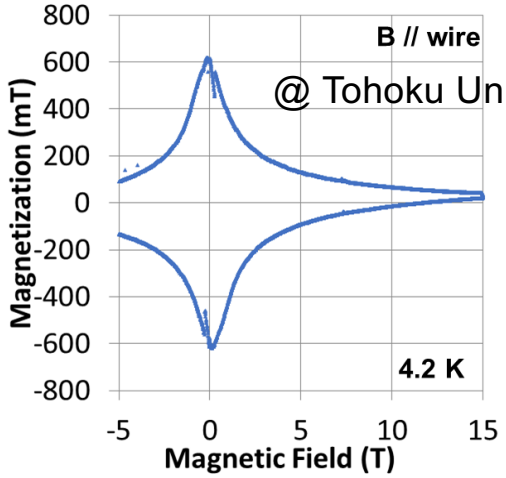
Magnetization characteristics

・For high *Jc* wire (T3-A,B), KSL/JASTEC evaluated magnetization characteristics and changes of *Jc* and RRR after rolling.

・The magnetization were measured at 4.2 K at CERN and Tohoku University, separately.

【Magnetizations of T3-A 】





【Calculated d_{eff} 】

Sample name	T3-A	T3-B
d_{eff} by CERN (μm)	54.5	55.0
d_{eff} by Tohoku Uni. (μm)	35.1	30.6

※Nominal Nb module dia.: 32μm

・There is no large flux jump.
・The calculated d_{eff} (effective filament diameter) were 30 to 60 μm, which was for one or two modules. It is possible to achieve a value close to the current target (≤ 60 μm).

KOBELCO
KOBE STEEL GROUP

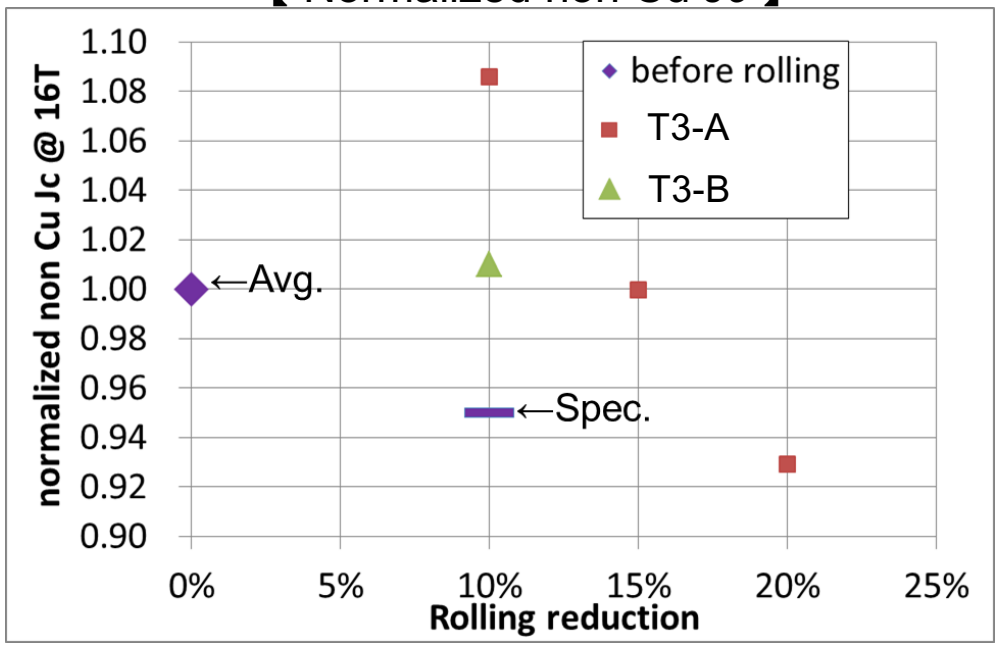
JASTEC
SUPERCONDUCTOR

Rolling test (J_C, RRR)

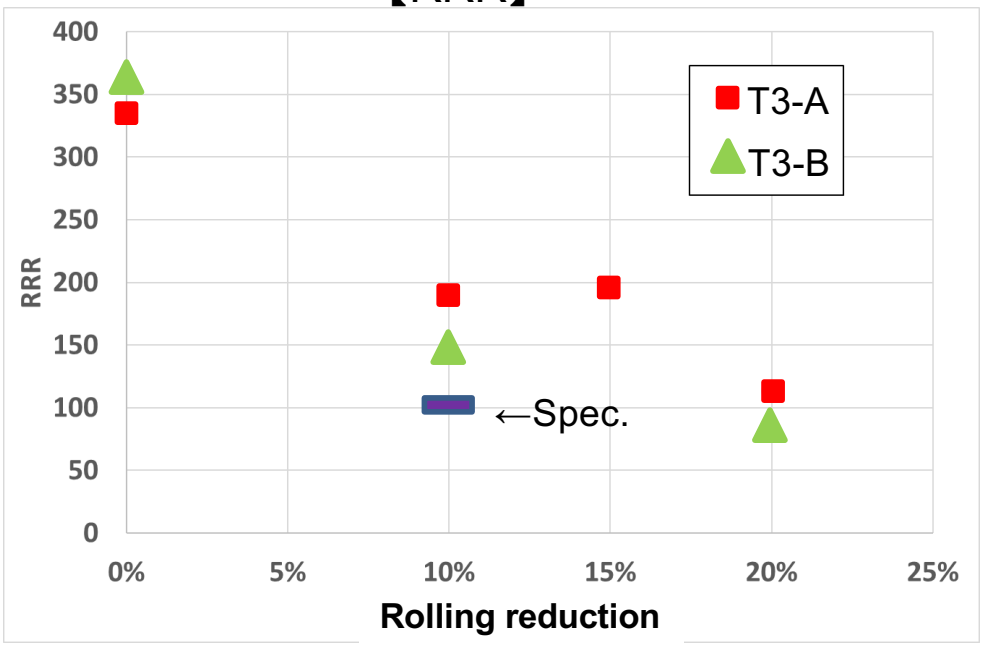
Required specifications for FCC wire (16 T dipole mag.)

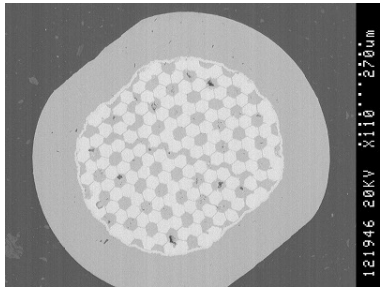
After 10 % rolling : 1) I_C (J_C) > 95 % for round wires, and 2) *RRR* > 100.

【 Normalized non Cu *Jc* 】

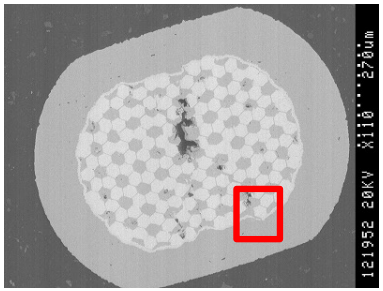


【RRR】

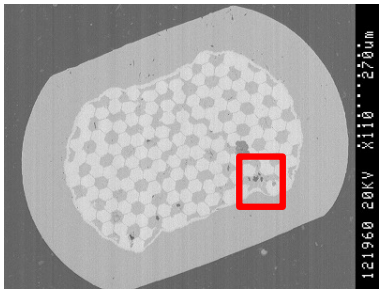




10% Rolling
No barrier breakage



15% Rolling
Barrier breakage



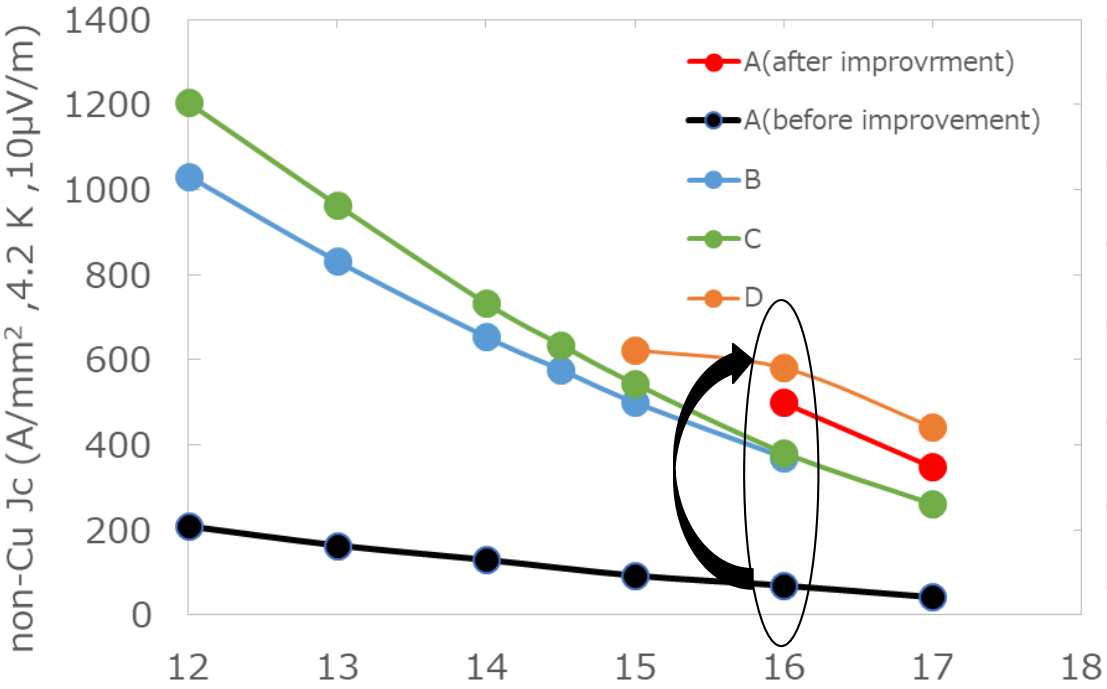
20% Rolling
Barrier breakage

KOBELCO
KOBE STEEL GROUP

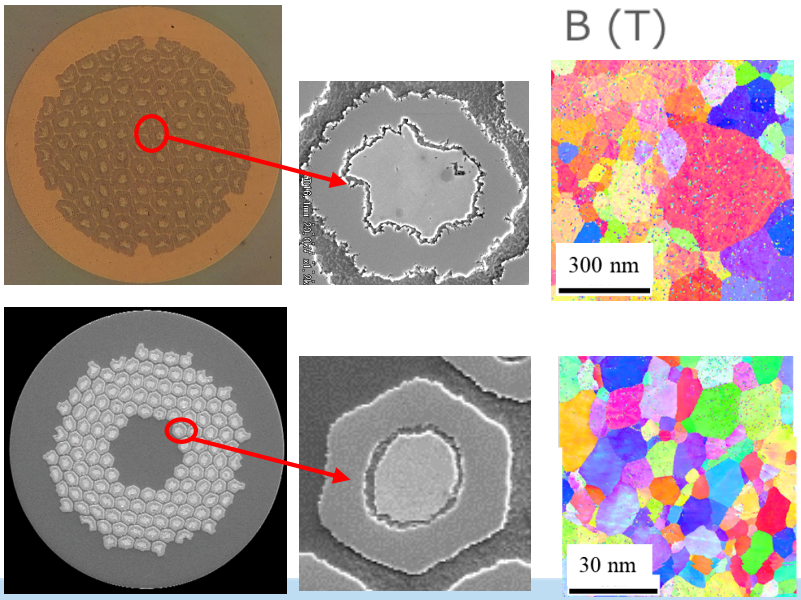
- Both J_C and RRR after rolling meet the specifications.
- From the SEM images of cross section, at any rolling reduction level, the deformation of Nb/Sn modules were only partial.
  Also at 10% reduction, there was no Nb barrier break.

JASTEC SUPERCONDUCTOR

Furukawa Electric Nb Tube: Non-Cu Jc



Wire	A	B	C	D
No. of Filament	85	132		
Filament Material	Nb			Nb-7.5wt%Ta
Nb/Sn ratio	~2.1			~3.3
Filament Dia. (at φ0.83)	64 mm	45 mm		
Cu/non-Cu ratio	~1	~1.6		
Nb pretreatment(°C)	1,150			850



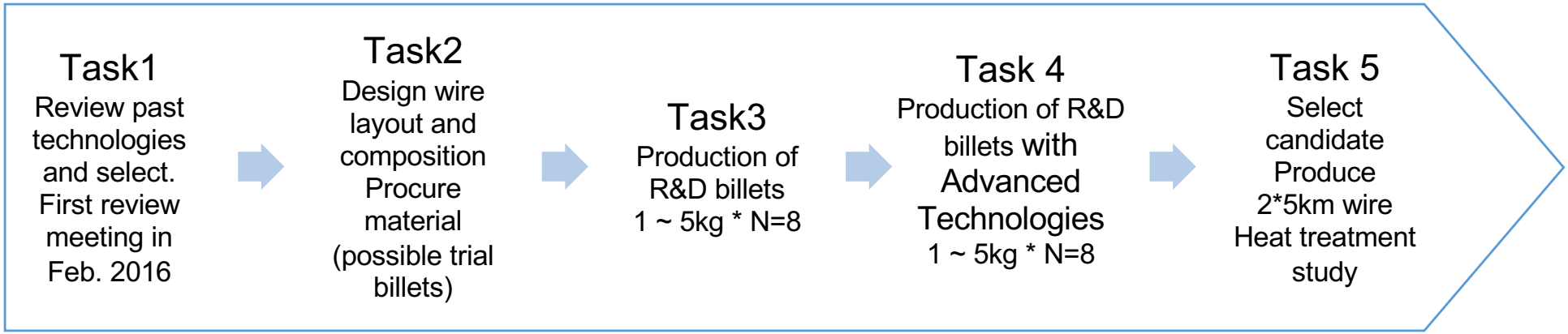
✓Non-Cu Jc of 580 A/mm^2 @16 T was obtained in Wire D.

✓Some improvements have been conducted for higher non-Cu Jc.

- Optimization of heat-treatment condition
- Nb/Sn ratio in filaments
- Grain size reduction of Nb_3Sn (including APC technique)

Nb_3Sn Summary

- Task 3 almost completed
- Review
  - May 17-24: D. Larbalestier, S. Hopkins, T. Ogitsu
  - Visit JASTEC, Furukawa, and Tohoku Univ.
  - Review R&D plan and discuss new plan
- The R&D work so far
  - 8 R&D contracts: DT reach 1100 A/mm^2, Nb Tube workability improved
- Propose to modify Task 4 and Task 5
  - Task 4: R&D contracts 4 more each for JASTEC and Furukawa
    - With advanced technologies to aim for 1500 A/mm^2 (Nb-Ta-Hf Alloy)
  - Task 5: Produce 5 km x 2 with best conductors



Summary

- On going projects
  - HL-LHC D1: Prototype started
  - J-PARC COMMET: Under construction
- Under development
  - J-PARC g-2/EDM (Muon Storage Ring): Detail design, field measurement standarization with FNAL and ANL
  - J-PARC MLF Second Target (Muon Capture Solenoid): Conceptual design
- Basic R&D
  - Radiation Hard Superconducting Magnet
    - Organic Material gamma ray irradiation test at QST Takasaki (in collaboration with CERN and LBNL)
      - On going some samples are already sent to CERN and LBNL
    - HTS conductor neutron irradiation test at IMR Oarai
      - Ready for PIE
    - Inorganic electric insulator development
      - On going, collaboration with LBNL and BNL
  - High Field Magnet and Conductor
    - CERN KEK collaboration for High Jc Nb3Sn conductor development with Kobelco/JASTEC and Furukawa Electric
      - Non-Cu J_c of 1100 A/mm^2 @ 16T Achieved
      - Aim for 1500 A/mm^2 with Nb-Ta-Hf