Magnet Technology Development with Nb3Al Superconductor for SLHC

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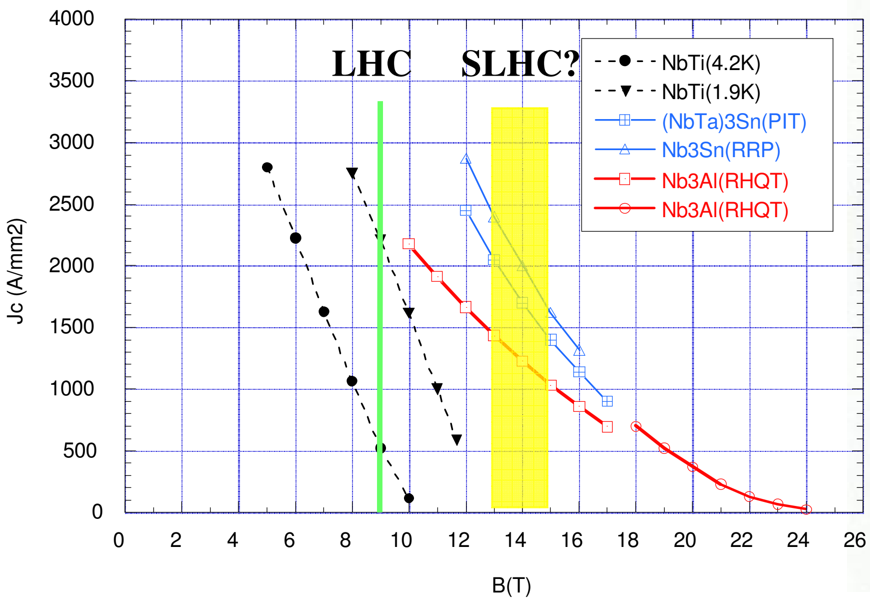
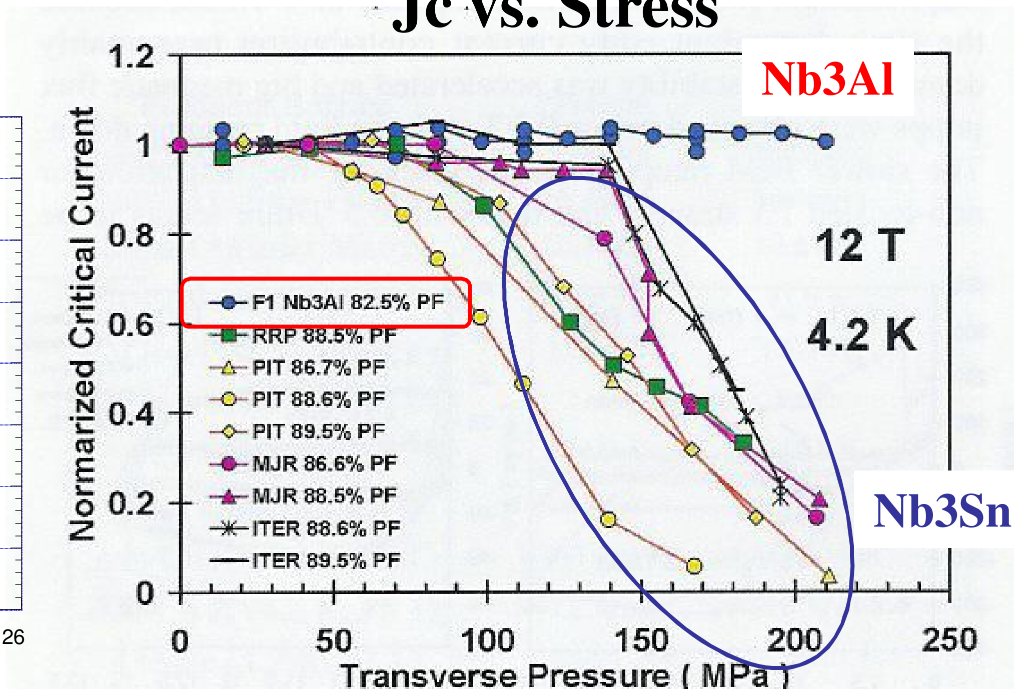
Advantage of Nb_3Al over Nb_3Sn

As of now, critical current density (Jc) of Nb3Sn is higher than Nb3Al. But, ….

Jc vs. B



Jc vs. Stress



Presented at MT-20
By A. Kikuchi et al.

Better mechanical performance of Nb3Al >> No degradation of Jc below 210 MPa.

For Nb3Sn (RRP), Jc is decreased to be around half at 150 MPa.

@B=12T Jc~3000 A/mm^2 --> 1350 A/mm^2

Objective

For the new Inner Triplet SC Quads in the SLHC:

- High field superconductor and cable made with Nb_3Al,
  - -Superconductor uniquely developed in Japan.
  - -Complementary to Nb_3Sn and magnet development at CERN and US-LARP.

- Model coils with Nb_3Al cable to demonstrate its feasibility at a field range of 13 T.

- Fundamental study
  - Neutron diffraction for Nb3Al at J-PARC
  - High radiation resistant materials development

Participants / Collaborators

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NIMS:	N. Banno, A. Kikuchi, T. Takeuchi

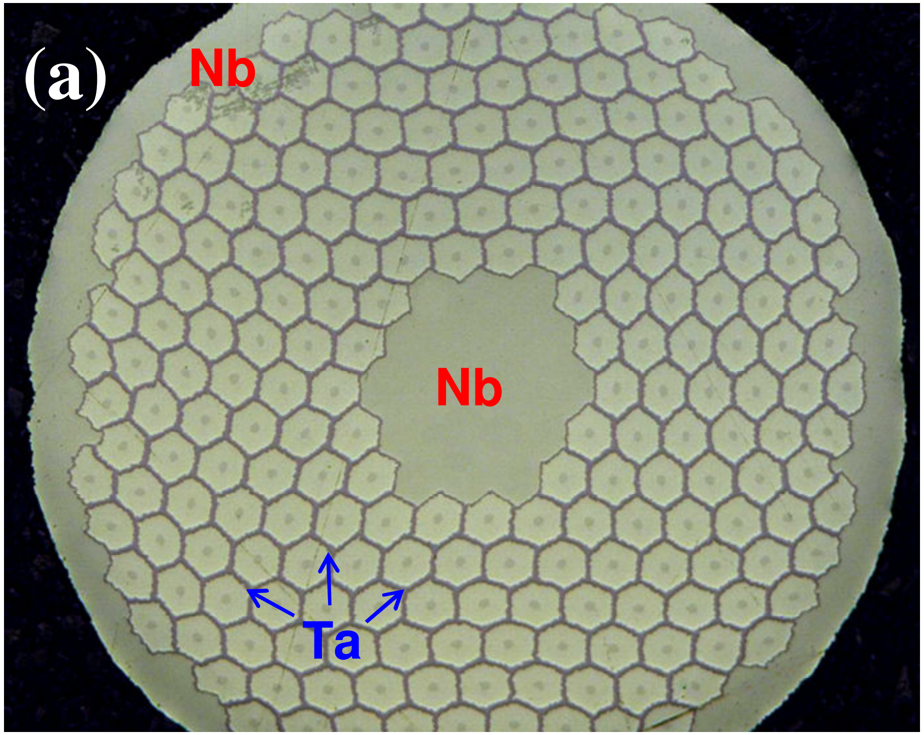
In cooperation of:

CERN:	L. Rossi, G. de Rijk, L. Bottura
LBNL:	G. Sabbi, S. Caspi et al.
Fermilab:	A. Zlobin, E. Barzi, R. Yamada
CEA/Saclay:	B. Bourdy et al.

Jelly-Rolled Nb/Al Precursor Before RHQ

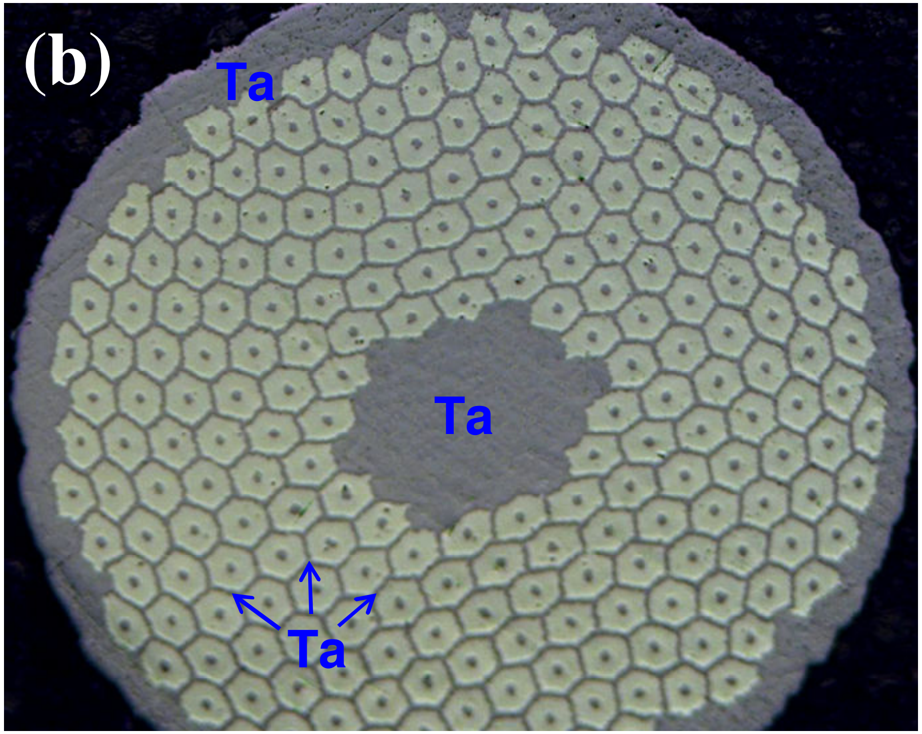
(a) K1 strand (partial Ta matrix)

(Nb skin, Nb central dummy, Ta interfilament)



(b) K2 strand (all Ta matrix)

(Ta skin, Ta central dummy, Ta interfilament)



OD : 1.35 mm, JR fil. num. : 222

JR fil. dia. : 70.4 μm, JR core : Nb

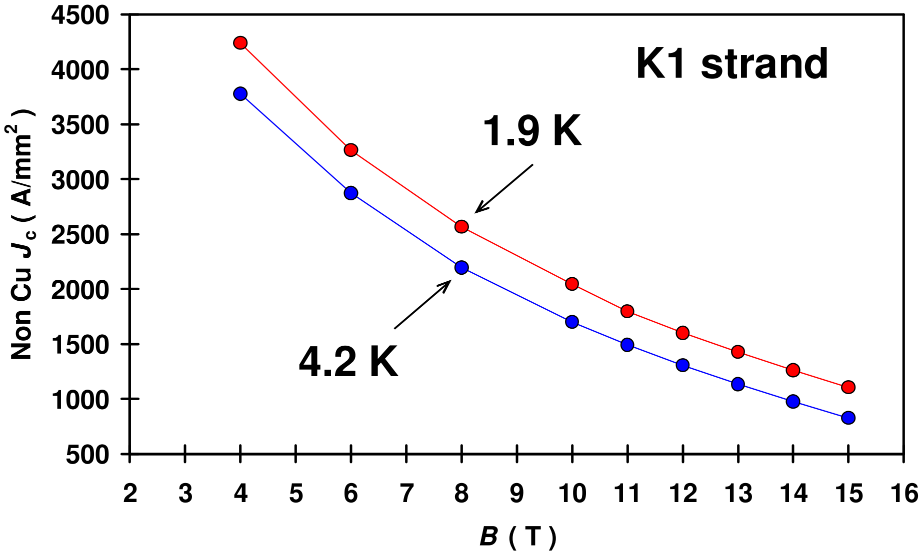
Ta+Nb matrix ratio to JR fil. : 0.8

OD : 1.35 mm, JR fil. num. : 222

JR fil. dia. : 70.4 μm, JR core : Ta

Ta matrix ratio to JR fil. : 0.8

J_c vs Magnetic Field

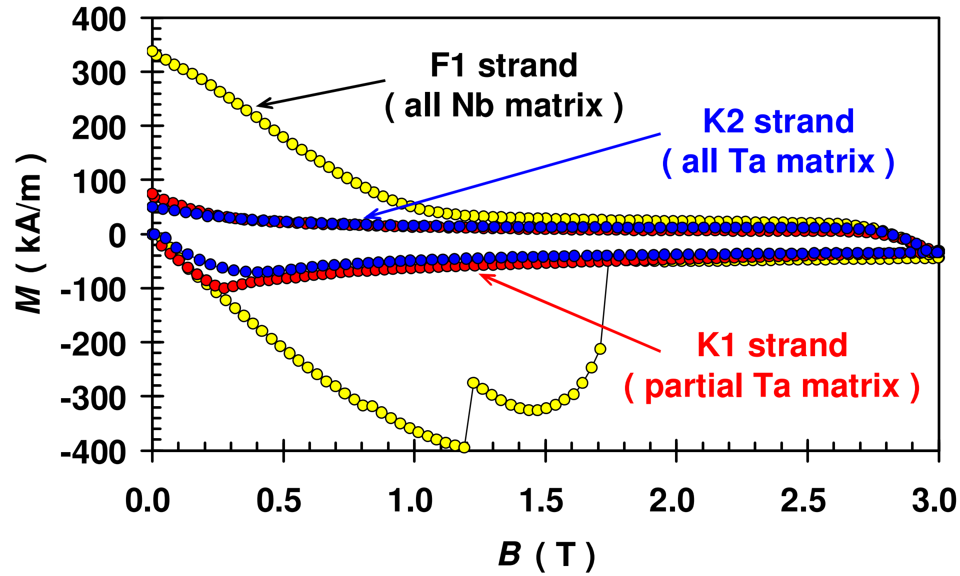


Non Cu Jc@12T, 4.2K : ~1300 A/mm2
Non Cu Jc@15T, 4.2K : ~800 A/mm2
2 T shift of Jc curve at 1.9 K

➡ Similar to the previous strands

Magnetization Curves at 4.2 K

Dia 1.0 mm, Cu ratio 1.0, Twist Pitch 45 mm, B ramp 1 T/min, Temp. 4.2 K



No flux jump.
Improvement of magnetization confirmed.

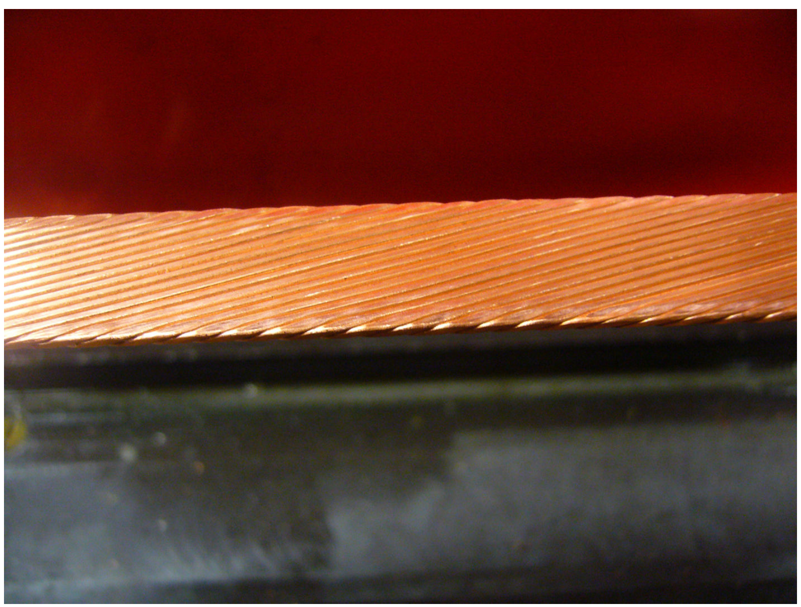
Cable Fabrication at Fermilab

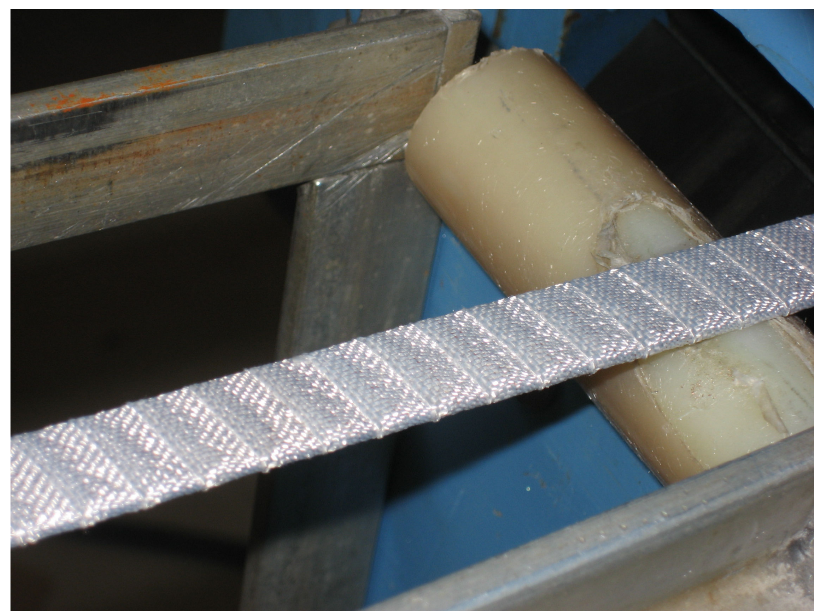
- 1st Cabling with ceramic insulation succeeded in Feb. 2009.

- K1 cable (w/ 28 strands): 22 m

  >> Coil winding

- K2 cable (w/ 27 strands): 9 m

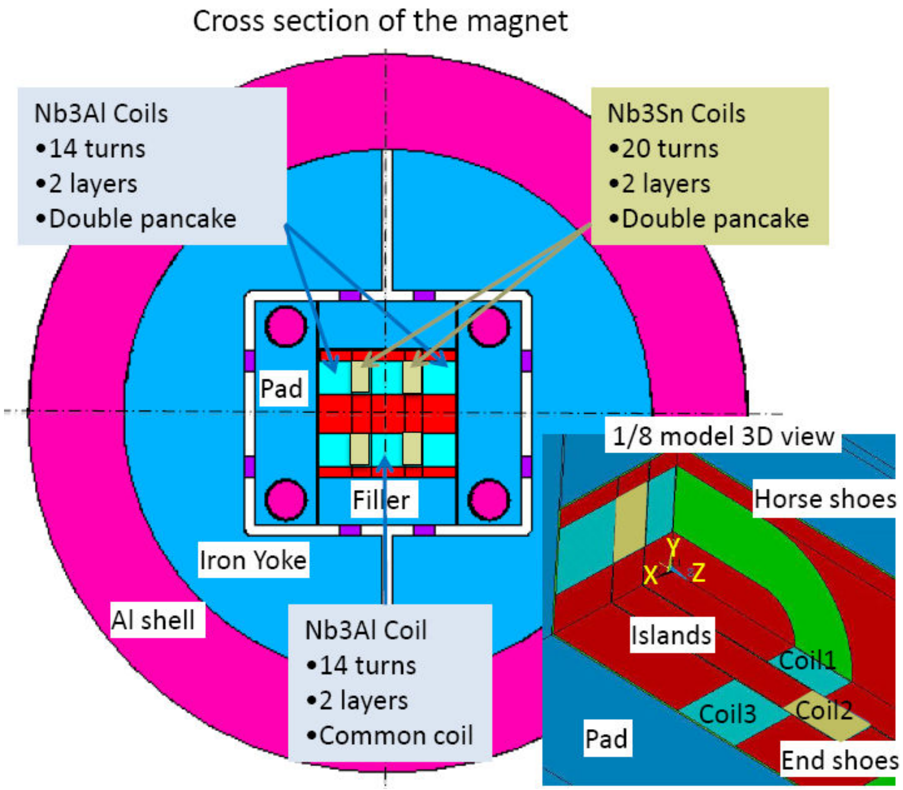




High Field Nb3Al Subscale Magnet R&D

First goal of this program

–to fabricate 13 T small magnet for demonstrating the feasibility of high field magnet with Nb_3Al.

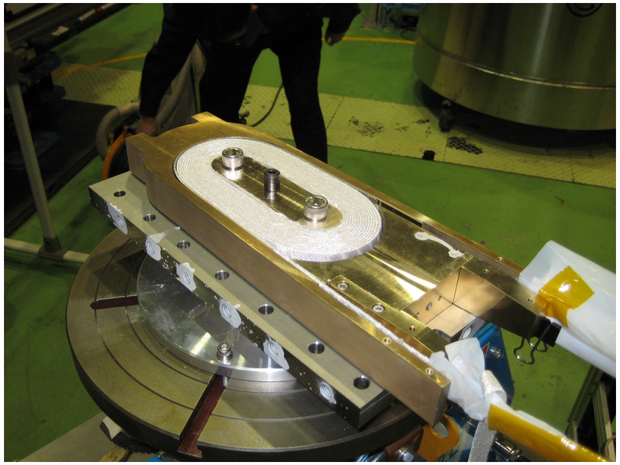


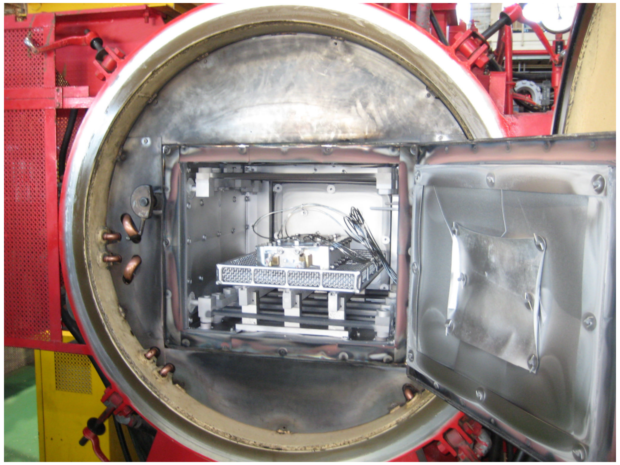
Item	Value
Operation current	12.1 kA
Peak field	13.1 T
Stored energy	71.8 kJ
Magnet Length	740 mm
Shell Dia.	680 mm
Nb3Al Strand Dia.	1 mm
Cu/Non-Cu ratio	0.96
No. of Stands	28
Cable dimension	13.93*1.84 mm2
Cable Insulation	0.25 mm
Nb3Al Coils No.	3
Turns No. per layer	14
Layers No. per coil	2
Nb3Sn Coils No.	2
Turns No. per layer	20
Layers No. per coil	2

Present Status

- Coil Fabrication -

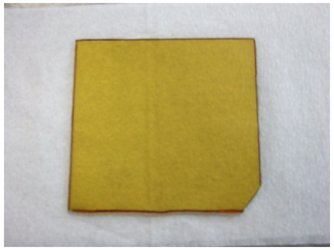
- The 1st practice coil winding w/ NbTi cable was completed.
- Heat reaction at 800 °C for 10 hours in a vacuum furnace was done to check uniformity of temperature. Vacuum impregnation is ready.
- Following another practice winding, the 1st Nb3Al coil will be completed soon.





- Resin Development-

- Radiation resistant resin of Cyanate Ester has been newly developed for the Nb3Al coil toward high field accelerator magnet.
- Spec.
  - low viscosity
  - control of solidification
  - mechanical strength



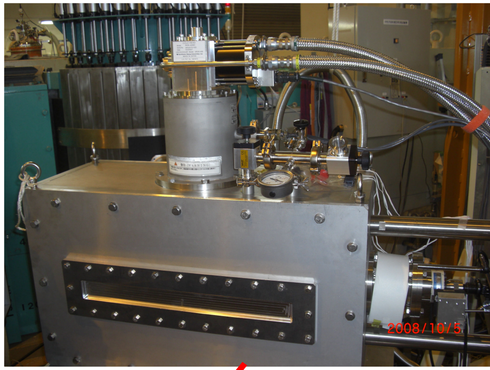
Neutron Diffraction at J-PARC

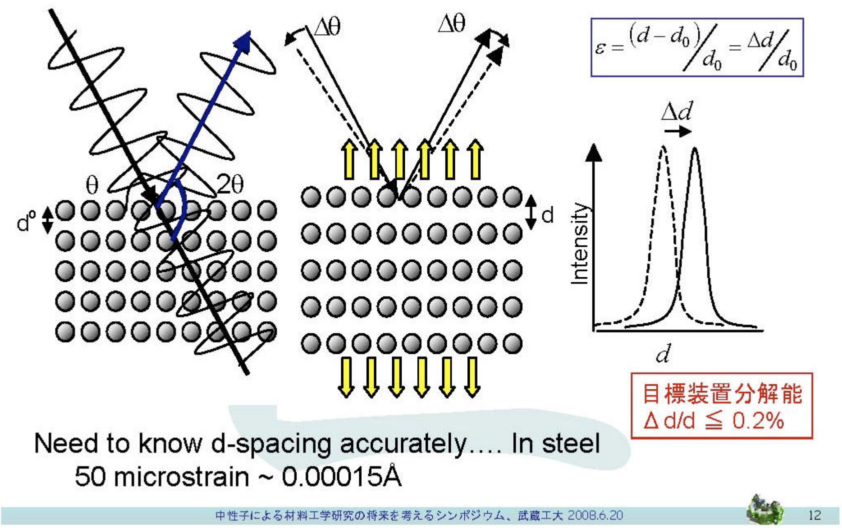
- The "lattice parameter" can be determined by the neutron diffraction J-PARC:
  - Strain of Nb3Al and Nb3Sn wires,
  - Strain distribution of the coil or 10-stacked cables,
  - at 4 K to RT.

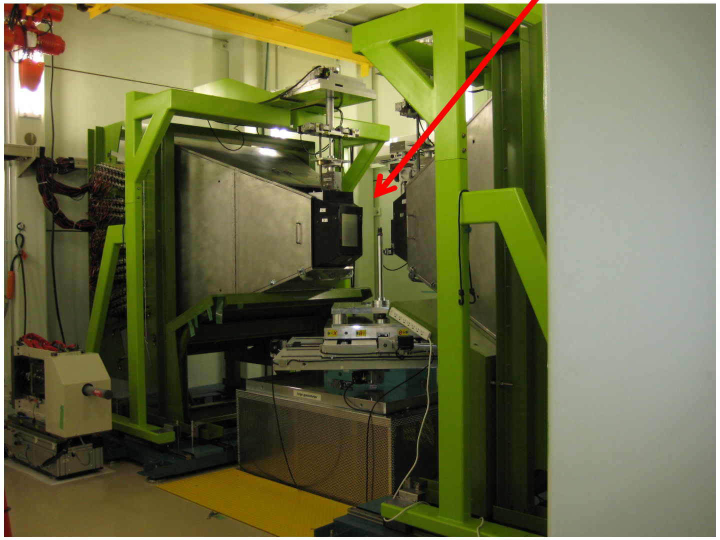
- In collaboration with JAEA-ITER group, the cold tensioner (4K, 50kN) is being developed and will be ready for measurement in JFY2010.

- The first measurement of Nb3Al is planned in May 2010.

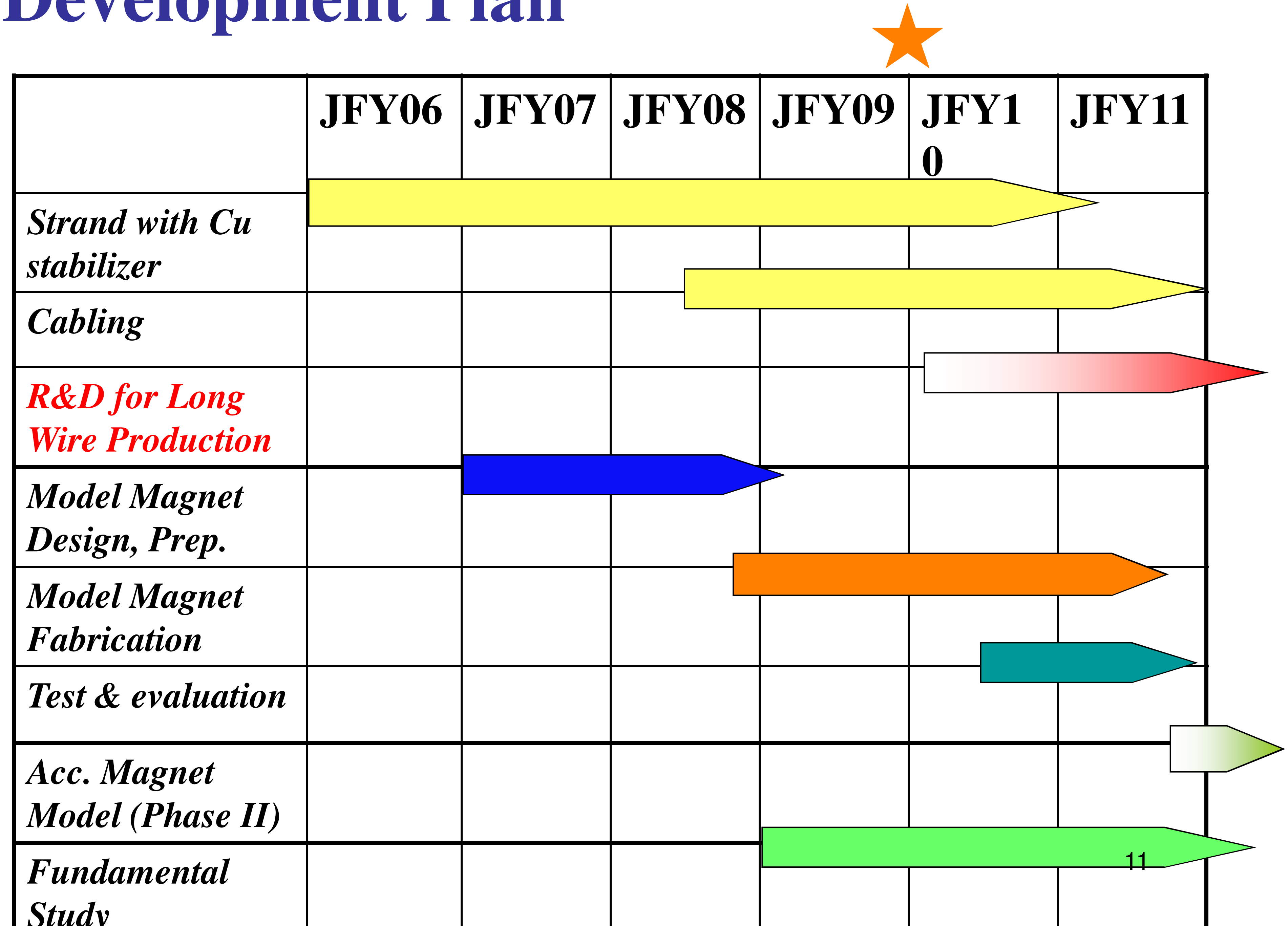
Cold tensioner for neutron diffraction







Development Plan



New Budget Proposal

(Unit: kJYen)

	JFY2009	JFY2010	JFY2011
Nb3Al wires, Subscale Magnet R&D Long wire R&D (New)	21,000	20,500	14,300
Fundamental Study	31,000	7,500	4,700
Travel, etc,	2,000	2,000	2,000
Total	54,000	30,000	21,000

Already approved in 2008

New budget request for
~10 km long wire production.

* Technological review for KEK-NIMS activities in JFY2009 was already made before this committee. The money transfer from CERN for JFY2010 was completed in this March.
* Travel expenses for CERN researchers coming to KEK is expected as the different item.

Summary

- The first Rutherford-type Nb3Al cable (K1) was successfully fabricated. The K3&K4 wires are being developed and cabling is anticipated May 2010. Fabrication of K5 precursor is underway.

- The first practice coil winding for 13 T Nb3Al sub-scale magnet was done. The first Nb3Al coil will be fabricated soon.

- Neutron diffraction measurement to study strain sensitivity on Nb3Al will be started May 2010 at J-PARC.

- Several studies regarding radiation resistance are underway:
  - -Cyanate ester resin, neutron irradiation at cold.

- R&D toward 10 km long SC wire production is to be started in JFY2010. Technical review for a new budget request is anticipated within JFY2010.

Nb3Al: Rapid Heating Quench Method

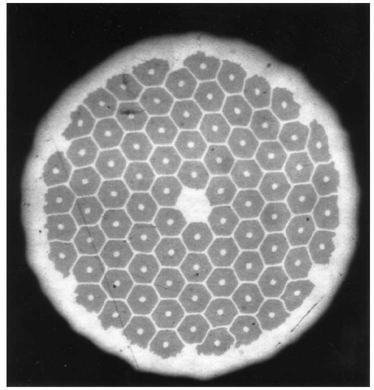
Mono-filament

↓ Jerry-Roll: Nb+Al sheets, Nb or Ta core

Multi-filament

↓

Precursor (Nb/Al)



>2000°C

↓ ⇐ **Rapid Heating Quenching**

(Nb/Al)ss — Strand w/o Cu

↓

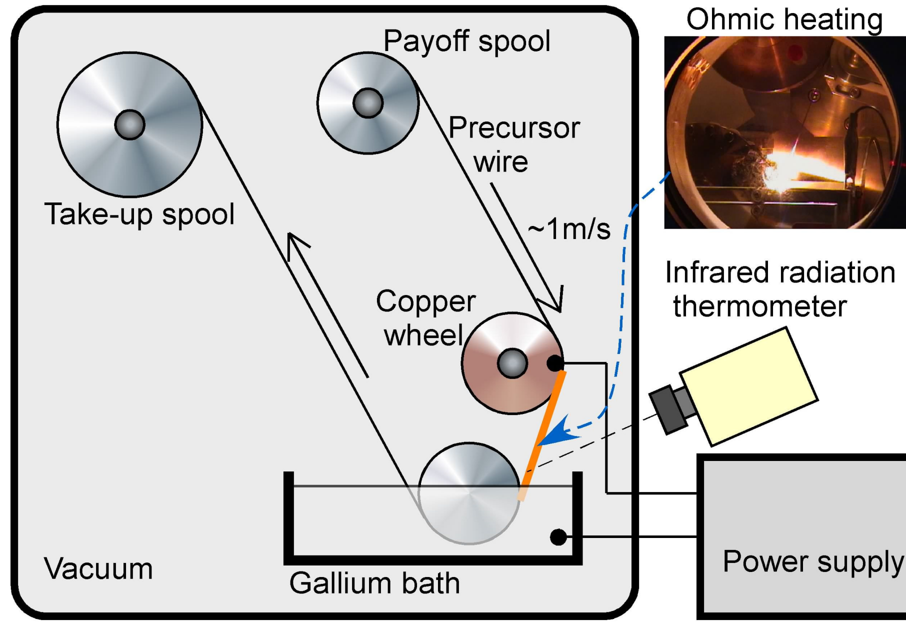
Cu stabilization

↓ (repeated cycle)

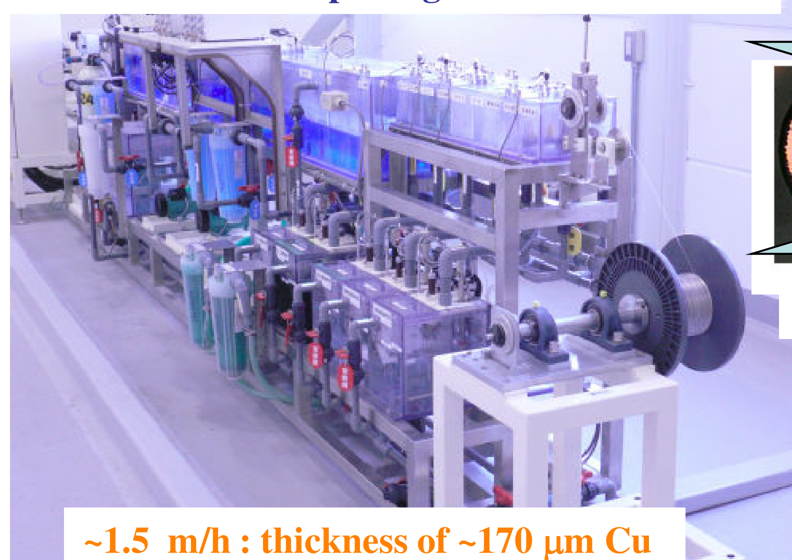
Area reduction

↓ ⇐ 2^{nd} heating (800°C×10h)

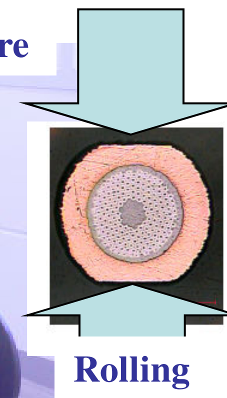
Nb_3Al — A15 strand w/ Cu



Continuous Electroplating for Ta-matrix Wire

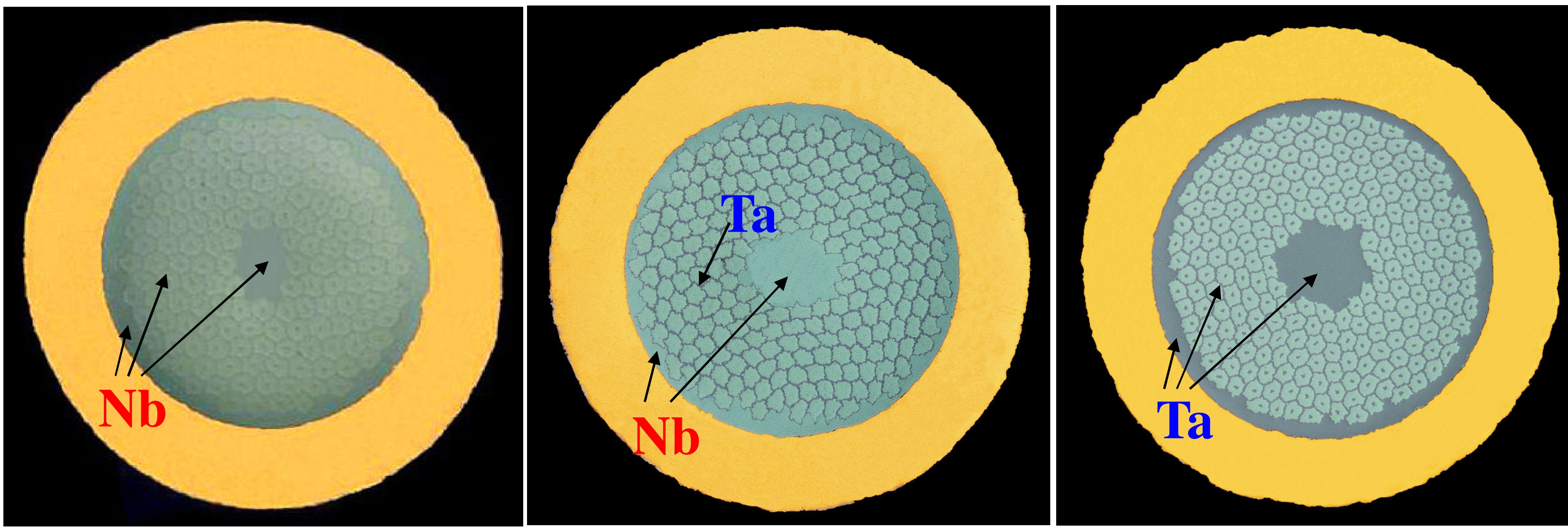


~1.5 m/h : thickness of ~170 μm Cu



Cu Stabilized Nb_3Al Strands with Different Matrix

(a) F1 strand (all Nb matrix) | (b) K1 strand (partial Ta matrix) | (c) K2 strand (all Ta matrix)

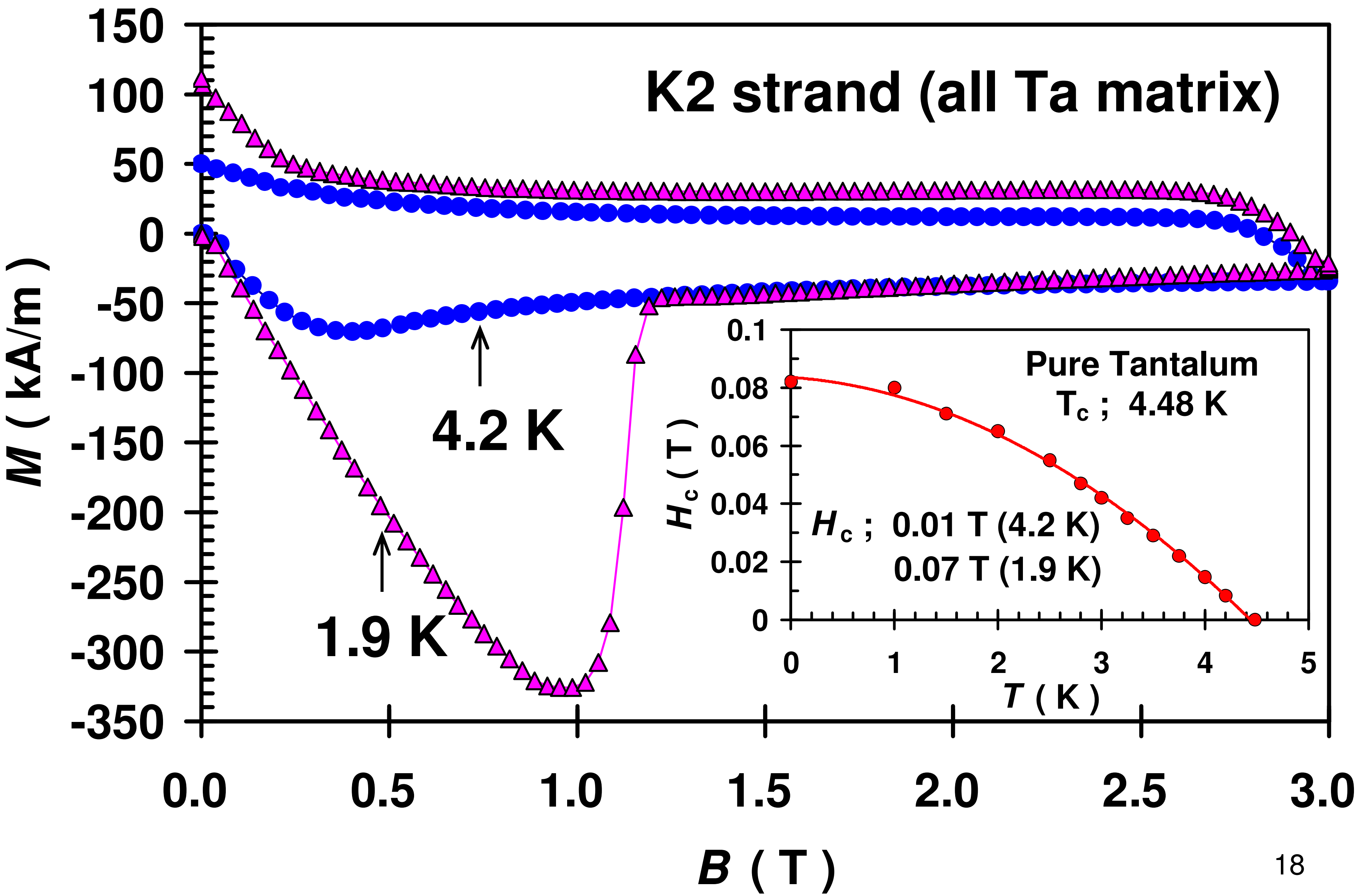


This work | This work

Development of Nb3Al Strands

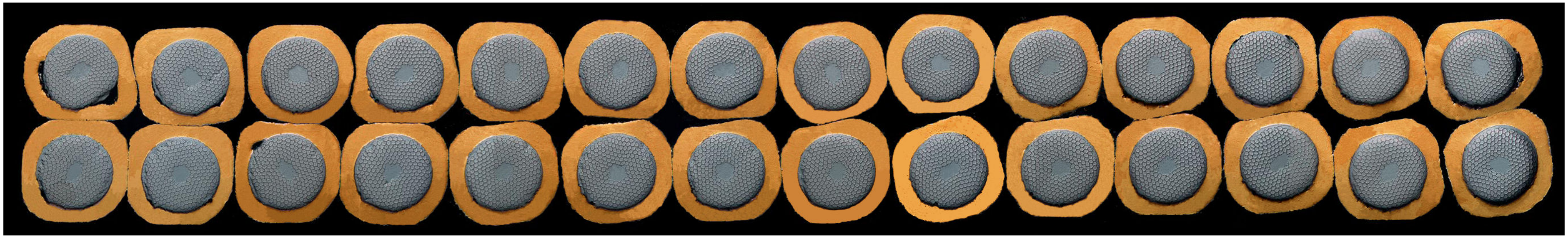
	JFY2007-2008		JFY2008-2009		JFY2009-2010	JFY2010-2011
Wire No.	**K2 (ME492)**	**K1 (ME493)**	**K4 (ME502)**	**K3 (ME501)**	**K5**	**K6**
Matrix material	Ta	Ta	Ta	Ta	Ta	TBD
Core & Skin material	Ta, Ta	Nb, Nb	Nb, Ta	Nb, Nb	Nb, Nb	TBD
Matrix ratio	0.8	0.8	0.95	0.8	0.89	TBD
Num of filaments	222	222	222 (241)	294 (313)	222 (241)	TBD
# of wire breaking	7	4	0	~10		
RHQ						
Wire dia (mm)	1.35	1.35	1.35	1.35	1.35	TBD
Filam dia (mm)	69.8	69.8	66	60	67	TBD
Barrier thick(mm)	8	8	11	8	10.8	TBD
Twist pitch (mm)	0	0	54	54	54	TBD
RHQ I (A)	202					
Final strand						
wire dia (with Cu)	1.00	1.00				
wire dia (w/o Cu)	0.72	0.71				
AR ratio (%)	72.00	72.00				
filament dia (mm)	37	36				
barrier thick (mm)	4.2	4.2				
twist pitch (mm)	45	45				
Non-Cu Jc (A/mm2)						
@ 10T with AR	1776	1563.5				
@ 12T with AR	1320	1202				
@ 15T with AR	785	761.4				
Application		Coil-A Test @FRESCA	Coil-C Test @FRESCA??	Coil-B	Coil-D	Backup

Magnetization Curve at 1.9 K



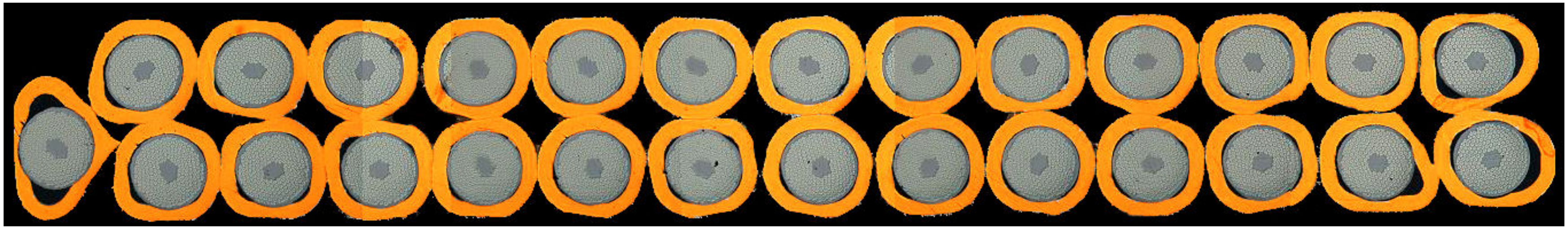
Rectangular Rutherford Cable

(a) K1 cable (Cu ion-plating (<1 μm) + Cu electroplating (150 μm))



Number of strand: 28, Width: 13.96 mm, Thickness: 1.84 mm, Lay angle: 14.9 deg., Packing factor: 86.7 %

(b) K2 cable (Ni electroplating (<1 μm) + Cu electroplating (150 μm))



Number of strand: 27, Width: 13.93 mm, Thickness: 1.84 mm, Lay angle: 14.5 deg., Packing factor: 85.0 %

Proposal of K1 Cable Tests at FRESCA

Goals of the cable tests at FRESCA

The Nb_3Al cable tests at FRESCA will be a feasibility study of a high field Nb_3Al common coil magnet, which will be fabricated by 2011. We expect to get the following data from the cable tests at FRESCA.

- Quench current at 4.3 K and 1.9 K at high fields (7 – 10 T).
- Ramp rate dependence on the quench current at 10 T.
- Maximum current (I ramps) and stability threshold (B ramps) at low fields (0 – 6 T).
- RRR measured during cool down and/or warm up.

+

Quench stability study using spot heaters

Summary of Wire R&D 2009

(1) New designed K1 and K2 strands and cables were fabricated. K1 strand used a tantalum for only interfilament matrix and K2 strand used for all strand matrix. Other strand parameters were arranged as the same.

(2) In this work, the wire breaking happened frequently on the drawing of both precursors, and it may be caused by the de-bonding of interfilament as well as a less cold-workability of a tantalum itself.

(3) Non Cu *Jc*'s at 12 T were 1,300 A/mm^2 at 4.2 K and 1,600 A/mm^2 at 1.9 K, and its improvement was about 20 %. The difference of strand matrix did not remarkably influence to the critical current density.

(4) The low field magnetic instabilities at 4.2 K could be suppressed on K1 and K2 strands because of the tantalum interfilament matrix. To reduce magnetic instabilities in low fields at 4.2 K, a tantalum interfilament matrix is effective predominantly.

(5) Rectangular K1 and K2 Rutherford cables with a similar geometry were fabricated using a compact cabling machine at Fermilab. A remarkable copper separation happened on K2 cable, although it did not apparently on K1 cable. The copper stabilizer prefers a niobium as an interface material to obtain a good bonding.

(6) A 22 m long K1 cable could be fabricated, and it will be used for the one of double pancake Nb_3Al coils in the near future. For another Nb_3Al coils, we are going to fabricate additional Nb_3Al strands and cables, which are based on a modified K1 design. The improvement of a cold-workability of precursors is necessary as well as that of the critical current density.

Budget Detail –Revised

(Unit: kJYen)

		JFY 2009	2009 closing (prediction)	JFY 2010	JFY 2011
Magnet R&D	Jigs, Yoke, Shell	Covered by another grant	1300	1000	0
	Coil	3000	1400	3000	1500
	PS, DAQ, Cryostat	2000	0	1000	2000
Wires and cable for the magnet	Completion of electroplating for wires07-08	6000	6900	0	0
	Wires(1 km)	8000	6600	10000	3000
	Cabling	Fermilab Collab.	Fermilab Collab.	Fermilab Collab.	Fermilab Collab.
	consumable	2000	1600	500	800
	Long wire production R&D	0	400	5000	7000
Fundamental Study	15T Solenoid, Jc Stress Depend.	17000	15200	2000	1000
	Thermal conductivity meas.	0	2600	1000	1000
	Cyanate ester resin	1000	1000	1500	700
	Cold tensioner for n diffraction	9000	9800	1500	1000
	Short strand R&D	4000	4700	1500	1000
Travel Expenses		2000	1500	2000	2000