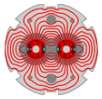


BNL -FNAL - LBNL - SLAC

LARP CM18
May 7-9, 2012
FNAL

LARP Conductor: Production, Performance and Plans

Arup K. Ghosh (BNL)

Outline

- OST 108/127 strand production
  - Piece length
  - J_c
  - RRR
  - Non-Cu %
- Ti-Ternary strand production
- Smaller Filament Strand
- Production Plan for Strand and Cable
- Summary

Ta-Ternary 108/127 Production at OST

- Presently OST is producing Ta-Ternary 108/127 f LARP
- OST provides the following test results for samples taken from the front-end (FE) and back-end (BE) of each billet with max. yield of ~ 35 kg of wire.
  - I_c and n-value at 12, 13, 14 and 15 T
  - J_c at 12 T and 15 T (required by Specs)
  - Wire average diameter
  - Non-Cu fraction
  - RRR
- Samples are reacted using a schedule optimized for the 54/61 stack wire
  - 210C/48h + 400C/48h + 665C/50h

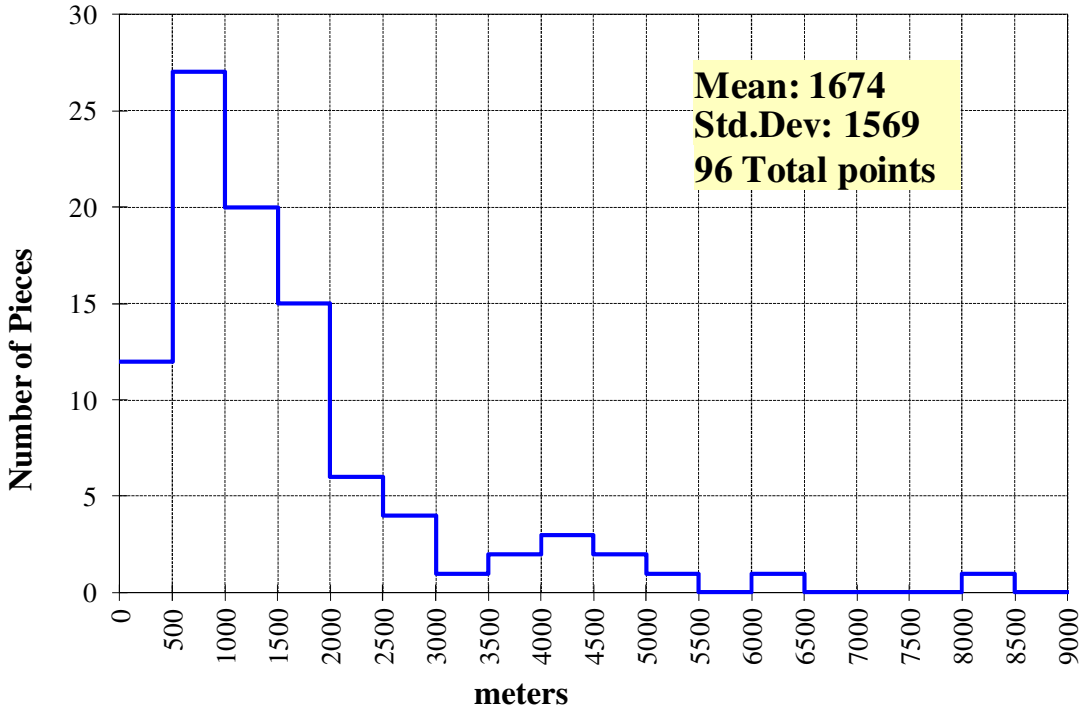
Ta-Ternary 108/127 Production

- LARP
  - 130 kg delivered Mar'2011
  - 115 kg delivered Sep'2011
  - 125 kg – delivered Feb'2012
  - 132 kg – delivered Mar'2012
  - 57 kg – delivered Apr'2012
  - 194 kg order – delivery July'2012
- CDP program
  - 180 kg order delivery in May-June'2012

These orders placed in FY'2010
Delivery time scale is 18-20 months

Conductor Piece Length

- Cable UL for full scale magnets of 120 mm aperture will be ~700 m
  (*considerably higher if aperture is increased to 140 mm*)
- Cabling losses are significant when strand piece length is comparable to UL
- After sustained production, RRP 54/61 achieved 1-2 pieces per billet (5-10 km range)
- RRP 108/127 is still delivered in relatively short pieces, with min spec 550 m



158 km delivered

> 550 m 98%

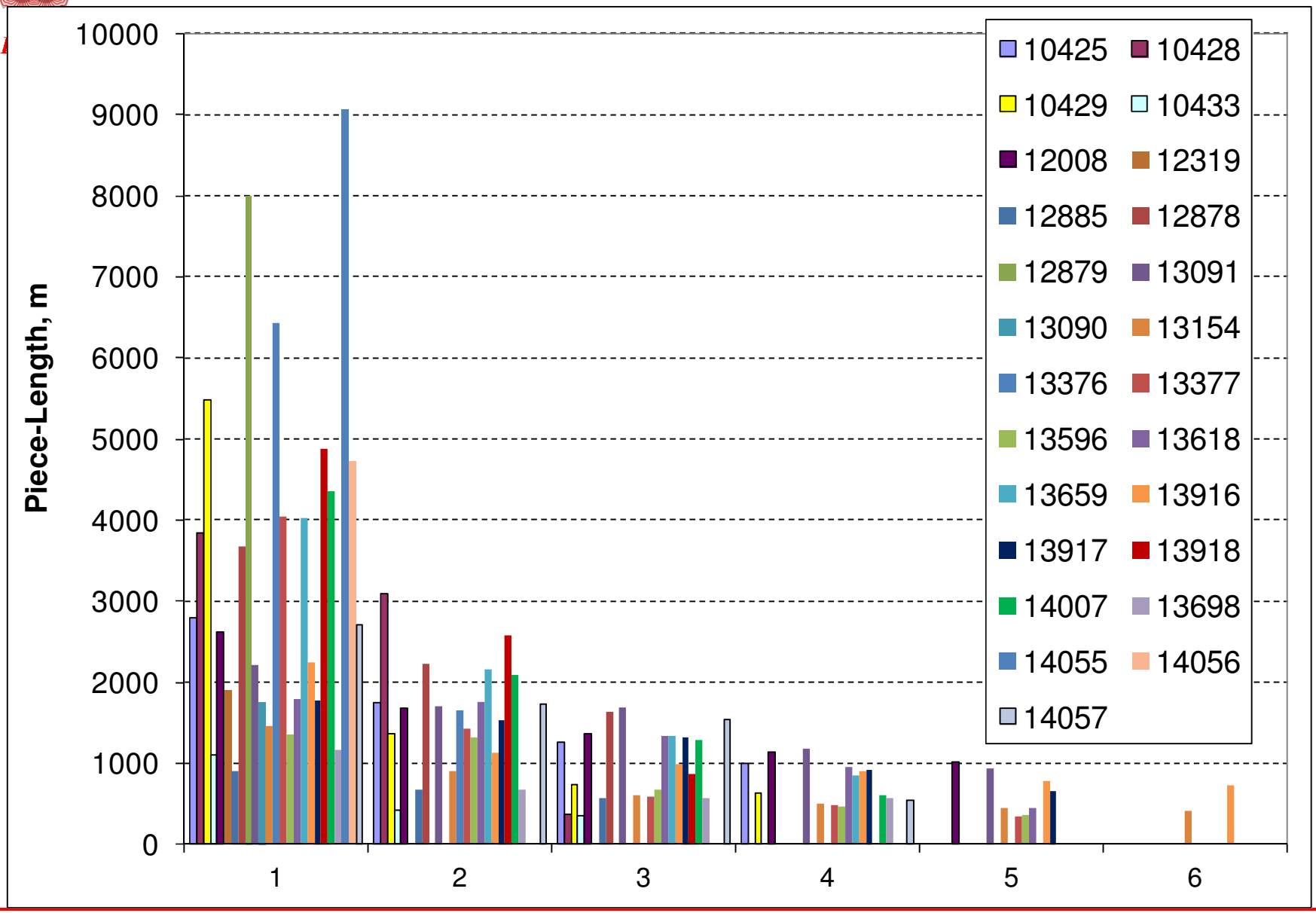
>1000 m 86%

>3000 m 37%

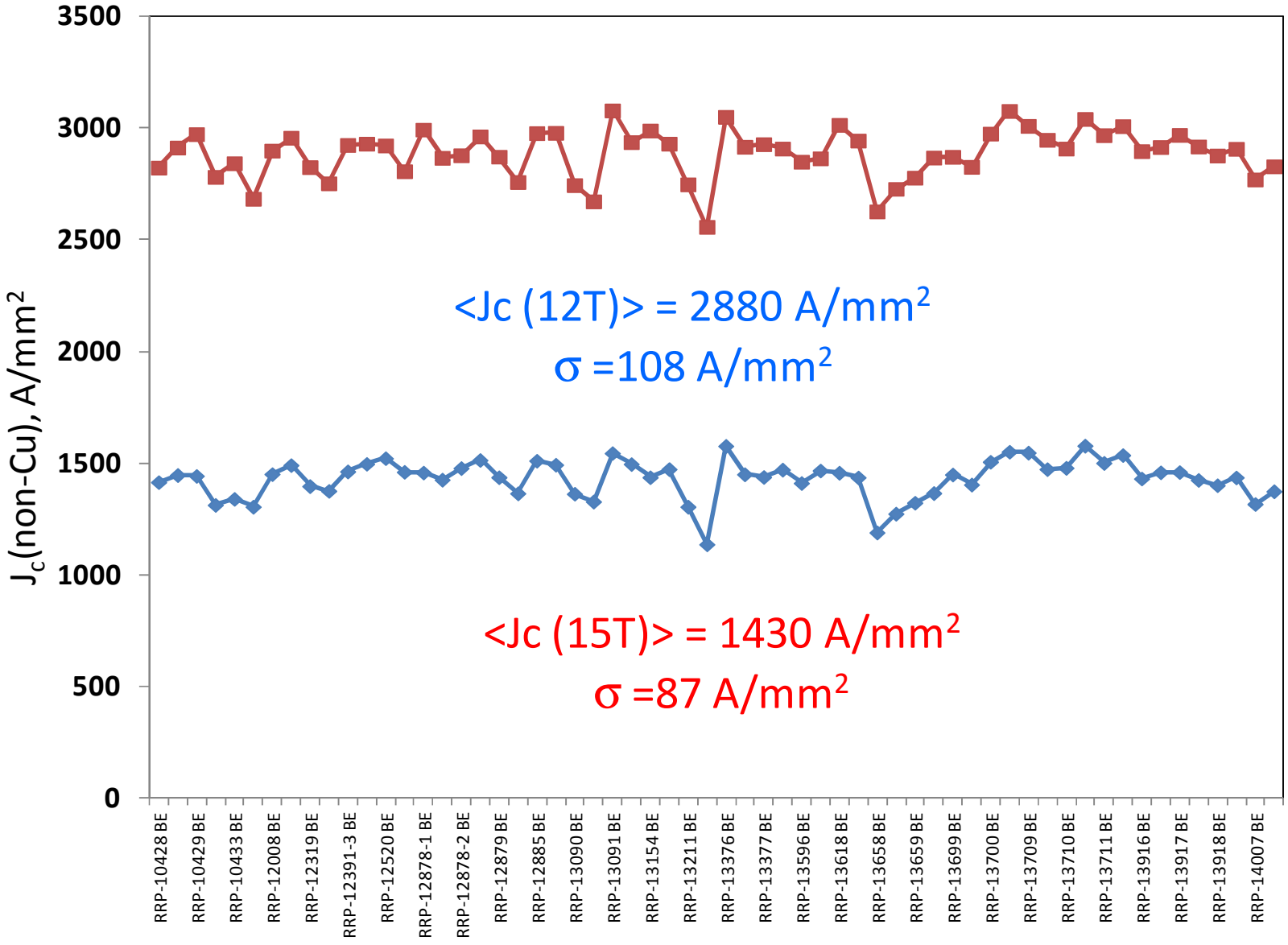
>5000 m 18%

Using this inventory Cabling Losses for LHQ - UL of 300 m is ~ 10%

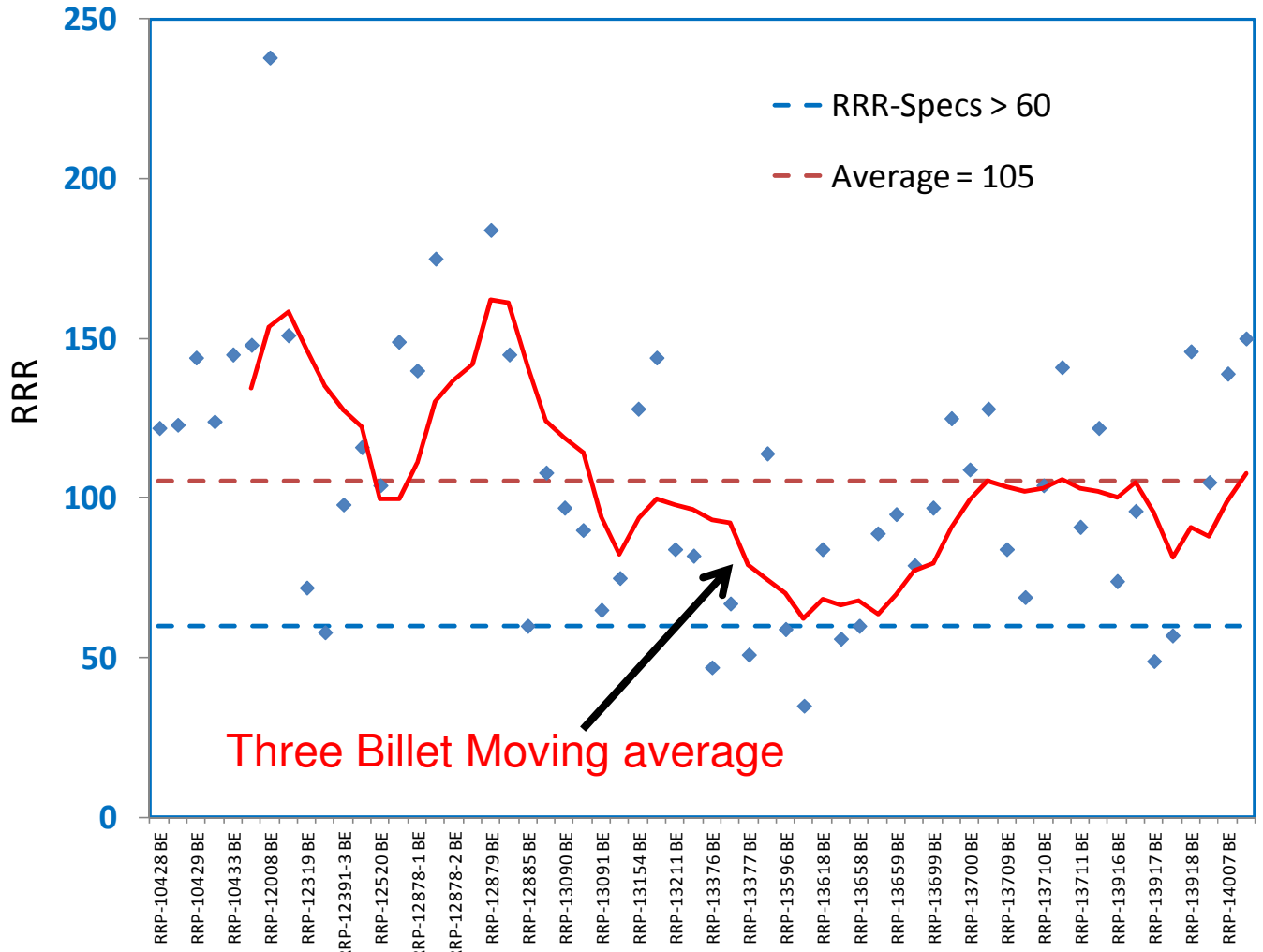
Piece Length, 25 billets



J_c(non-Cu)


3500
3000
2500
2000
1500
1000
500
0
J_c(non-Cu), A/mm^2
<Jc (12T)> = 2880 A/mm^2
σ =108 A/mm^2
<Jc (15T)> = 1430 A/mm^2
σ =87 A/mm^2
RRP-10428 BE
RRP-10429 BE
RRP-10433 BE
RRP-12008 BE
RRP-12319 BE
RRP-12391-3 BE
RRP-12520 BE
RRP-12878-1 BE
RRP-12878-2 BE
RRP-12879 BE
RRP-12885 BE
RRP-13090 BE
RRP-13091 BE
RRP-13154 BE
RRP-13211 BE
RRP-13376 BE
RRP-13377 BE
RRP-13596 BE
RRP-13618 BE
RRP-13658 BE
RRP-13659 BE
RRP-13699 BE
RRP-13700 BE
RRP-13709 BE
RRP-13710 BE
RRP-13711 BE
RRP-13916 BE
RRP-13917 BE
RRP-13918 BE
RRP-14007 BE

RRR
Some measurements are <60

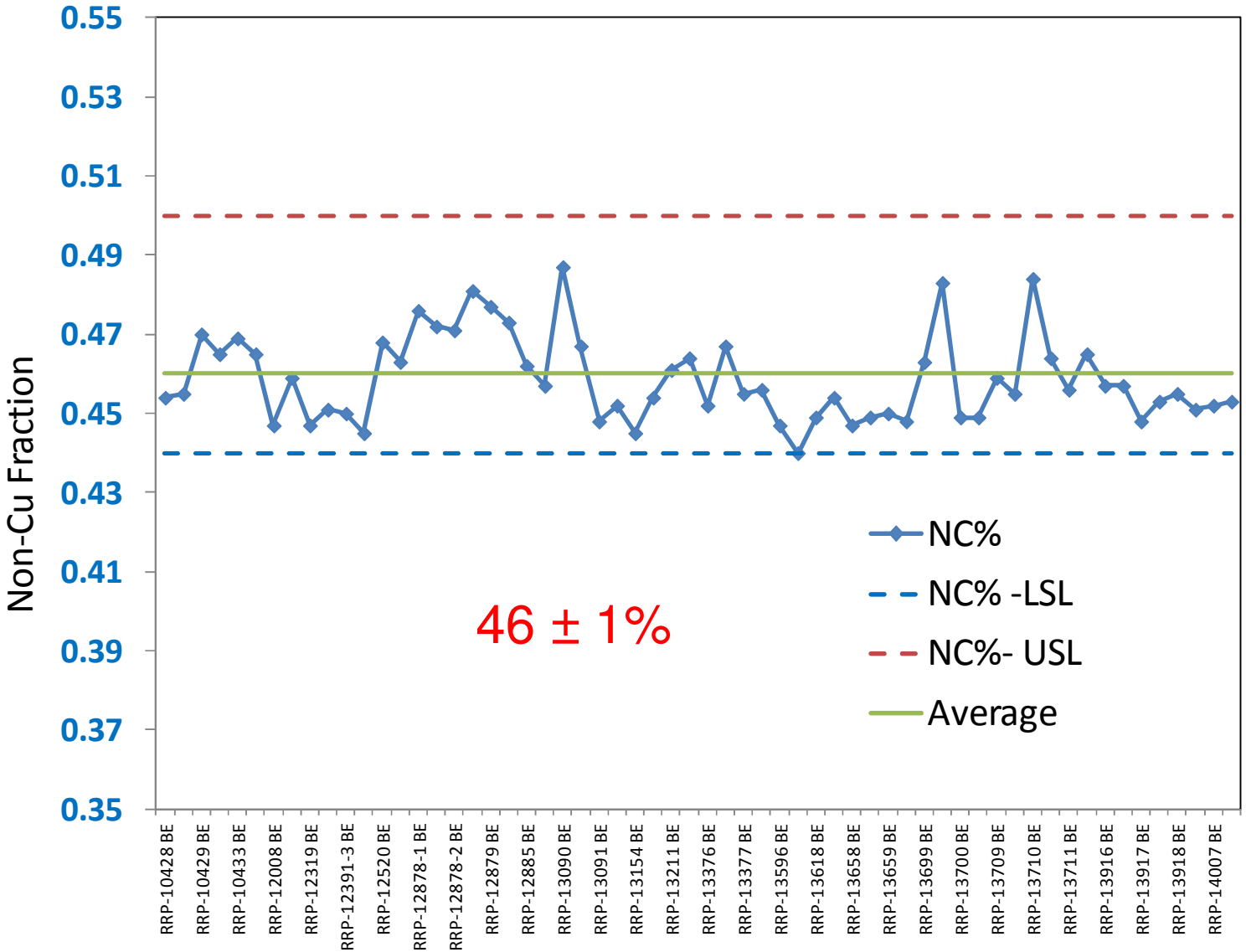


Reaction schedule for HQ coils modified to 650C/48h to increase RRR

$J_c(12T)_{AVG}$ ~ 2750 A/mm^2

~5 % lower J_c

Non-Cu %

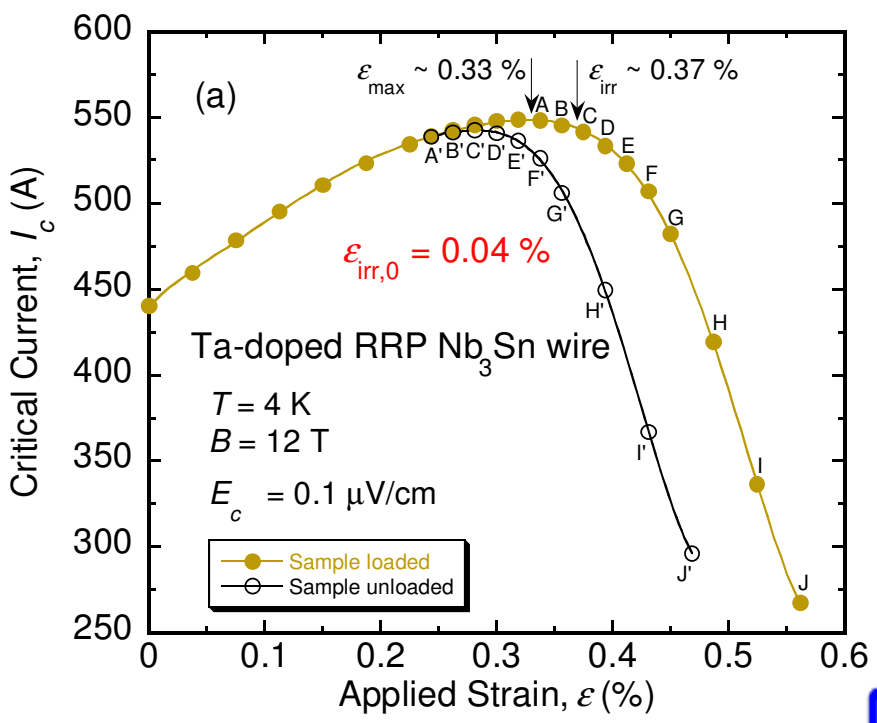

Non-Cu Fraction
0.55
0.53
0.51
0.49
0.47
0.45
0.43
0.41
0.39
0.37
0.35
46 ± 1%
NC%
NC% -LSL
NC%- USL
Average
RRP-10428 BE
RRP-10429 BE
RRP-10433 BE
RRP-12008 BE
RRP-12319 BE
RRP-12391-3 BE
RRP-12520 BE
RRP-12878-1 BE
RRP-12878-2 BE
RRP-12879 BE
RRP-12885 BE
RRP-13090 BE
RRP-13091 BE
RRP-13154 BE
RRP-13211 BE
RRP-13376 BE
RRP-13377 BE
RRP-13596 BE
RRP-13618 BE
RRP-13658 BE
RRP-13659 BE
RRP-13699 BE
RRP-13700 BE
RRP-13709 BE
RRP-13710 BE
RRP-13711 BE
RRP-13916 BE
RRP-13917 BE
RRP-13918 BE
RRP-14007 BE

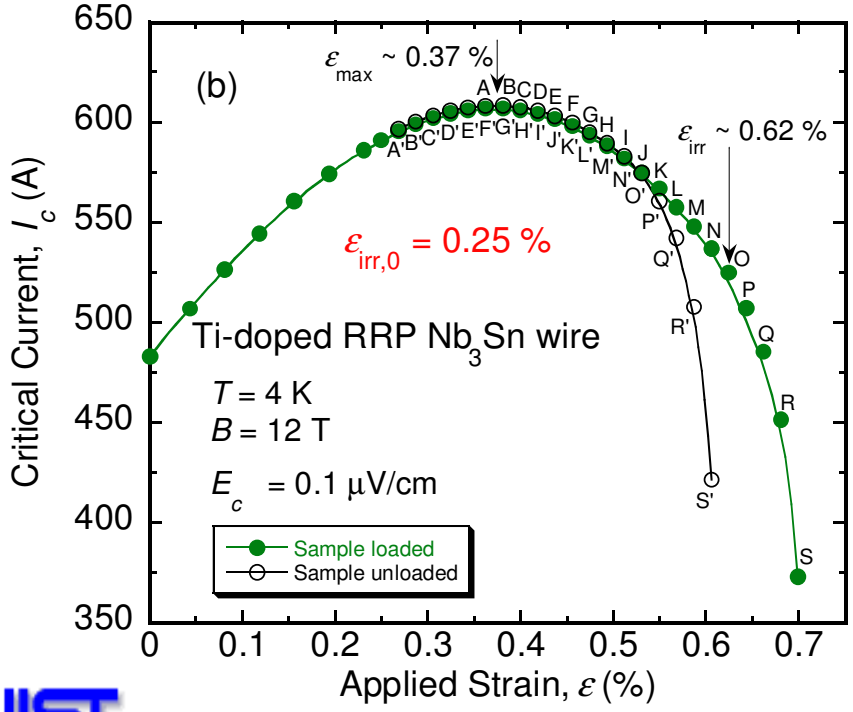
RRP® Ti-Ternary vs. Ta-Ternary

- Advantages of Ti-Ternary:
- Does not require Nb-7.5wt% Ta alloy rods
- Ti content can be tweaked easily to maximize B_{c2}
- Ti accelerates Nb_3Sn reaction
- At 650C/48h , Ti-Ternary has higher J_c(15T) than Ta-Ternary
- Higher strain tolerance

OST is using Ti-Ternary for ITER production

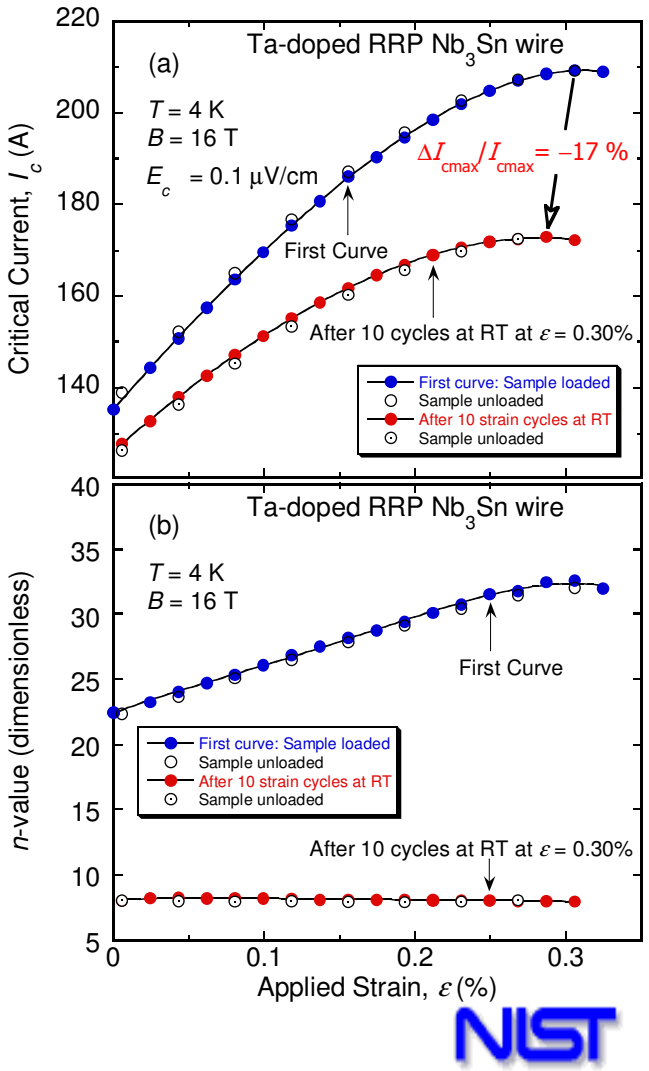
Ti-Ternary vs. Ta-Ternary





In tension, Ti-doped Nb_3Sn wire more strain tolerant than Ta-doped

Strain Cycling: Ta-Ternary



Strain cycling at room temperature at a strain of 0.3 % (~ ε_{max} at 4 K) causes

(a) a noticeable degradation of I_c ~ 17% (with a small shift of ε_{max}),

(b) a drastic depression of the *n*-value in the Ta-doped RRP wire.

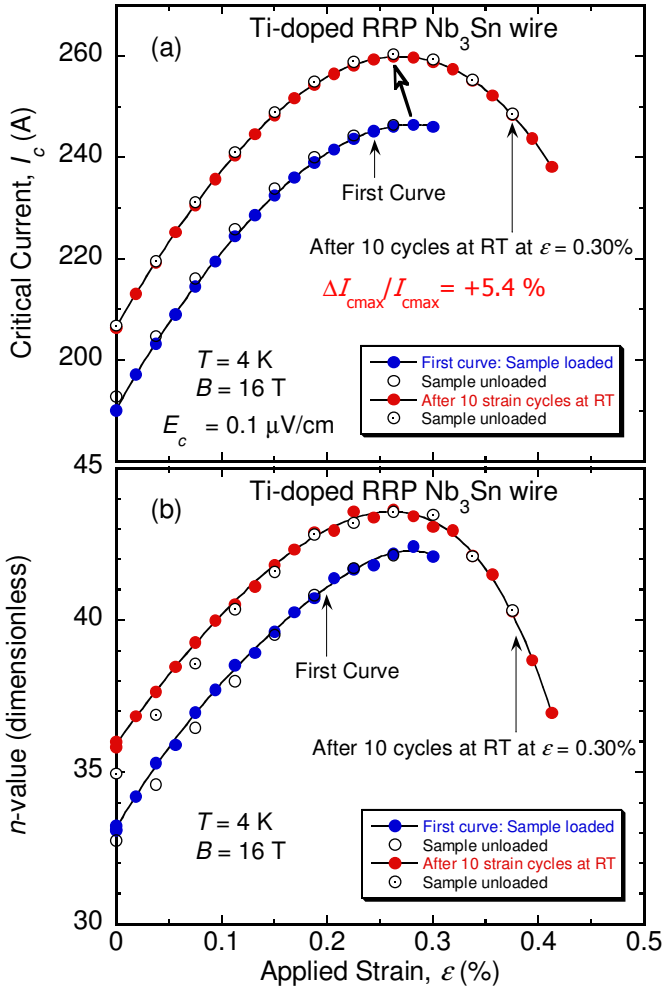
Strain Cycling: Ti-Ternary

Room-temperature *strain cycling* of the Ti-doped wire at a strain of 0.3 % (~ ε_{max} at 4 K) *was not only safe, but caused an increase in*

(a) I_c ~ 5.4% (with a small shift of ε_{max})

(b) *n*-value.

Influence of Ta and Ti doping on the irreversible strain limit of ternary Nb3Sn superconducting wires made with restacked-rod process*
N. Cheggour, L. F. Goodrich, T. C. Stauffer , J. D. Splett , and X.F. Lu, A. K. Ghosh, G. Ambrosio
Supercond. Sci. and Tech., 20, (2010)



Under Cyclic strain at RT., Ti-doped Nb_3Sn wire more robust than Ta-doped

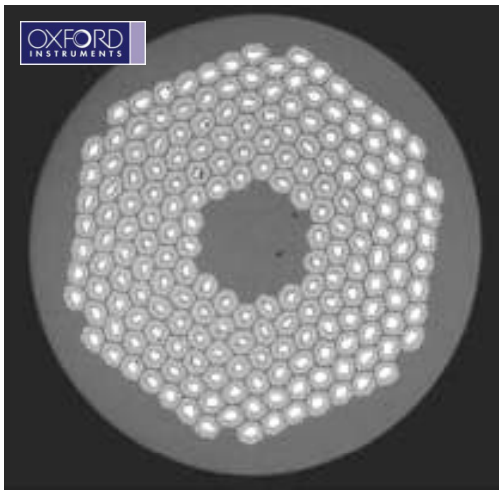
Ti-Ternary 108/127 RRP Strand

- CDP program
  - 22 kg of 1.5 a% Ti delivered in Feb'2010
  - 29 kg of 2.0 a% Ti delivered in 2011
    - Cable HQ-B1010R ⟹ used for HQ-C11
  - 90 kg of 1.5 a% Ti delivered in Mar'2011
    - J_c (12T) ~ 2805 A/mm^2, J_c(15T) ~ 1505 A/mm^2, RRR ~ 75
      - Good Piece length
      - Cable HQ-B1024Z, 500 m , cabling loss ~ 7%
        - ➢ HQ-C18
- LARP
  - 400 kg order (~ 12 billets)
    - 280 kg delivery Oct'2012
    - 120 kg delivery Dec'2012

CDP-Conductor Development – 217 stack

Development of 217 sub-element stack

- 3000 A/mm^2 class could not be processed
- 2400 A/mm^2 class processed to 1.07 mm in one piece
  - However, it had a low RRR for optimized Jc 665C/48h
  - Need thicker barrier or reduced Sn content



WireDia, mm	1.001	0.800	0.701
Ds, um	51	40	35
Jc(12T), A/mm2	2428	2482	2424
Js, A/mm2	2987	3093	3313
RRR	25.6	7.3	4.6

- Very difficult to maintain High-Jc and RRR > 50 for smaller filaments

Conductor Development – 217 stack cont.

Requires new design of sub-element

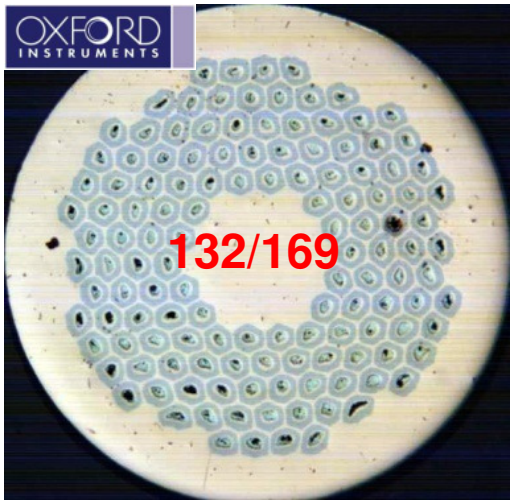
Target "54/61 component dimensions" for wires with diameter of 0.8mm.

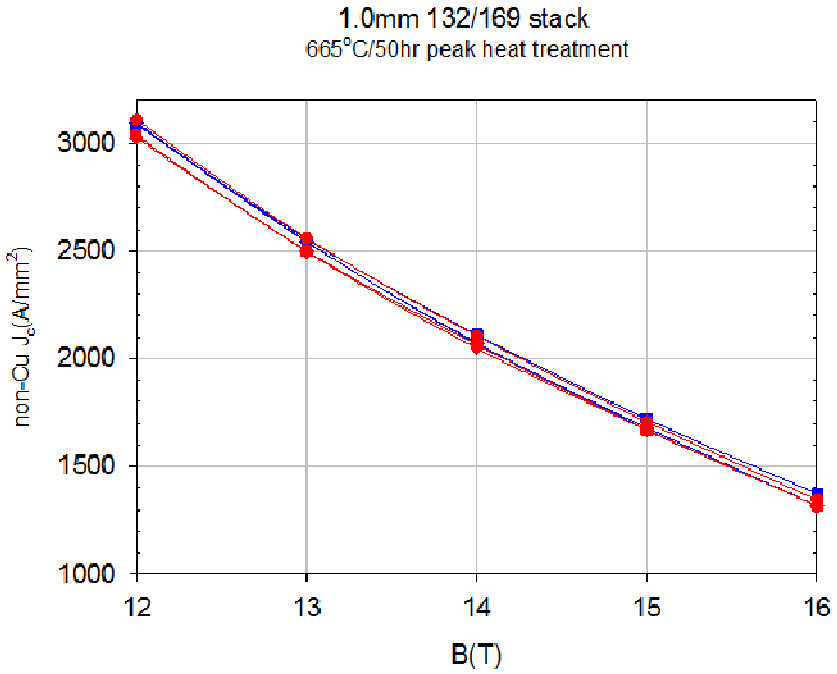
- Increase starting Nb filament diameter
- Increase spacing between Nb filaments
- Increase initial barrier thickness

New 2700 A/mm^2 class conductor being developed under CDP. First results Aug-Sep'12

Conductor Development: Another Option- 169 stack

- 2-3 billets fabricated for CERN
  - Ti-Ternary, 1.0 mm
  - D_s ~ 50 mm, J_c > 2500 A/mm^2, RRR >75
  - 10 km delivered





J_c(12T) ~ 3026 - 3109
J_c(15T) ~ 1652 - 1721
RRR 142 - 201

0.8 mm drawdown:
J_c(12T) = 3000
J_c(15T) =1537

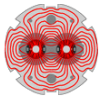
Planning for LHQ and beyond

- LHQ
  - Ta-Ternary
    - Fabricate 4 UL's in FY'12
    - 4 UL's in early FY'13
  - Ti-Ternary
    - Plan to fabricate 6 UL's
- 140 mm aperture magnet cable
  - Initial design is 40 strand cable using 0.84-0.85 mm strand.
  - Plan to hold wire at 1.07 mm pending final design of cable.

108/127 Strand Production and Cabling Plan

Month	108/127 Delivery, kg	Coil ID	Cable ID	Strand Req. kg	Cable Unit Lengths	108/127 0.778mm kg	Ti-108/127 0.778 mm kg	108/127 1.074 mm kg
Jul-11						130	90	
Aug-11		HQ1 C15-C16	B1020Z	80	4	50	90	
Sep-11	115					165	90	
Oct-11						165	90	
Nov-11		HQ1 C17	B1021Z	89	5	76	90	
Dec-11						76	90	
Jan-12						76	90	
Feb-12	125	HQ1-C18	B1024Z	90	5	201	0	
Mar-12	132	LHQ-PC01	B1025Z	60	1	273	0	
Apr-12	57					330	0	
May-12	125	LHQ-PC02	B1026Z	60	1	395	0	
Jun-12	65	LHQ-PC03		60	1	335	0	65
Jul-12	194	LHQ-PC04		60	1	275	0	259
Aug-12		LHQ-C05/06		120	2	155	0	259
Sep-12						155	0	259
Oct-12	280	LHQ-C07/08		120	2	35	280	259
Nov-12		LHQ-		120	2	35	160	259
Dec-12	120	LHQ-		120	2	35	160	259
Jan-13		LHQ-		120	2	35	40	259
Feb-13						35	40	259
Mar-13						35	40	259
Apr-13						35	40	259
May-13						35	40	259
Jun-13						35	40	259

- Cable ID ending in Z denotes cable made with annealed strand with core.
- HQ: 1 m, LHQ: 3.4 m
- 1 UL of HQ requires 18 kg, LHQ: 60 kg



Summary

- OST production of Ta-Ternary 108/127
  - Piece length needs to be better
  - J_c is good but RRR not under control
    - Reducing Sn-content to increase RRR is one option
    - Presently, reaction schedule for HQ coils modified to 650C/48h to increase RRR
- Ti-Ternary production has been phased in.
- For LHQ Magnet
  - 0.778 mm strand planned for 14 -15 coils.
  - 250 kg of wire will be maintained at 1 mm diameter
    - This can be used for the 140 mm aperture cable
- Prospects for conductor with filament diameter much less than 50 μm at 0.8 mm.
  - 150/169 ⇨ 45 μm ⇨ 2 years
  - 192/217 ⇨ 39 μm ⇨ 3-4 years

➢OST is scaling up re-stack diameter to make it easier to pack larger # of sub-elements.

Supplementary Slides

Ron Goldfarb *et al.*

Suppression of Flux Jumps in Marginally Stable Niobium-Tin Superconductors

IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY, VOL. 11, NO. 1, MARCH 2001