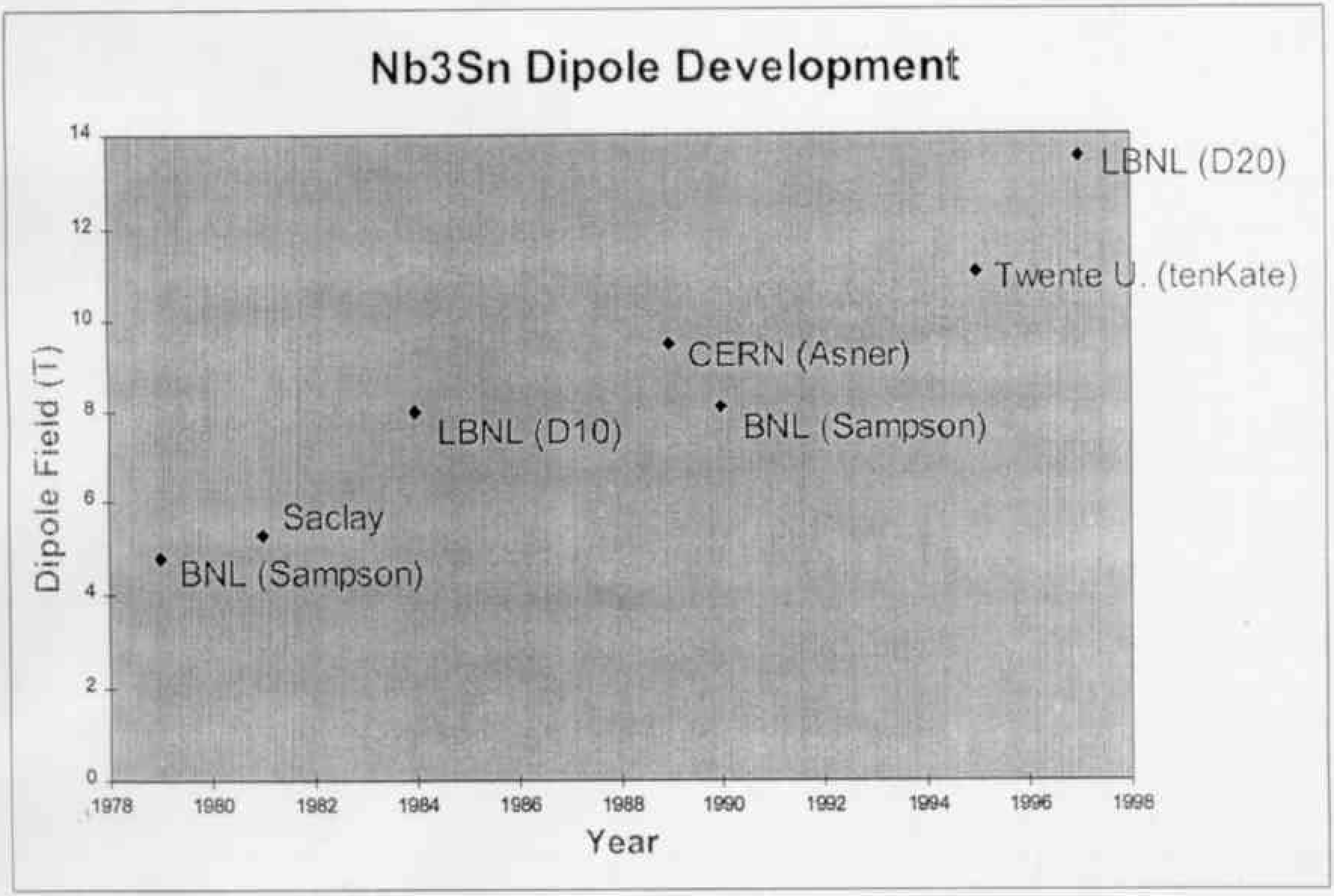
VLHC Magnet Workshop

Lawrence Berkeley National Laboratory Program

R.M. Scanlan

November 16, 1998

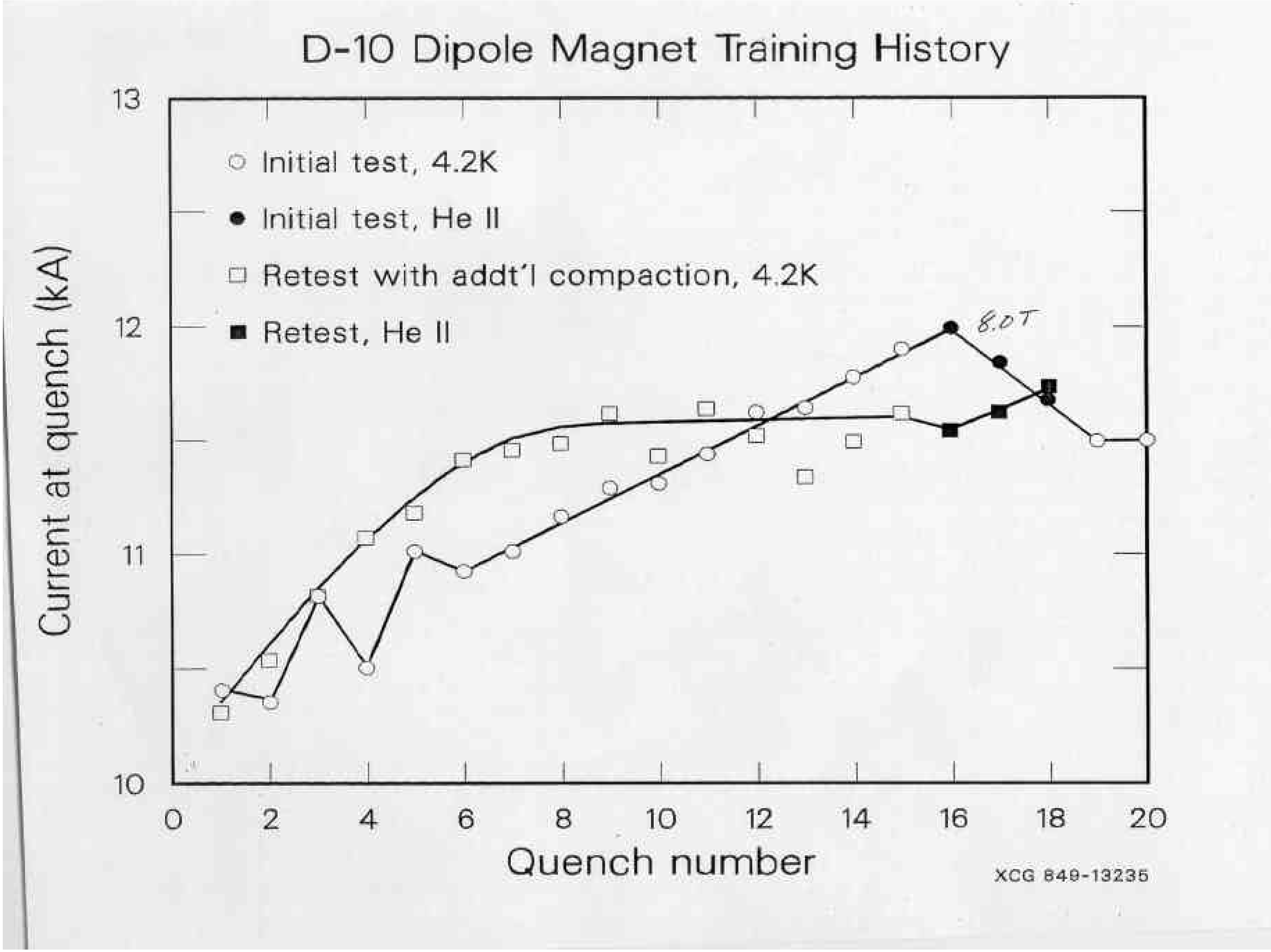

Nb3Sn Dipole Development
Dipole Field (T)
0
2
4
6
8
10
12
14
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
Year
BNL (Sampson)
Saclay
LBNL (D10)
CERN (Asner)
BNL (Sampson)
Twente U. (tenKate)
LBNL (D20)

LBNL Nb3Sn Magnet Chronology

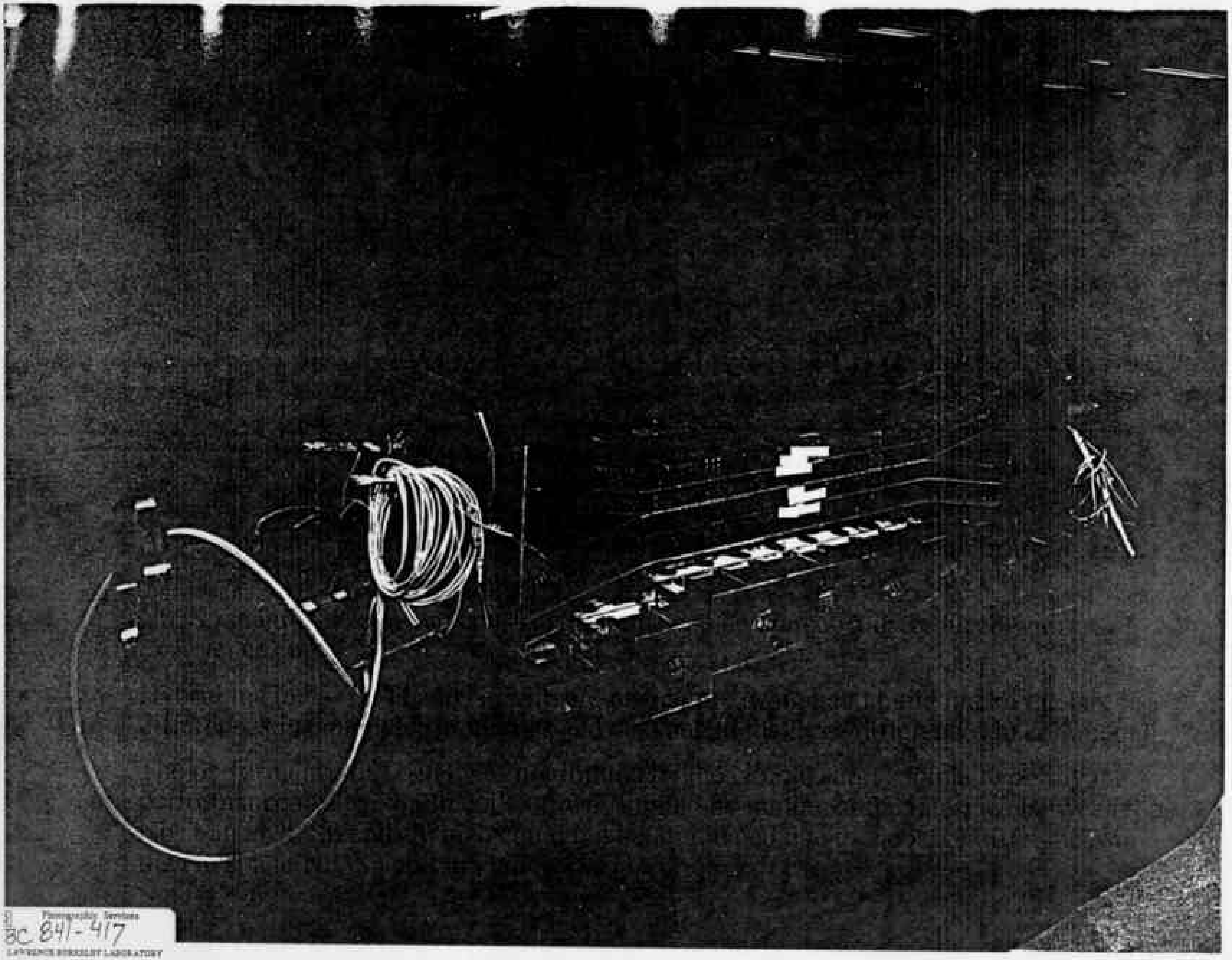
- D-10(1984)--Wind and react, IGC internal tin, racetracks with turned-up ends, 50 mm bore, 8 T central field at 4.3K.
- D19H(1996)--Wind and react, IGC internal tin inner layer, SSC NbTi outer layer,two layer cos theta,50 mm bore, 9 T central field at 1.8K.
- D20(1997)--Wind and react, IGC internal tin and TWCA jelly roll, 4-layer cos theta, 50 mm bore, 12.5 T at 4.3 K, 13.5 T at 1.8K.
- RD2(1998)--Wind and react, TWCA jelly roll ITER strand, common coil racetrack, 5.9 T central field at 4.3K.

What we learned from D10:

- We can build high field dipole magnets from brittle materials such as Nb3Sn
- Lead splices should be designed so that they are well cooled
- Magnets should have active protection and redundant protection systems

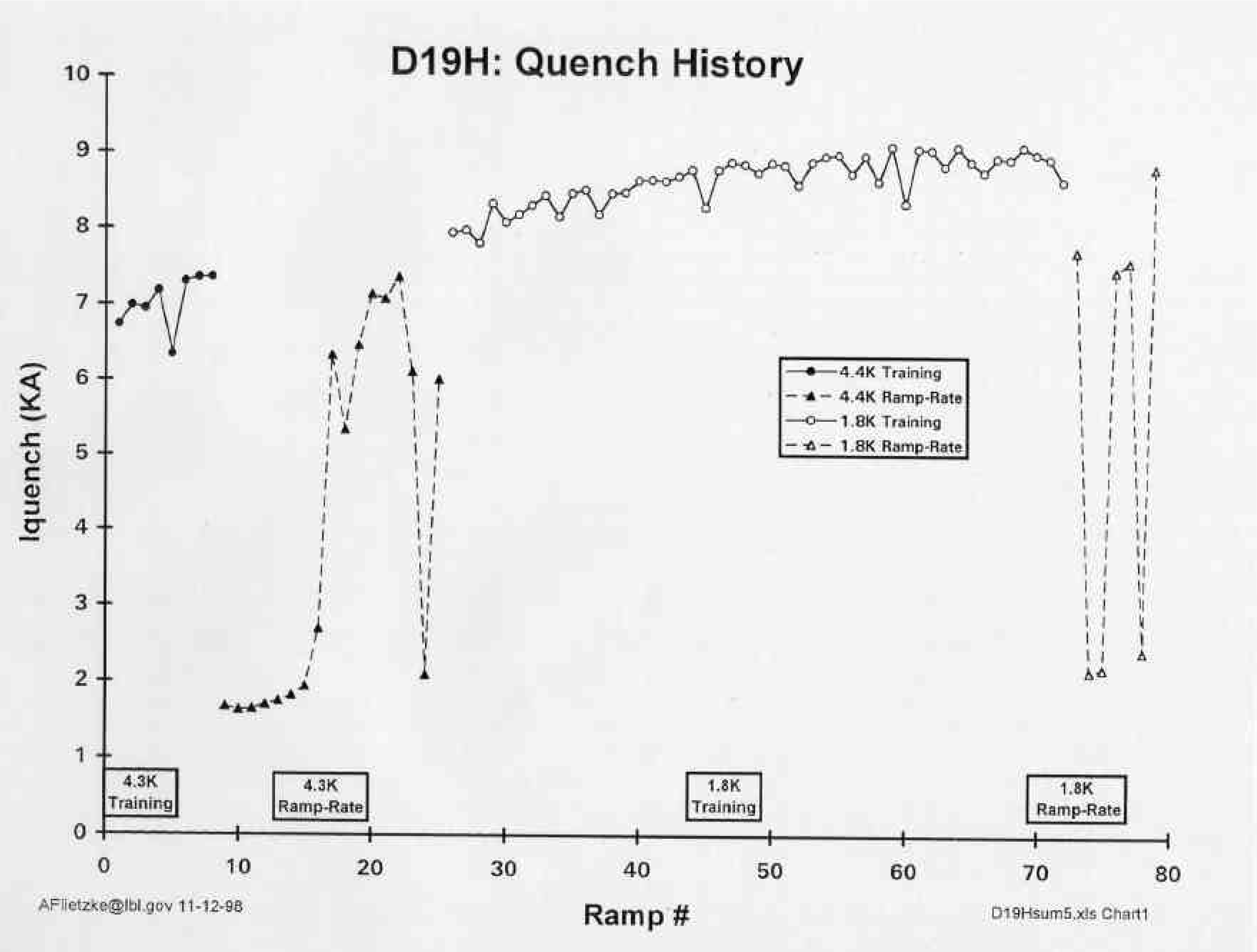


D-10 Dipole Magnet Training History
Initial test, 4.2K
Initial test, He II
Retest with addt'l compaction, 4.2K
Retest, He II
8.0T
Current at quench (kA)
13
12
11
10
0
2
4
6
8
10
12
14
16
18
20
Quench number
XCG 849-13235


Photographic Services
BC 841-417
LAWRENCE BERKELEY LABORATORY

What we learned from D19 H:

- As we demonstated earlier with D10, dipole magnets can be built with brittle materials such as Nb3Sn
- Nb3Sn magnet design and construction time can be dramatically reduced with experience
- Hybrid magnets (NbTi and Nb3Sn) are difficult to design and build due to the large differences in conductor properties and also due to the large differences in coil moduli
- The performance of D19H was not limited by the Nb3Sn short sample Ic nor by the performance of the Nb3Sn coils. It was limited by motion at the interface between the NbTi and Nb3Sn coils, which could not be eliminated due to the large differences in the NbTi and Nb3Sn coil moduli



D19H: Quench History
Iquench (KA)
10
9
8
7
6
5
4
3
2
1
0
4.4K Training
4.4K Ramp-Rate
1.8K Training
1.8K Ramp-Rate
4.3K Training
4.3K Ramp-Rate
1.8K Training
1.8K Ramp-Rate
0
10
20
30
40
50
60
70
80
Ramp #
AFlietzke@lbl.gov 11-12-98
D19Hsum5.xls Chart1

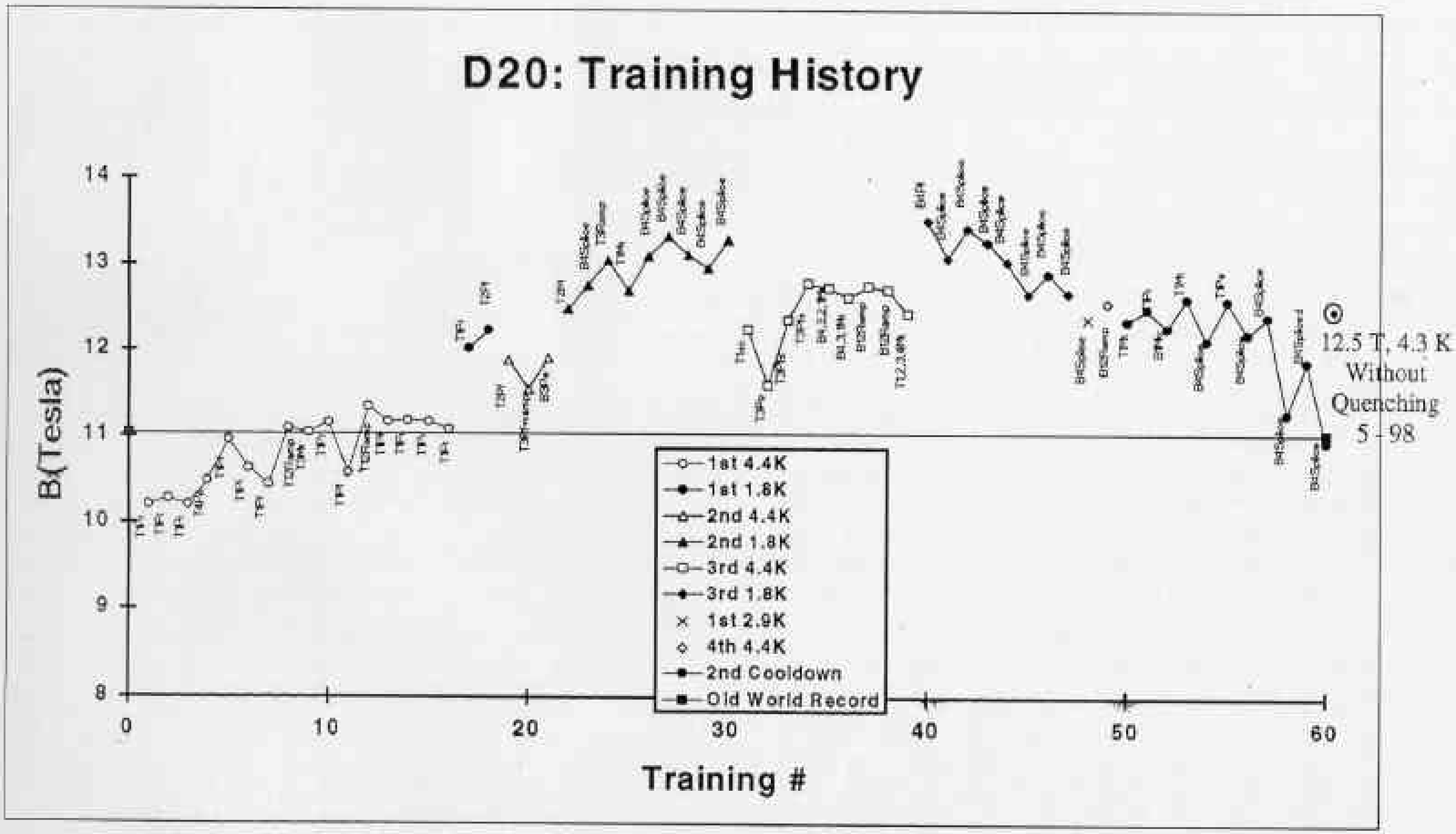
What we learned from D20:

- Both IGC and TWCA internal tin conductors performed well--D20 reached 13.5 T and was limited by a magnet assembly flaw, not by the conductor
- The Nb3Sn to NbTi splice joint technique is reliable and reproducible
  --Joint resistances were less than 1 nano-ohm
  --Joints show a low ramp rate sensitivity (not limiting up to 1.2 T/min)
  --Much less ramp rate sensitive than Twente U. joints
- We need better Jc vs strain measurement capabilities
  --Uniform field region at Twente U. too short (50 mm)
  --New facility at NHMFL
- The mechanical structure functioned well
  --End loads were predictable and the structure adequate for 13.5 T
  --Radial restraint system is capable of applying a uniform, high prestress
  --More prestress can be applied with additional wire wraps
  --Training started above 10 T (a field and stress level reached by only a few NbTi magnets
  --After repeated thermal cycling, the magnet returns to 12.5 T at 4.3 K

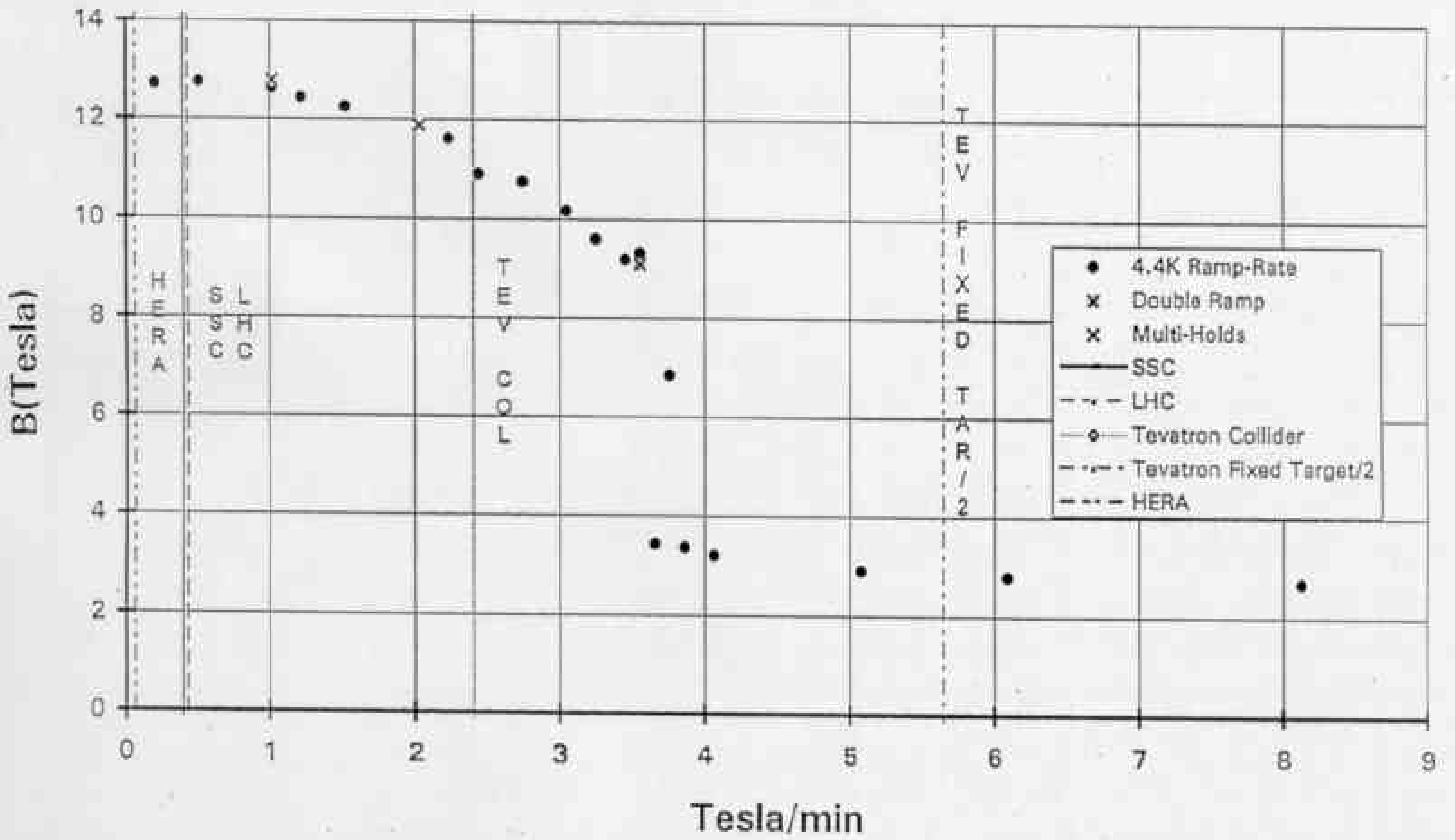
What we learned from D20 (continued):

- D20 appears to be a robust magnet
  - --over 60 quenches above 10 T to date
  - --over 38 quenches above 12 T
  - --can operate at 12.5 T and 2.0 K with a heat input of 20 W between layers 2 and 3
- Heater protection system functions well
  - --Magnet is protected both at 4.3 and 1.8 K ;7.6 MIITS were handled safely
  - --Magnet temperature after quench was typically less than 200 K
  - --As a bonus, we were able to use redundant heater system to measure thermal conductivity in the potted coils
- The magnet field quality is good
- There is still much to be learned about D20
  - --can we reach a higher field by replacing the coil that is limiting performance?
  - --can we improve training by adding a mica separation plane at the poles?

D20: Training History



D20: Ramp-Rate Dependence

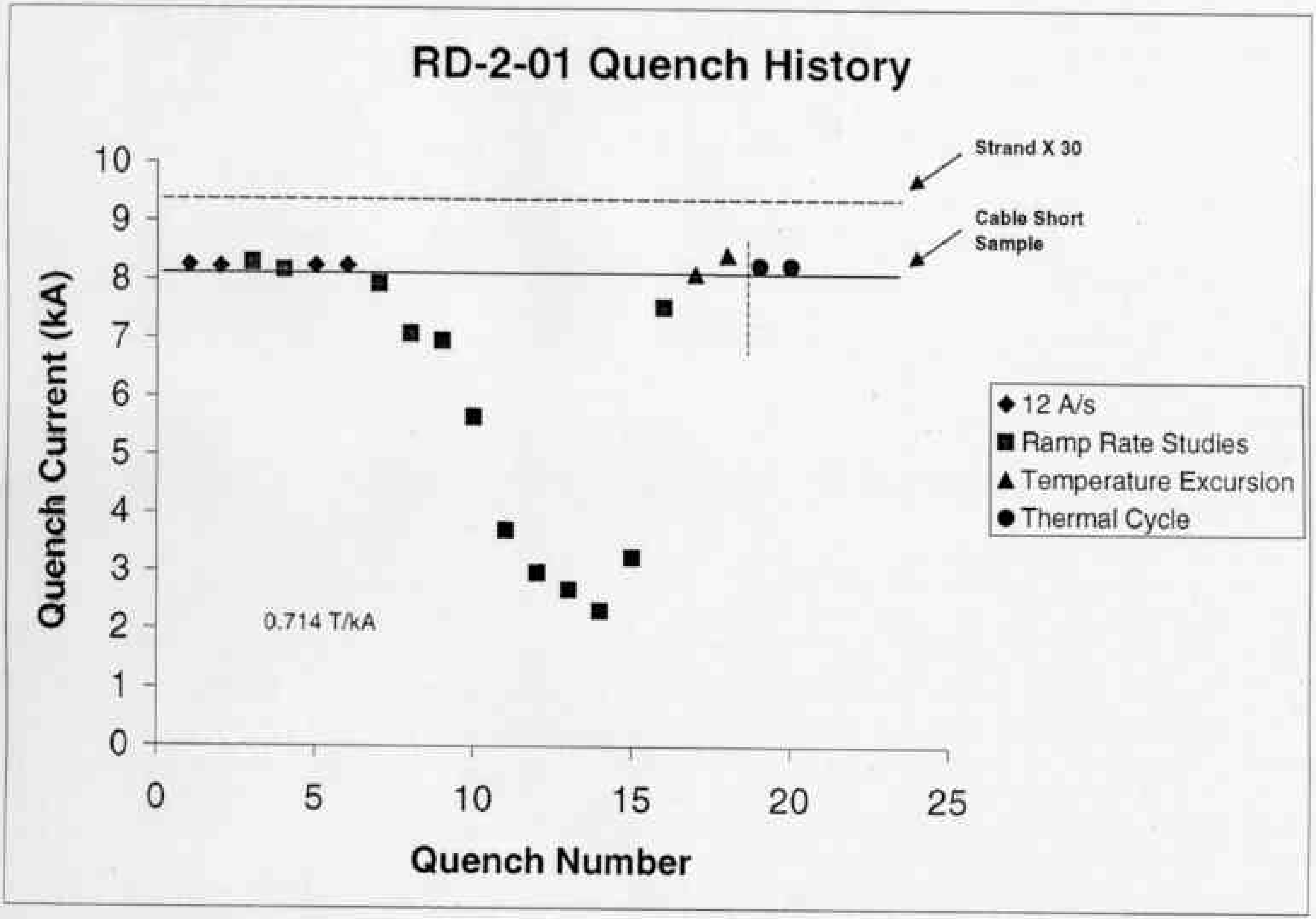


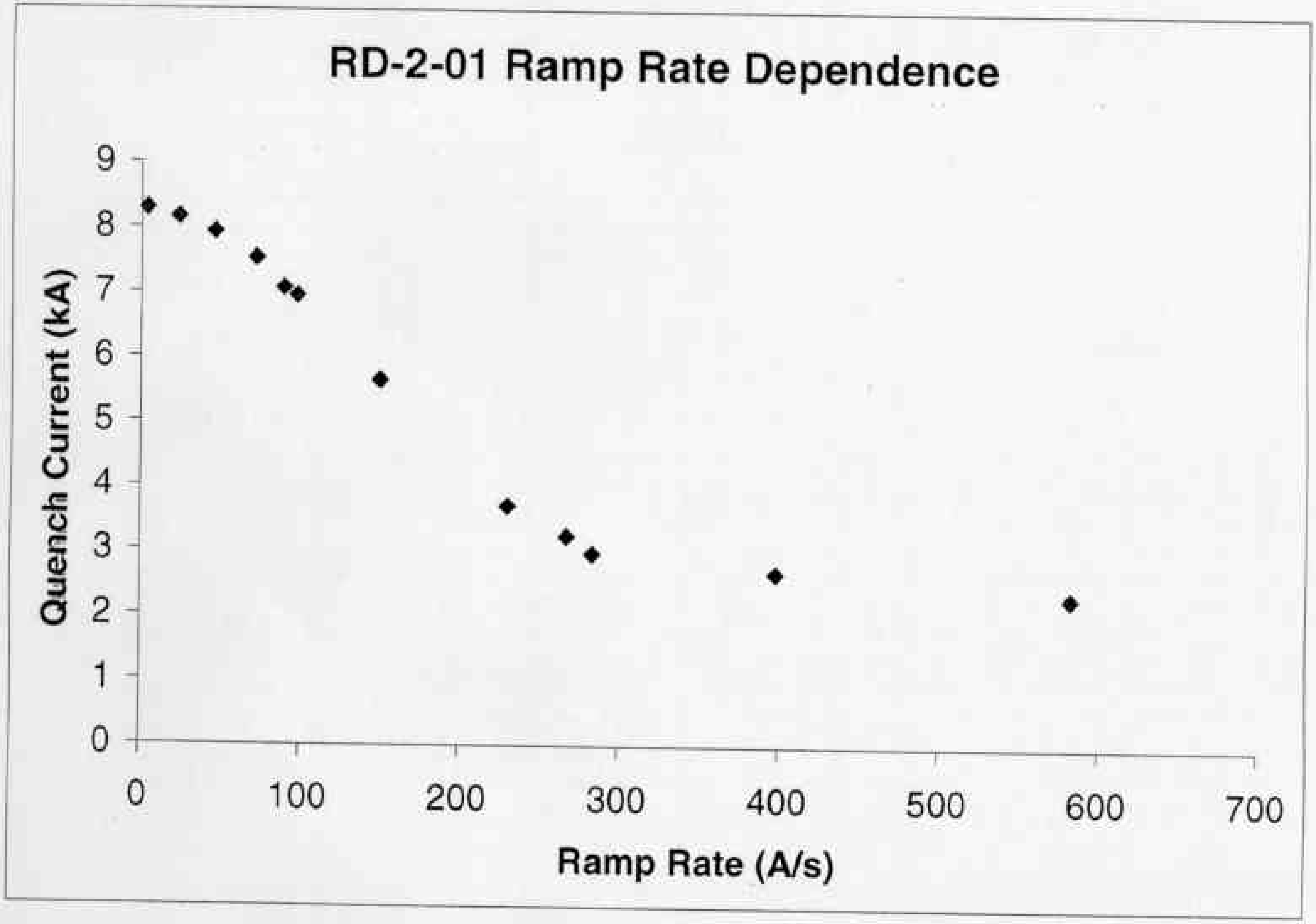
R.Benjegeredes

4/3/97 4:17 PM Loc Sheet

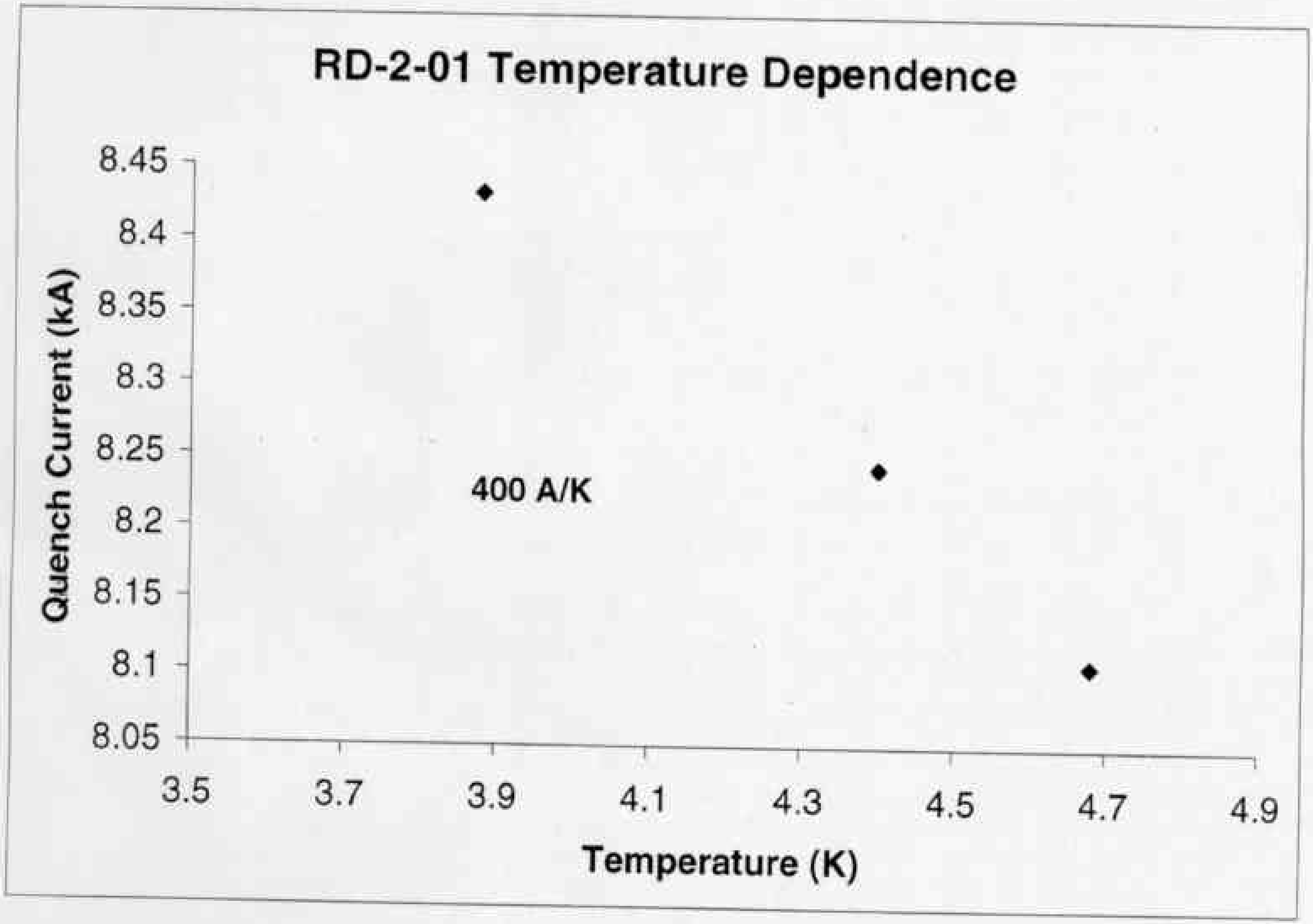
Racetrack coil program chronology

- van Oort dual bore block dipole with active flux return--ASC, 1994
- TAMU dual bore block dipole with internal structure--ASC, 1994
- LBNL workshop on high field magnet designs--Feb.1997
- D20 completed and tested--April 1997
- New staff on board--Gourlay, Sept 1997 and Gupta, Nov.1997
- New program plan presented to DOE--Nov. 1997
- First Nb3Sn common coil racetrack magnet ready for test--Aug. 1998


RD-2-01 Quench History
Strand X 30
Cable Short Sample
Quench Current (kA)
Quench Number
0.714 T/kA
12 A/s
Ramp Rate Studies
Temperature Excursion
Thermal Cycle
0
1
2
3
4
5
6
7
8
9
10
0
5
10
15
20
25



RD-2-01 Ramp Rate Dependence
Quench Current (kA)
0
1
2
3
4
5
6
7
8
9
0
100
200
300
400
500
600
700
Ramp Rate (A/s)

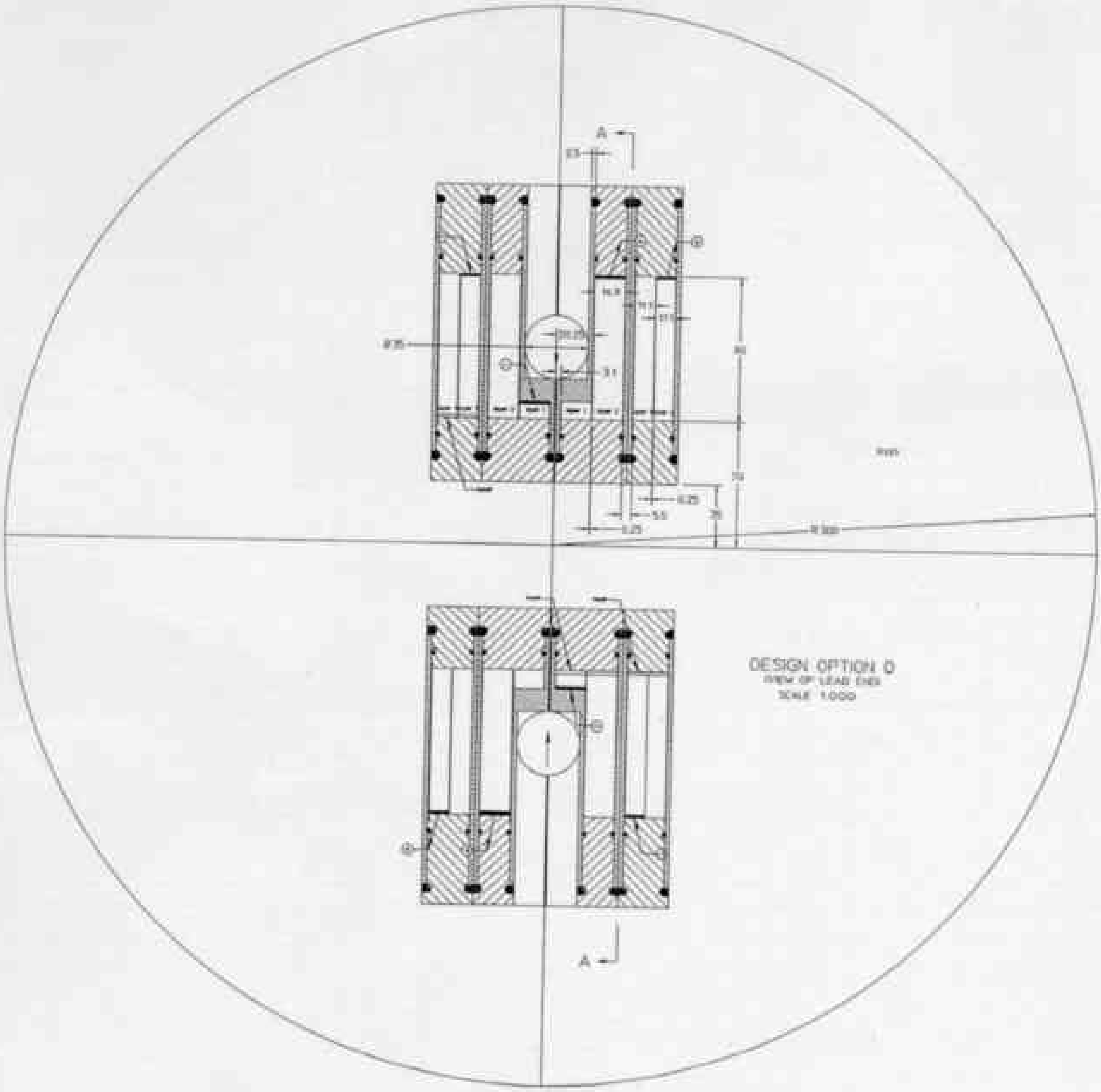


RD-2-01 Temperature Dependence
Quench Current (kA)
8.45
8.4
8.35
8.3
8.25
8.2
8.15
8.1
8.05
400 A/K
3.5
3.7
3.9
4.1
4.3
4.5
4.7
4.9
Temperature (K)

What we learned from RD2:

- Compared with cos theta coils, flat racetrack coils are fast, simple, and economical to design and fabricate
- This magnet reached the cable short sample limit without training
- The magnet repeated this performance after a thermal cycle in which the horizontal prestress was reduced by a factor of 5 (from 30 Mpa to 6MPa)
- The cycle time between the first test and the second test was less than three weeks (including warmup, replacing the horizontal loading bolts, and retesting)
- We will continue to learn from RD2
  - --reduce the vertical prestress
  - --reduce the end load
  - --measure the thermal conductivity
  - --use RD2 coils to provide background field for testing insert coils of new conductors (Bi-2212, Nb3Al)

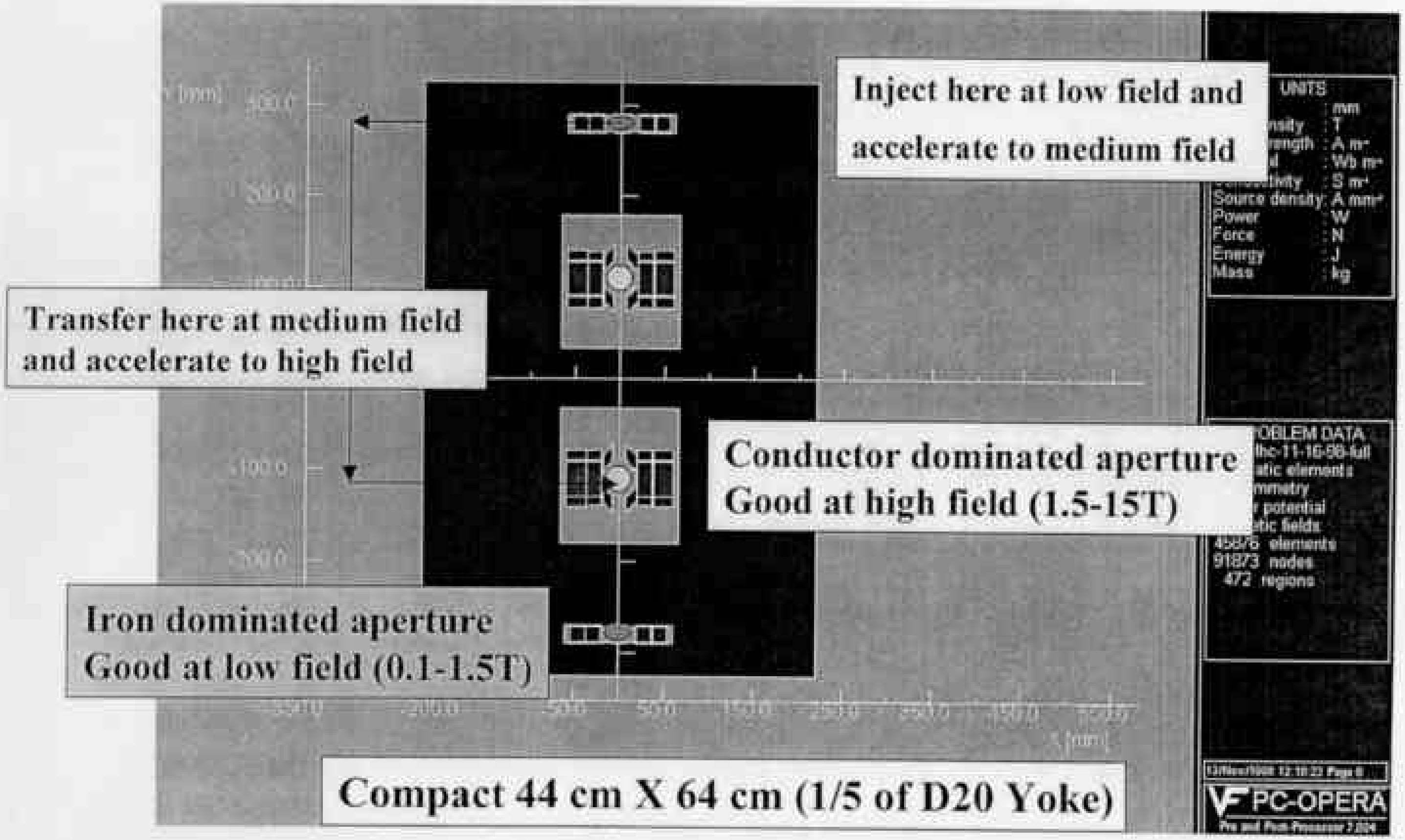
14 T Racetrack Magnet



R. Gupta, 11/15/98

Common Coil Design Magnet System

[Return turns of the auxiliary coils (away from the center) **make two low field apertures]**



How Do We Build Accelerator Magnets From Brittle Materials?

Key issues are:

1. Understanding the materials (strain-J_c measurements, thermal contraction measurements, cable degradation)

2. Improving the materials properties (grain size refinement in Nb_3Sn, substitute Nb_3Al for Nb_3Sn, composites with structural members)

3. Magnet designs based on the use of brittle materials (2-D racetrack coils, common coil design with large radii, subdivided coils with structure)

4. Improved magnet assembly techniques (uniform loading on coils, cooldown and Lorentz stress compensation, high modulus coils)

Note: All High Field Superconductors beyond NbTi are Brittle Materials!

High Field Magnet Design Requirements

BERKELEY LAB

Materials

Nb_3Sn, Nb_3Al, HTS
J_c (B, T, σ)
Fabrication
Cost

Magnet Design

Operating Field
"Conductor Friendly" Designs
Operating Stress and Strain
Field Quality

Mechanical Design

Stress and Strain Limits
Differential Thermal Expansion
Simple Assembly
Tolerances
Prestressing Methods

15 - 16 T
Dipole Magnet

Conductor Fabrication

High Aspect Ratio Multistrand Cables
Controlled Interstrand Resistance
Low I_c Degradation
Insulation
Compaction
Tape or ICCS Geometries?

Coil Manufacturing and Magnet Assembly

Coil Winding
Single or Double Layer
Splices
Heat Treatment
Epoxy Impregnation
Insulation
Diagnostics
Protection
Assembly Stress
Slip Planes

Systematic studies of racetrack coil mechanics with RD2 include:

Assemble in bolted plate tooling to study the effects of different levels of horizontal, vertical, and end prestress.

Vary horizontal, vertical, and end prestress independently and systematically

Use this information to design next generation of higher field racetrack coil assemblies

Change aperture by changing racetrack coil spacing.

Modular design to allow fast and simple change in aperture/coil spacing

Decrease aperture/spacing to produce higher fields and Lorentz forces

Use this information to design next generation higher field magnets

Change coil wiring mode.

Normal mode for high Lorentz load perpendicular to cable edge surface

"Split solenoid" mode for high Lorentz force perpendicular to cable face

FY 99 Goals and Milestones

- We will complete the detailed design of the 14 T common coil magnet. High field inner coils will be fabricated as soon as we receive the conductor (due in Dec. 1998). Outer coils will be fabricated, assembled with the inner coils before the end of the year. Testing will begin in Oct 1999.

- Additional tests of the first racetrack dipole magnet will be done to define prestress requirements. Design work will be completed on modifications to RD2 which will allow us to evaluate new coil fabrication techniques and to test new conductors.

- Subject to completion of construction, and availability of program personnel, the magnet test facility will be commissioned in B51. This will include a vertical test cryostat for the racetrack coils and the horizontal cryostat for the D20 dipole.

- The TAMU block dipole magnet will be tested and the performance compared with the common coil magnets.

- We will continue the work with industry on scaleup of manufacturing capabilities of Nb_3Sn, Nb_3Al, and HTS materials. The promising wires will be made into cables and Jc vs strain measurements will be made at NHFML. Racetrack coils will be made for insert coil testing in RD2.

- LHC project work on cable manufacturing support and cryoboxes will continue.

FY 00 Goals and Milestones

- The inner coils of the 14 T racetrack magnet will be modified to produce accelerator field quality and the magnet will be tested. Quench performance, ability to withstand thermal cycling, and field homogeneity will be evaluated. This performance, together with fabrication and materials costs, will be analyzed and compared with the cosine theta magnet data. A plan for fabrication of long magnets will be developed in collaboration with FNAL.These data from short and long magnet tests will be used in the ongoing national studies of the next generation HEP accelerator options, including the Very Large Hadron Collider and the Muon Collider.
- A new series of racetrack coils with the improved conductors will be fabricated in order to push up the field level to 15-16 T.
- Consolidation of the Magnet Program facilities in B51 will continue with the installation of cabling, magnet fabrication, mechanical testing, and heat treatment facilities.
- Our participation in ongoing HEP programs (LHC, muon collider studies, VLHC) will continue. The principal LHC effort will be on the cryoboxes. Muon collider work will include solenoids for the cooling experiments and Nb3Sn magnet design work for the collider ring.
- A national HEP plan for conductor process optimization and scaleup will be initiated.

FY 01 Goals and Milestones

- The magnets originally tested in FY 00 will be rebuilt with the higher current density main racetrack coils and retested with the goal of reaching 15-16 T
- Using the design experience obtained on the earlier common coil magnets, together with improved high field conductors, a new series of magnets will be designed to explore the field range above 16 T
- A long model magnet program will be initiated in collaboration with FNAL
- Conductor cost optimization program will continue. The results of the first phase of the conductor manufacturing scaleup will be used to select the most promising conductor for further scaleup and cost optimization work
- Magnet manufacturing cost optimization will continue. We will collaborate with industry and/or other labs on developing realistic cost estimates of the high field magnet accelerator option
- LHC work will continue, with the main effort on fabrication and test of cryoboxes

LBNL collaborations and conductor support

- TAMU-- Block Magnet fabrication and test support
- Ohio State U.--Interstrand resistance control for NbTi, Nb3Sn, and HTS cables
- Ohio State U.--Nb3Al rapid quench process development
- U. Wisc--Bi-2212 processing and microstructure control
- NHMFL--Jc vs. transverse strain testing
- FNAL--HGQ design and cable development
- IGC--Bi-2212 cable and strand development
- OST--Bi-2212 cable and strand development
- ASC--Bi-2223 tape
- IGC--Nb3Sn Jc and process development
- OST--Nb3Sn Jc and process development
- IGC--Nb3Al rapid quench precursor wire
- OST--Nb3Al rapid quench precursor wire