High Field Magnet Designs

HTS Based R&D Magnets

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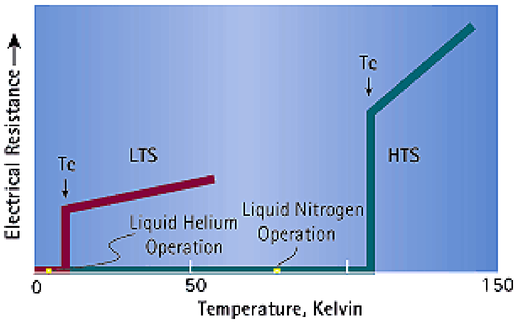
BNL

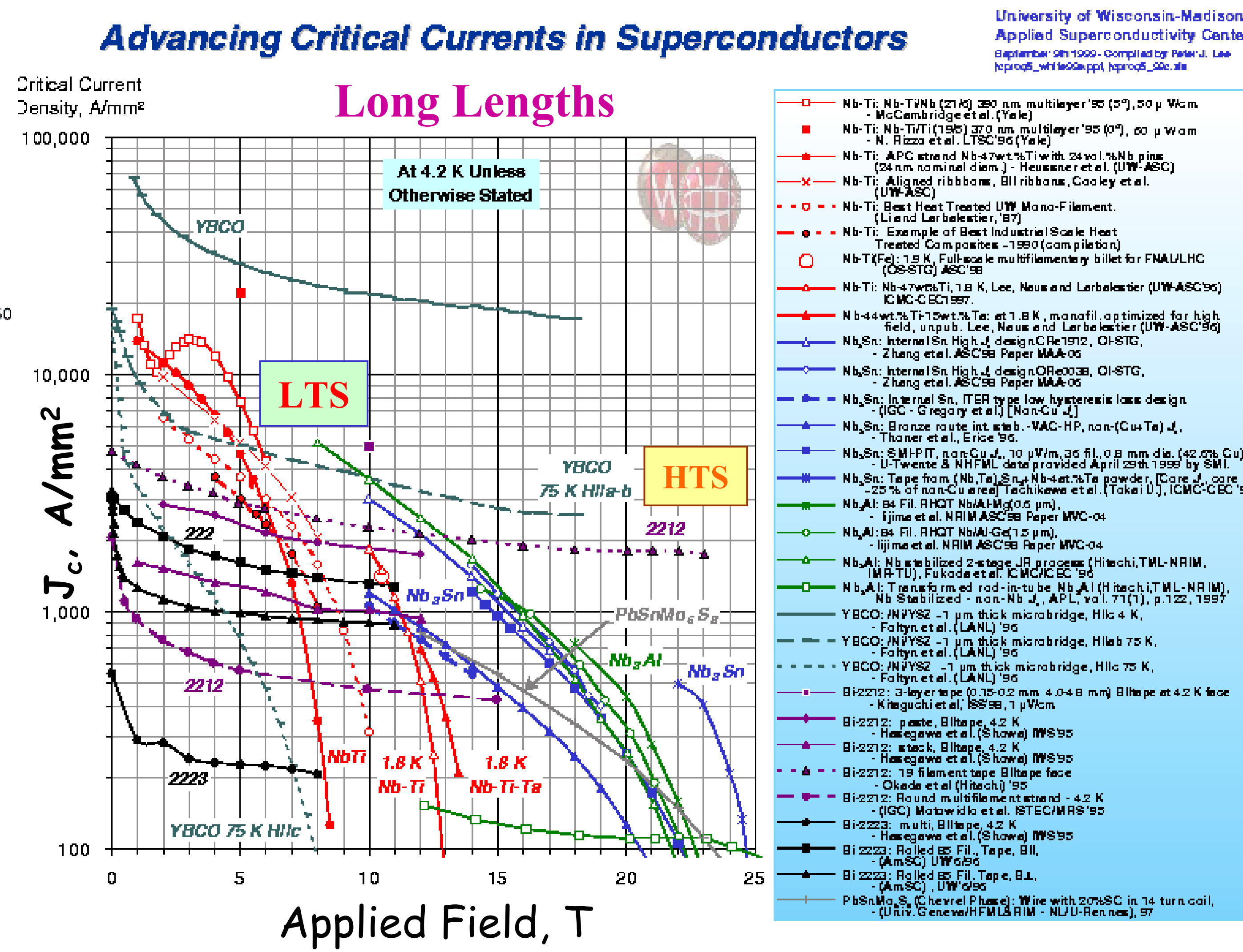
High Field Magnets and High Temperature Superconductors (HTS)

American Supercondctors

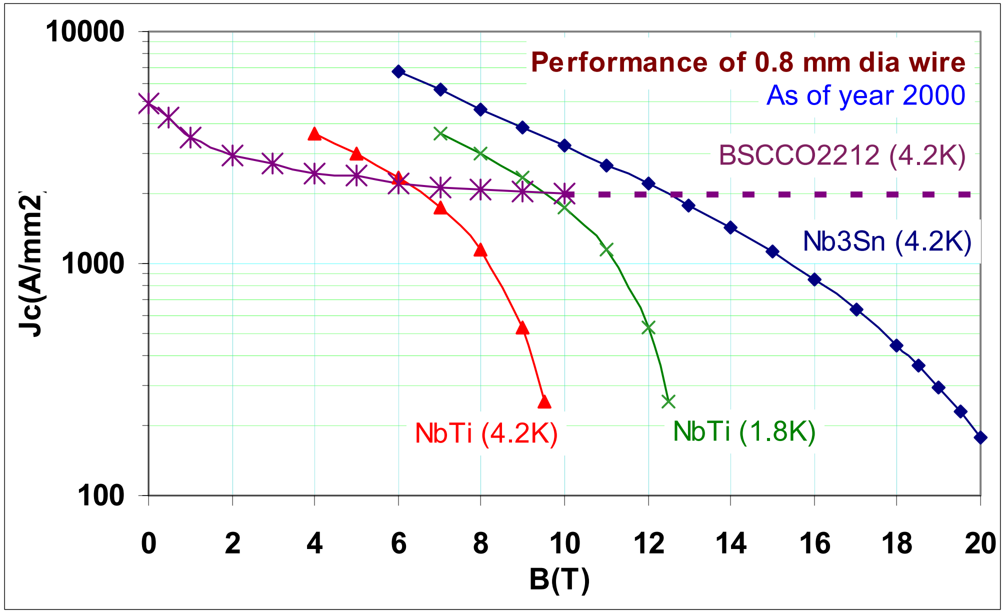


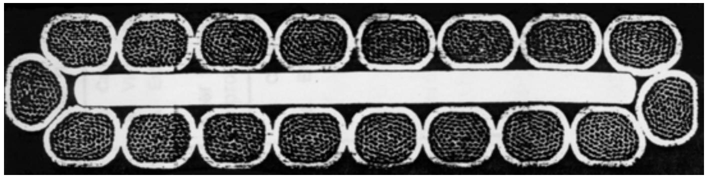
For high field magnets, we are interested in the "Low Temperature", performance of "High Temperature Superconductors".

At very high fields, HTS have a better performance.



Improvements in HTS Technology And Challenges for Magnet Design





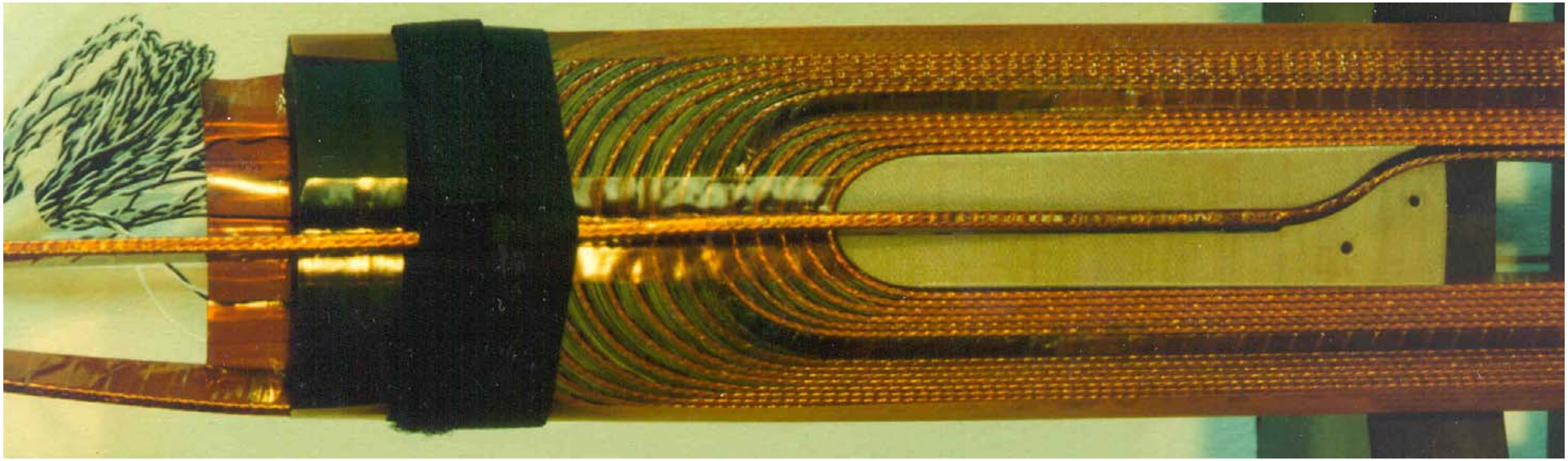
KAmp Rutherford cables:
BNL/LBL/Industry collaboration

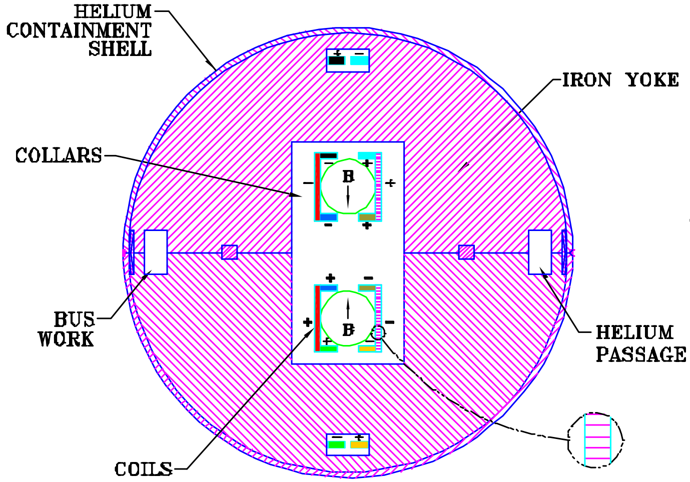
- HTS have made significant progress - enough to make R&D magnets now
- To be shown that they are practical for accelerator magnet application
- It takes a long time to do magnet R&D (many technical questions remain)
- Start magnet R&D now, so that if the situation improves they can used in next machines
- Likely first application: Specialty high performance magnets for insertion regions (the place where a few magnets may make a significant improvement in luminosity)

HTS and Ends of A Convention Cosine Theta Design

- The ends of the conventional cosine theta designs are not well suited for HTS. HTS it’s too brittle.
- One must use “wind and react technology” as a very high temperature uniformity is required during high temperature reaction cycle(< 1 K at ~ 850 C)

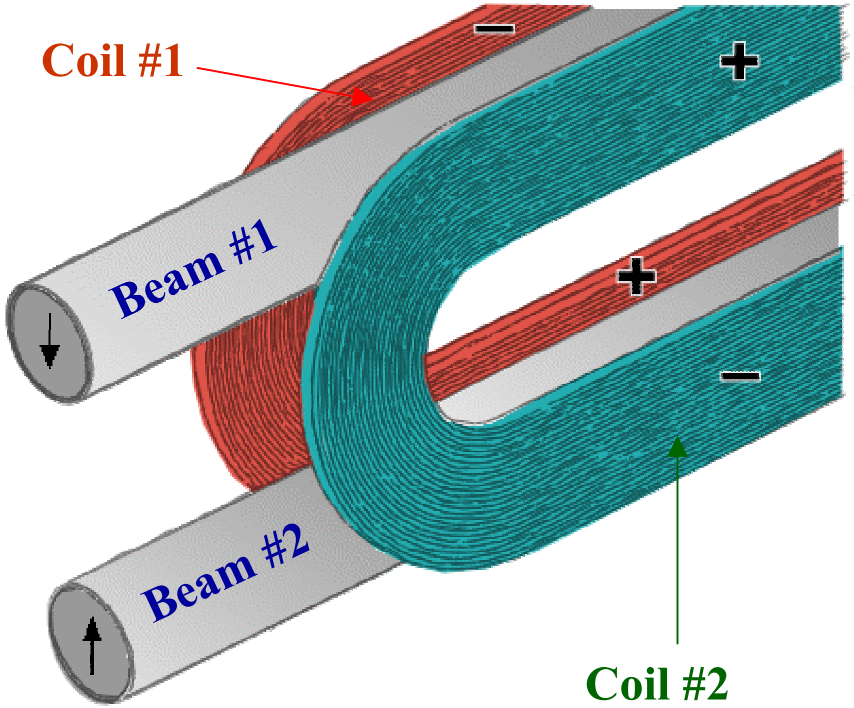
End of a conventional cosine theta magnet design





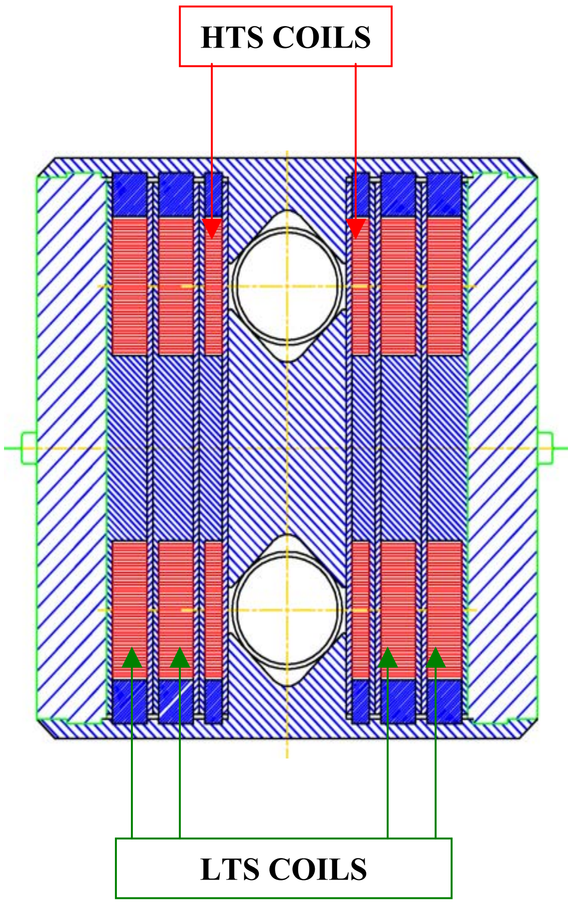
Common Coil Design
(The Basic Concept)

- **Simple 2-d** **geometry with large bend radius (no complex 3-d ends)**
- **Conductor friendly** **(suitable for brittle materials - most are - Nb_3Sn, HTS tapes and HTS cables)**
- **Compact** **(compared to single aperture LBL's D20 magnet, half the yoke size for two apertures)**
- **Block design** **(for large Lorentz forces at high fields)**
- **Efficient** **and methodical** **R&D** **due to simple &** **modular design**
- **Minimum** **requirements on big expensive** **tooling and labor**
- **Lower cost magnets** **expected**



Main Coils of the *Common Coil Design*

HTS in a Hybrid Magnet



- **Perfect for R&D magnets now.**

  HTS is subjected to the similar forces that would be present in an all HTS magnet. Therefore, several technical issues will be addressed.

- **Field in outer layers is ~2/3 of that in the 1st layer. Use HTS in the 1st layer (high field region) and LTS in the other layers (low field regions).**

- **Good design for specialty magnets where the performance, not the cost is an issue. Also future possibilities for main dipoles.**

Magnet Program Design Philosophy

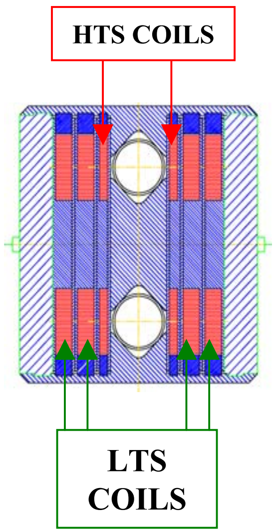
- If it takes well over a year to build and test a product, we tend to become conservative. We tend to stay with the proven technology since so much rides on each test.

- Since significant cost reduction is unlikely to come with "the comfort zone technology", the magnet program must be designed for rapid throughput. This will scientifically evaluate old "comfort zone" issues and test feasibility and profitability of new ideas.

- In an atmosphere of limited funding, "*designing a magnet program*" is just as important as designing a magnet.

☼ It sets the tone and nature of magnet R&D.

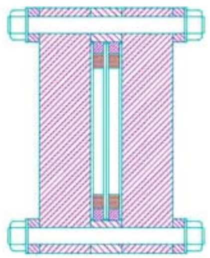
Common Coil Magnet R&D at BNL



Primary Goal of the Program:

Design and build a ~12.5 Tesla, "React & Wind" Common Coil Magnet with HTS playing a major role.

R&D Plan to Develop Technology:



A "*mini 10-turn magnet R&D program*" to systematically develop and test new ideas, designs and technologies (React & Wind HTS) in a time and cost effective manner.

At this price, we can afford to built many coils and afford to see some destroyed in an attempt to understand and develop new technology and find a limit of others.

That philosophy is in-built in the "Program Design"!

"React & Wind" Approach at Brookhaven

- Find out if we can adopt most of the NbTi tools, facilities and procedure in building coils and magnets with brittle materials
- Payoffs are significant, it gives a big jump start
  - NbTi Magnet Technology has matured, adopting and scaling it up should be easier, faster and relatively less expensive
  - Since the coil does not to go through the "reaction cycle", there is much more choice in selection of associated components

Must for HTS

Long Term High Field Magnet Program At BNL

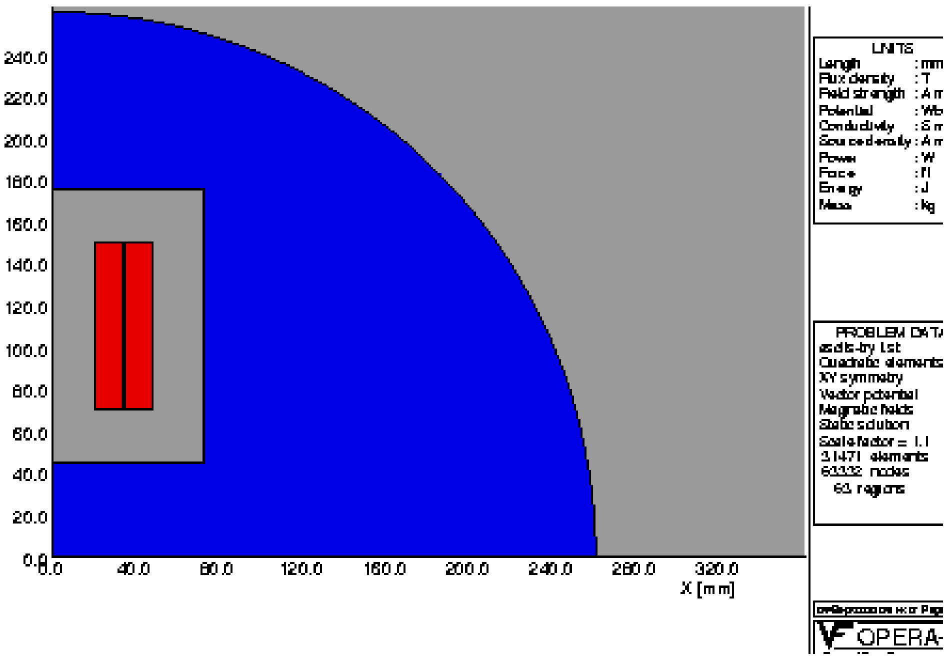
First Phase: Magnet with two "React & Wind" Nb_3Sn coils

Similar technology as HTS (React & Wind) and similar design (Common Coil)

Nb3Sn coils provide high background field for HTS coils in next phase

Second Phase: Additional HTS inner coils in a hybrid design

HTS coils are subjected to high field and high forces



Basic Design Parameters:

Expected Short Sample: ~12.5 T

J_c~ 2000 A/mm^2

2 Layers Nb_3Sn Coils

No. of strand (both layers): 30

Strand diameter (both layers): 0.8 mm

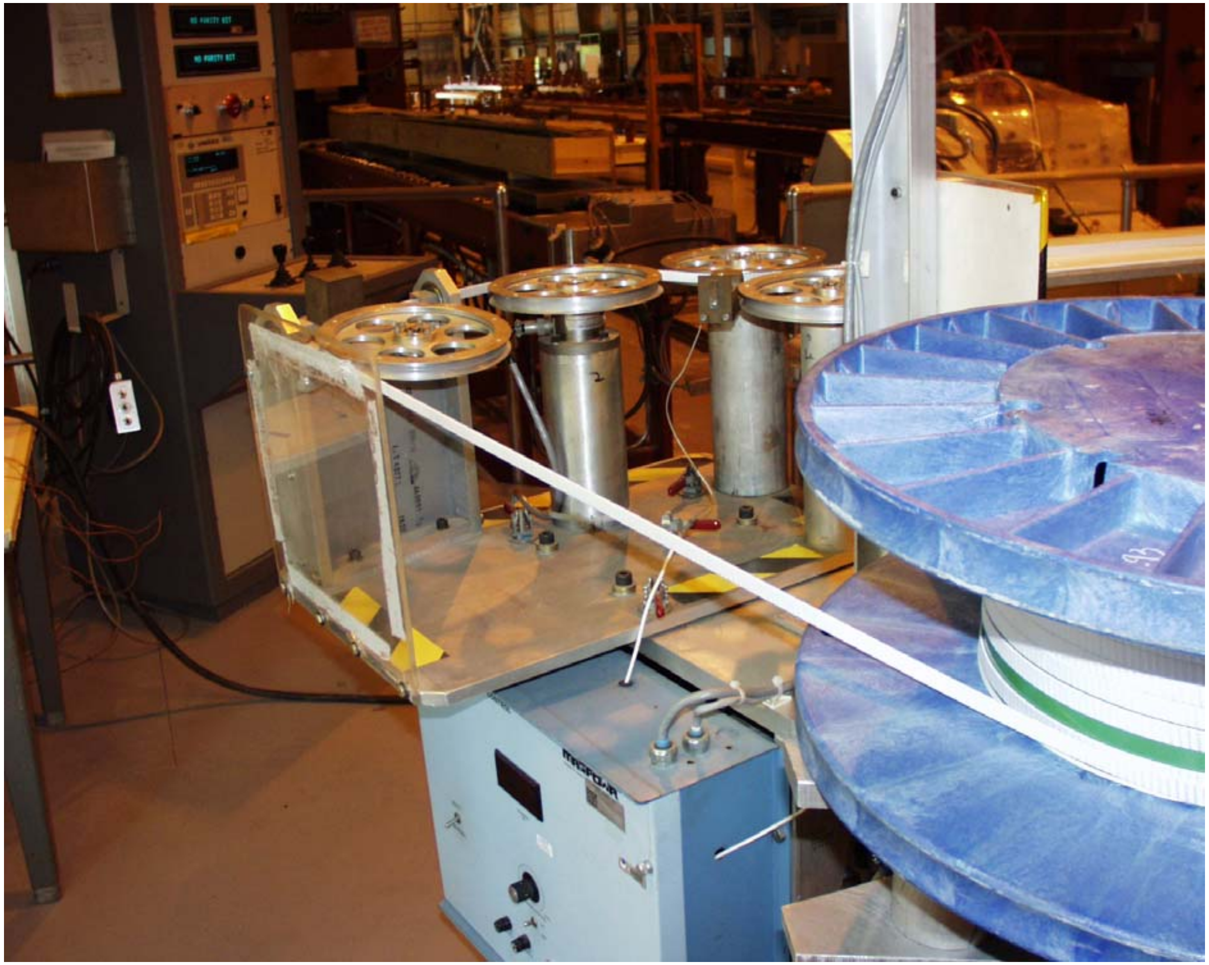
Cu/Sc: 1.0 (inner); 1.86 (outer)

J_{cu}: 1400-1500 A/mm^2 (both layers)

Nb_3Sn Cable Coming Out of Spool

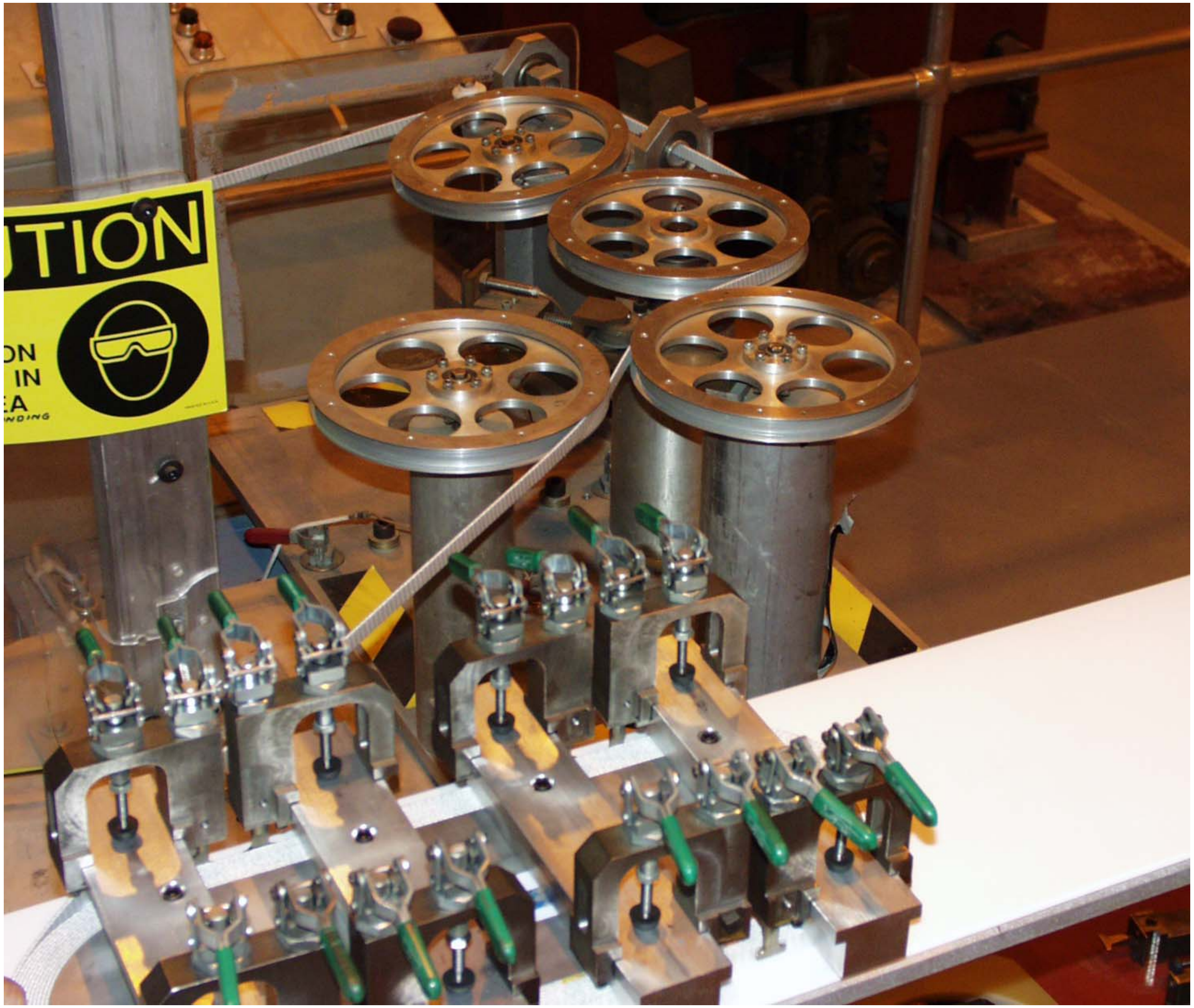
The coil is wound like a regular NbTi coil, of course with proper care (e.g., lower tension). This should help establish procedure, care (cost) required for Nb_3Sn magnets.

NOT SUITABLE FOR HTS
TOO BRITTLE

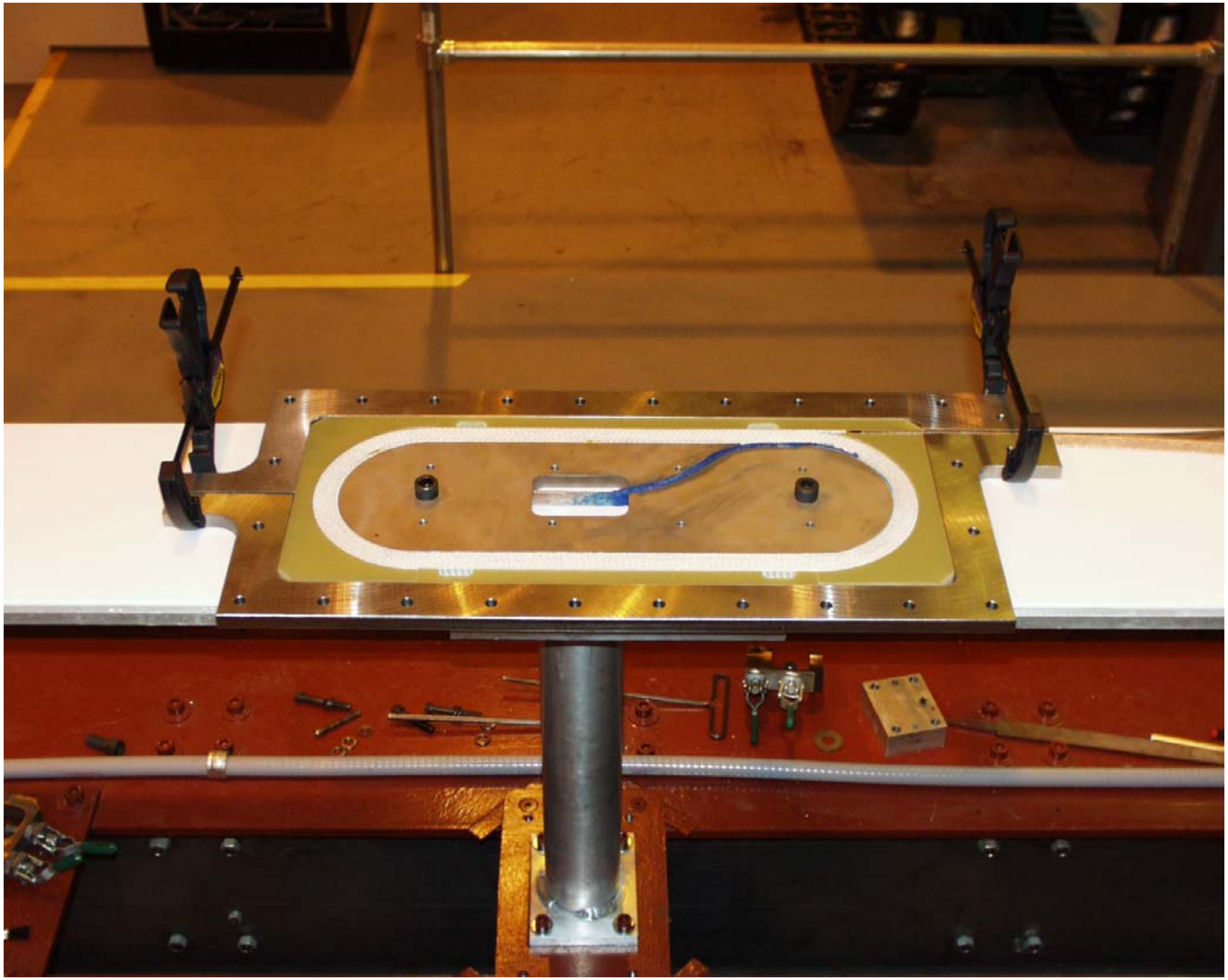


Coil Tensioner with 10-turn coil on the Winding Table

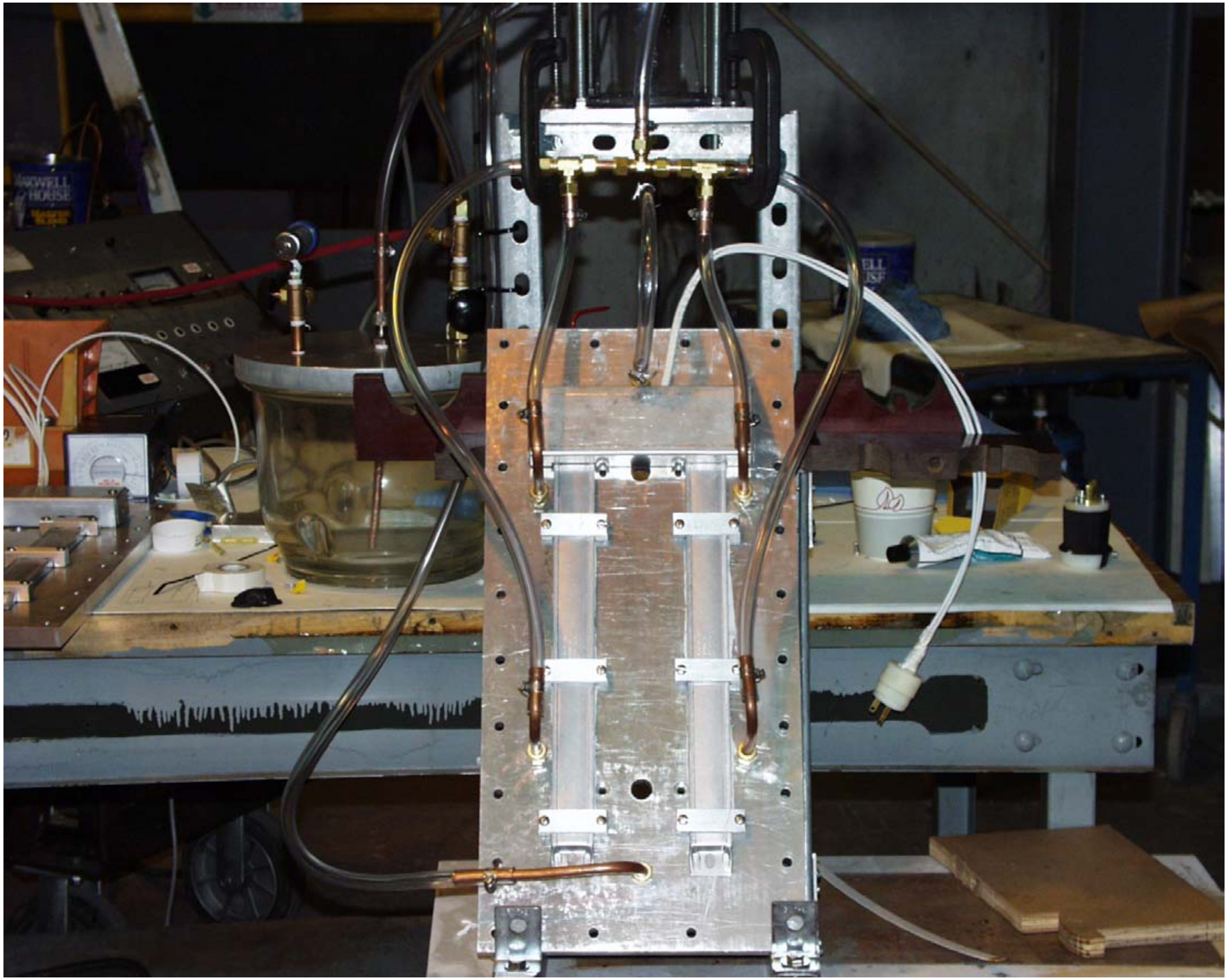
NOT SUITABLE FOR HTS
TOO BRITTLE



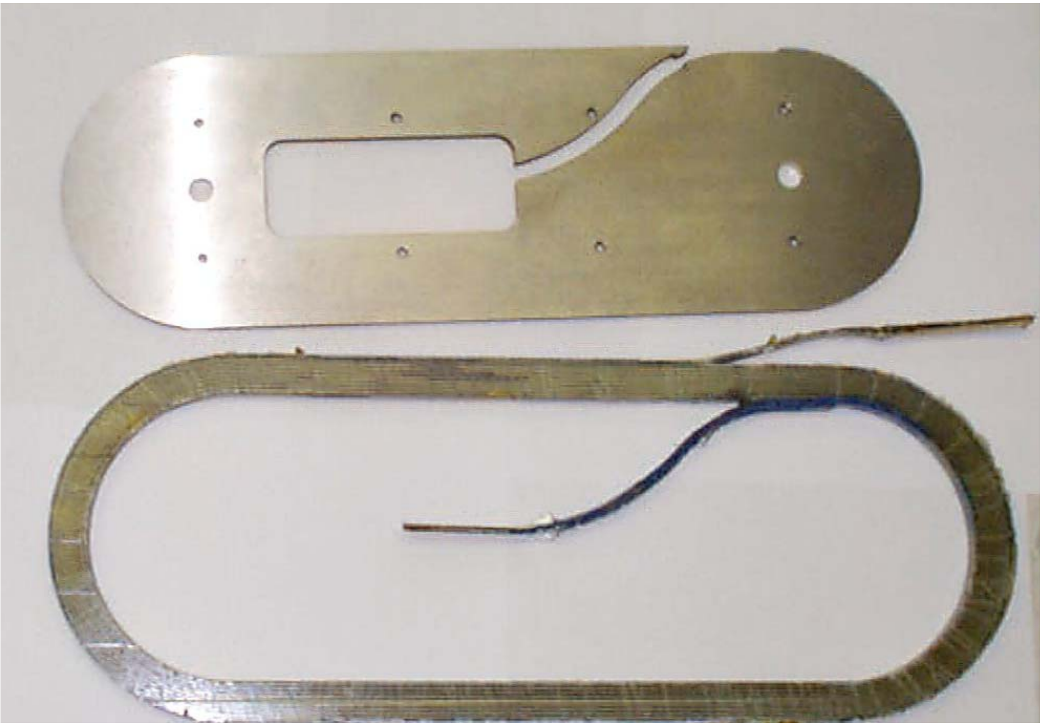
10-turn Coil Being Prepared for Vacuum Impregnation



Vacuum Impregnation Setup

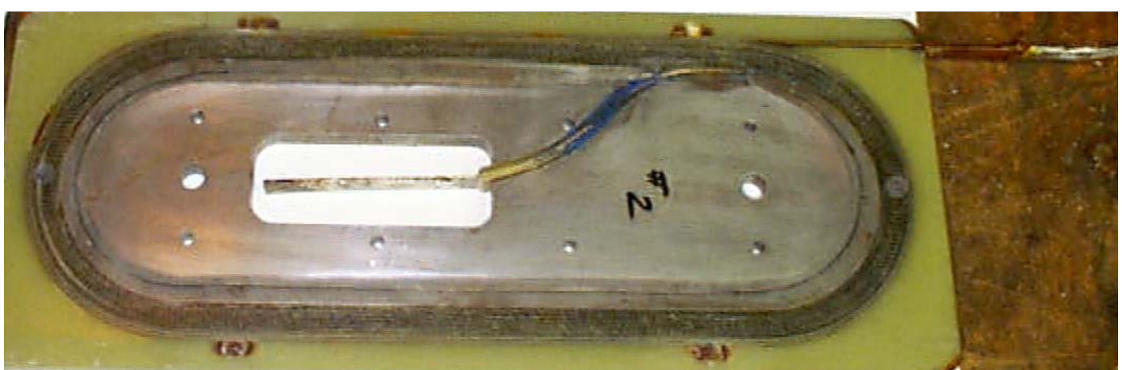


The Bobbin and the 10-turn Coil



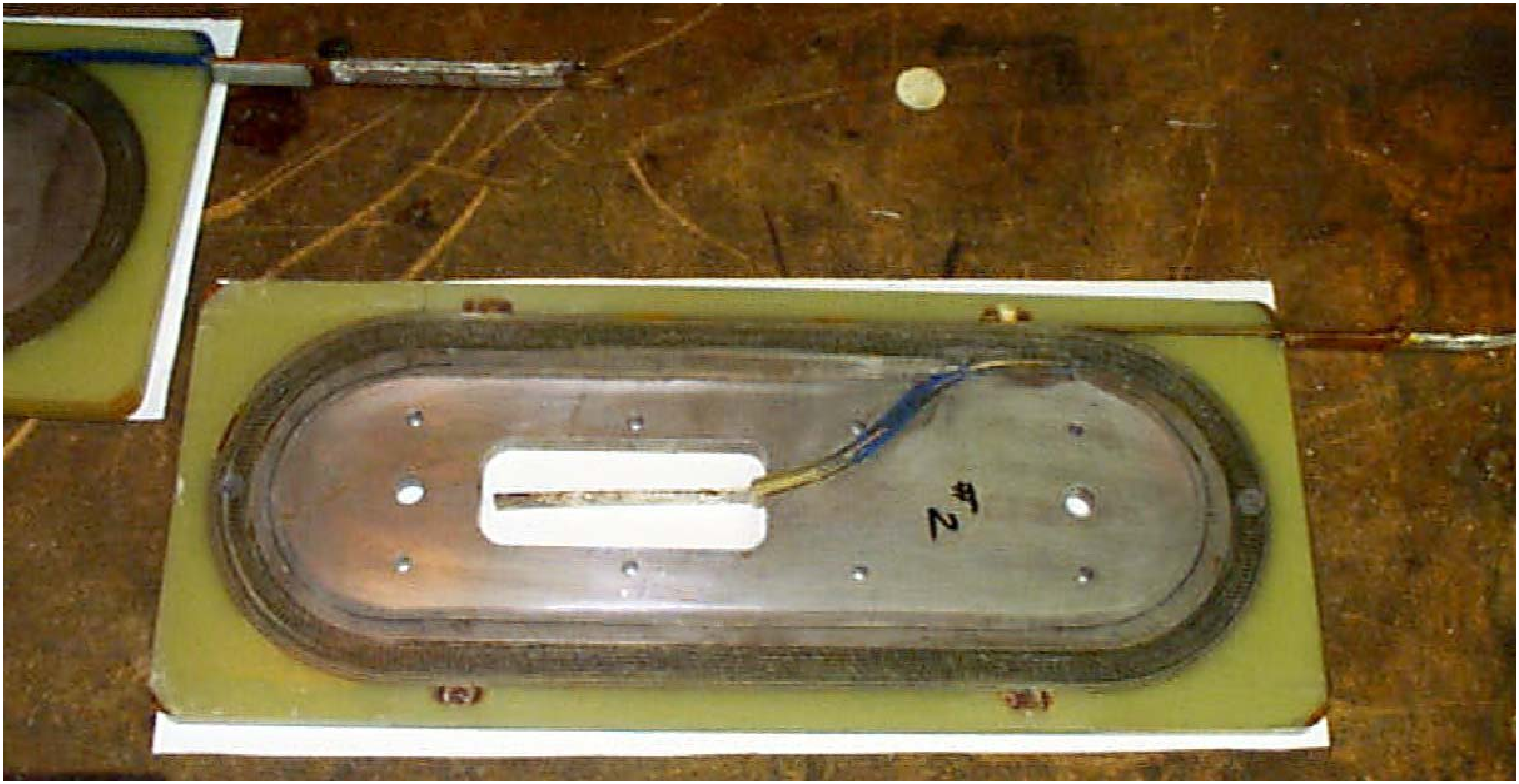
The bobbin
(the coil is wound on it)

The first 10-turn practice coil
(removed from bobbin after impregnation)



The complete cassette module
(vacuum impregnated coil in bobbin)

Vacuum Impregnated Coils



Vacuum impregnated coils made after "react and wind" technique.

This picture was taken after the coils were tested and removed from the support structure.

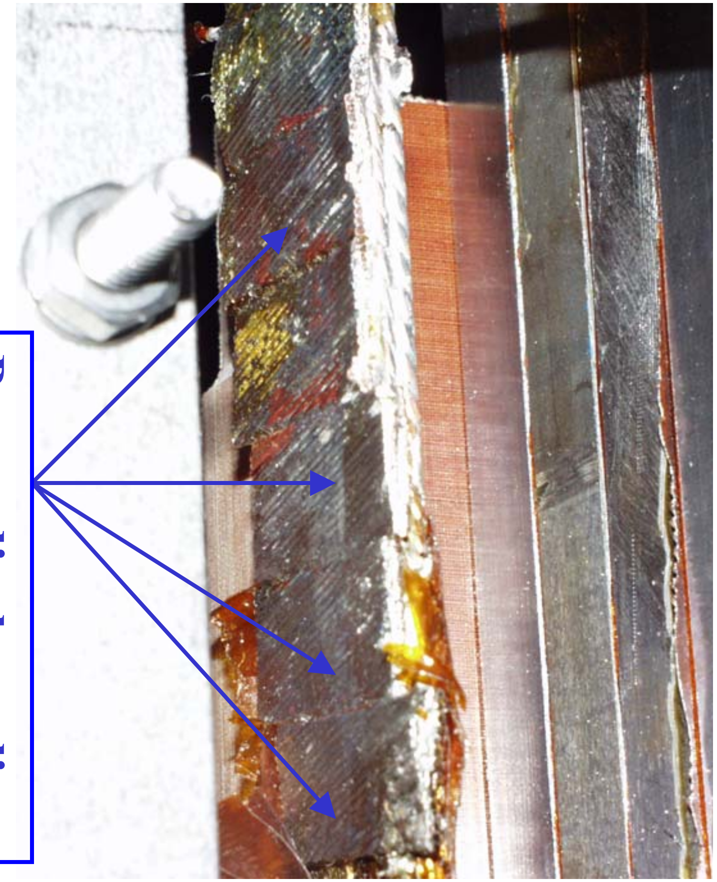
Coils in Support Structure

Two coils in a support structure

Internal Splice in Common Coil Design
(splices are perpendicular and are in low field region)

Splice for a single coil test
(perpendicular splice take out
the current to outside lead)

Perpendicular splices



Internal splice between two coils in
a common coil configuration
(note several perpendicular splices)

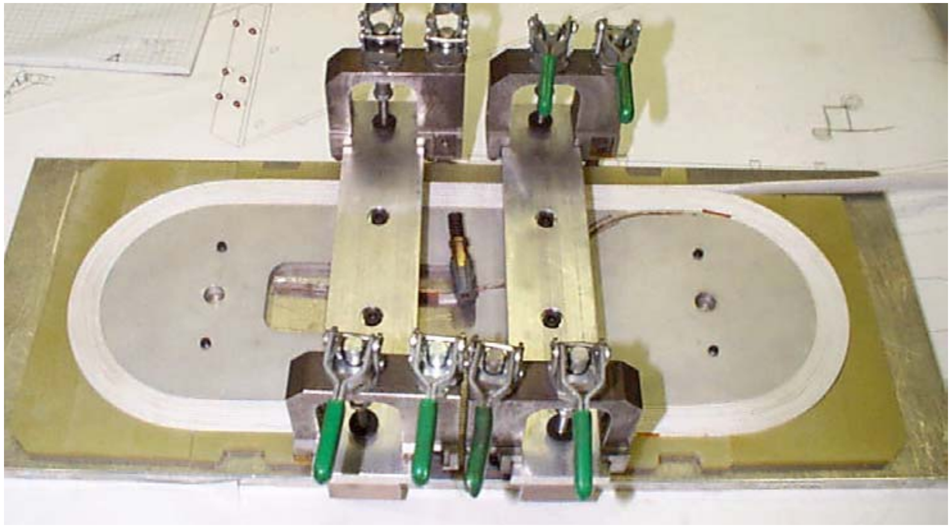
HTS Coils in Support Structure

Coils are heavily instrumented. There is a voltage tap after each turn. Data were recorded from all 26 voltage taps.

Coils are assembled for the most flexible and extensive testing. Four leads are taken out of the cryostat. During the test the coils were powered separately and together in “common coil” and “split-pair solenoid mode”.

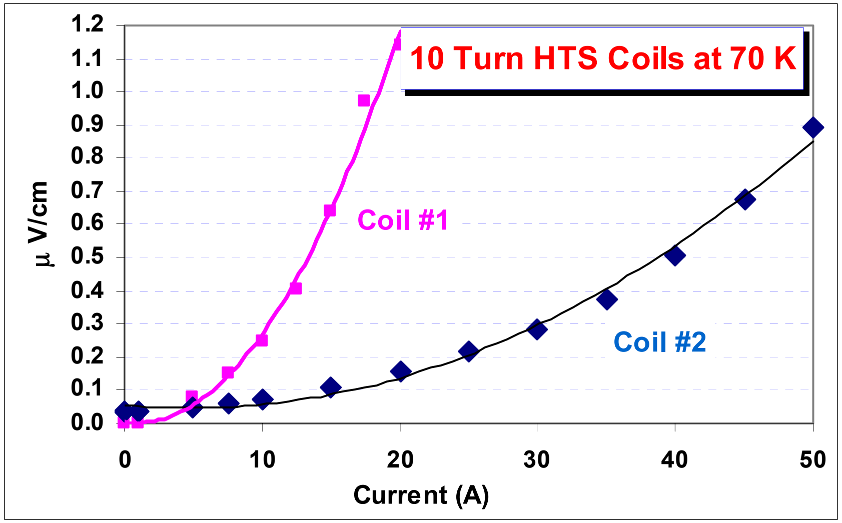
Two hall probes (in between two coils and at the center of two coils) also recorded the central field.

Common Coil Magnets With HTS Cable



HTS cable coil prior to vacuum impregnation

Two coils were tested in Liquid Nitrogen



A coil cassette made with HTS cable after vacuum impregnation and instrumentation

The HTS cables were from two different batches. They behaved differently:

- Different Ic
- Different Tc

Based on preliminary analysis, no large degradation was observed.

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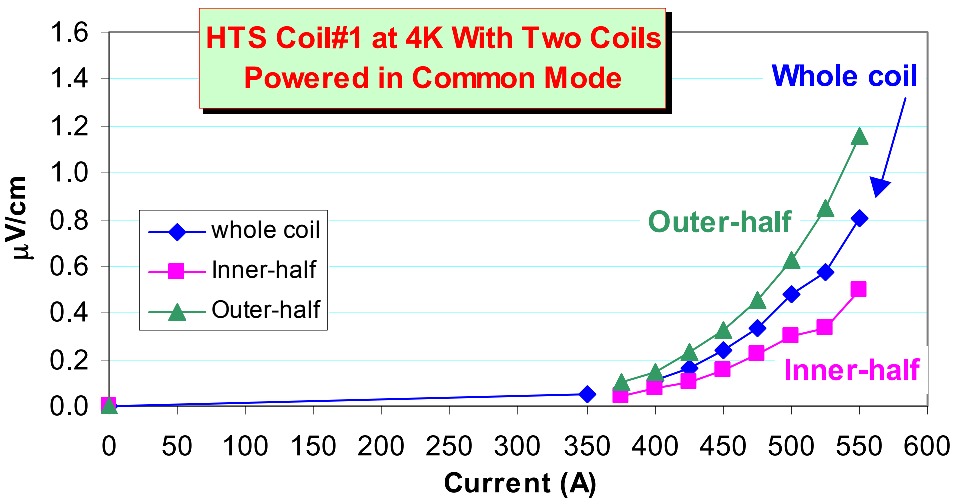
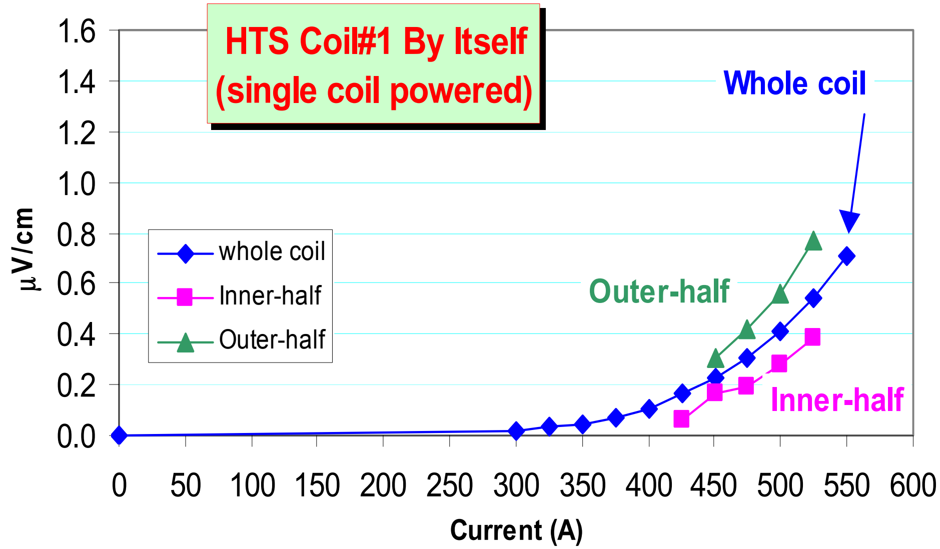
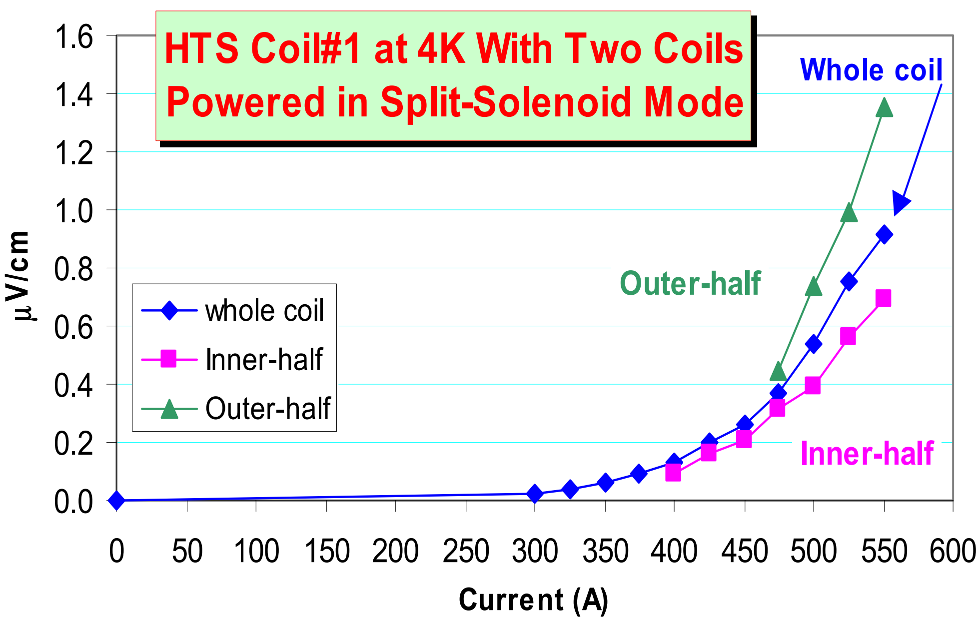
Superconducting Magnet Division

4K Performance of 1st Common Coil HTS Magnet



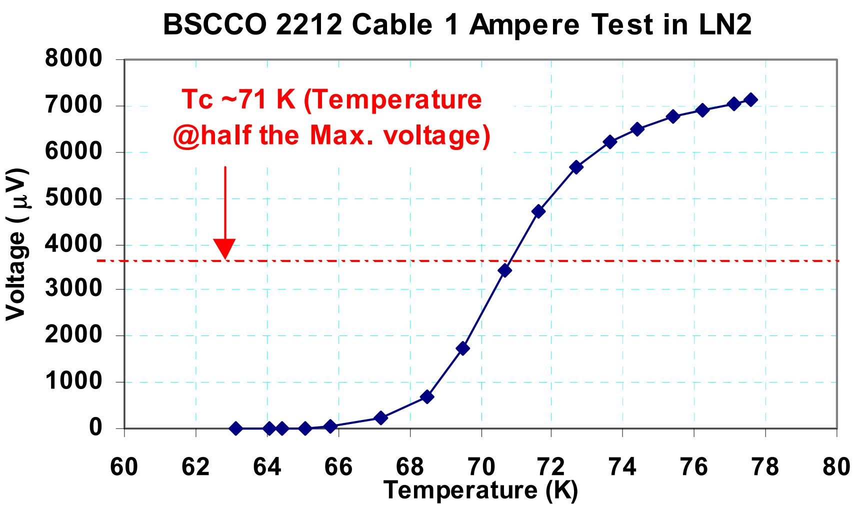


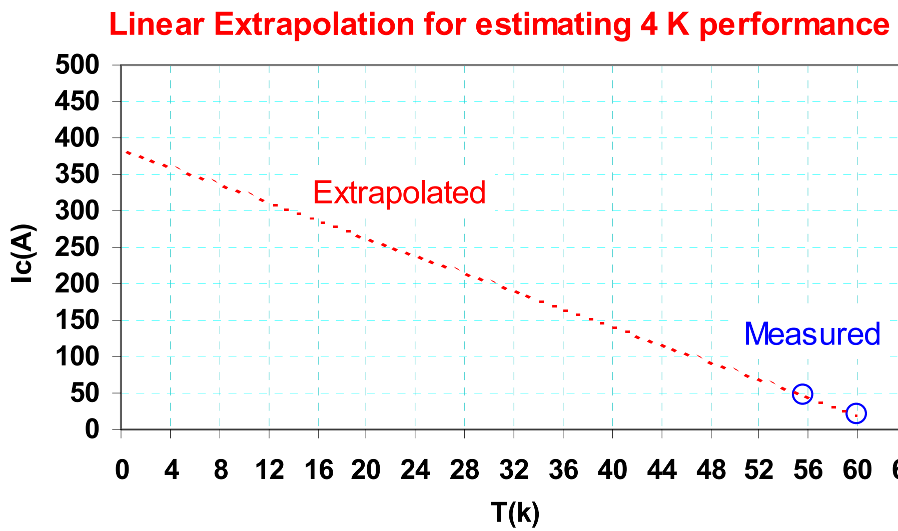


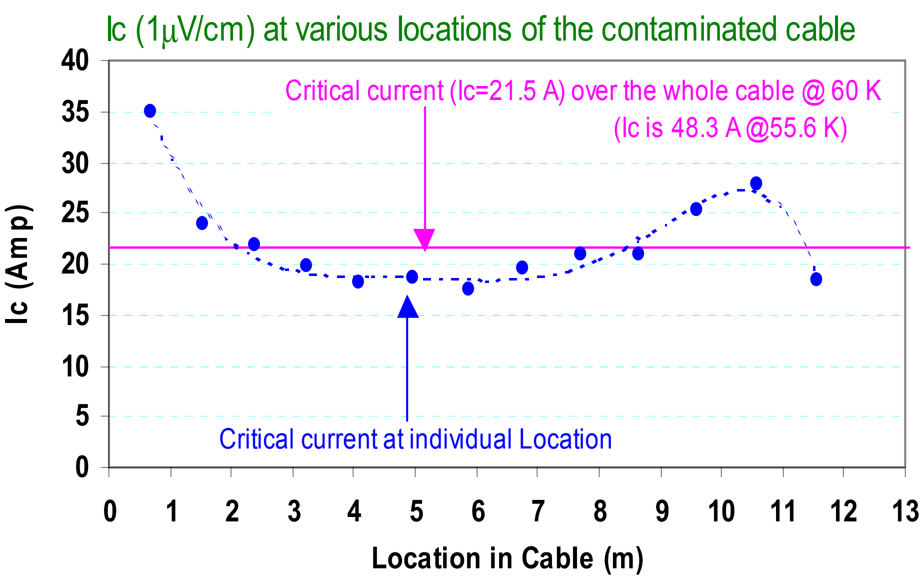
Notes:

- The cable in coil#2 was better than that used in coil #1; no clear onset of resistive state was observed up to 550 A. See results of next tests at higher current.
- Observed performance of coil#1 is line with expectation (no large/significant degradation was observed).
- The inner coil half (smaller bend radius) has better performance. It was made with the better part of cable - as per LN2 measurements. This means that the cable performance rather than degradation during manufacturing is determining the performance --- an encouraging result indeed.

HTS Cable Test at LN2 and Extrapolation to 4 K







Notes:

- Measurements at LN2 give important QA information
- This cable was a reject cable; we used it to obtain initial experience in winding HTS coils
- The cable has large variation in I_c across the length
- Expected Ic at 4K ~360 A based on linear extrapolation

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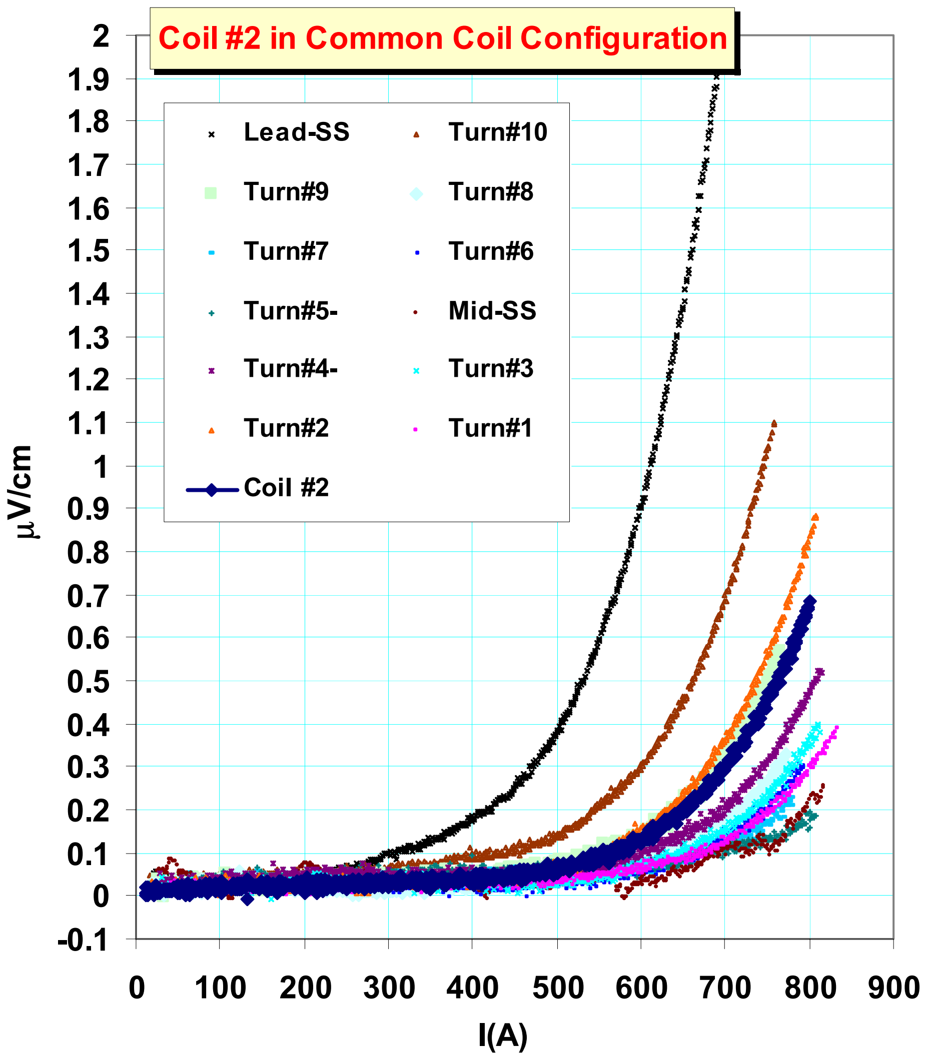
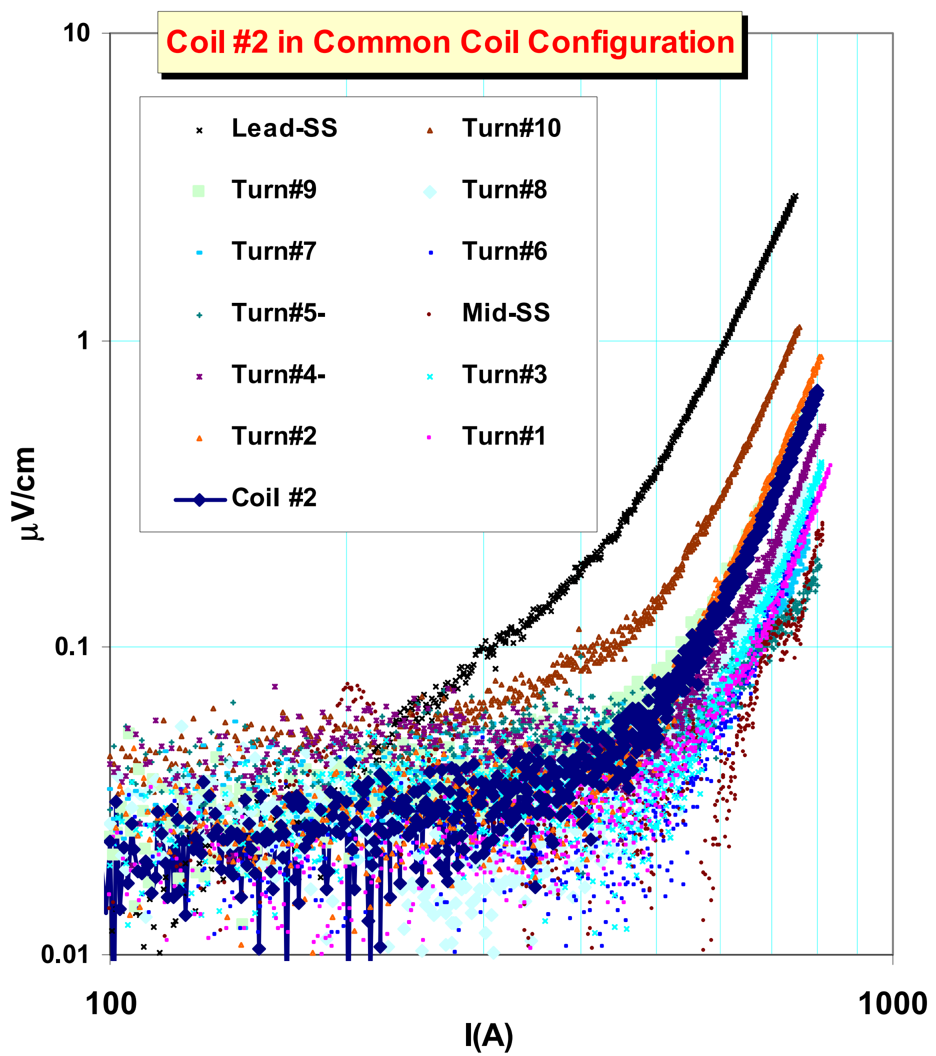
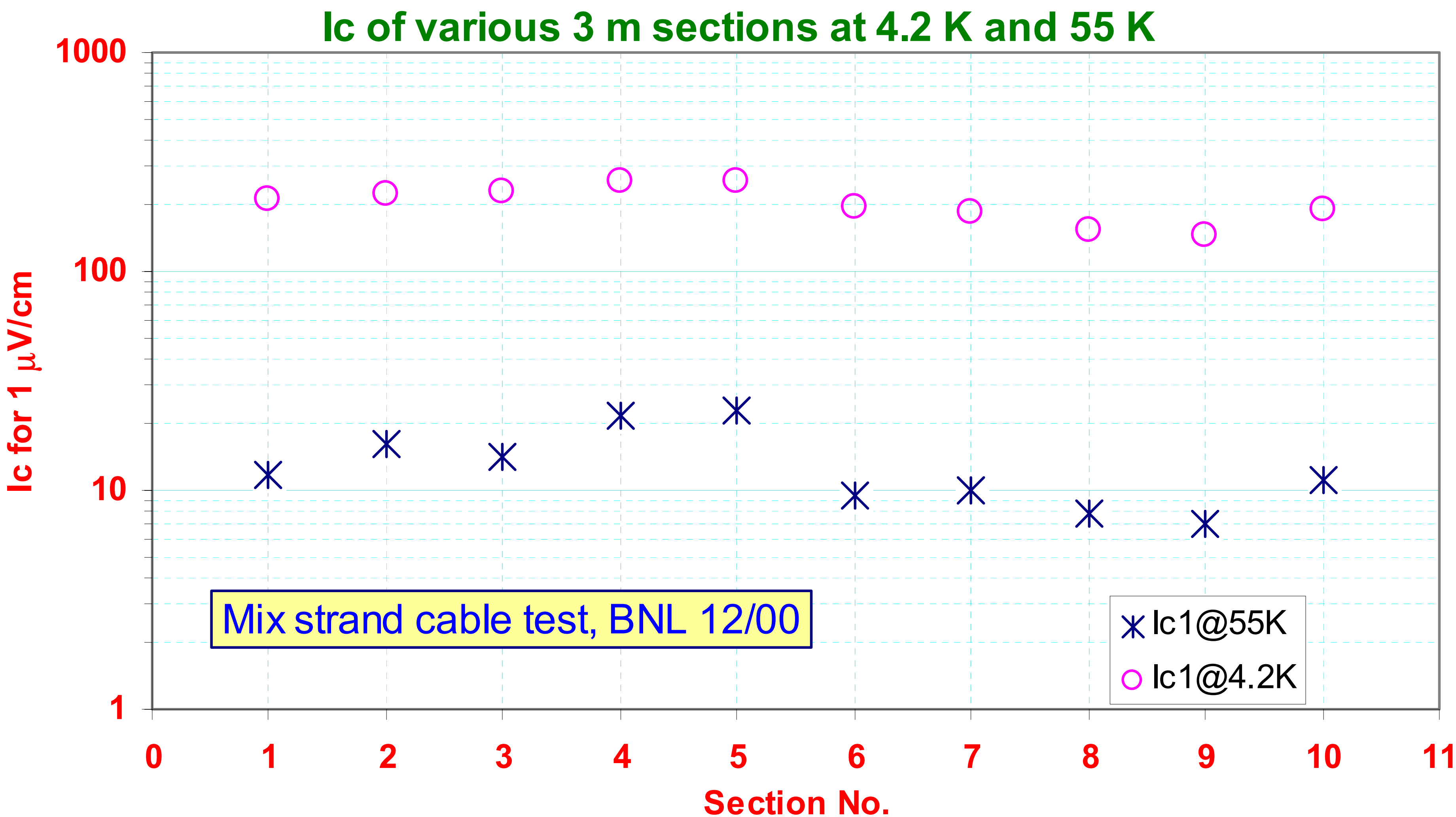
Performance of Coil #2 in Common Coil Configuration

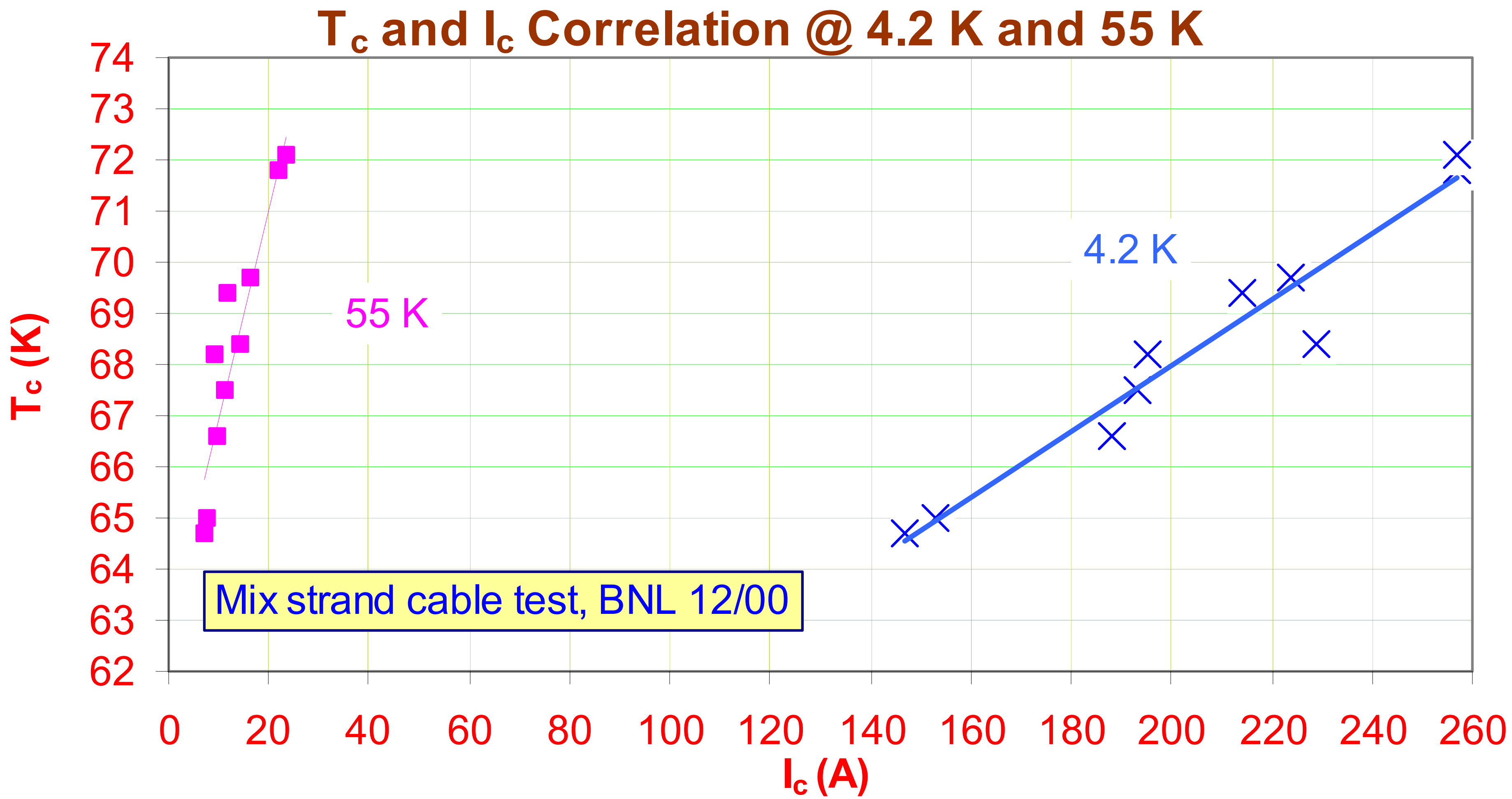




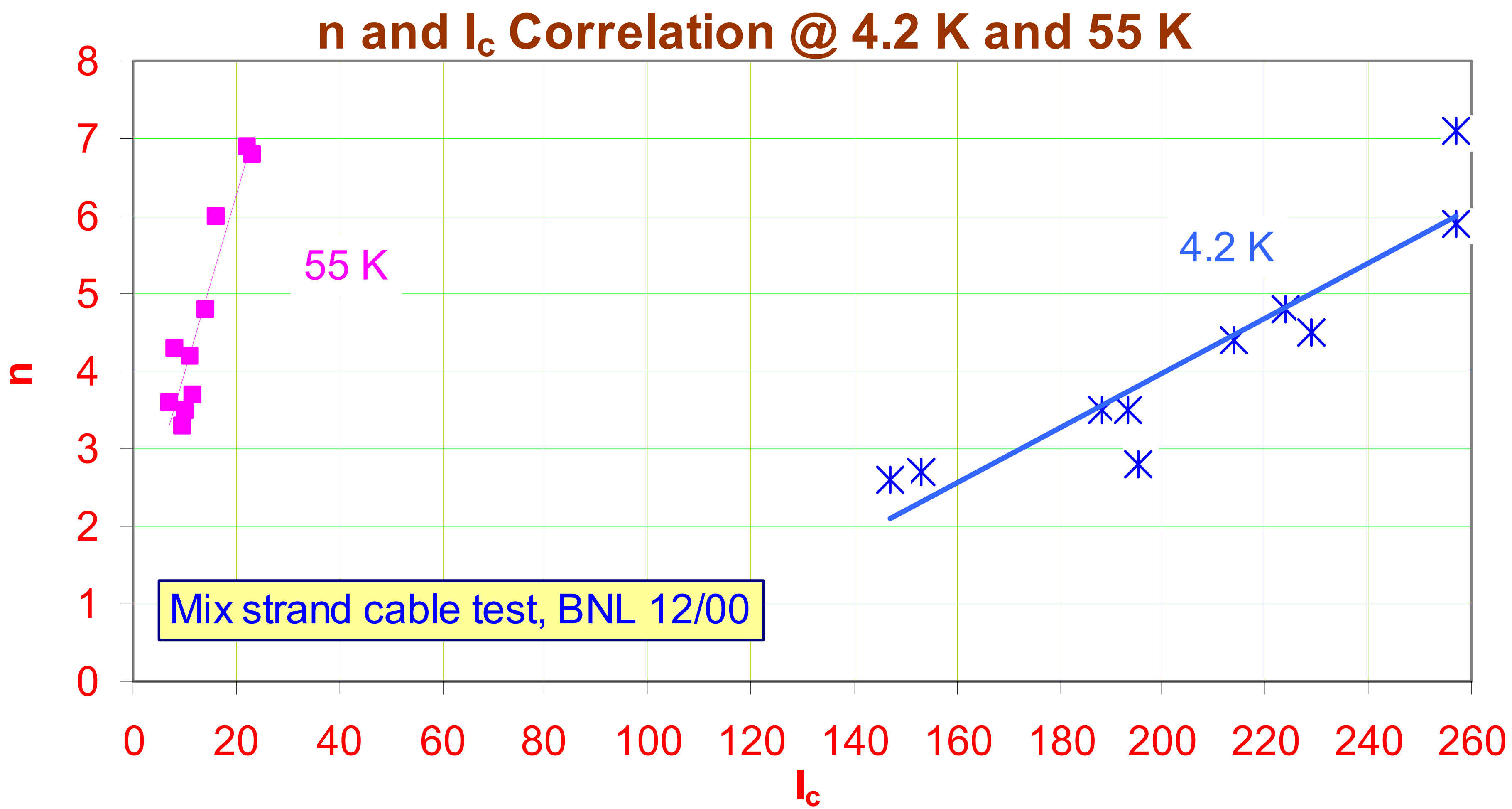
Ic Tracking Between 4.2 K and 55 K



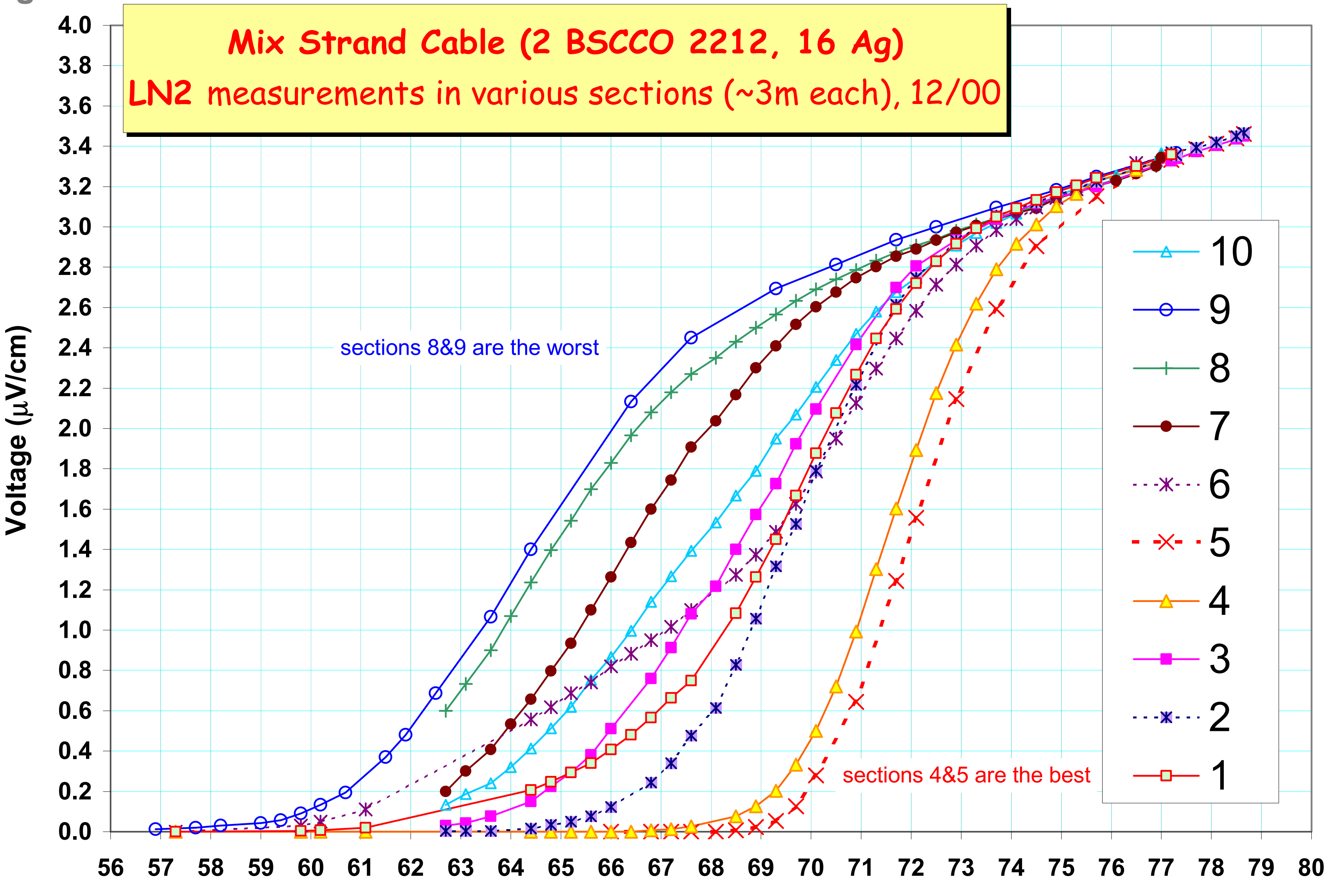
Correlation between T_c and I_c



Correlation between T_c and n-value

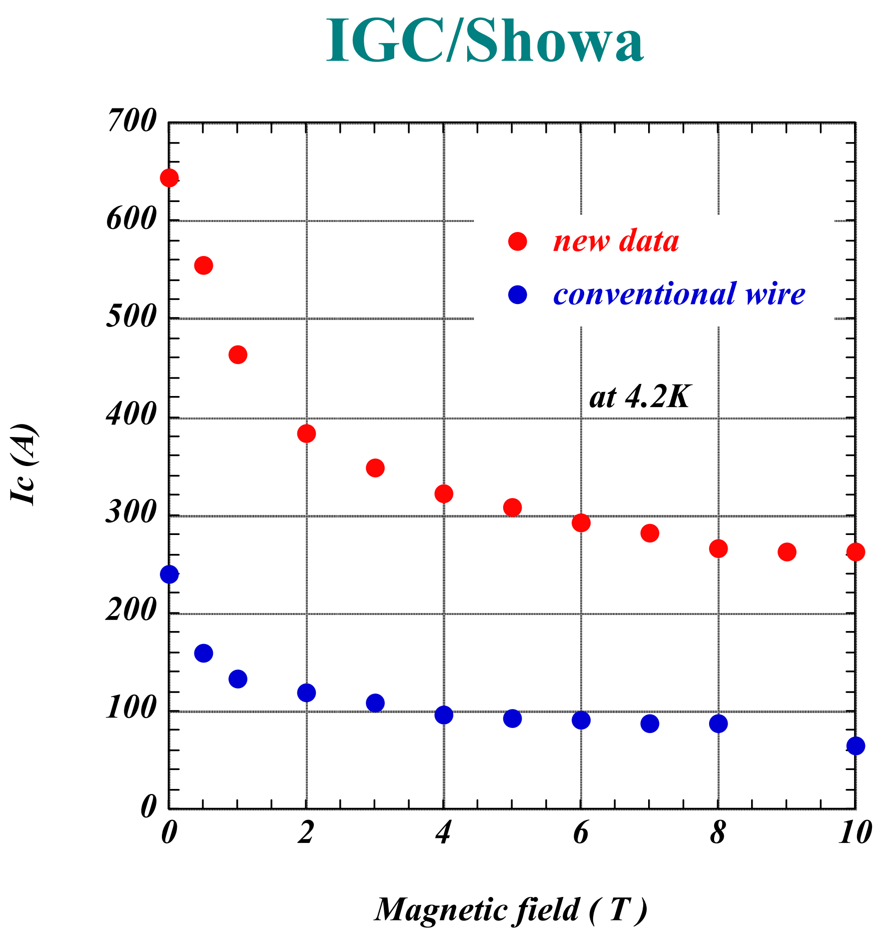


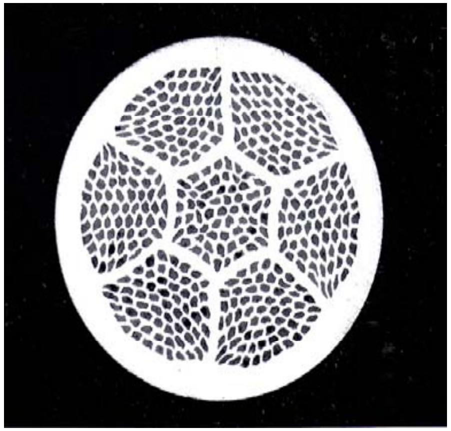
Measurements in Liquid Nitrogen



The BSCCO Wire Today

Ic-B characteristics of new wire



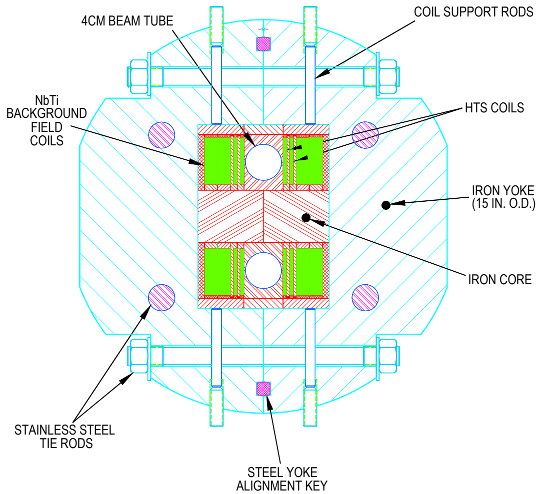


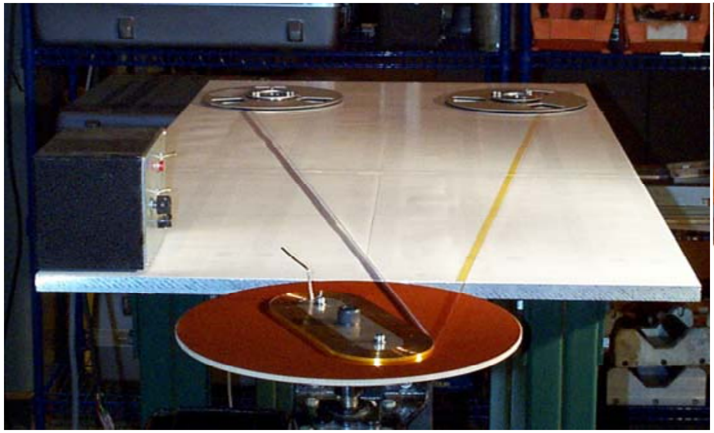
I_c (4.2K 0T) : 640A
J_c (4.2K 0T) : 490kA/cm²
Size : $0.81mm^d$
Number of filament : 427
Material of outer sheath : Ag alloy
Material of inner sheath : Ag
Ag/SC ratio : 3.0
Tensile strength (R.T.) : 120MPa

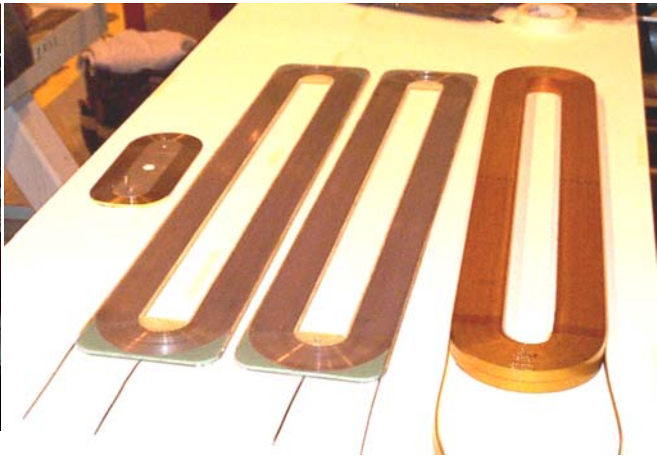
This is about a factor of 5 better than what was used in our coils

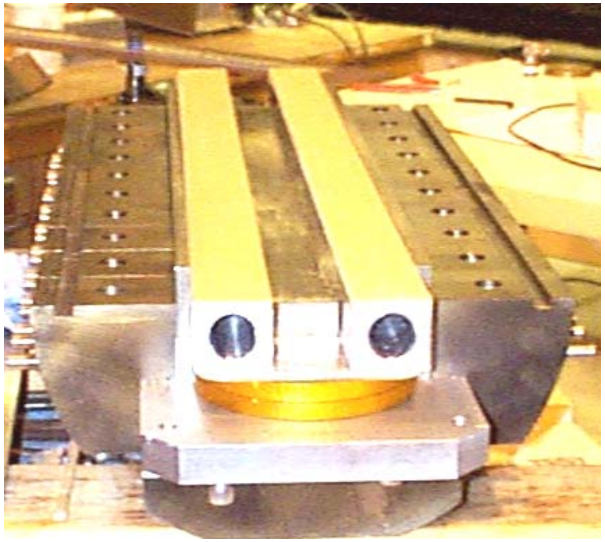
20/05/00

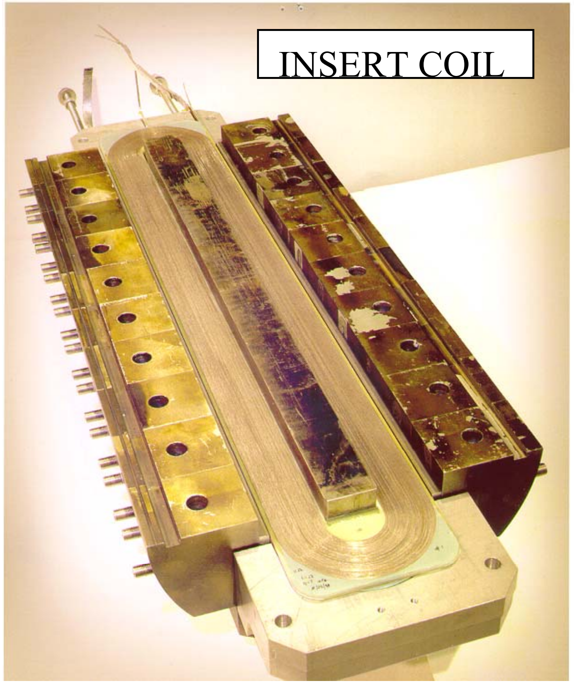
Hybrid Common Coil Magnet at BNL



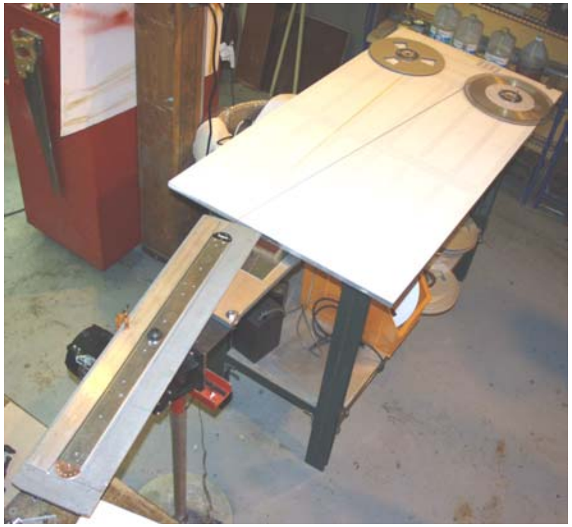






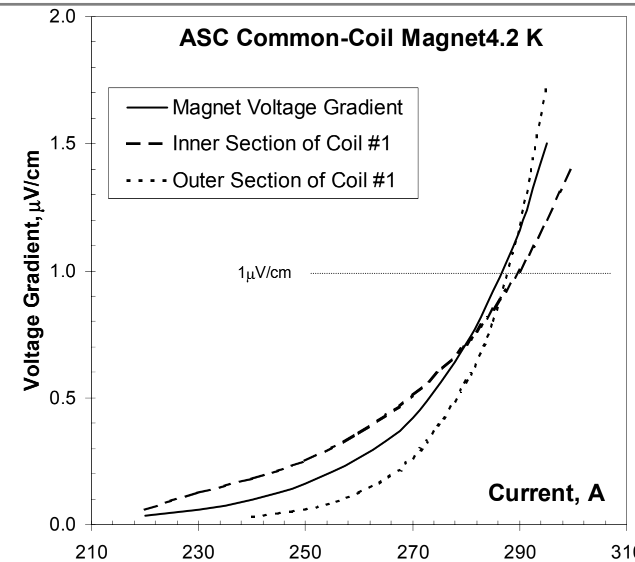


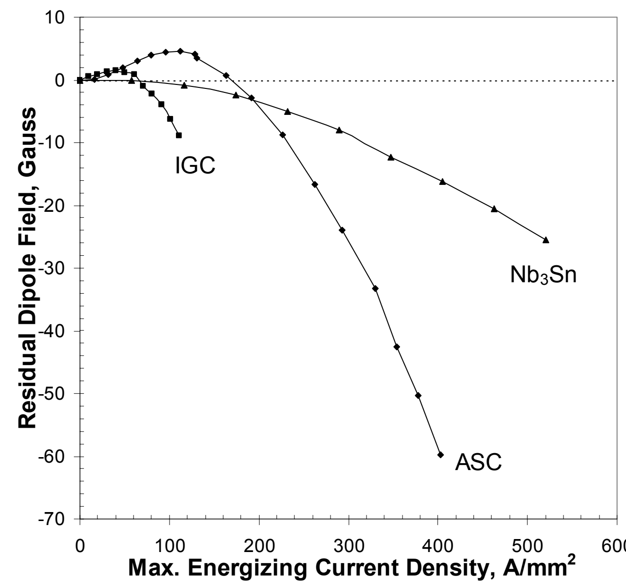
Common Coil Magnets With HTS Tape



A coil being wound with HTS tape and insulation.

Two HTS tape coils in common coil configuration





Status of HTS tape coils at BNL

	Size, mm	Turns	Status
Nb_3Sn	0.2 x 3.2	168	Tested
IGC	0.25 x 3.3	147	Tested
ASC	0.18 x 3.1	221	Tested
NST	0.20 x 3.2	220	Under construction
VAC	0.23 x 3.4	170	Under construction

Other Advantages of HTS

A slow transition to non-superconducting stage.

If there is a degradation or if the operating conditions become such that a part of the magnet can no longer remain in an ideal superconducting stage, then there is only a modest temperature rise locally. If the local temperature rise can be tolerated and if the heat can be removed, the magnet will continue to operate in a superconducting stage.

This is in contrast to a sharp transition to "normal zone" in conventional low temperature superconductors where the whole magnet must be switched to normal stage for protection.

This implies a more relax design & operating conditions for a magnet built with HTS.

The cost and performance issues still remain.

Fast Turn-around Studies with 10 turn Coils

Examples of systematic studies in a modular approach

- Different technologies
  - Wind & React Vs. React & Wind
- Different conductors
  - Nb_3Al, HTS, etc.
- Different insulation
- Different geometry's
  - Tape, cable
- Stress Management/High Stress Configuration
- Coil Winding/Splice

*** A Dynamic Program with fast turn-around time for exploring new frontiers/ideas ***