Theme II-Thrust 7

Develop High Temperature Superconductors and Other Magnet Innovations to Advance Fusion Research

ReNeW Magnets Panel

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ReNeW Workshop

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Bethesda, MD

Broad effort on advanced magnet R&D, focusing primarily on the new opportunities enabled by:

High Temperature Superconductor (HTS) **materials, which have enormous potential**

→ to revolutionize Magnetic Fusion Systems
→ to advance high field magnet technology in many critical scientific areas

Benefits for Magnetic Fusion Energy and Other Scientific Applications

- HTS is potentially a *'game changer'* for fusion devices in several respects:
  - *high performance*
  - *high reliability, availability and maintainability*
  - *acceptable cost*
- Flexible experimental scale devices
- Steady-State tokamaks,
- Stellarators, and other 3-D magnetic configurations
- Synergism with other DOE and scientific programs:
  - High Energy Physics
  - Superconductivity for Electric Systems
  - High field NMR
  - Medical (MRI, Proton Radiotherapy)

Key issues to be addressed

- **Development of practical conductors and cables suitable for demanding fusion applications.**
  - *Can the present fragile HTS tape geometry be integrated into high current cables with the high current density needed for fusion experiments?*
  - *Can HTS materials, currently thin, flexible, tapes of YBCO or fragile, Ag-sheathed multifilament wires of Bi-2212 be made into round wires with high Jc and irreversibility fields for easier magnet application?*

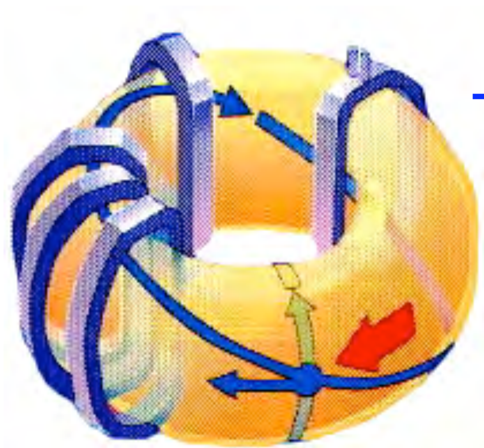
- **Integration of HTS cables into practical magnet systems for fusion experiments.**
  - *Can HTS be used to make magnet systems with increased performance, reliability and maintainability?*
  - *Which applications will most enhance performance, and reduce costs, of fusion research experiments, and ultimately enable more attractive reactors?*

Relation to Other Thrusts

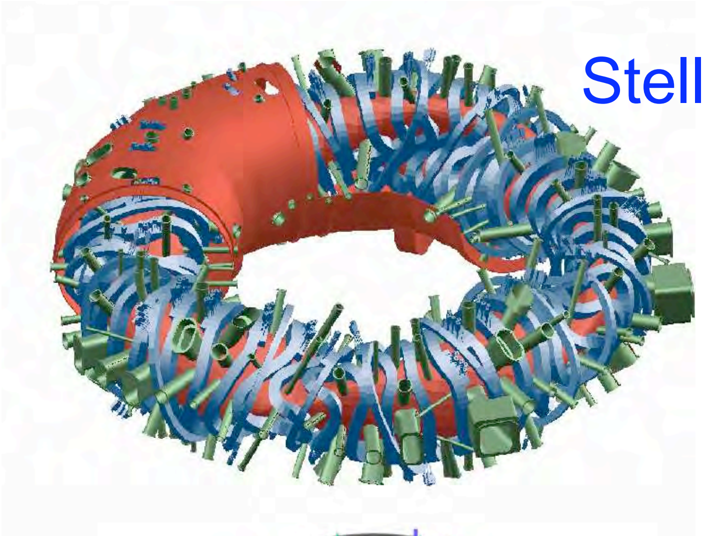
This enabling Thrust would broaden the range of options for experimental fusion research in all Themes:

- Steady state integration experiments for Themes II and/or III
- A component test facility for Theme I
- Complex magnetic configurations for Theme V
- Demountable coil element may strongly enhance the achievement of RAMI (Theme IV).

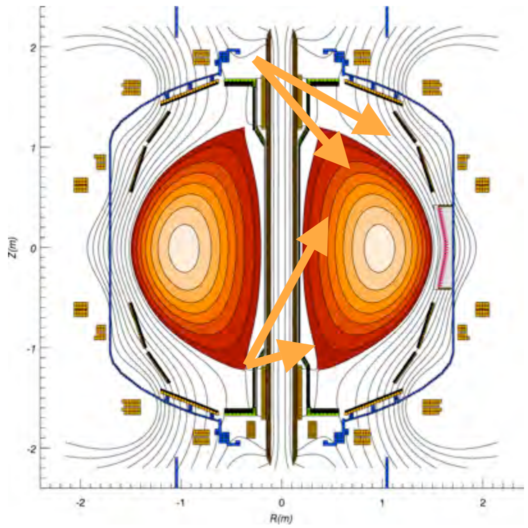
Theme 7 Impacts All Magnetic Fusion Configurations



Tokamak



Stellarator



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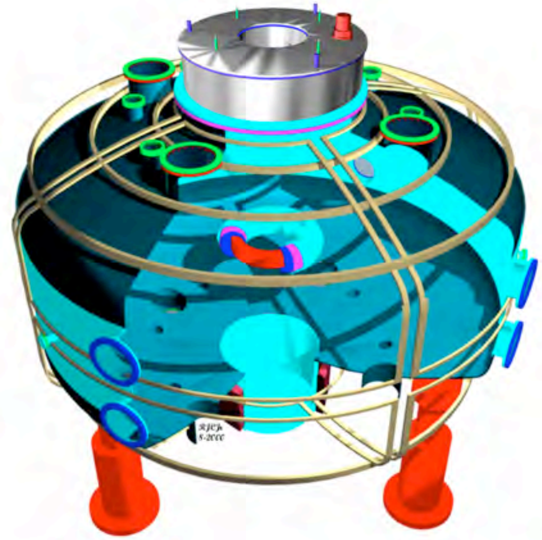


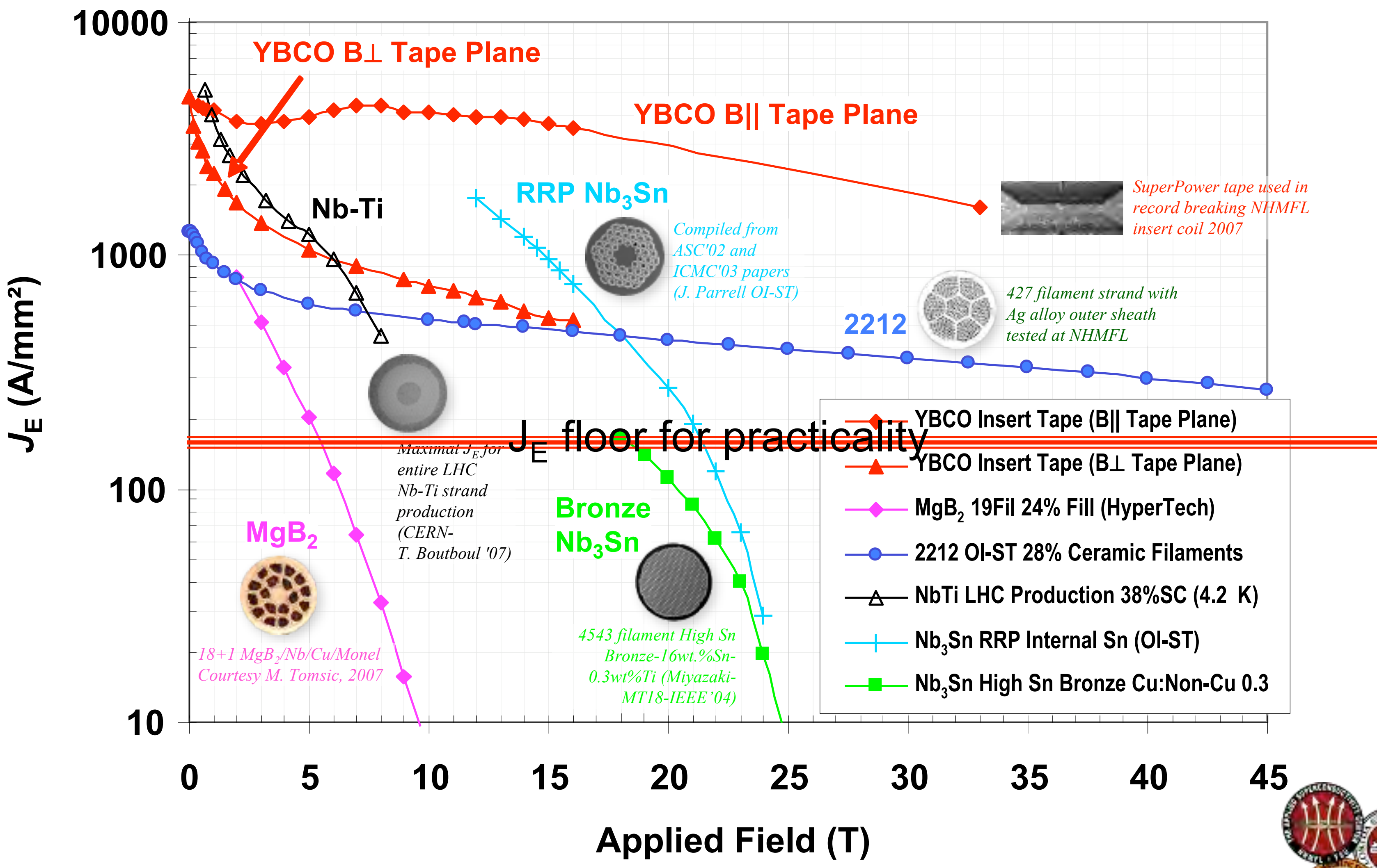
Dipole

Thrust Elements

A structured research and development program consisting of the following elements:

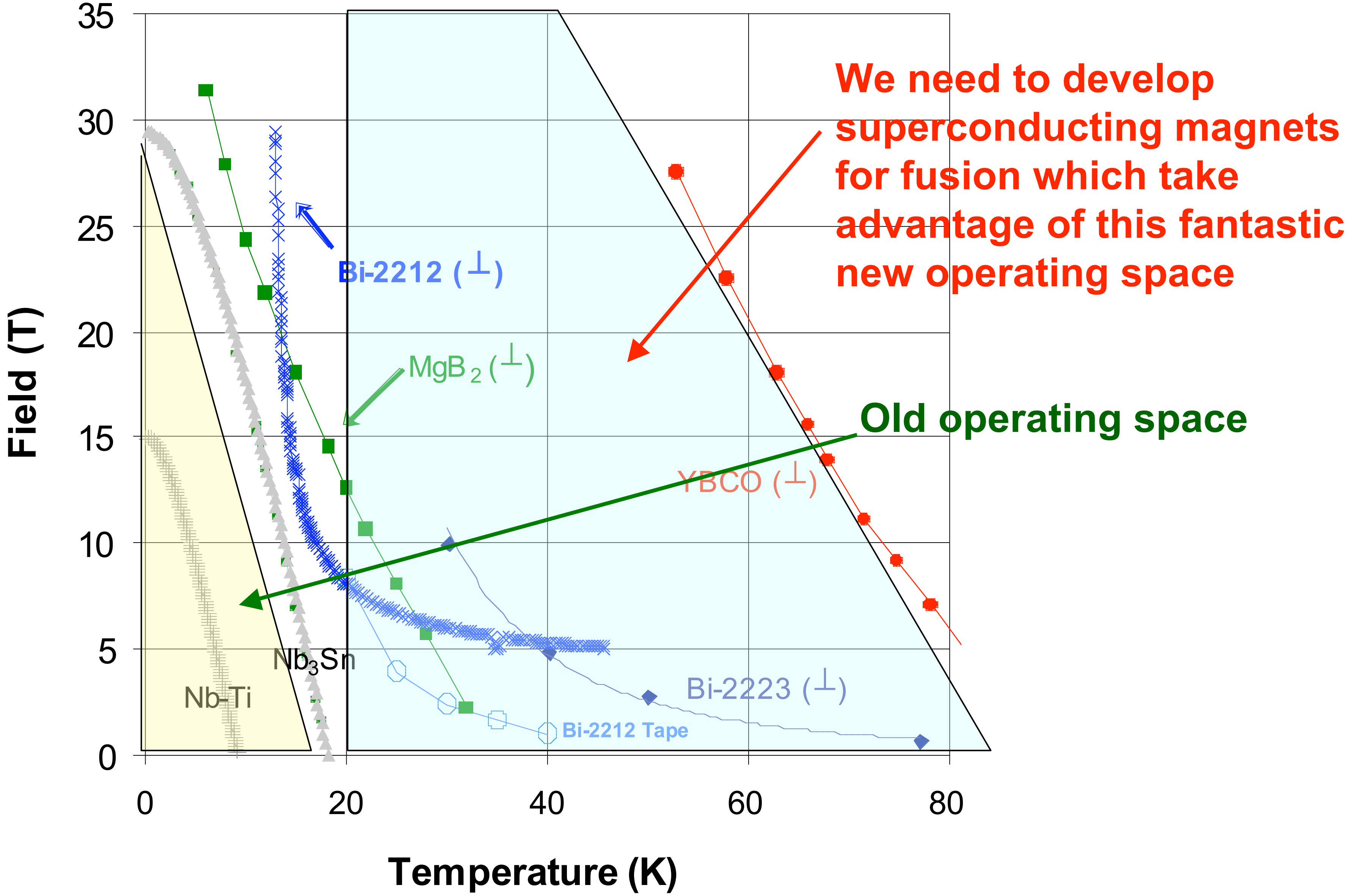
1. HTS wire/tape
2. High current conductors/cables
3. Advanced magnet structural materials/structural configurations
4. Cryogenic cooling methods for HTS magnets
5. Magnet quench detection/protection specific to HTS magnets
6. Advanced radiation tolerant insulating materials
7. Integration of conductor with structure, insulation, and cooling
8. Demountable joints for coils
9. Coil fabrication technology incorporating the unique features of elements 1-8

HTS greatly extends the capability at 4K

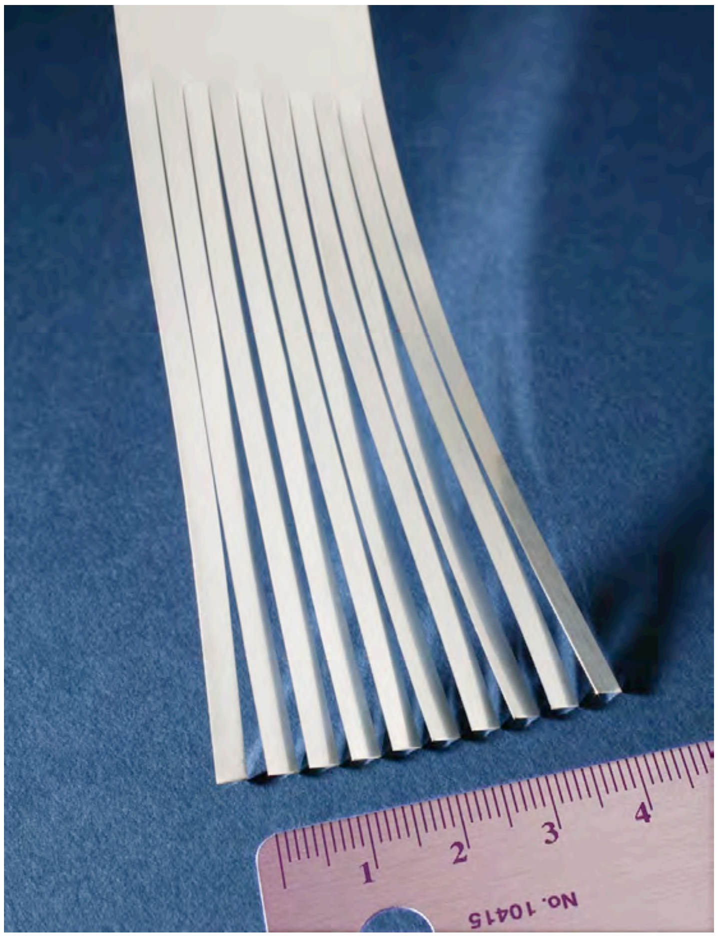


Courtesy Peter Lee www.asc.magnet.fsu.edu

HTS make much higher magnetic fields accessible………



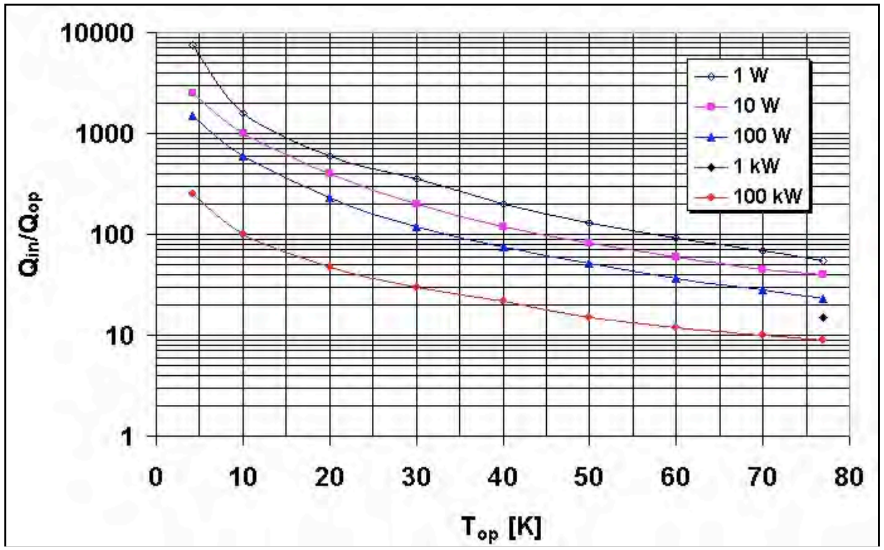
Superconductors Offer Very High Current Density



HTS versus Copper
Equivalent current carrying capacity

Advantages of HTS Operating at Elevated Temperature

- Increase in thermal conductivity (5-10 times)
- Increase in specific heat (10-100 times)
- Very high stability
  - (Disadvantage very slow quench propagation making projection more difficult)
- Less refrigeration wall power required (gain in fraction of Carnot Efficiency)

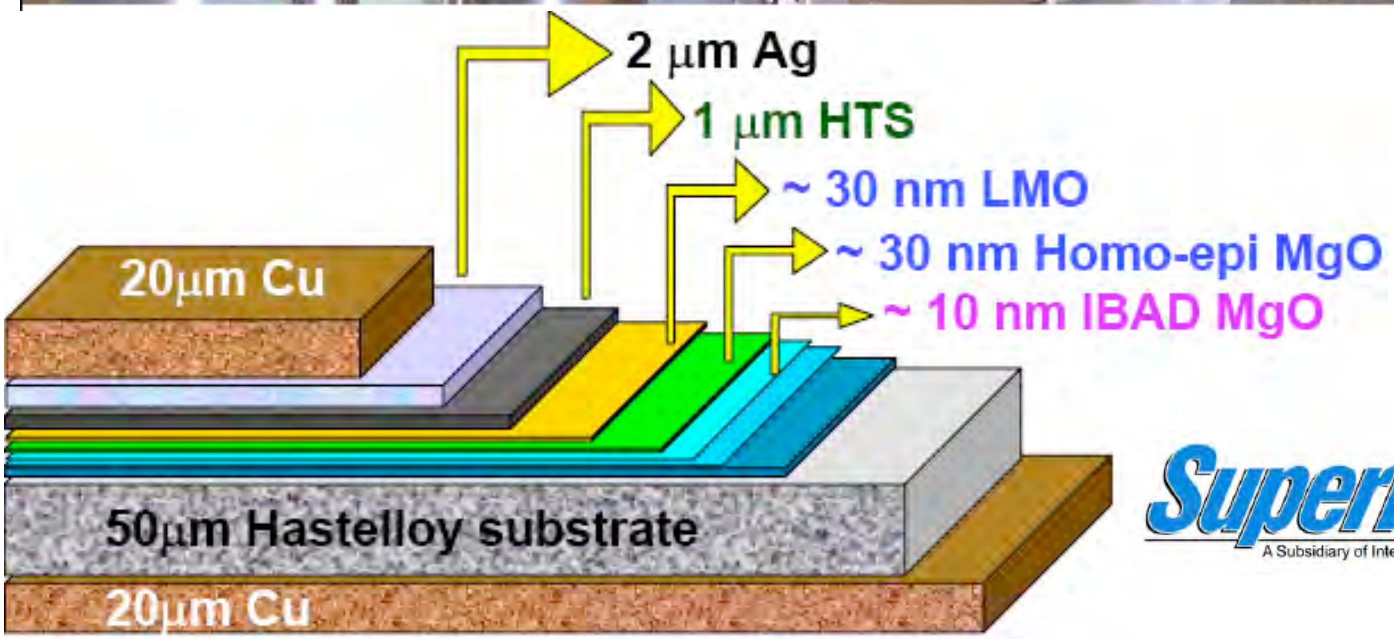


ITER Cryogenic Refrigeration Requirements

Heat Load (kW)	Temperature (K)	Q_{wall}/Q_{in}	Wall Power (MW)
65	4.5	180	11.7
1300	80	9	11.7

YBCO Tape (2nd Generation-HTS)

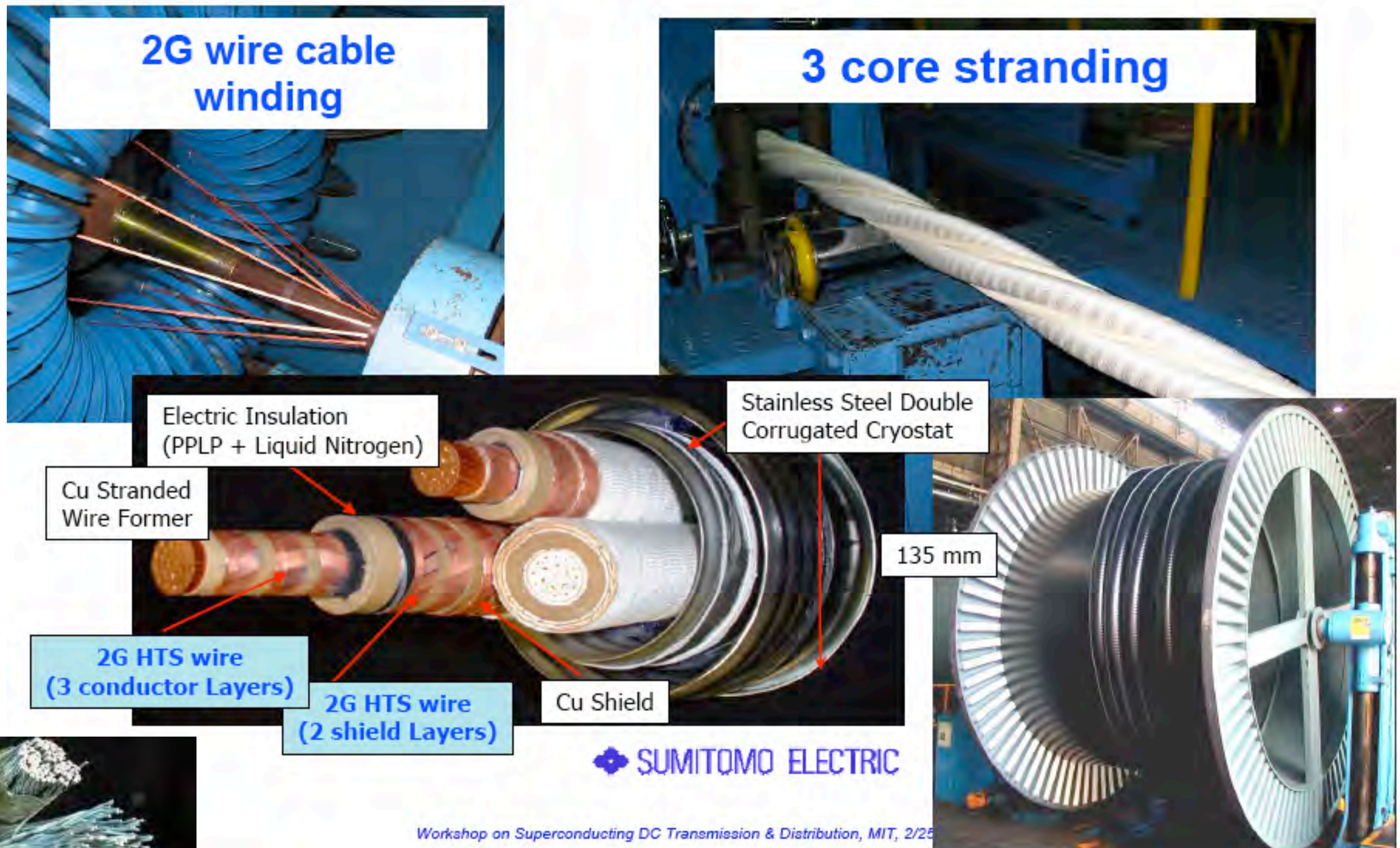
- SuperPower (Latham, NY) uses a reel-to-reel system for tape production



SuperPower Inc.
A Subsidiary of Intermagnetics General Corporation

SuperPower Inc.

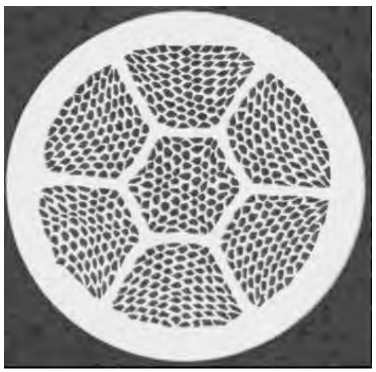
In 2007, 30 m cable was manufactured by Sumitomo Electric with ~10,000 m of SuperPower® 2G HTS wire

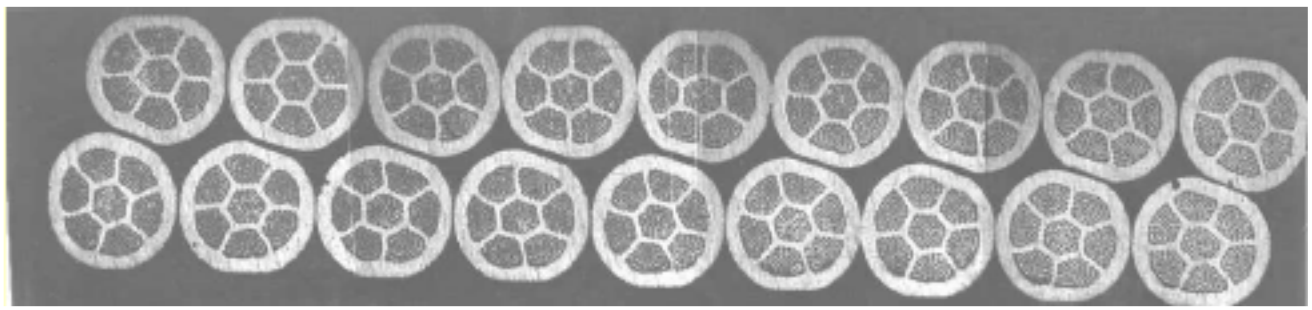


ITER TF Conductor 65,000A

BSCCO-2212

- Good properties in high magnetic field at **4K**
- Round wire allows cabling for higher operating current

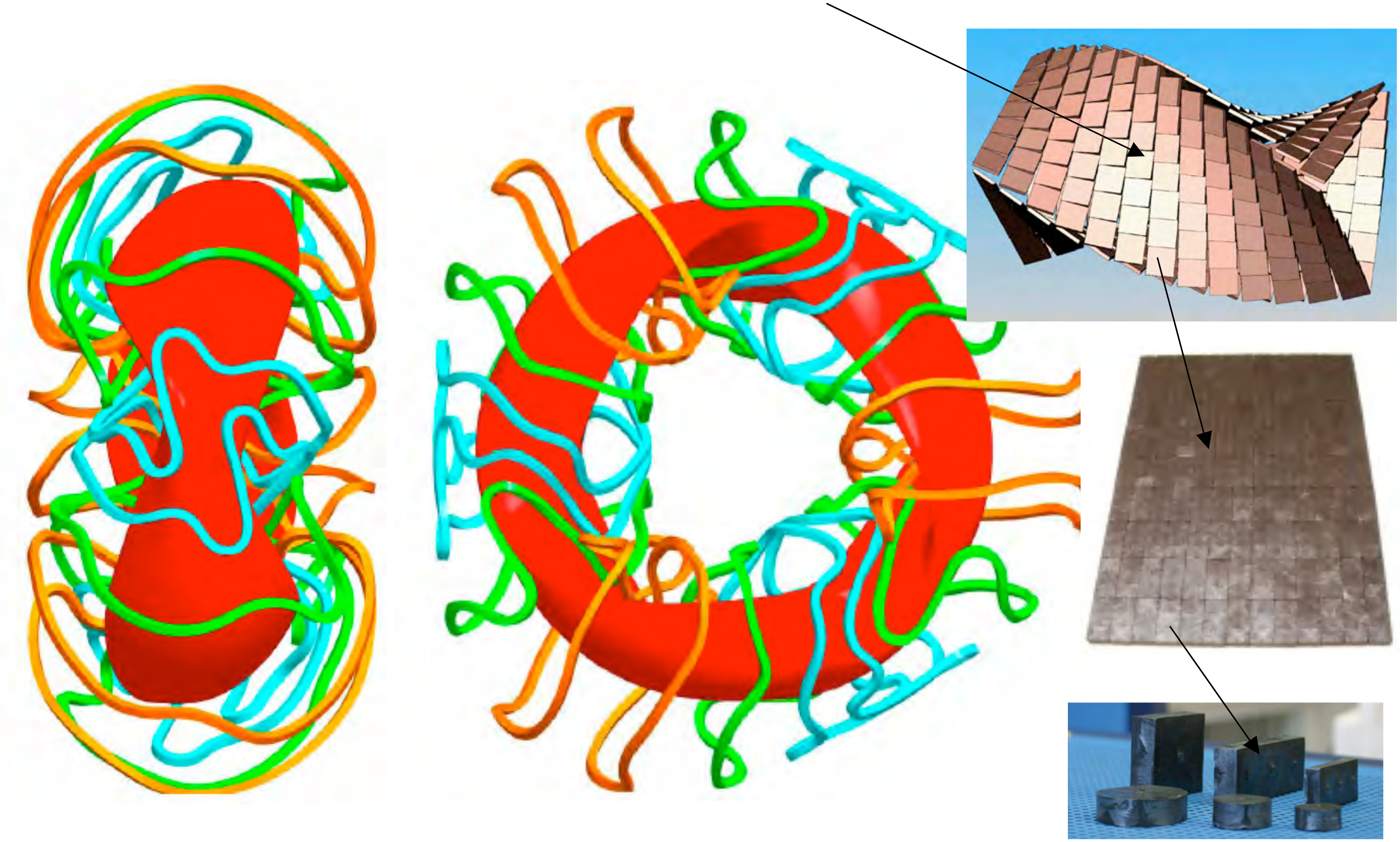




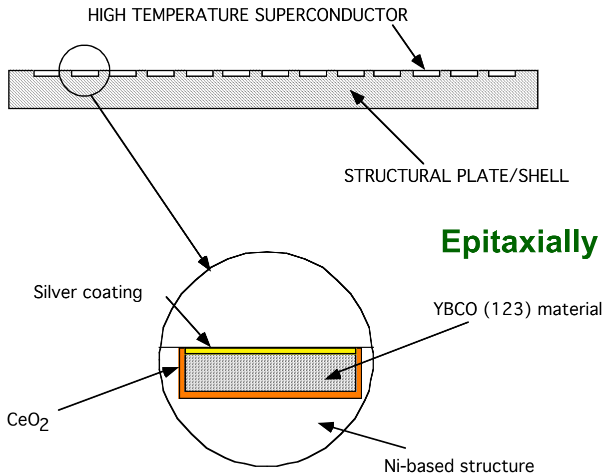
- *Can YBCO coated conductor tapes be made in round wires?*

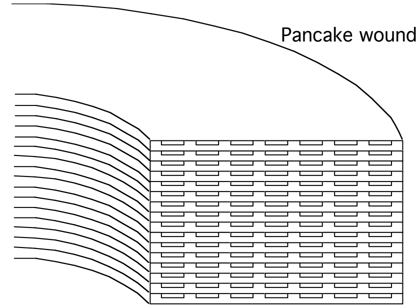
Stellarator Designs (ARIES-CS)

Use diamagnetic properties of *Bulk Superconducting Tiles* to define flux surfaces?

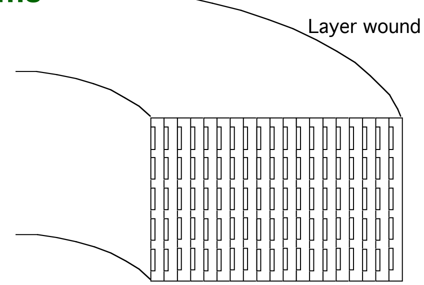


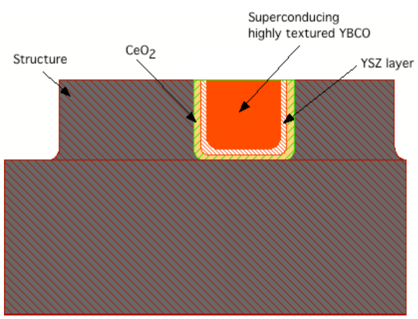
ARIES-AT magnets

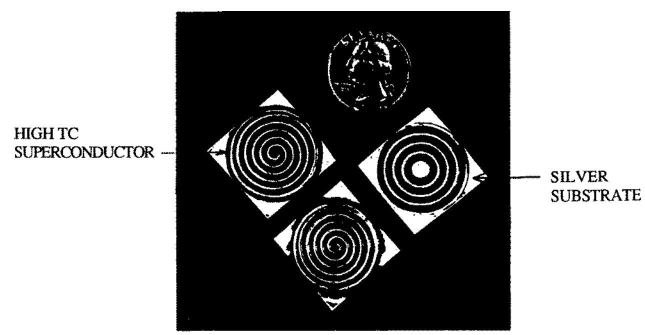




Epitaxially Deposited YBCO Thick Films







Thick YBCO layer (~ 20 μm), CuO_2 insulation, Inconel structure

Conductor-in-plate winding – small stress risers

Demountable SC Magnets?

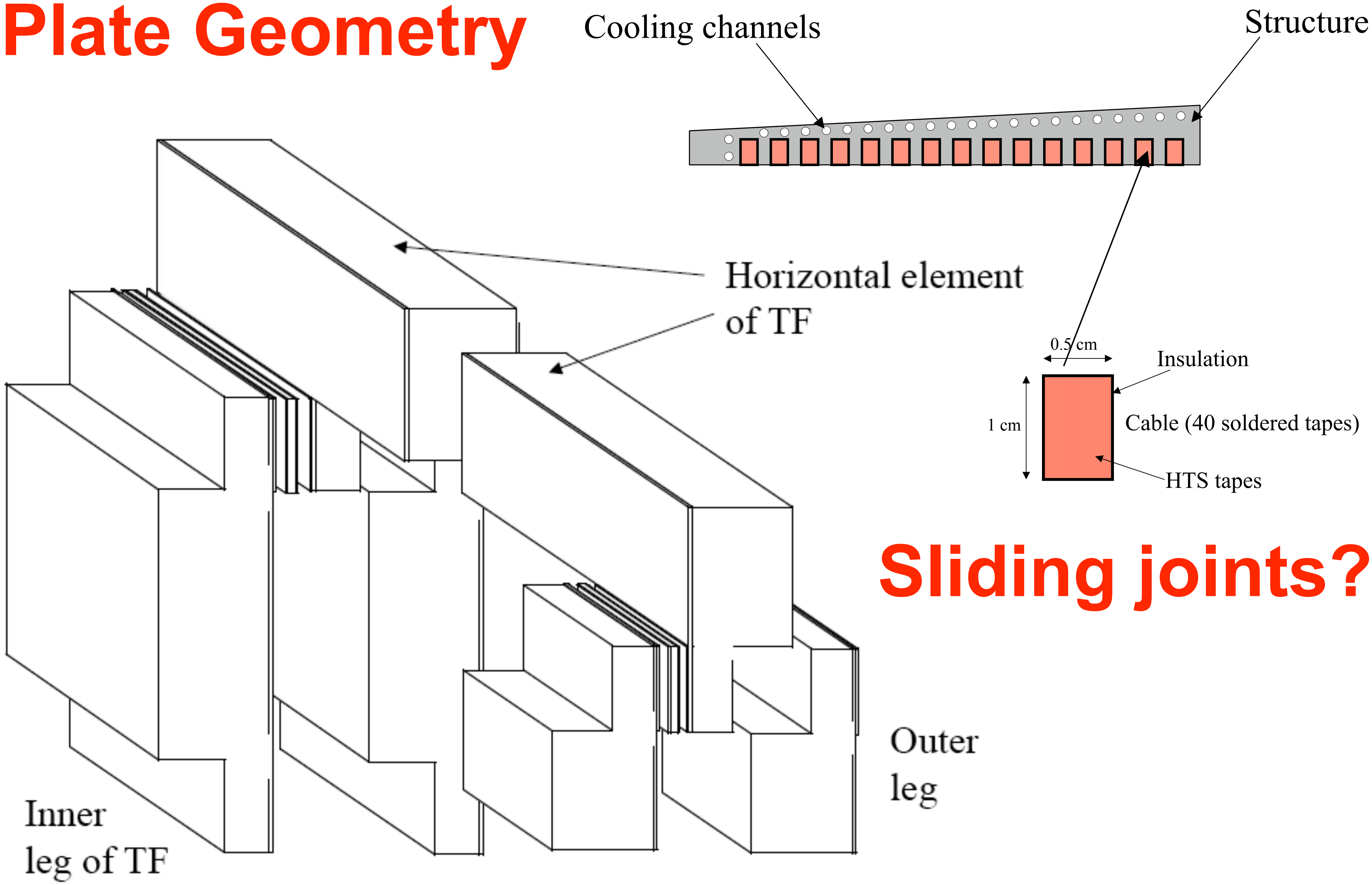
- Requires development
  - Potentially huge payback
- High field operation
  - PF system inside TF system?
- Create easy access to plasma core
  - Increase maintainablity

Joints

- **Option to be investigated:**
  - Joint geometries
  - Cables in series, low current (~ 12 kA)
    - Joint reliability critical,
  - Cables in parallel, very high current (200 kA)
    - Need to understand current distribution in plates
  - Scarf joints to minimize resistance across joints

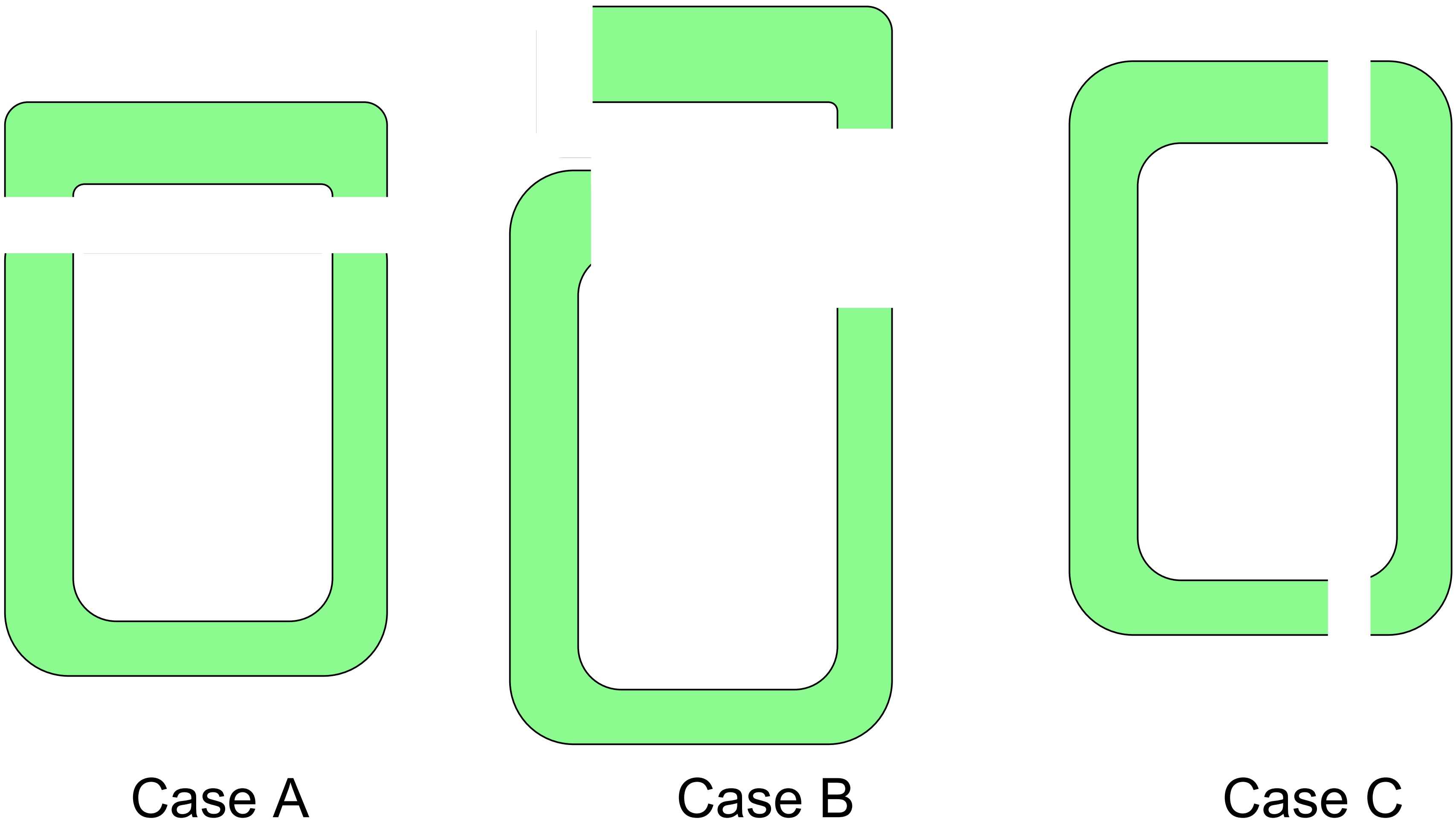
- **This area is critical and needs resources for proof-of-concept**
- **A concept that combines C-MOD and DIII-D joints may be feasible**

Plate Geometry



Sliding joints?

Some Options for Demountable Coils



Split Helical Coils for a Heliotron Reactor Concept

N. Yanagi, NIFS, Japan

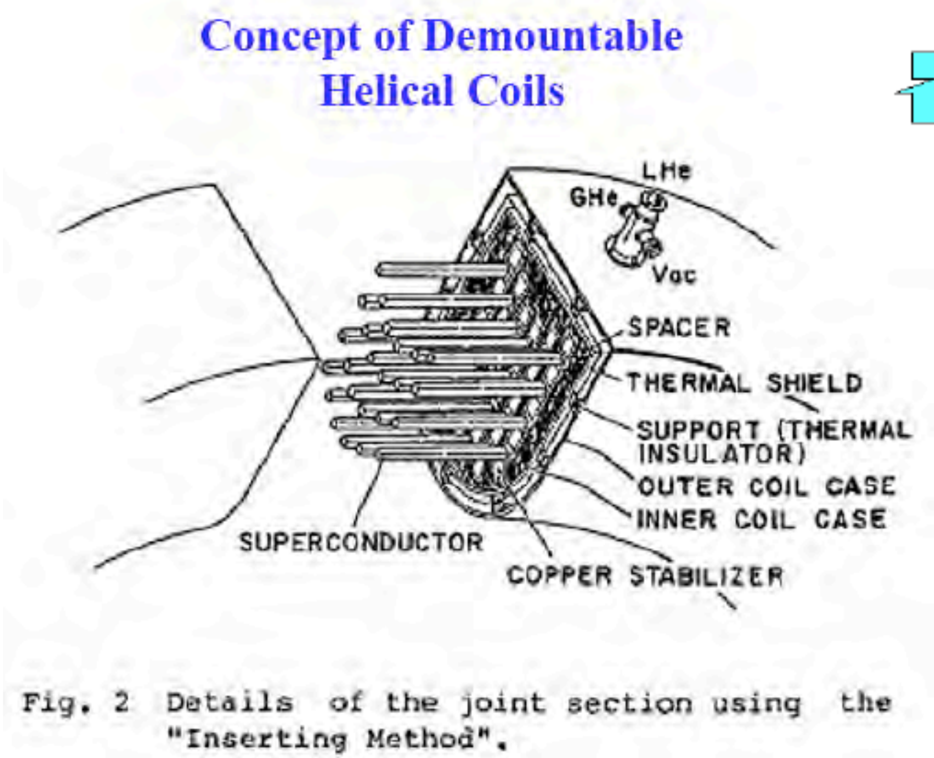
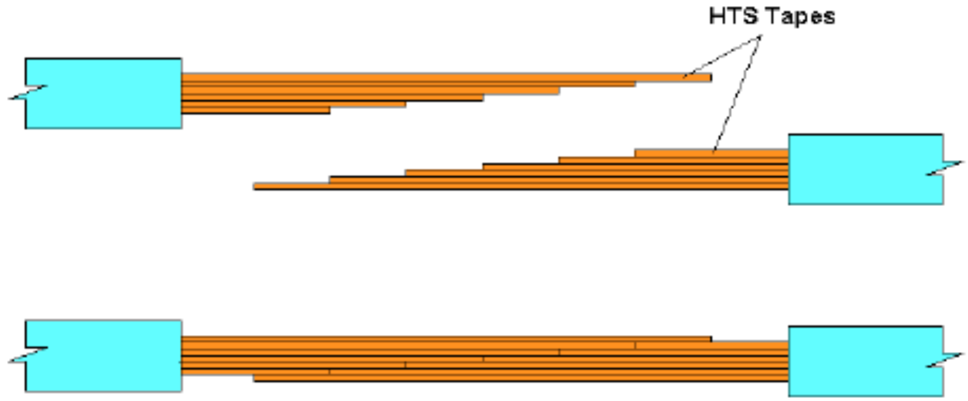
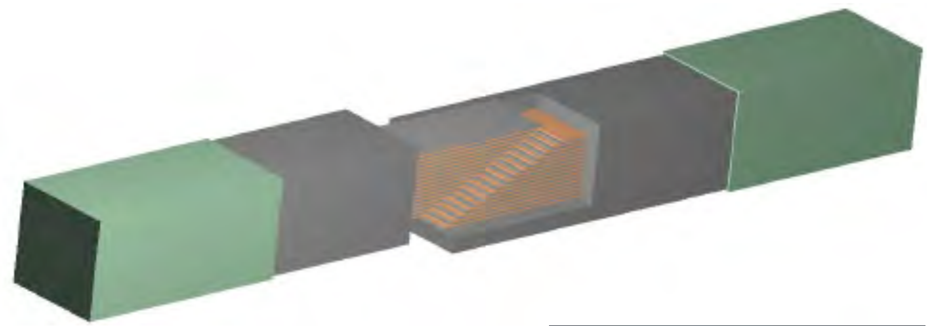
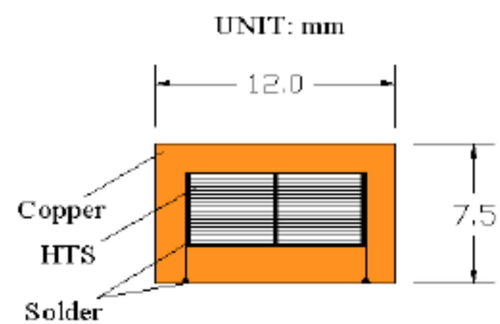


Fig. 2 Details of the joint section using the "Inserting Method".

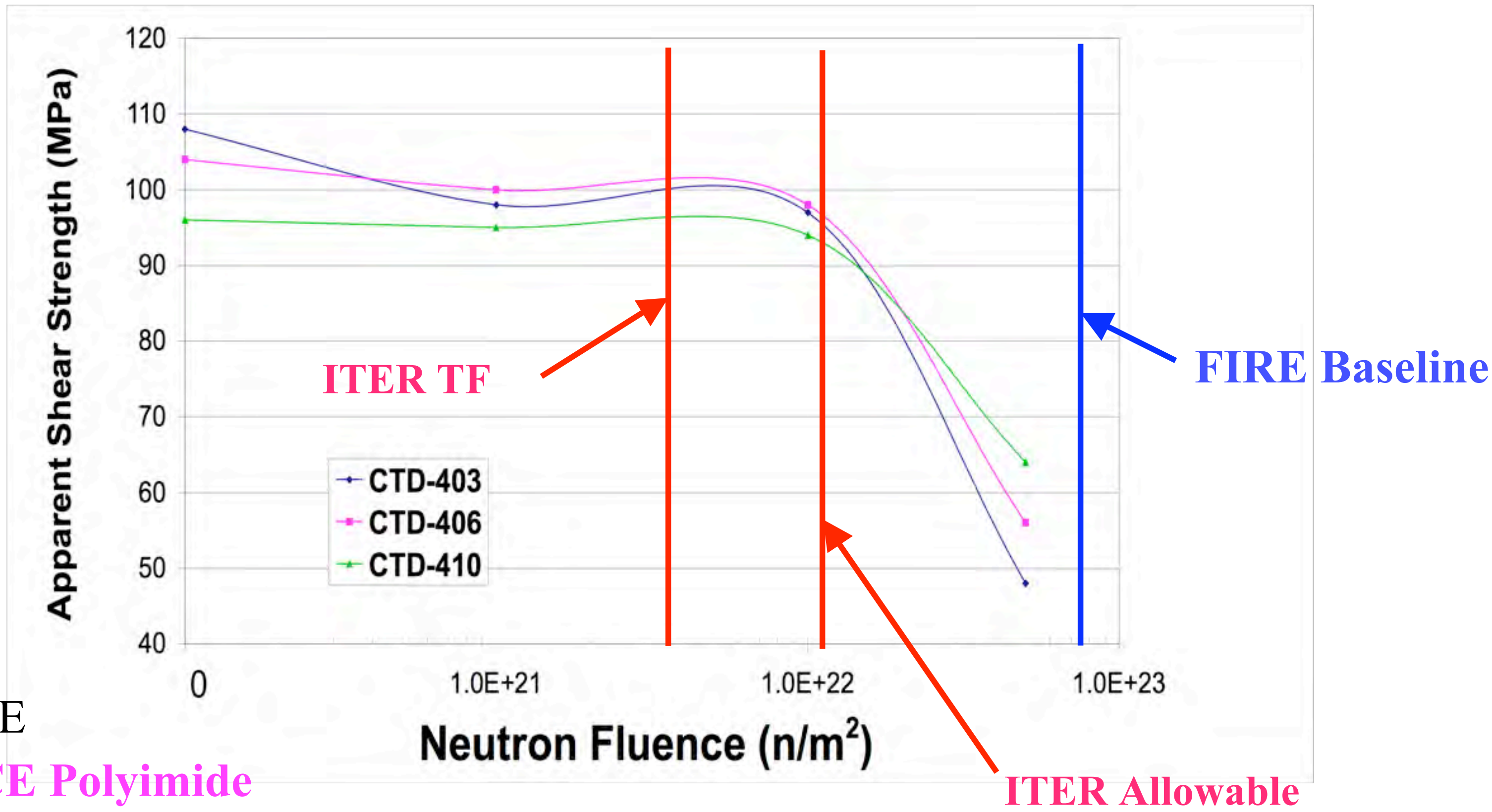
K. Uo et al., Proc. 14th Symposium on Fusion Technology(1986) 1727-1732.







Insulation
Shear Strength vs. Neutron Fluence
Imide & Cyanate Ester Hybrids



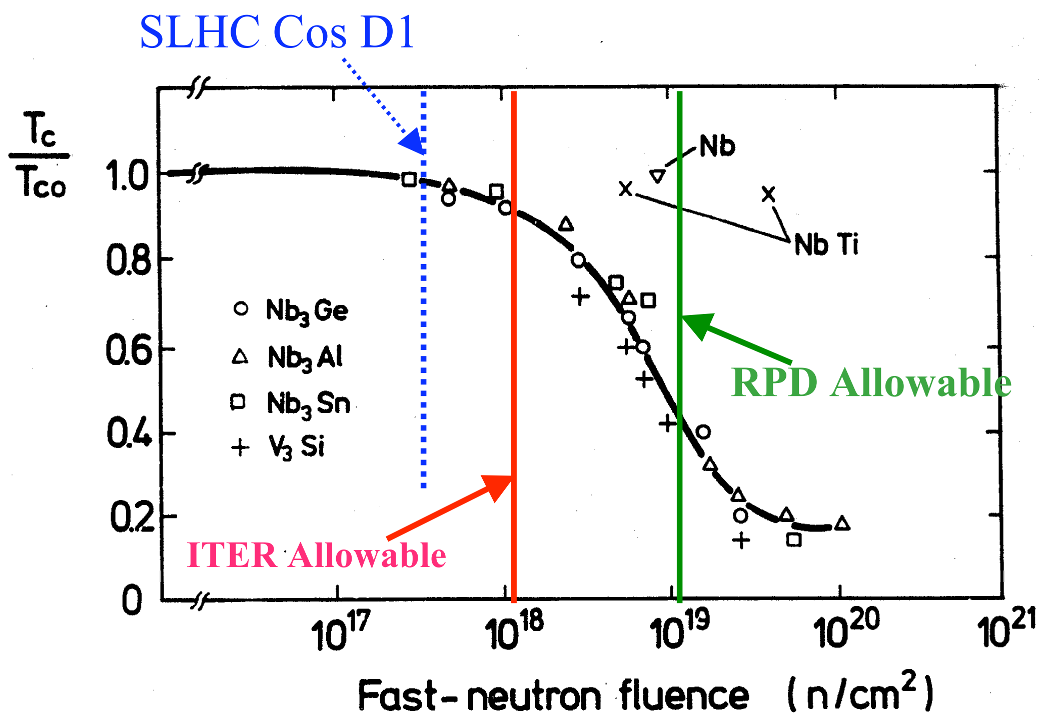
CTD-403-CE

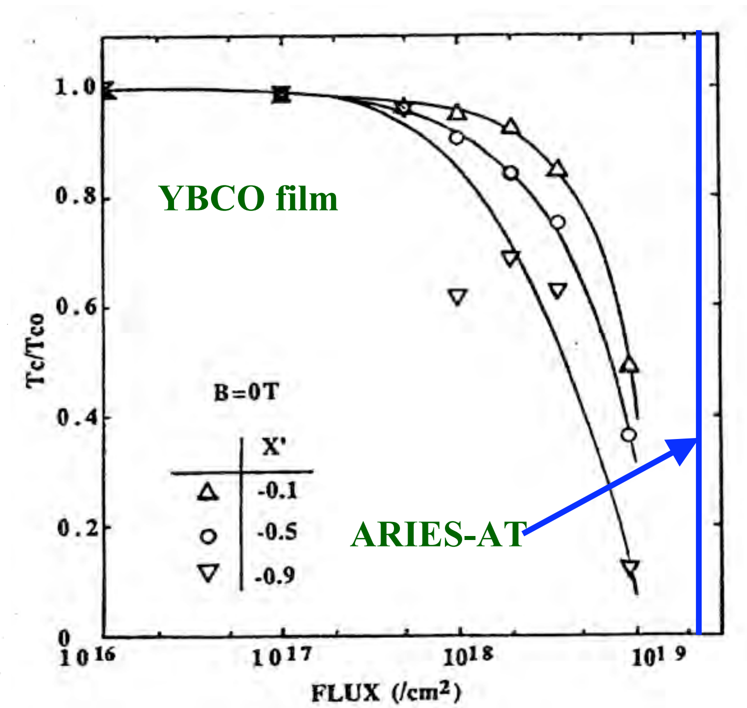
CTD-406-CE Polyimide

CTD-407-CE Bismaleimide

Preliminary Radiation Results for Cyanate Ester Hybrids

Superconductor Critical Temperature Neutron Degradation of T_c, A15's and YBCO





- All A15's have same T_c/T_{co} degradation vs. fluence
  - 1-2 orders of magnitude more sensitive than NbTi
- YBCO films have faster T_c/T_{co} degradation than A15's

Summary

- Advanced Superconducting Technology is critical to development of a reliable and economic fusion reactor
- Demo and commercial fusion reactors will not be built with 1990's ITER magnet technology
  - Can't afford to wait 20-30 years and then try to catch up
- Advances in magnet materials and design concepts will enable a scientifically and technically robust magnetic fusion program
- HTS technology may open up new areas for fusion innovation not yet forseen