Advanced Magnets and Implications for BPX-II

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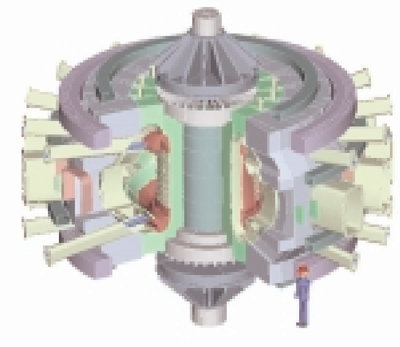
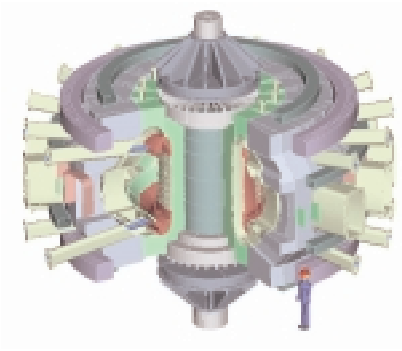


Materials Development

- 1) Radiation-resistant insulation
- 2) High-temperature superconductors
- 3) Nb_3Sn



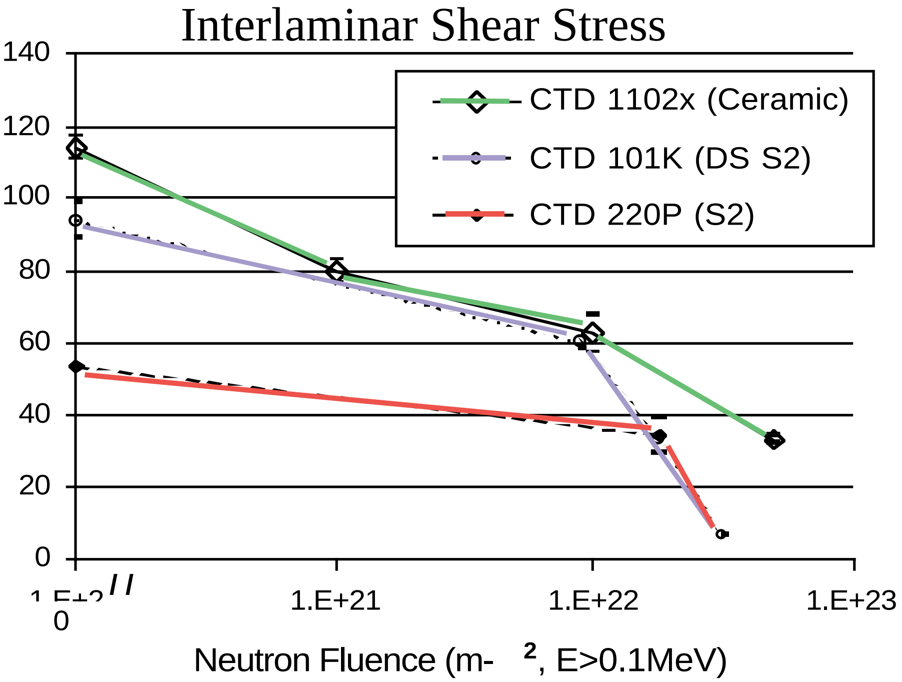
Radiation Resistant, High Shear, VPIable Insulation

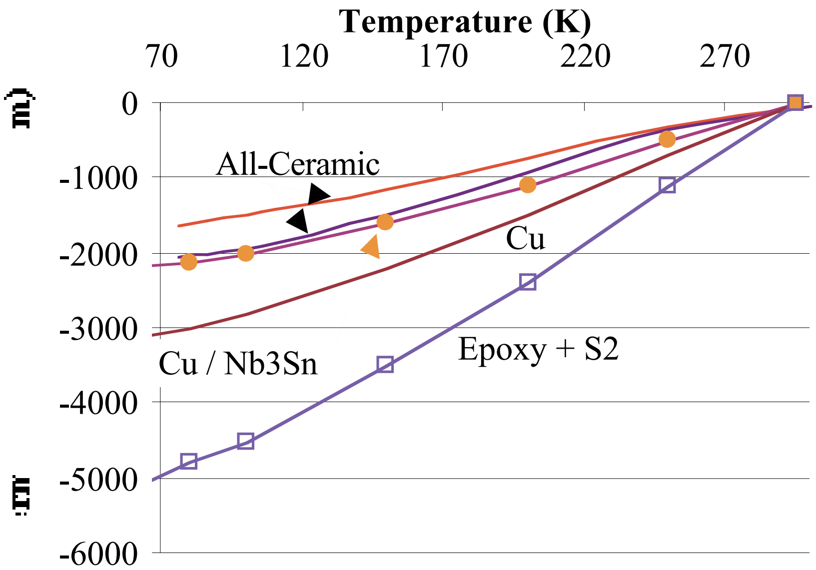
SBIR's to CTD, CMI, and Eltron: Highly aromatic organics (Cyanate Ester);

Ceramics (ceramic binder before HT, VPI after), better mechanical and electrical

FIRE/NSO - 2 x 10^{10} for full life/performance

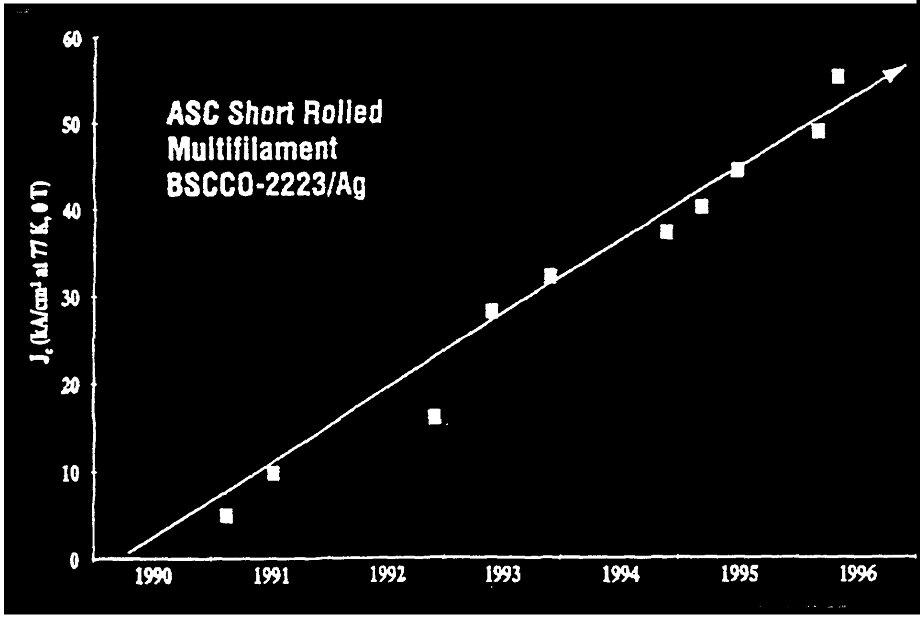
Insulation testing beginning at MIT (Bromberg)

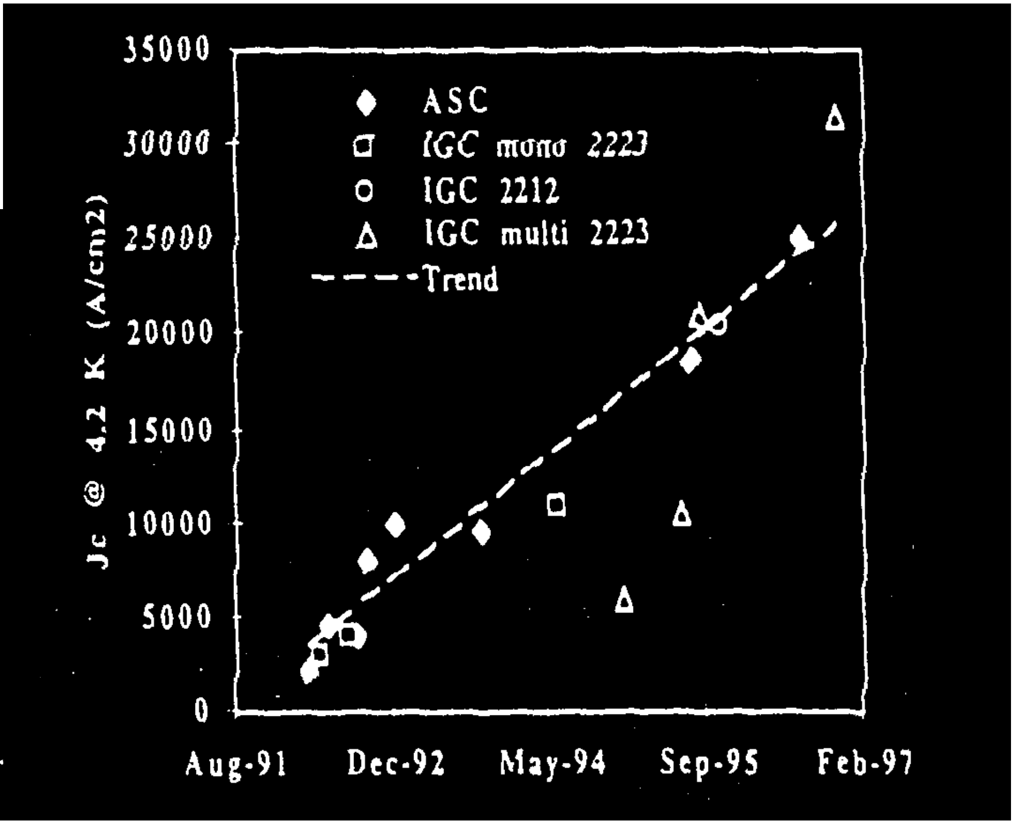




Malozemoff's Law for HTSC

Malozemoff's Laws for J_c, J_{eff}:
J_c=9 (Annum-1990); J_{eff} (2001)=99 kA/cm^2=990 A/mm^2
J_{eff}=4 (Annum-Aug 1991); J_{eff} (Dec 2000)=37.3 kA/cm^2=373 A/mm^2

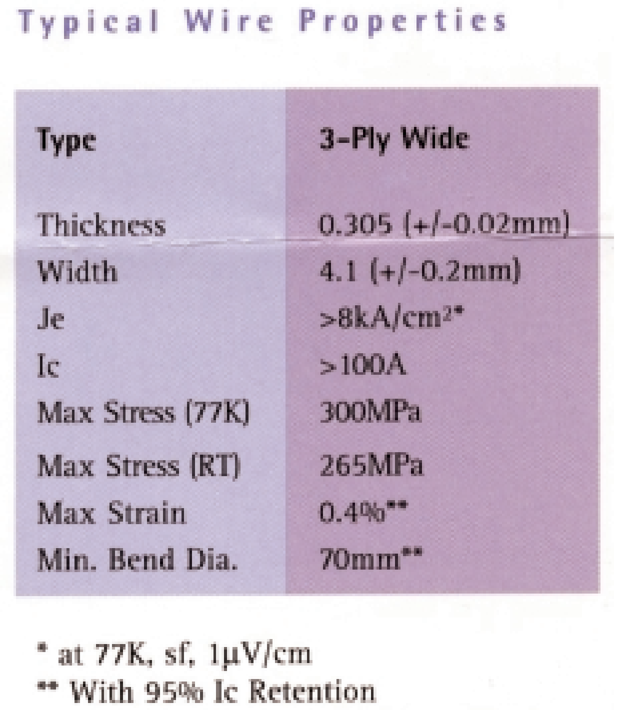




Malozemoff's Reality-Checked Law

ASC Commercial Tape: J_{eff}=12 kA/cm^2 (8 kA/cm^2, reinforced)

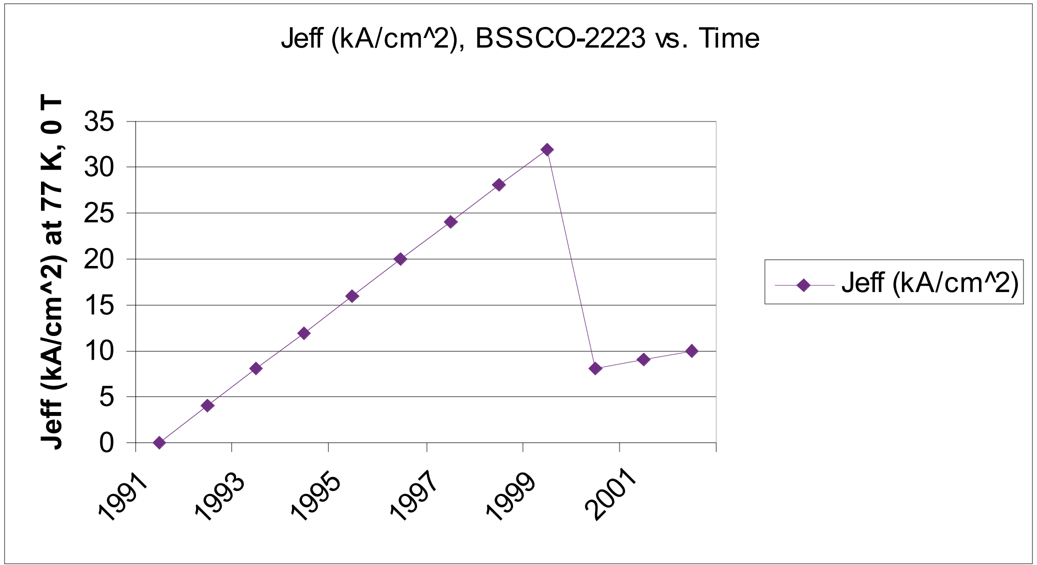
Malozemoff suddenly optimistic by 33.3/12, 8 = 2.6x or 4.2x



Typical Wire Properties

Type	3-Ply Wide
Thickness	0.305 (+/-0.02mm)
Width	4.1 (+/-0.2mm)
Je	>8kA/cm^2*
Ic	>100A
Max Stress (77K)	300MPa
Max Stress (RT)	265MPa
Max Strain	0.4%**
Min. Bend Dia.	70mm**

* at 77K, sf, 1μV/cm
** With 95% Ic Retention

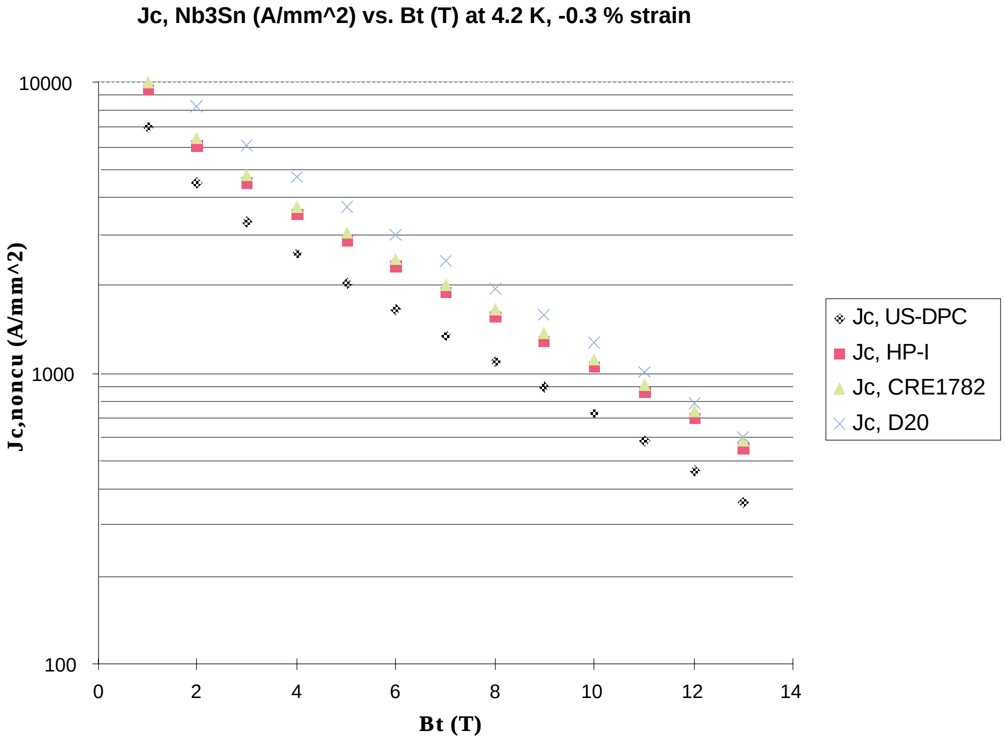


Malozemoff's Reality-Checked Law

At 12.5 % growth in 2001, Malozemoff's Reality-Checked Law it takes:

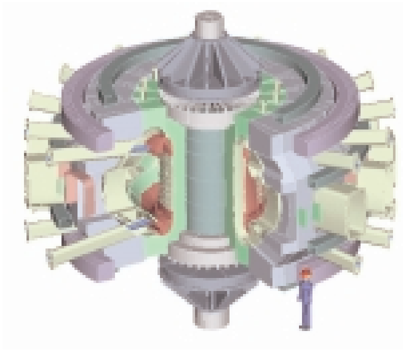
14 yrs to get to Dec 2000 predicted (unreinforced) & 21 yrs (reinforced)

Progress in Nb3Sn



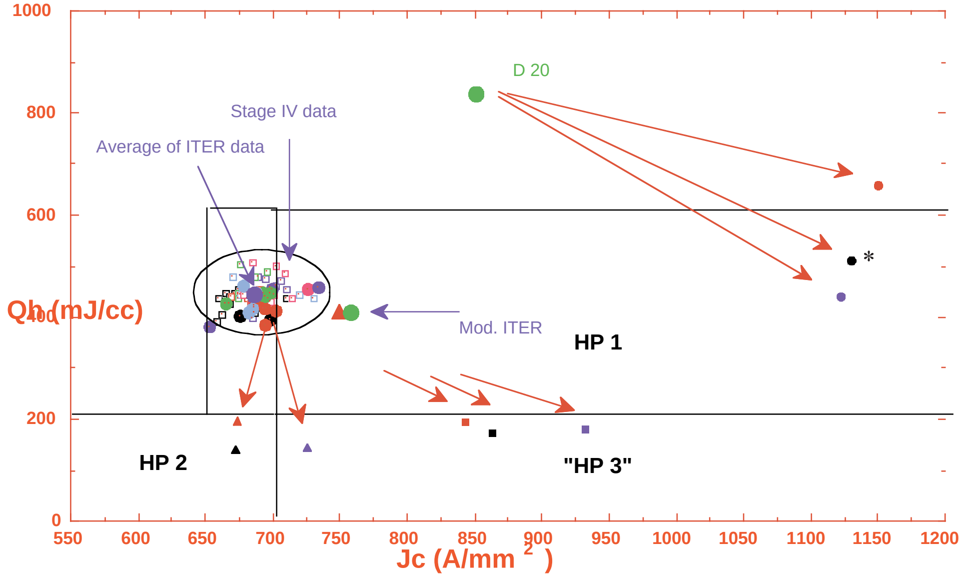
Through ITER, Nb3Sn improved 70 % in 9 years = 6.1 %/year

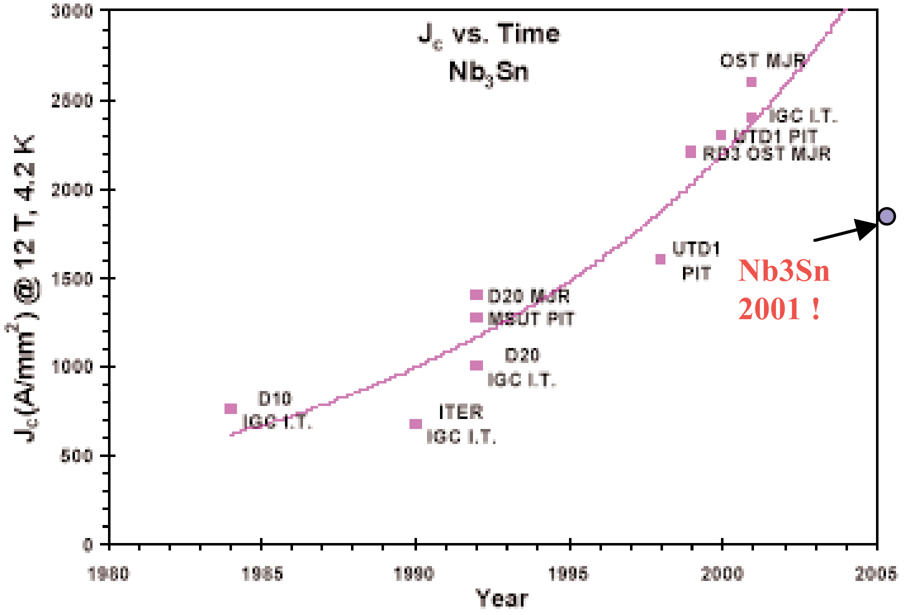
No large customers outside fusion program, HEP selected NbTi and superfluid He for LHC; ITER EDA cancelled



The Revolution in Nb3Sn

VLHC goal: 3 kA/mm^2 @ 12 T, 4.2 K x D$_{eff}$=40 µm
(vs. ITER 700 A/mm^2, D$_{eff}$=25 µm

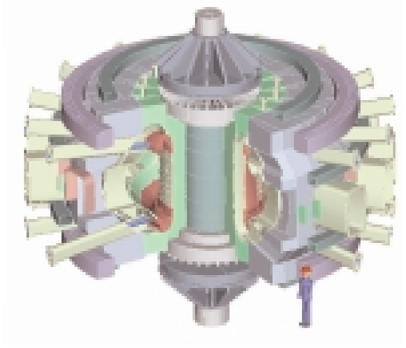




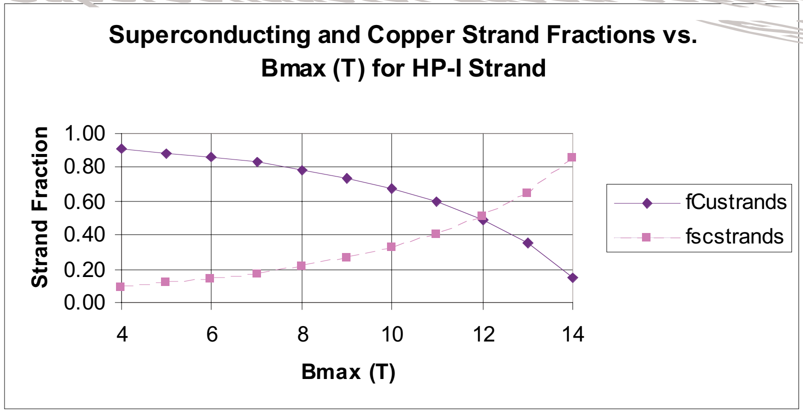
Already up to 2 kA/mm^2, x 3 improvement,

J$_{eff}$ up x 5 from 280 A/mm^2 to 1.4 kA/mm^2, 71 %/year!

(New SSI PM strand: 1 data point-J$_{eff}$=2270 A/mm^2 @ 13.5 T!!)

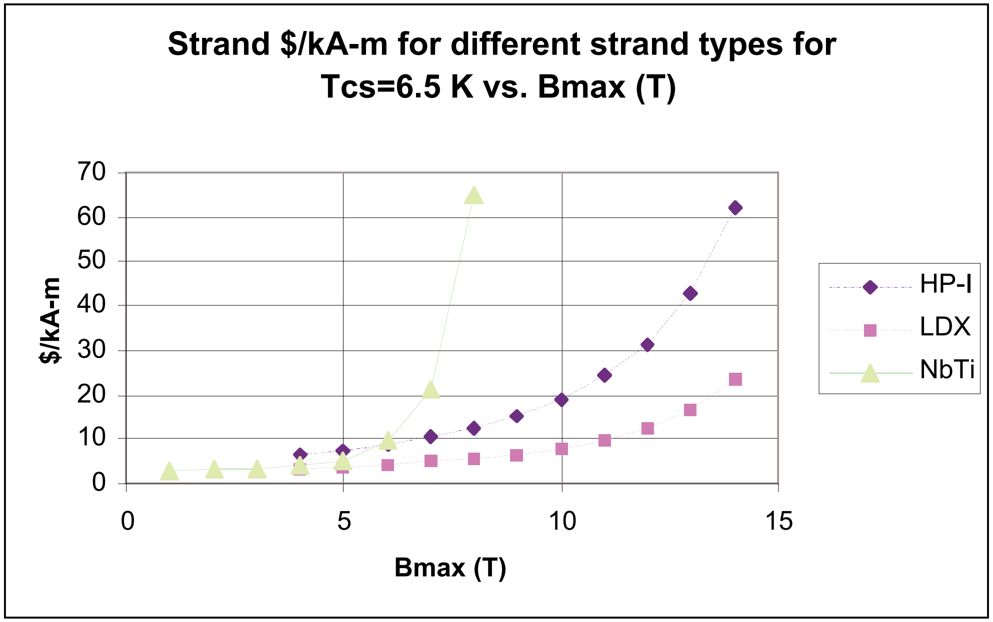


Superconductor-Laced Copper Conductor Concept (SLCC)

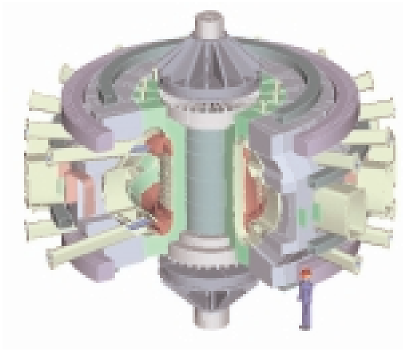


Place copper needed for protection/recovery in pure copper strands; major cost benefits for high J_{ceff} strand

Tested in ITER sECRETS (1/3 Cu)



Next-generation coils with only 1/3 or 1/6 sc strands possible out to 12-14 T!



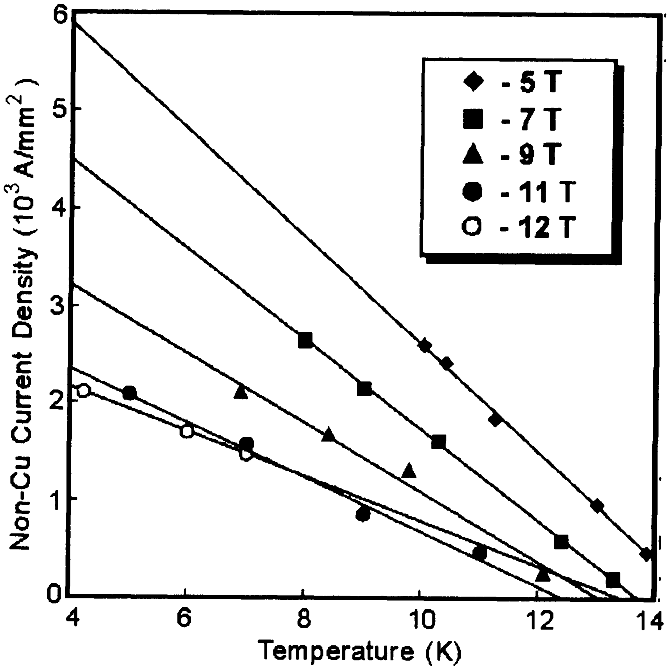
MTS Magnet Design

Medium Temperature Superconductor

10 K < Top < 25 K

Class A:	*LTS/Nb3Sn at 10 K*	*LDX F-Coil* *NCSX 2001 (sc option)*
Class B:	HTS/BSSCO at 20 K	LDX L-Coil NCSX 2000 (sc option)
Class C:	MTS/MgB_2 at 25 K	VASIMR Mirror (ISS stationing, Mission to Mars)

Medium Temperature Superconductor (MTS) operation with Nb3Sn



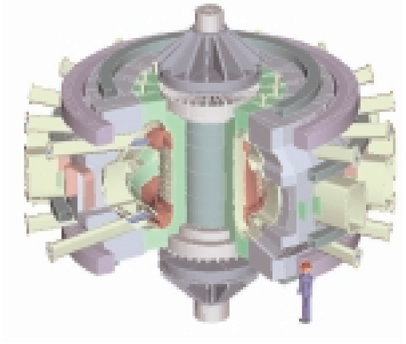
Low-loss (D_{eff}=9 μm) Internal Tin Nb_3Sn with NbTi inserts

(Bochvar Institute; Moscow)

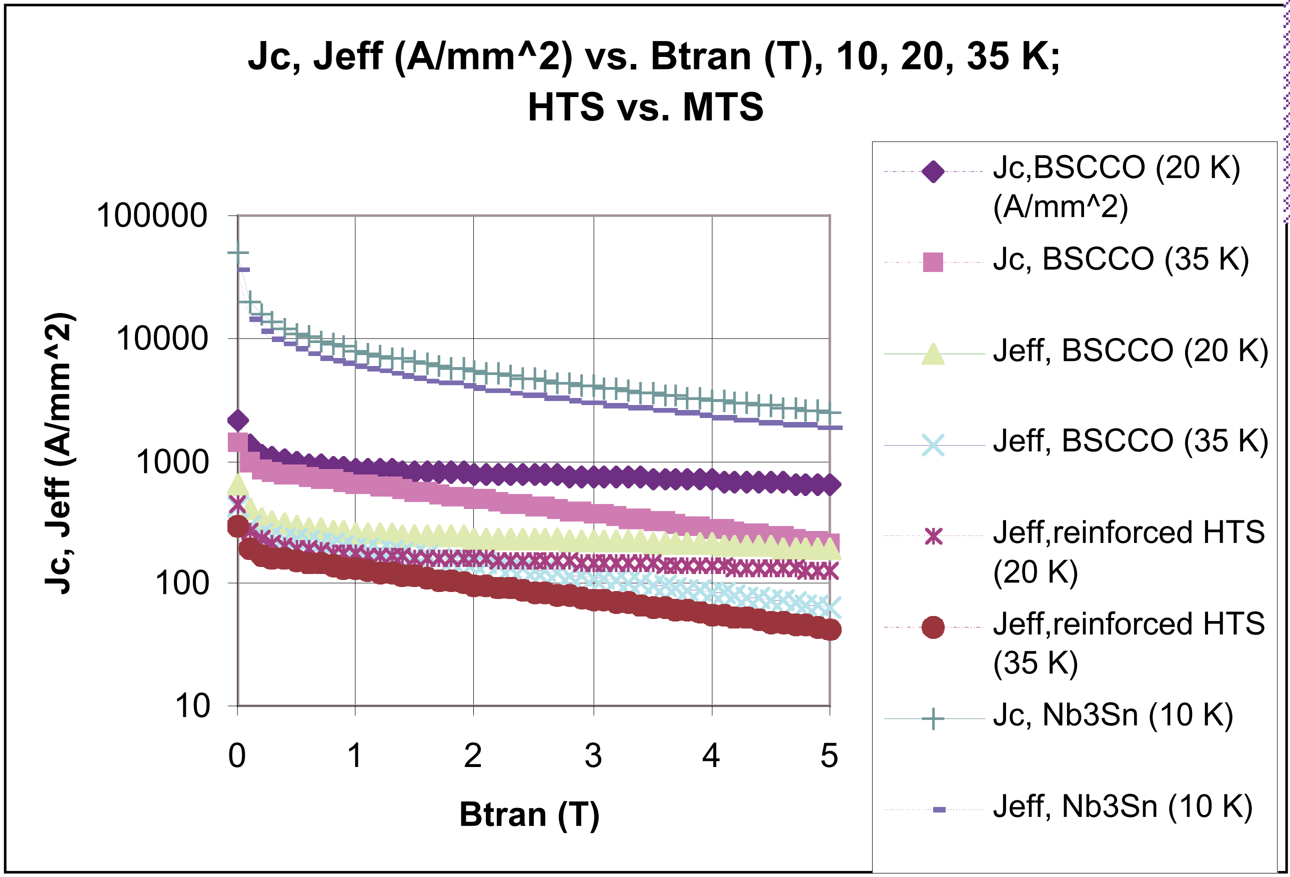
J_c (2 T, 10 K) ~ 5500 A/mm^2
J_c(5 T, 10 K) = 2800 A/mm^2
(same as NbTi at (5 T, 4.2 K)

J_c(12 T, 10 K) = 800 A/mm^2
(>~ ITER HP-I at (12 T, 4.2 K)

Possibility of replacing NbTi 0-8 T at 10 K
Even of replacing "Old Nb3Sn" at 10 K @ 8-13 T



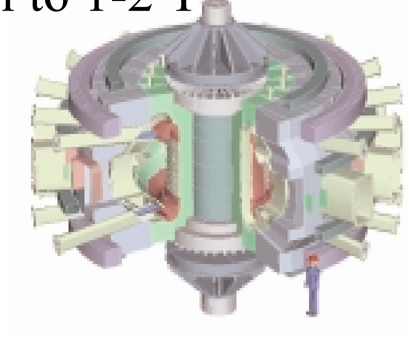
Jc_Nb3Sn vs. Jc_BSSCO-2223
(Low field MTS Operation)



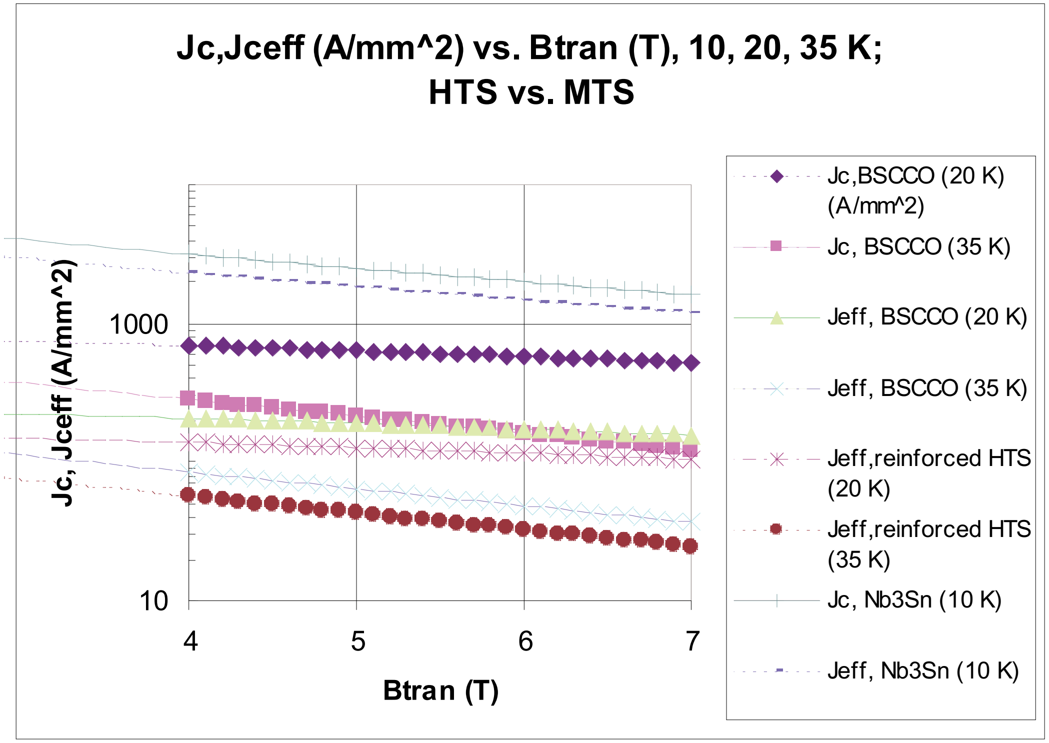
$J_{eff,Nb3Sn}$ (10 K) > 10 x $J_{eff,BSSCO}$ (20 K), all fields

$J_{eff,BSSCO}$ (20 K), useful out to 5 T

$J_{eff,BSSCO}$ (35 K), useful to 1-2 T



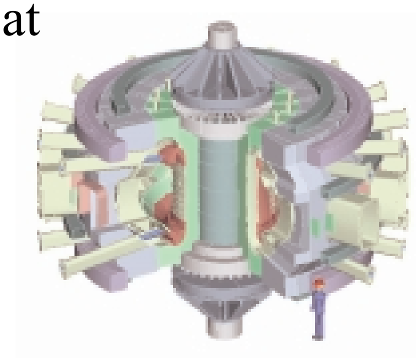
Jc_Nb3Sn vs. Jc_BSSCO-2223 (Medium field MTS Operation)



$J_{eff,Nb3Sn}$ (10 K) still > 10 x $J_{eff,BSSCO}$ (20 K), all fields

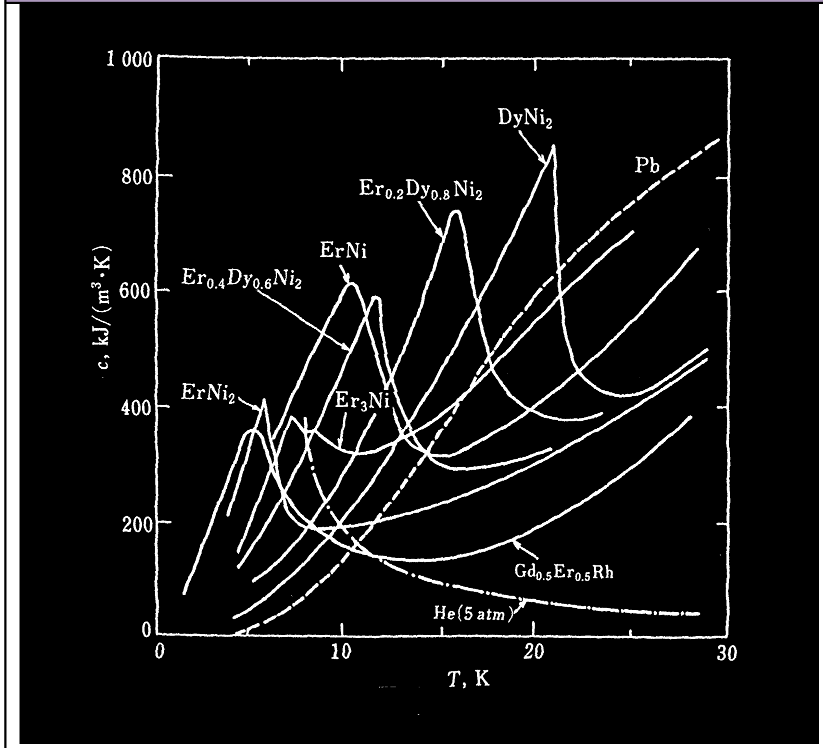
$J_{eff,BSSCO}$ (20 K), still useful out to 7 T, gaining on Nb3Sn

$J_{eff,BSSCO}$ (35 K), hors de combat



MTS Advantage:
Dry Enthalpy is Just Right

Enough dry enthalpy for stability | *Not too much for protection*



Can guarantee ramp to 4 T with Nb3Sn and Pb Solder
Toshiba experimenting with ErNi mats, EM up to 1 J/cc at 10 K

LDX F-Coil can be protected passively
(PW Wang, A Radovinsky simulations)

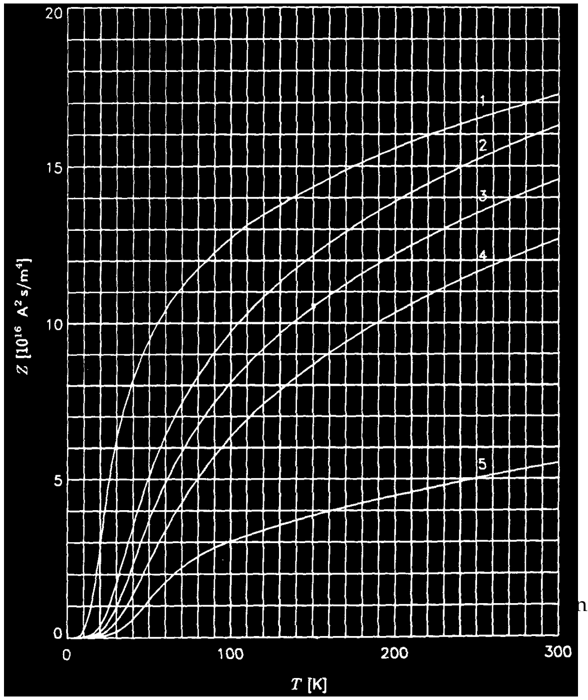
Passive protection vanished by 40 K

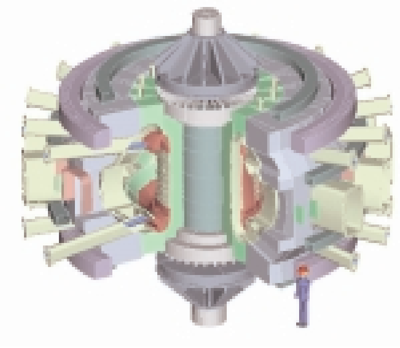
Protection Problems at High T

	Units	*4.2 K (LTS)*	*10 K (MTS)*	*35 K (HTS)*	*Protectability, MTS/HTS*
Cp (Cu)	(J/kg-K)	0.093	0.863	42.3	49.0
J^2t (to 150 K)	(10^{16} A^2-s/m^4)	10.2	10.1	8.0	1.25
$v_{propagation,norm}$	(m/s)/(A/m^2-(W-m/K)$^{1/2}$)	12.3	2.83	0.123	16.2
E_{heater}	(J/kg) (T_{cs}/Top=1.25)	0.098	2.16	370	171

C_p, v_{prop}, E_{heater} = O's(M) worse at 35 K than at 10 K

(which is O(M) worse than 4.2 K)



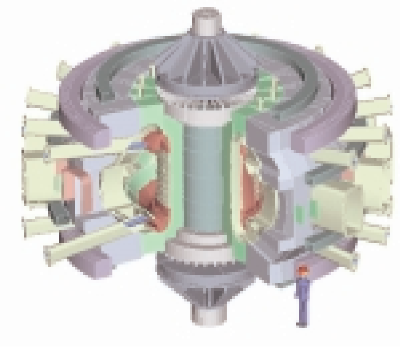


Apologies to:

Heavy Ion Fusion Drivers

- potential for revolutionary magnet improvements

(and Stellarators, ST's, Diode Lasers)



Conclusions-II

1) New radiation-resistant insulations should allow 2 x 10^{10} Rad BPX

2) RRI + MTS allow near-term neutron shield reduction,
refrig reduction for SC magnet systems

3) Nb_3Sn revolution & SLCC allows "copper-cost" magnet systems
out to 12-14 T for near-term BPX