High Field Approach to Demo

Miklos Porkolab
In Collaboration with:
P.T. Bonoli, L. Bromberg, J. Minervini, J.Schultz

MIT Plasma Science and Fusion Center

35 YEAR DEVELOPMENT PATH
FESAC SUBPANEL MEETING

General Atomics, San Diego,CA
January 14, 2003

Power-Plant Studies Indicate the Need for Steady State
DEMO Must Be an “Advanced Tokamak” or “AT”

- **Attractive AT reactor concepts are Aries-RS and Aries-AT**
- **Efficient off-axis non-inductive (RF) current drive needed to accompany the high bootstrap current fraction in the core**
- **Aries-RS operates at 8.0 T on -axis, 16 T at the coils;**
  → coils can be developed in a 20 year time horizon
- **Need accelerated SC magnet development program**
- **Aries-AT and Aries-RS unify**

Higher Magnetic Field is a Winner

- Higher B-field (16 T at the coil, 8 T on-axis) would reduce some of tokamak's physics constraints:

  -Higher plasma current for better confinement -
  More stable MHD operation (higher q) at given current
  -Higher off-axis non-inductive (LH) current drive efficiency
  -Density limit mitigated

- Fusion Power Density: $P \sim \beta^2 B_T^4 = (\beta/\varepsilon)^2(\varepsilon B_T^2)^2$
- Need to take advantage of potential advances in SC magnet development to accelerate fusion energy

Example of an Aries-RS Size AT Tokamak:

Advanced Tokamak Burning Plasma Experiment: ATBX

M. Porkolab, J. Schultz et al., 1998 IAEA Fus. Conf. 1998, **V4** p.1267

- For 6.35T, Q_{fus} = 10 at ITER89-L=2.5 (ITER98-H=1.3), f_{BS}=0.71, P_{CD}=80MW (Nevin's Spreadsheet)
- (**Red** values are new, corresponding to **B_T=8.0 T**)
  - a= 1.75 m; R_0 = 5.60 m; I_P = 12 MA; B_T = 6.35 (- **8.0**)T ;
  - $n_e(0) = 2.0 \times 10^{20}$ m^{-3}
  - $T_e(0) = T_i(0)$ = 22 **(30)** keV;
  - E_{NBI} = 0.5 MeV, 20 MW **(1.0 MeV, 20 -10 MW)**;
  - f_{LH} = 5.5 GHz, 60 MW **(30 - 40 MW)**
  - nIR/P = γ_{LH} = 0.20 - 0.23 (**0.30-0.35**)
  - **At B=8.0T, Q_{fus} = 15-20 feasible with 50 MW total P_{CD}**

ACCOME Current Drive Results for ATBX at 8.0T: Increase LH current drive efficiency from 0.20 to 0.30

Case	T_{e0} (keV)	P_{LH} (MW)	I_{LH} (MA)	**γ_{LH} (A/W/m^2)**	I_P (MA)	**f_{BS}**	P_{NB} (MW)	I_{NB} (MA)
1	22	60	2.93	**0.36**	12.20	**0.68**	20	0.96
2	30	60	3.20	**0.33**	14.51	**0.70**	20	1.15
3	30	40	2.01	**0.30**	13.20	**0.76**	20	1.15
4	30	30	1.50	**0.29**	12.70	**0.79**	20	1.15
5	30	30	1.53	**0.30**	12.30	**0.82**	10	0.69
6	30	40	2.08	**0.31**	12.84	**0.78**	10	0.69

Cases 1 – 6: $P_{LH\text{-}R} = 0.1 \times P_{LH}$, $\Delta n_{//} = 0.10$, $n_{//\text{-}F} = 1.6$, $n_{//\text{-}R} = 4.8$

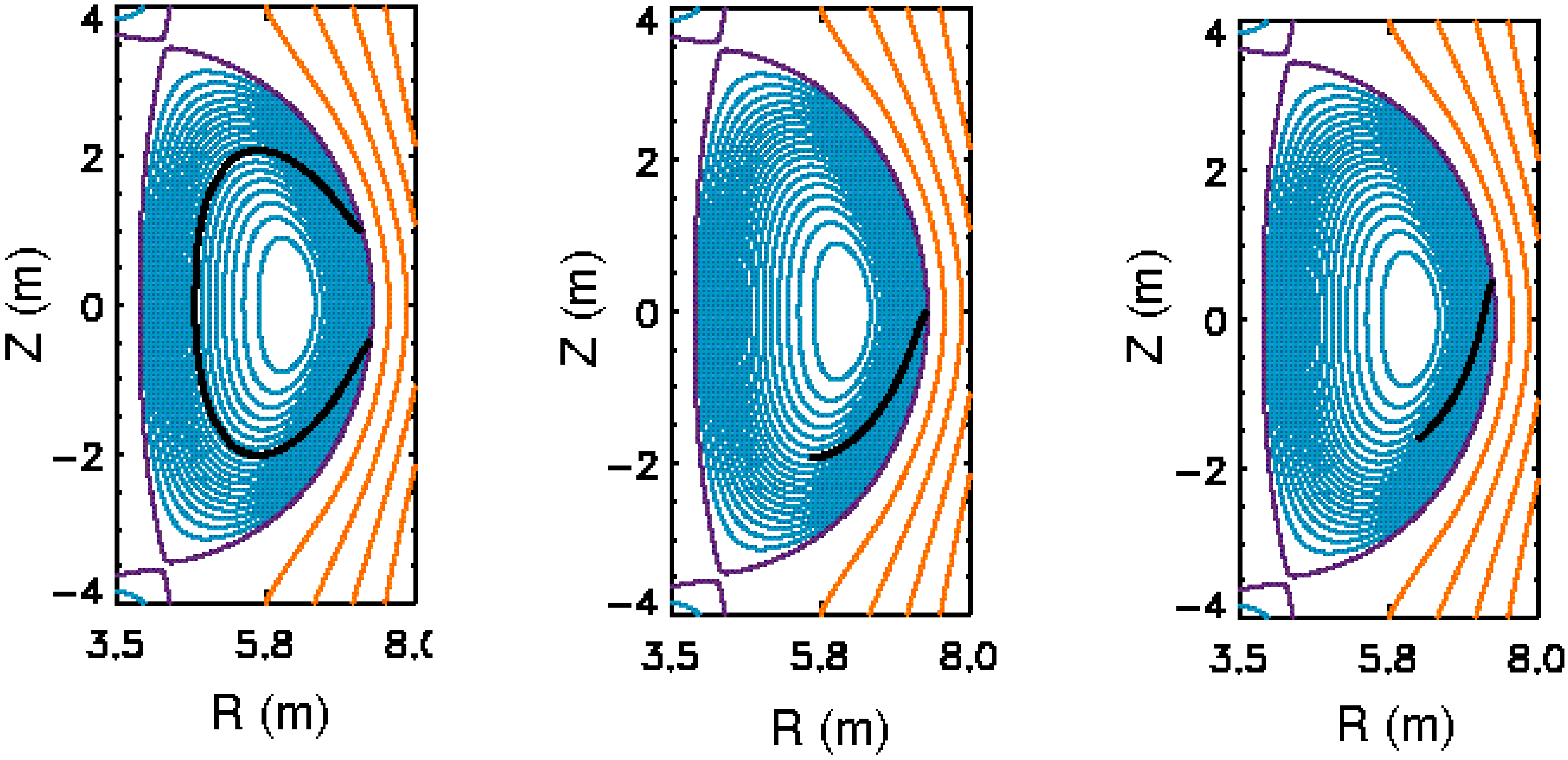
Cases 1 – 4 run with $E_B = 0.5$ MeV

Cases 5 & 6 run with $E_B = 1.0$ MeV

M. P./ 35 year plan/1.14.2003

ACCOME Simulation of 8T ATBX - Case 6

P_{LH} = 40 MW, f_0 = 5.5 GHz, $n_{//-F}$ = 1.60

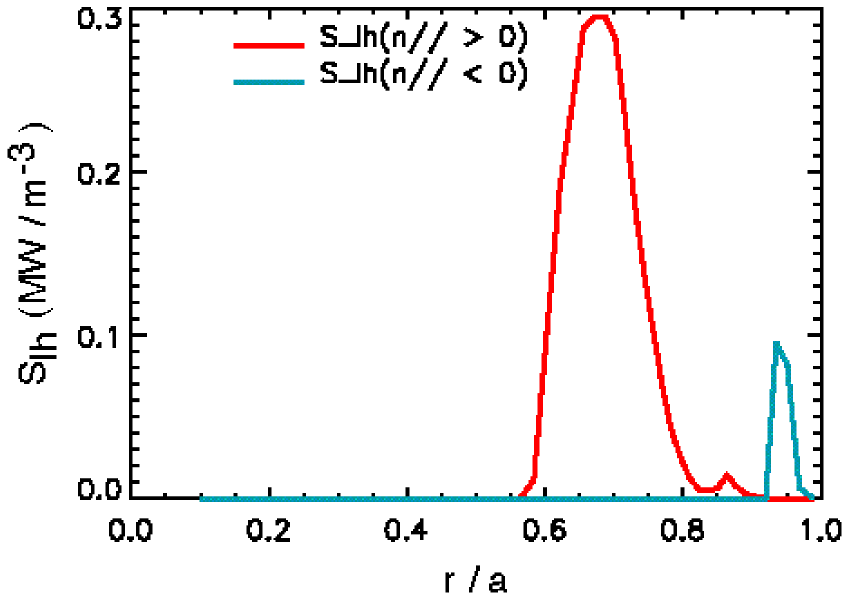


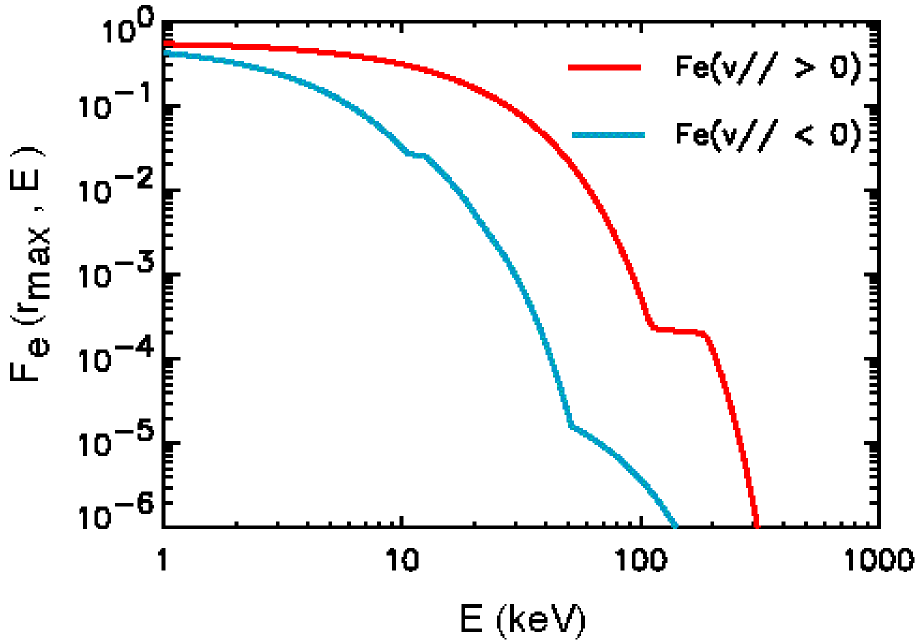
ACCOME Simulation of 8T ATBX - Case 6

LHRF Power Deposition and F_e (r, E)

P_{LH} = 40 MW, f_0 = 5.5 GHz

$n_{//-F}$ = 1.60 $\Delta n_{//}$ = 0.10

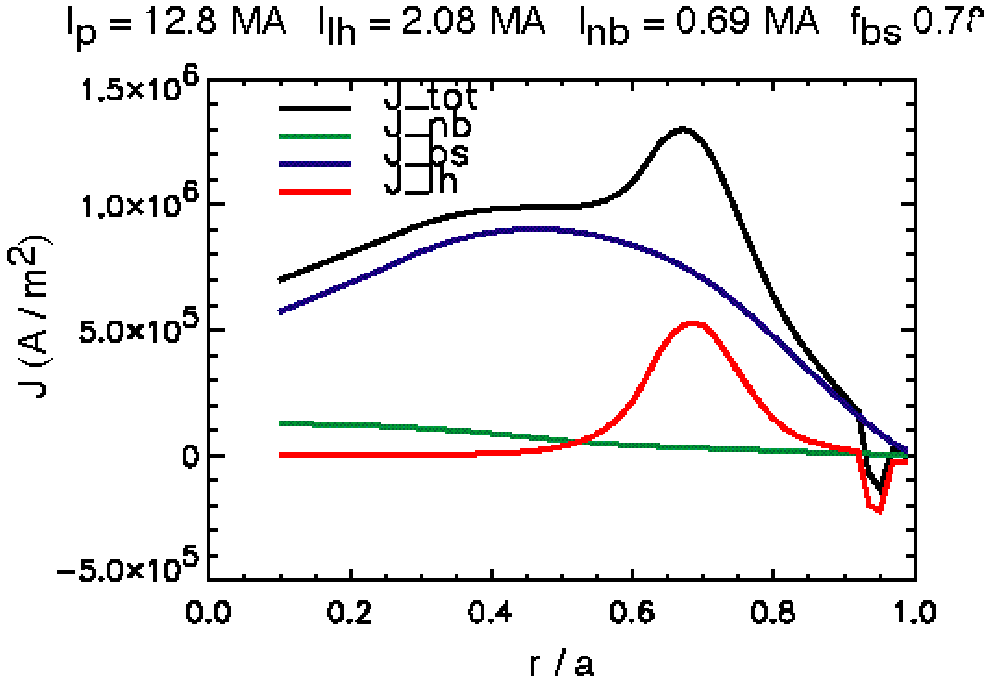


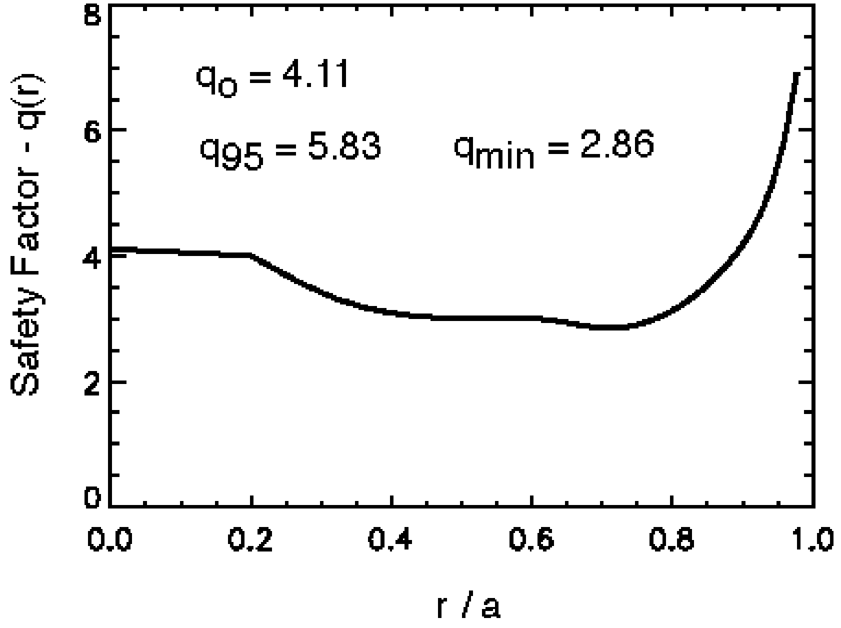


ACCOME Simulation of 8T ATBX - Case 6

P_{LH} = 40 MW, P_{NB} = 10 MW

β_t = 2.64%, β_N = 2.88





Magnet Technology Can Be Ready for DEMO Requirements

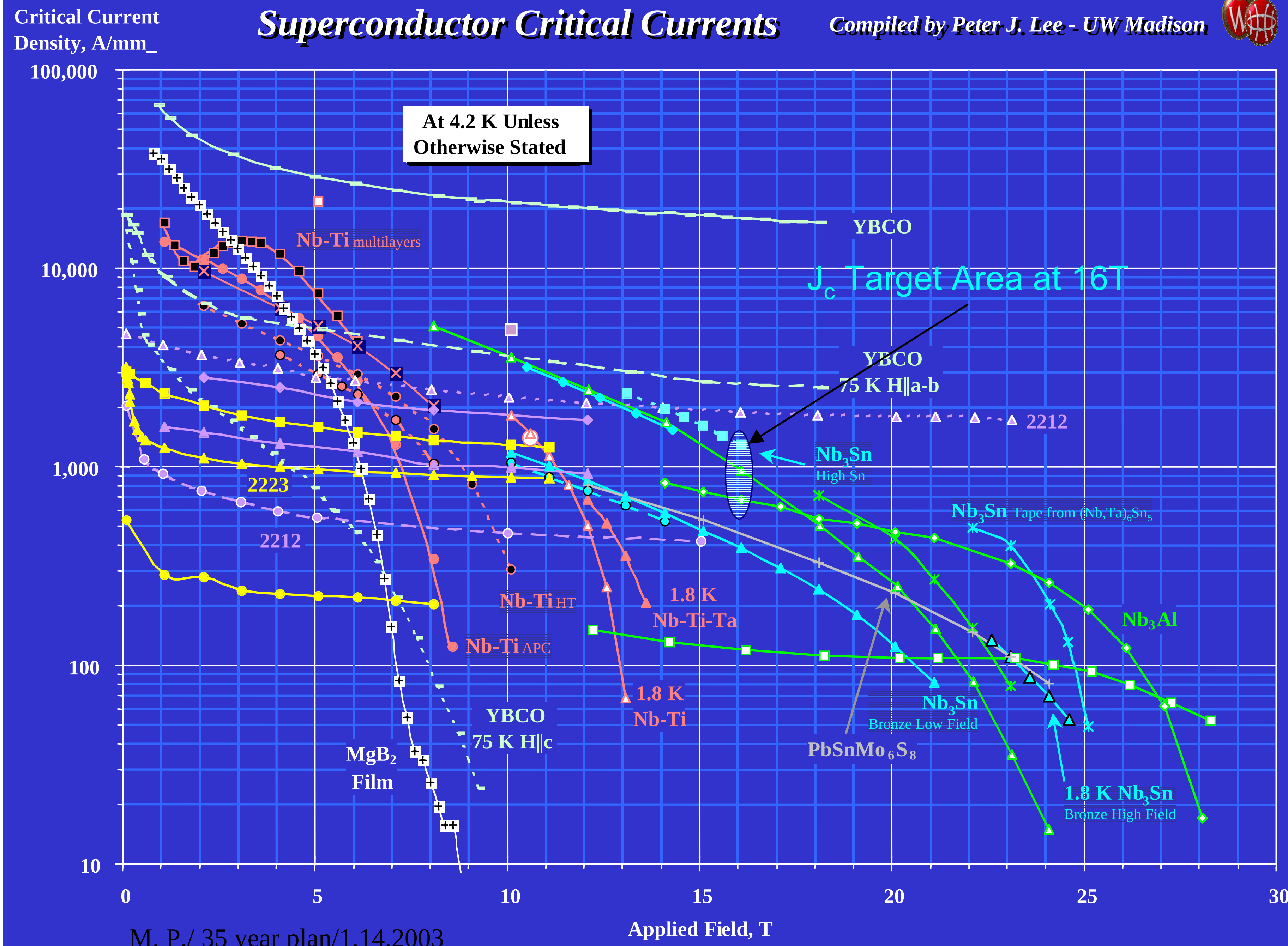
- Superconductors can easily achieve 16 T peak field operation using Nb_3Sn
  - Laboratory magnets operate today routinely at ≥16 T
  - 900 MHz NMR magnets operating at 21.2T are beginning service now - 1000 Mhz at 23.4T are near term

- Fusion magnets are many orders of magnitude larger in size and stored energy than NMR magnets and operating conditions are much more severe (pulsed fields, radiation environment)

- Technology advances are required for:
  - Support structures including cases and plates
    - **Significant area for innovation, including advanced materials development**
  - Increased radiation life of insulation and superconductor
  - Cost reduction of superconductor for large scale production
  - Innovative instrumentation and quench detection and protection systems for safety and enhanced reliability
  - Advanced superconductor (e.g., high temperature superconductors) for higher temperature operation and increased heat capacity are desirable but not necessary

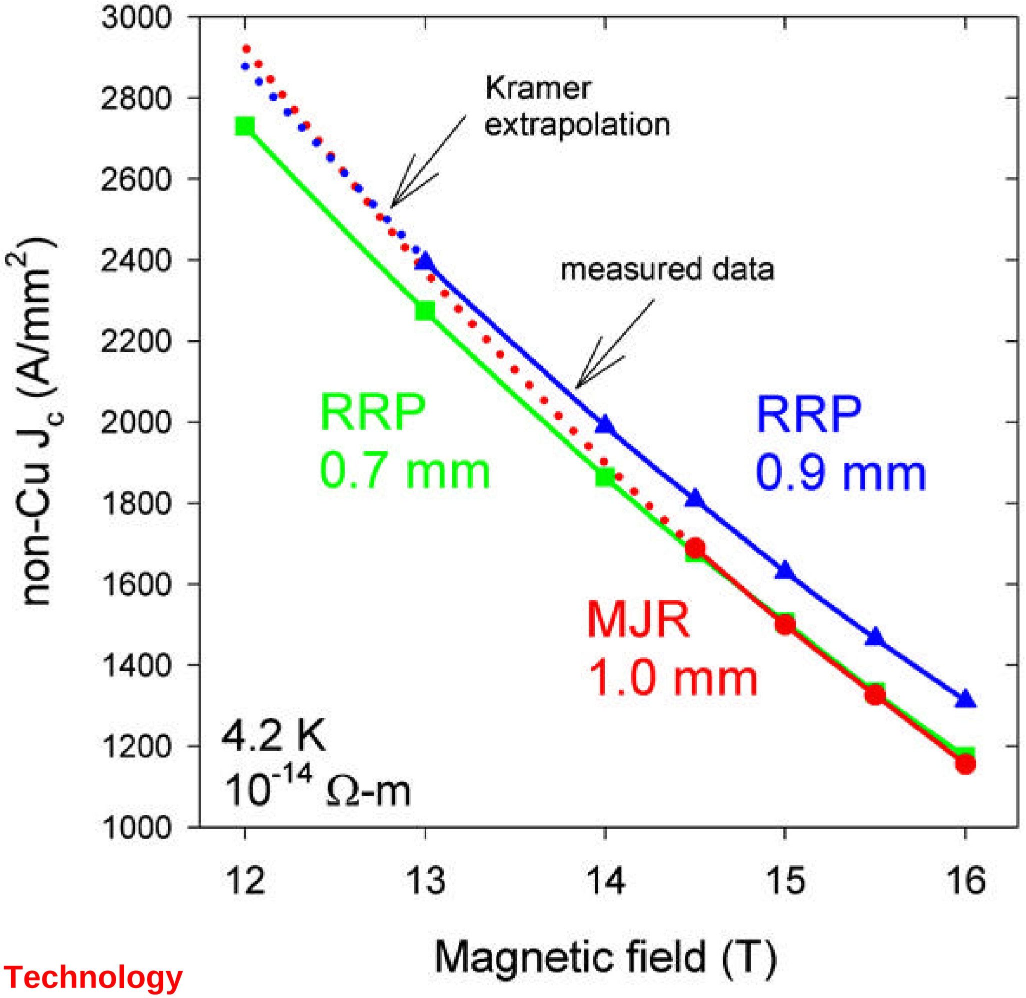
Superconductor Critical Currents

Compiled by Peter J. Lee - UW Madison



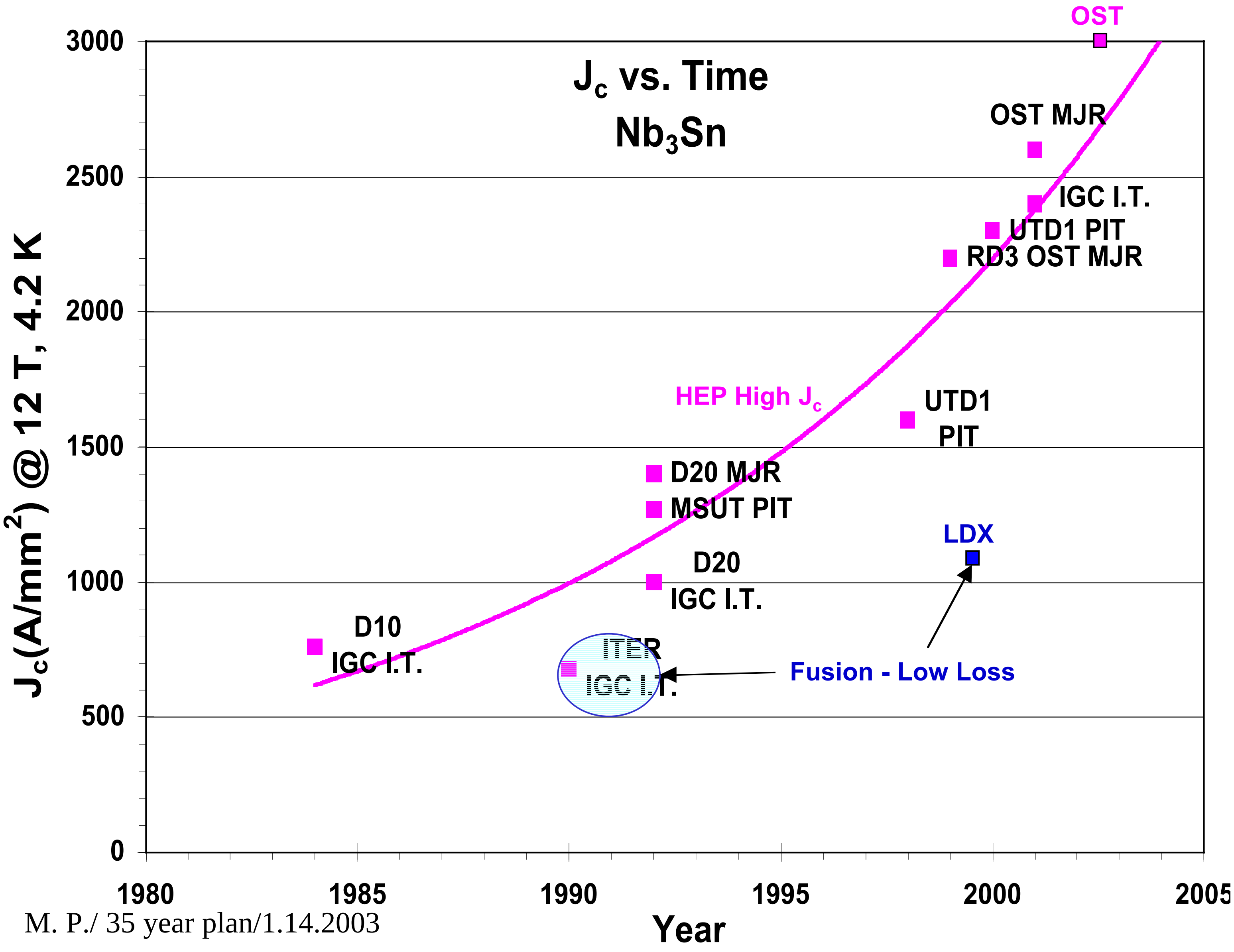
M. P./ 35 year plan/1.14.2003

OST has achieved world record Jc values for Nb_3Sn made by two processes



Oxford Superconducting Technology

Progress in Development of Nb_3Sn for High Field Use Has Been Extraordinary



M. P./ 35 year plan/1.14.2003

35 Year Plan for Magnet Technology (Preliminary)

- <u>1st Requirement</u> : Need enhanced emphasis on base magnet technology program (cost per year !)

	Present Annual Funding **(FY-03$)**	**0-5 Years** **(FY-03$)**	**5-10 Years** **(FY-03$)**	**10-20 Years** **(FY-03$)**
Conservative Funding Profile	$2M (actual)	$4M	$6M	$10M
Aggressive **(i.e., realistic)** **Funding Profile**	$3M (needed)	$5M	$8M	$12M

M. P./ 35 year plan/1.14.2003

20 Year Plan for Magnet Technology (continued)

- 2nd Requirement : Need new magnet test facilities (integrated cost!)

Time Frame	**0-3 Years**	**3-6 Years**	**10-20 Years**
Facility	Pulsed Superconducting Magnet (PSM) at 12T + PTF Upgrade	Upgrade PSM to 16T	Prototype DEMO Magnet* at 16T
Facility Cost (FY03-$)	PSM - \$2M PTF - \$1M	\$4M	\$100M

**** Test in international test facility***

35 Year Plan for Magnet Technology (continued)

- **Technology improvements must be made in the following components***:
- High performance/cost superconductor (both low and high temperature superconductors)
- Stabilizer
- Improved coil structure
- Conductor structure (e.g., conduit, plates)
- Radiation resistant insulation
- Thermal Isolation
- High current, low loss joints
- Leads
- Improved quench detection and instrumentation for increased system reliability
- Higher voltage, lower losses isolators and feedthroughs
- Reduced cost, increased reliability refrigeration system

*** "US Fusion Program Requirements for Superconducting Magnet Research", J.V. Minervini and J.H. Schultz, to be published in IEEE Trans. On Applied Superconductivity.**

Summary

- Higher field approach to fusion (8 T) is a winner
- Some of the physics advantages of Fire/Ignitor accommodated
- Aries-RS and AT would unify with easier physics
- The basic SC magnet technology is rapidly improving and the US should invest more aggressively to develop this technology for fusion applications
- 16T coils can be developed for DEMO on time
- Benefits to other MFE approaches