MIT Plasma Science and Fusion Center

Fusion Technology & Engineering Division

Advanced Magnets and Implications for BPX-I

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M.I.T. Plasma Science and Fusion Center

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San Diego, CA
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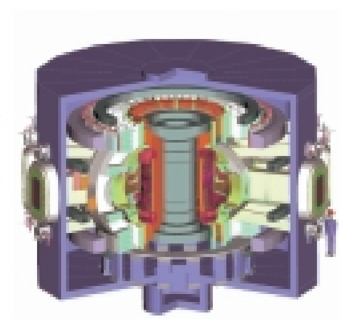
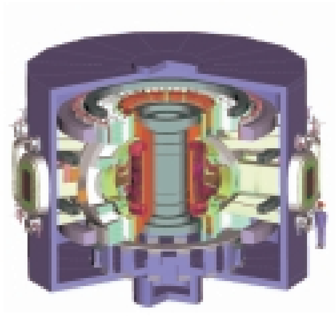


Issues in BPX Advanced Magnet Systems

1. Magnet System Goodness Factors
2. Progress in BPX Magnets
3. Progress in BPX Magnet Materials



Tokamak Magnet Systems are Scaleable

$B = Const$

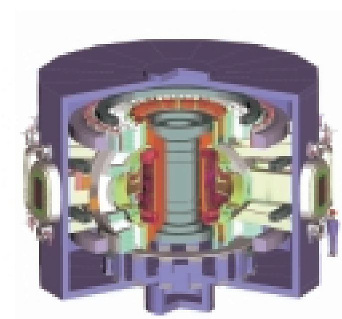
$\sigma = Const$

$J = R^{-1}$

$t = R^{2}$

☺Any advanced magnet system can be scaled-up to FIRE or ITER

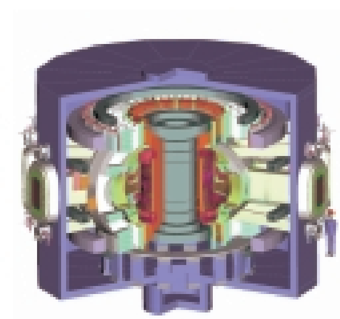
☹There are no advanced magnet systems, not even close



IpA/R as Tokamak Magnet System Goodness Factor

Dimensionally same as Bt, but:

Feature	IpA/R	Bt
Scaleable	Yes	Yes
CS/TF Interface	Yes	No
In-plane vs. OOP Forces	Yes	No
K, Δ	Yes	No



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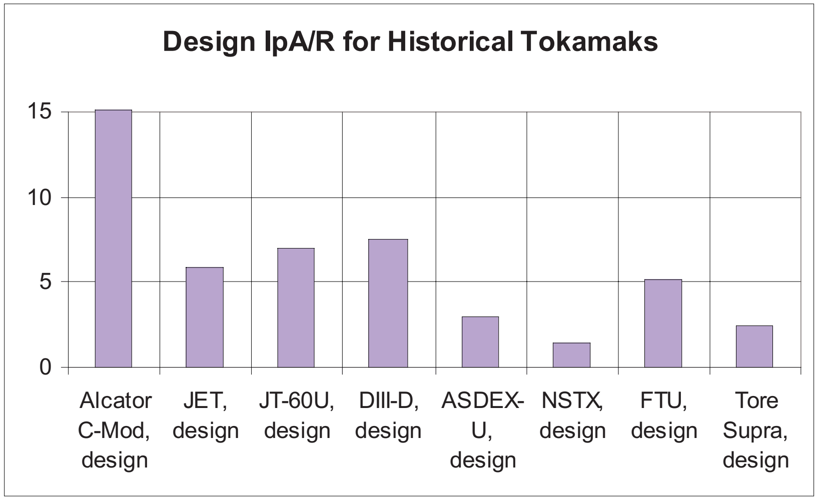
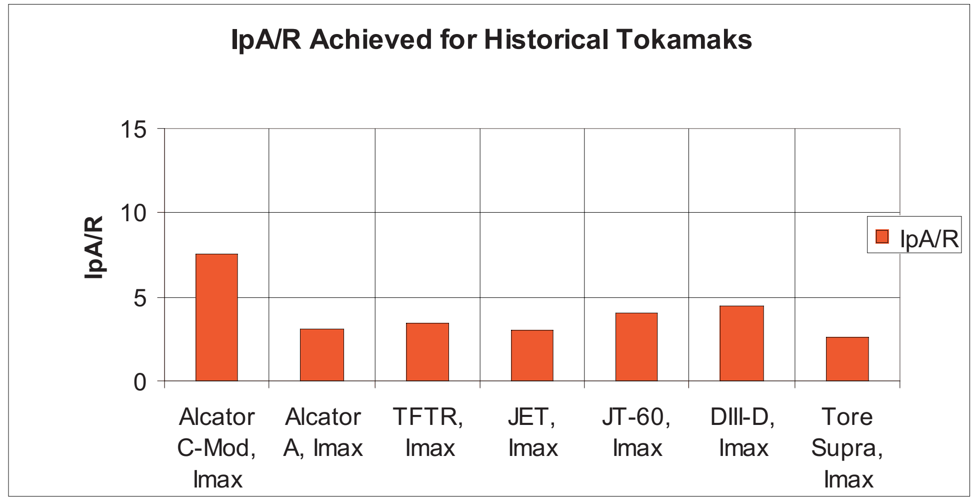
IpA/R Historical Survey

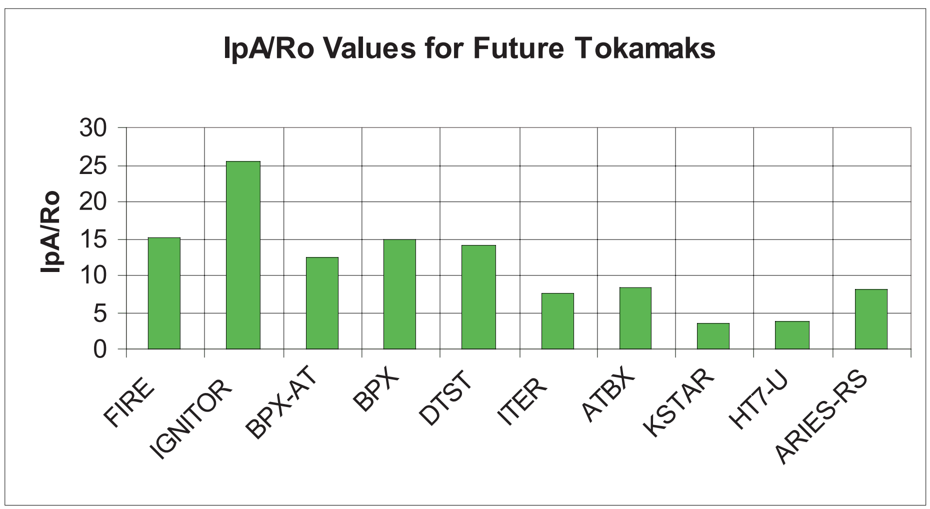


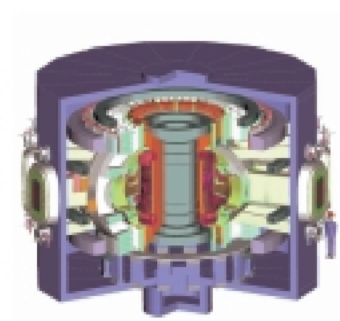


FIRE IpA/Ro 2x as high as world record

IGNITOR IpA/Ro 70% higher than other designs

FIRE IpA/Ro 2x as high as ITER





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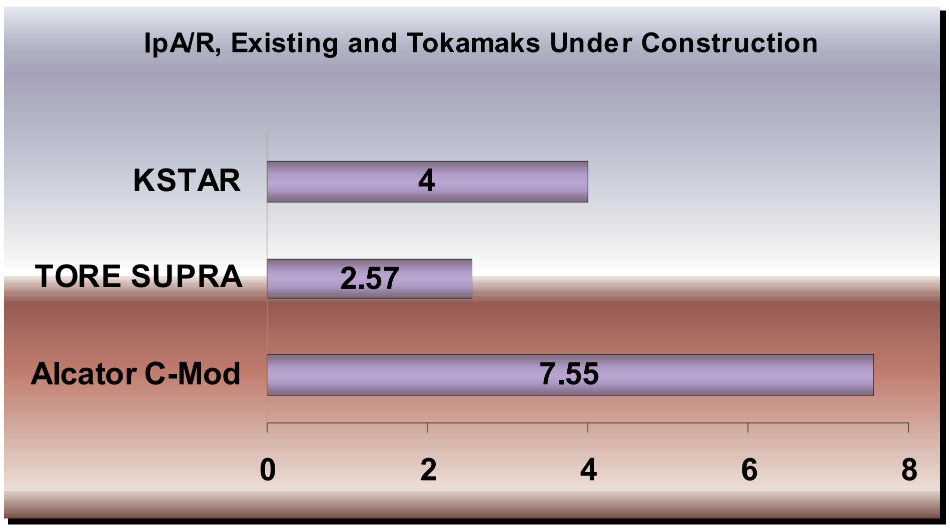
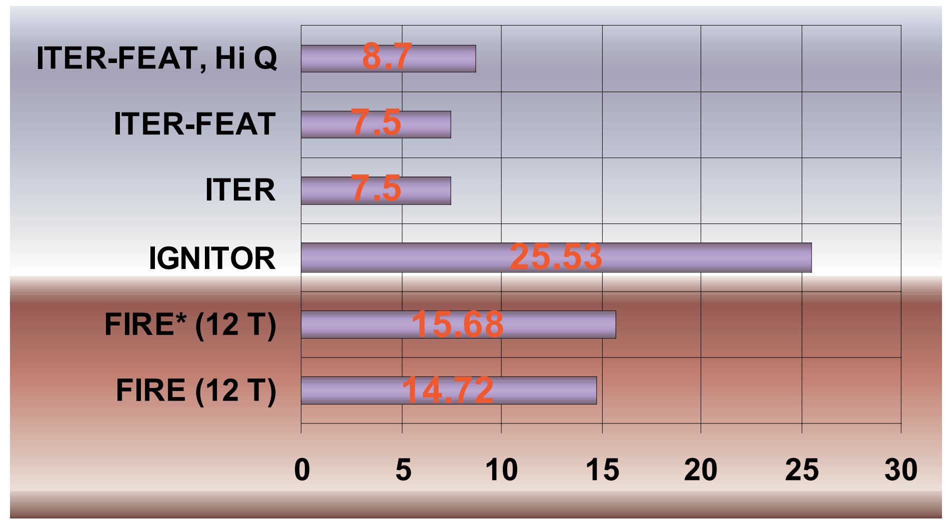
The Superconducting Shortfall
(and the Absence of Scale Models)

Existing and Tokamaks Under Construction



Tokamaks Under Design



Tore Supra: World's Best Superconducting Tokamak, IpA/R only 1/3 that of Alcator C-Mod

KSTAR: 56 % improvement,

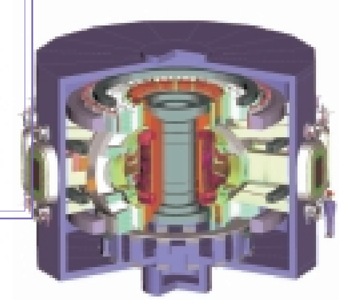
C-Mod IpA/R still 89 % better than KSTAR

ITER/ITER-FEAT: 88 % improvement on KSTAR,

= CMod

IpA/R half as good as FIRE,

27 % of Ignitor



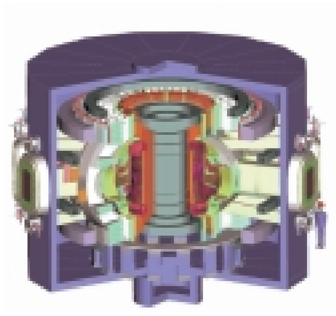
Why is FIRE higher-IpA/R than existing (esp. Alcator) tokamaks?

1) Plate construction, adiabatically nitrogen-cooled (e.g. Alcator)

2) Bucking/Wedging

3) Compression Rings

4) Zero-turn loss scarf joints

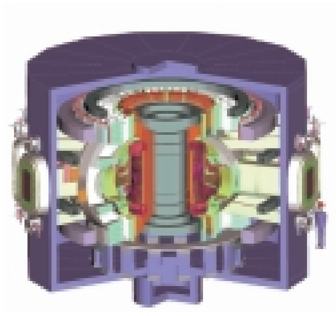


Why is IGNITOR higher-IpA/R than FIRE?

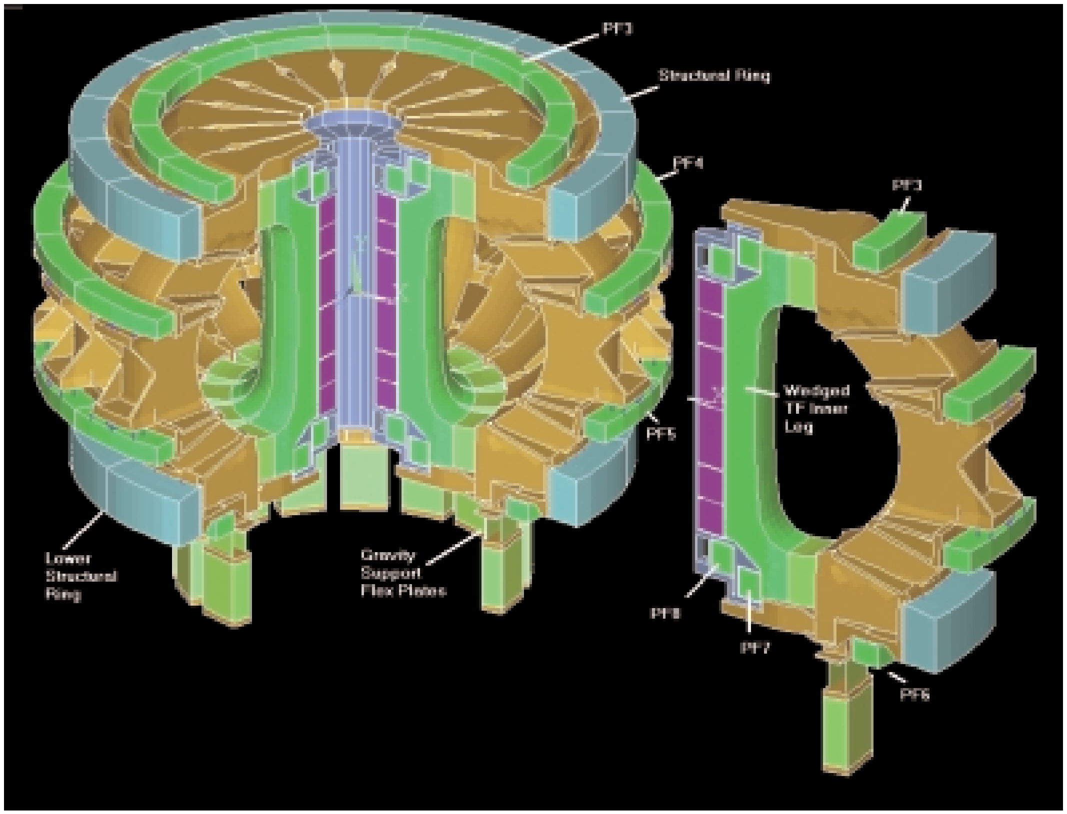
1) No divertor, plasma optimized for low OOP

2) Active clamping

3) Recool to 30 K



Buck/Wedged Design with Copper Inner Leg (FIRE)



Bladder preinserted before assembly

- epoxy shims injected after assembly

(high reliability with reasonable tolerances)

Cu replaces 68 % IACS BeCu

Main benefit to power supply

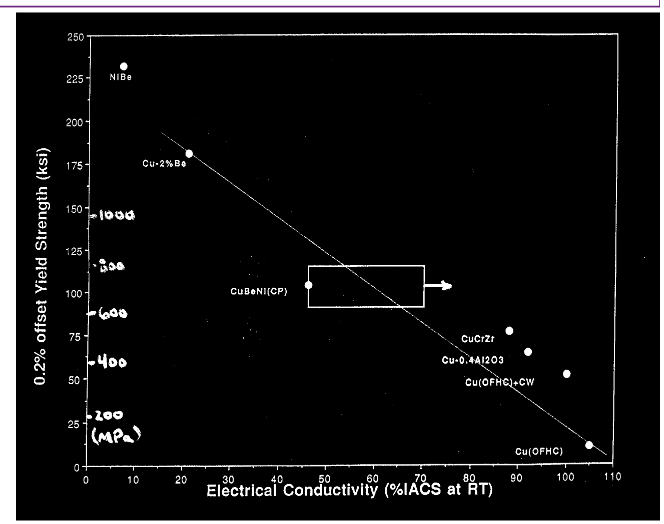
Stress in inner leg reduced x 2

Expect IpA/R improve by 20 % (2 1/4)

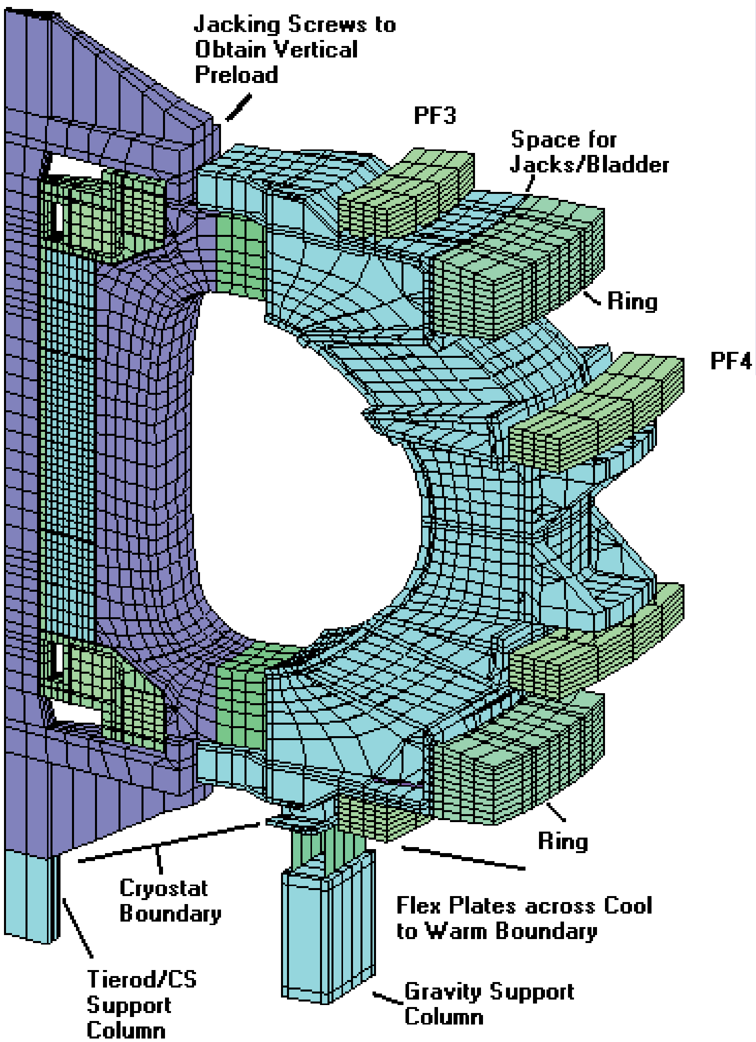
IpA/R improvement only 10 % in FIRE

- desensitized by Copper Alloy selection

	Bmax (T)	*tflat, nonuc (s)*	*tflat,nuc (s)*
Buck and Wedge	10	51	62
Buck and Wedge	11.5	44.5	36
Wedge	10	21	18.5
Wedge	12	15	12



The FIRE Compression Rings

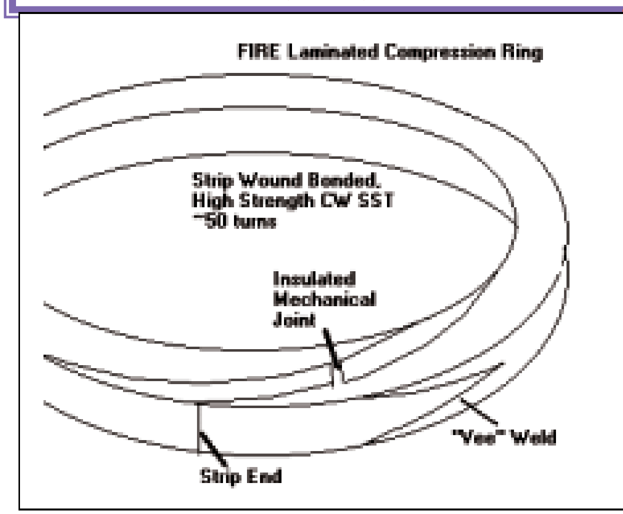


External rings prevent excessive shear between TF plates, due to OOP moments

Add compression to bond between insulating sheets and cases

Without compression rings, insulation shear allowables are exceeded at ~ 1/10 IB product

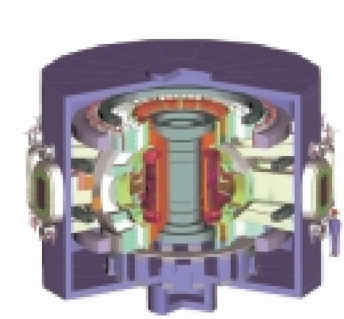
i.e. 4 T x 2 MA (TPX) vs. 12 T x 7.7 MA



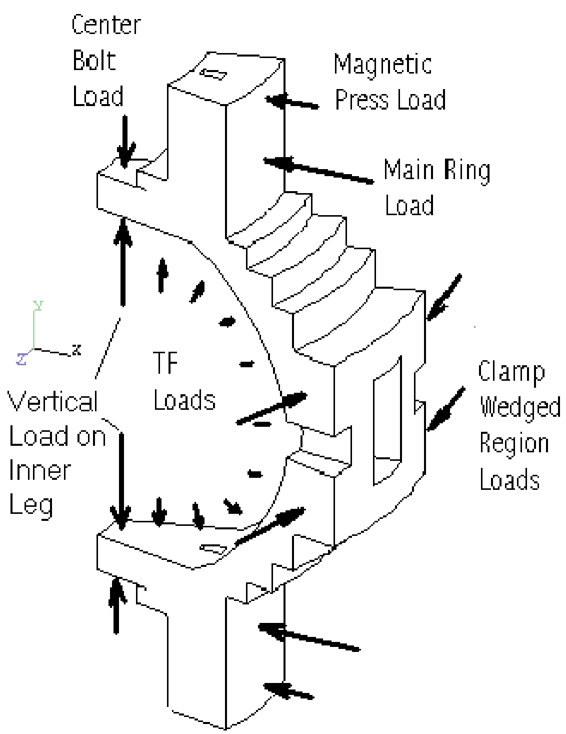
50 turns, welded 1 cm 304 SS plate

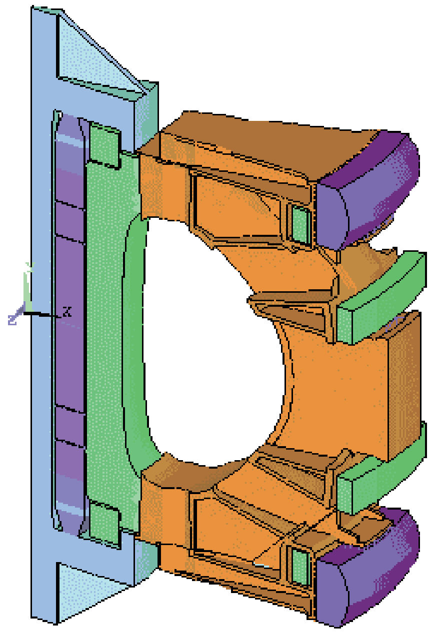
Turns, insulated, bonded

Mechanical connection from inside-outside



Active Compression Rings





FIRE with Radial Compression Rings, and Vertical Preload using a Tierod

In IGNITOR the Main Ring and Mag. Press Overcome Radially Outward Loads and Cause a Vertical "Pinching" of the Inner Leg.

In FIRE, The Proposed Rings are Intended to Augment Wedging Pressures in the TF Inner Leg Corners to Help Support OOP Loads.

Clamp Function Can be Chosen based on Ring Vertical Position with Respect to the Horizontal Leg.

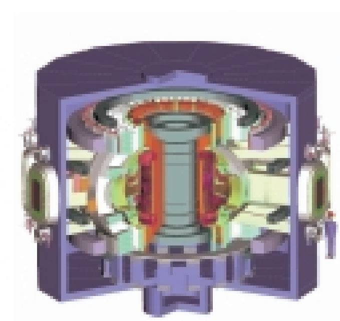
Ignitor Magnetic Press

Reduces/eliminates primary membrane stress in nose

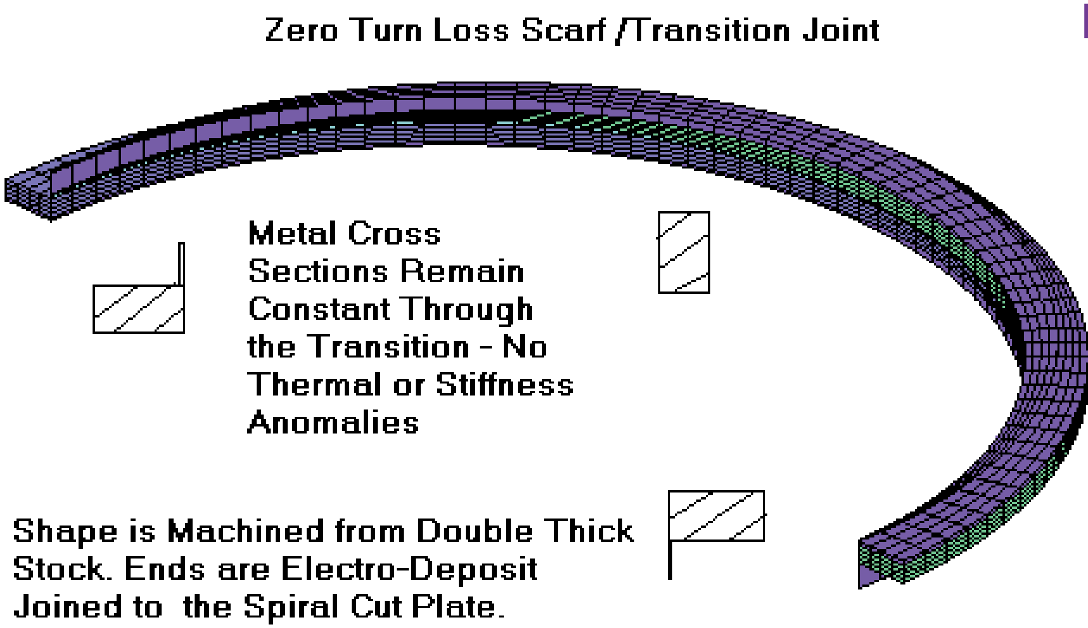
Active - can track thermal and Lorentz stresses: e.g. FIRE: peak stress after assembly, not operation

Can match "shear advantage" for special case of PF field lines nearly parallel I_{TF}

Advantage of 13 % over FIRE compression ring



Zero Turn Loss Scarf/Transition Joint

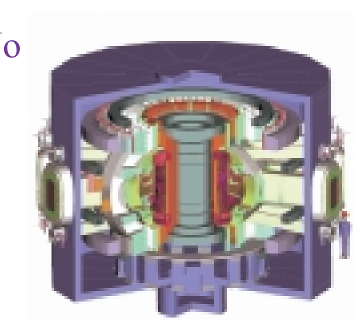


Peak local stress reduced x 2

Ip improvement ~ 10 %

Inner Joint for Pancake Wound Coils

- No Stress or Stiffness anomaly - Working Stress is the Same as for the Winding.
- No Thermal Anomaly in Normal Conductor Coils - No Differential Thermal Strains
- No Turn Loss
- No Projection into the Bore
- Electrodeposited joint as strong as base metal



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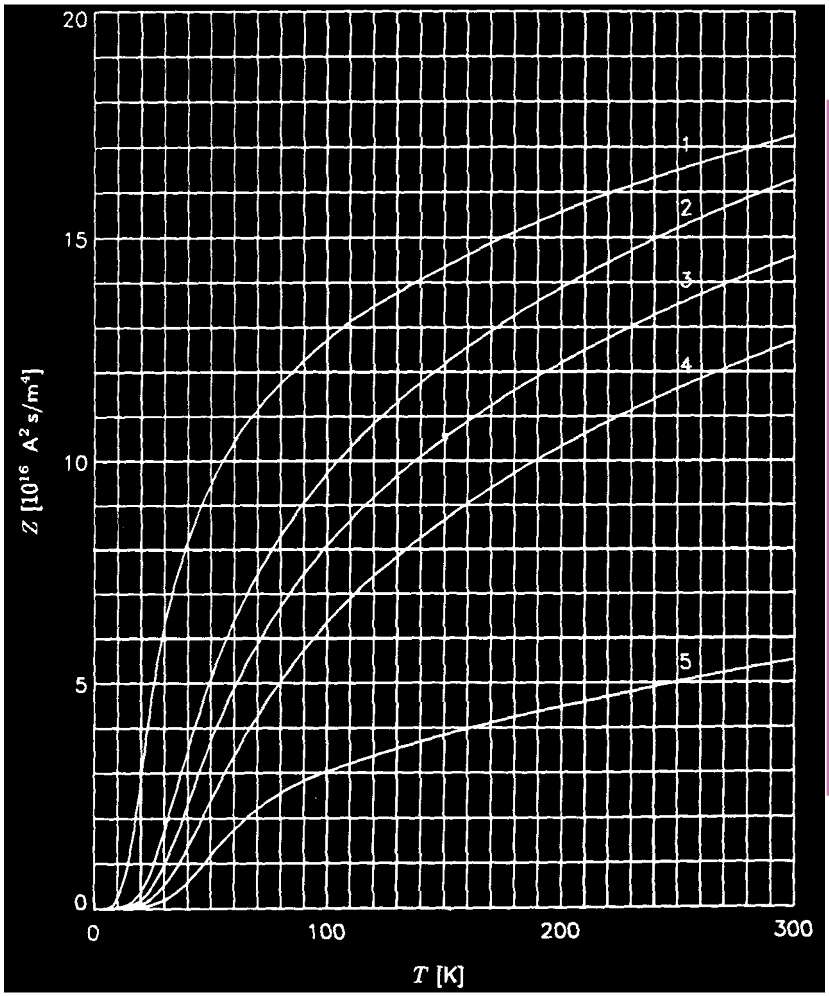
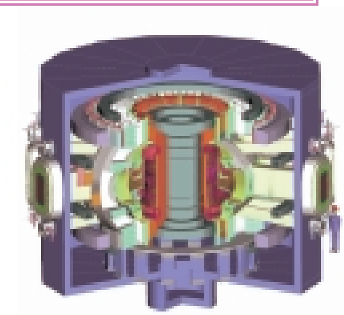
Subcooling in Ignitor



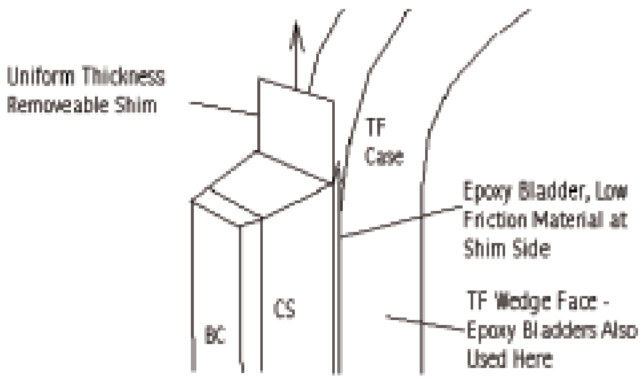
$Z(T_f)$ functions: 1. Silver (99.99%); 2. Copper (RRR 200); 3. Copper (RRR 100); 4. Copper (RRR 50); 5. Aluminum (99.99%)

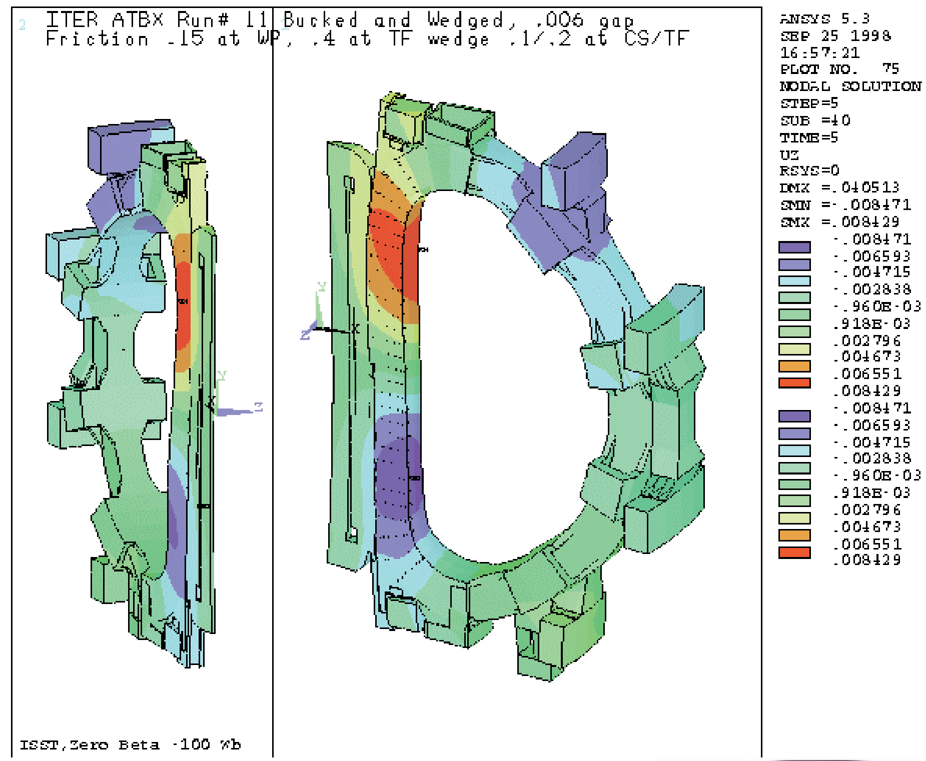
- Tinit,Ignitor = 30 K; Tinit,FIRE=77 K
- Entropy generations ~ equal, lower temperature vs. smaller size
- 5 hr cooldown, Ignitor; 3 hr, FIRE
- Neither has activated IN2
  - FIRE flushes with He gas, after IN2 cooldown
- 40 % improvement in J^2t
  - 20 % in Jcu, 10 % in IpA/R



Advanced Structural Concepts for Global Machine Behavior

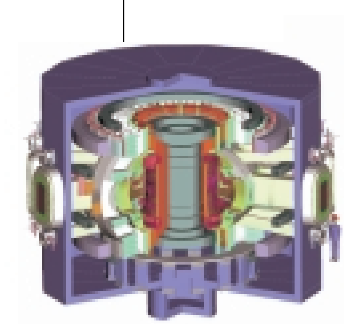
Bucked and Partially Wedged - ATBX - FDR ITER concept with partial wedging to control CS torsion.





IpA/R ATBX was 12 % higher than ITER

OOP displacements of the toroidal field coil are imposed on CS. Torsional shear stress in the CS is reduced by partially wedging the TF case. Set gap obtained with inflatable and removable shims.



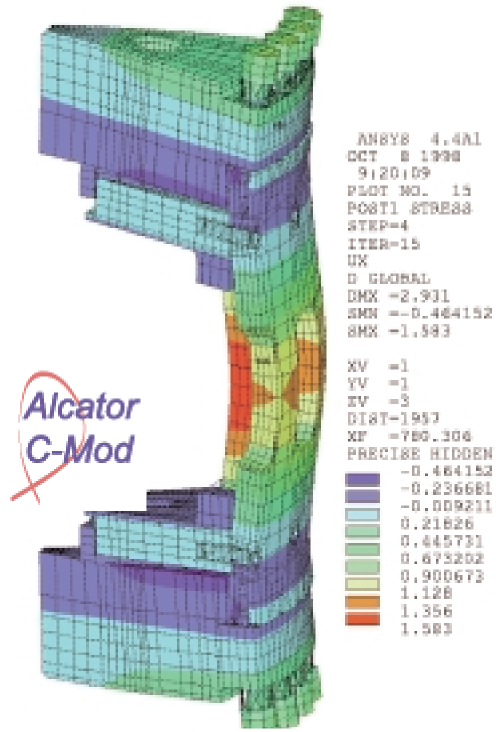
Advanced Structural Concepts for Global Machine Behavior

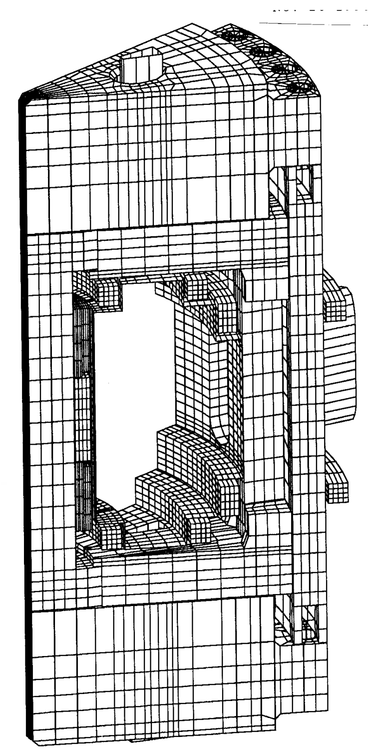
Sliding Joint Picture frame TF Coils.

- (NSO C-Mod Scale-up Studies)
- (Ron Parker Proposed Steady Burn Experiment, SBX)
- The in-plane behavior of the Inner Leg of C-Mod is structurally decoupled from the rest of the machine.

Upgrade to 2.5 MA planned

Original 3.0 MA design IpA/R=FIRE





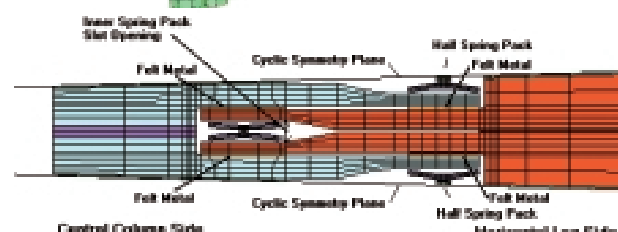
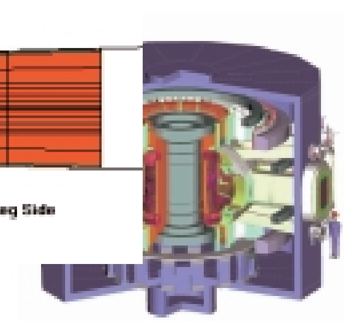
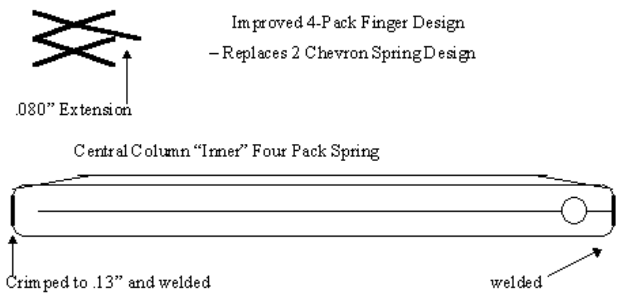


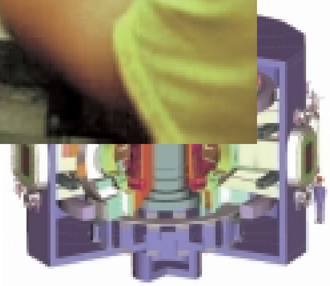
Figure 2
Alcator C-Mod TF Inner Sliding Joint



TF Finger Spring Upgrade



- Felt Metal was degraded
- Failure Analysis Yielded no Clear Cause
- Increased Spring Plate Pressure and Extension Improved FM Contact
- "4 Pack" Replaced "2 Pack"
- C-Mod has Worked OK Since



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Conclusions-I

1) IpA/R > 15 MA/m tokamaks appear available for BPX's

- not yet demonstrated x factor of 2, C-Mod can come close

- superconducting tokamaks need to catch up

2) Key to high IpA/R to tokamaks is topology, not materials

Buck-wedge, Compression Rings, Magnetic Press, Scarf Joints, Sliding-Joints, Subcooling

3) Beyond Ignitor and C-Mod?

- Ignitor topology highly optimized - but possible extension to 30-370 K

- Further optimization of C-Mod topology possible