NCSX CDR kickoff Requirements and Scope for WBS-1, Stellarator Core

M. Cole, B. Nelson, D. Williamson (ORNL)
W. Reiersen (PPPL)

NCSX WBS-1 CDR kickoff

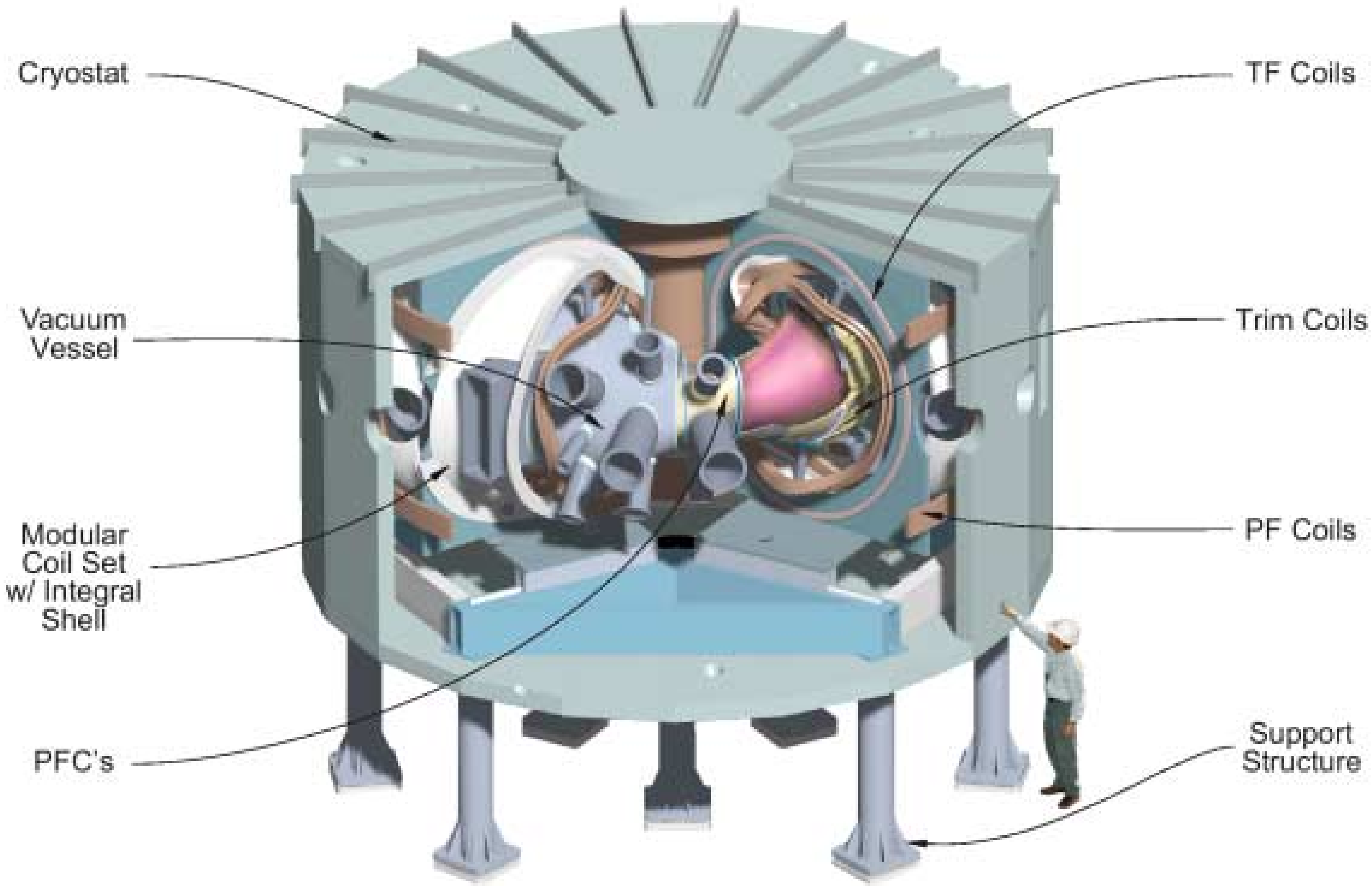
October 9, 2001

Outline

For each major subsystem:

- **What is present configuration and scope?**
- **What are top level requirements?**
- **What are some of the key issues with respect to:**
  - **Requirements**
  - **Design**
  - **Fabrication**
  - **Assembly**

Stellarator core



Priorities for conceptual design were established at PVR

- **Involve industry**
  - ***Fund* participation for manufacturing studies, R&D and prototypes**
- **Improve modular coil geometry**
  - **Improve manufacturability, reduce cost, reduce J, eliminate sharp bends, improve access (18 coil solution)**
- **Optimize design for flexibility**
  - **Optimize VV shape, liner configuration, and PF coil design**
- **Optimize design for access**
  - **Address geometric requirements of diagnostic access, incorporate RF scheme into the engineering design, improve personnel access.**
- **Finalize requirements**
  - **Finalize requirements well in advance of CDR (present sched: Dec ‘01)**
  - **Establish defensible and achievable dimensional tolerances**
- **Develop “bottoms up” schedule estimate**
  - **Need to determine project duration, critical path activities**
- **Refine cost estimates**
  - **Pursue cost effective design and manufacturing solutions**

PFC requirements

- Basic requirements
  - Carbon based, bakeable to 350C
  - NBI armor needed day 1
  - Trim coil armor
  - Inboard limiter / coverage
  - Divertor plates needed day 1
  - 3 MW for 0.5 s
  - > 60 % of power to divertor region, balance can be intercepted by walls
  - Provide penetrations, accommodate in-vessel diagnostics mounted on VV

- Upgrade requirements
  - Full coverage of surfaces with carbon
  - 12 MW for 1.2 s
  - Provision for divertor pumping
  - Energetic ion loss armor

PFC design concept

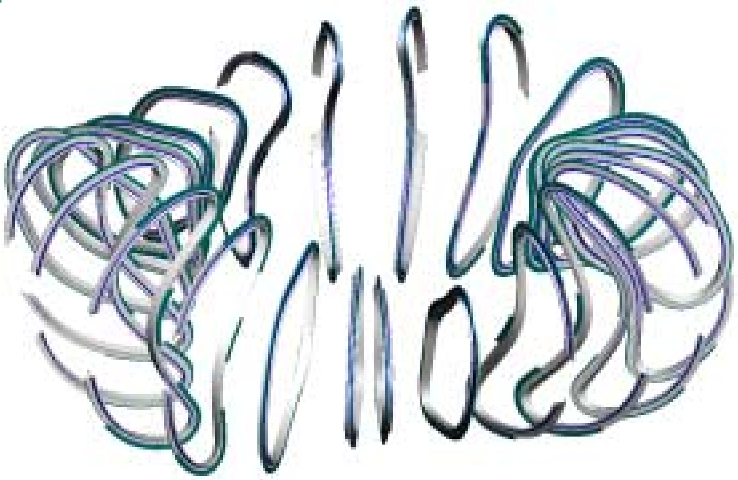
- **Staged implementation planned**
  - **Initial coverage with low Z tiles mounted on poloidal ribs to form array of poloidal limiters**
  - **Panels for NB armor and divertor region will also be provided**

- **Full coverage provided by mounting molded carbon fiber composite (CFC) panels on poloidal ribs**
  - **Panel size based on advice from BFG aerospace (~ 60 cm square, 1 cm thick)**

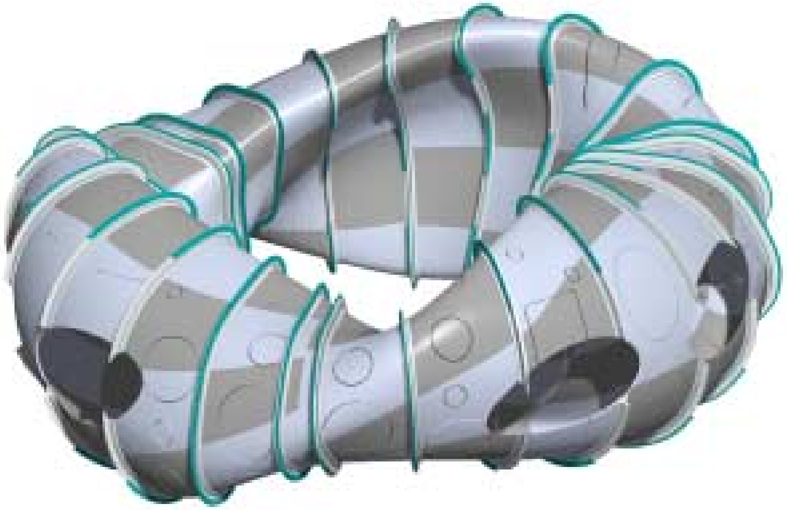
- **Ribs are separately cooled / heated with He gas for bakeout (350C) and normal operation**

- **Ribs are registered toroidally to VV but allowed to grow radially and vertically**

Poloidal ribs



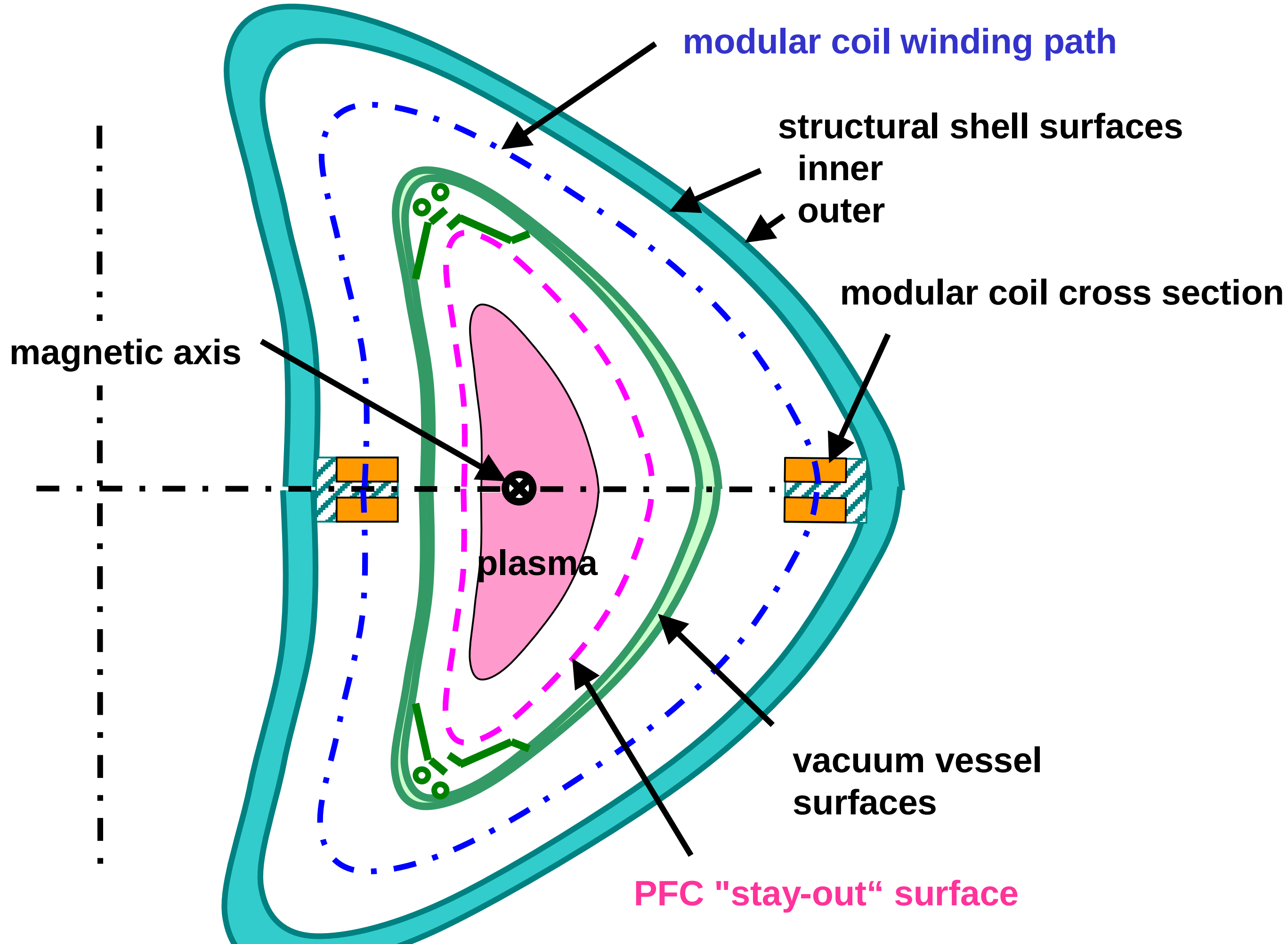
CFC panels mounted on poloidal ribs



PFC issues

Requirements	Design	Fab.	Ass'y
• PFC stayout zone • divertor geometry • In-vessel diagnostics (e.g., magnetic loops) • Max plasma current • Divertor pumping upgrade, if any	• transition from day 1 to full coverage • RF launcher integration with limiters, diag. • trim coil integration • low z rail covers	• CFC cost • Low z coating	• personnel access for –installation –reconfiguration

Reference geometry definition

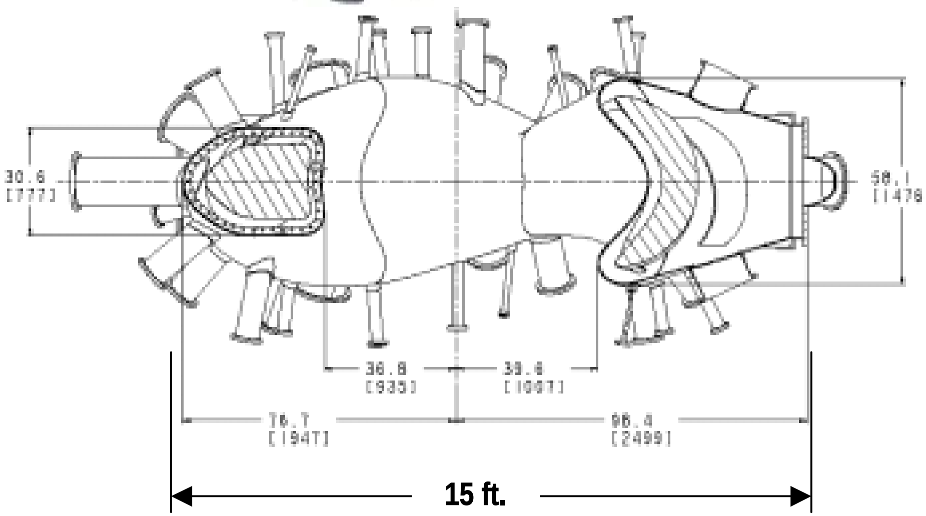


Vacuum vessel requirements

- **Vessel must be bakeable to 150 C**
- **Low permeability (< 1.02 nominal goal)**
- **Provide as large a volume as possible for plasma shape flexibility and power and particle handling systems, consistent with assembly of modular coils. Must provide space for inboard RF launcher at phi = 60 deg sections**
- **Provide support for internal components such as internal liner, trim coils, magnetic sensors**
- **Provide access ports for diagnostics, vacuum pumping, heating systems, and personnel access. Must provide radial diagnostic access at v=1/2 symmetry planes for Thomson scattering and radial diagnostic beam**

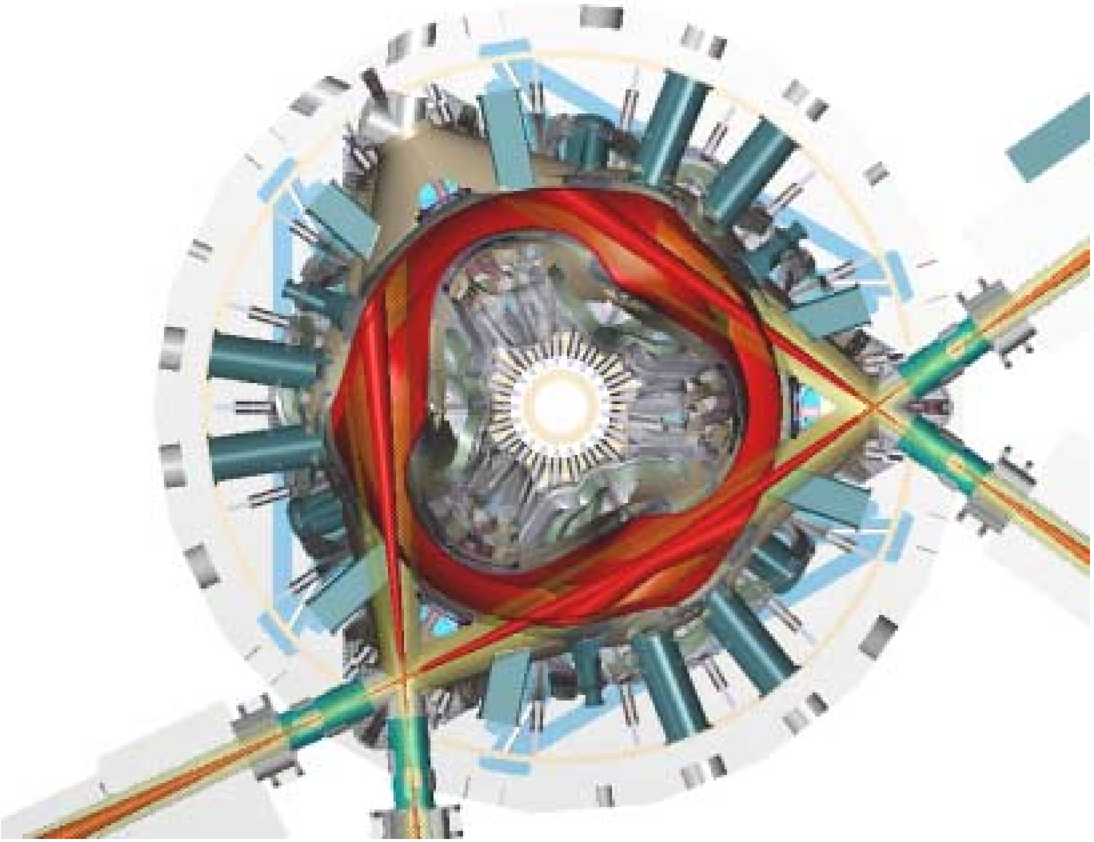
Vacuum vessel design concept

- **Shell material** — **Inconel 625**
- **Thickness** — **.375 inch**
- **Time constant** — **< 10 ms**
- **Total wt w/ports** — **~ 12000 lbs**
- **Bolted joints connect field periods**
- **Traced with He gas lines for heating (to 150C) and cooling**
- **Combination Microtherm and Solomide foam insulation between VV and cold mass**



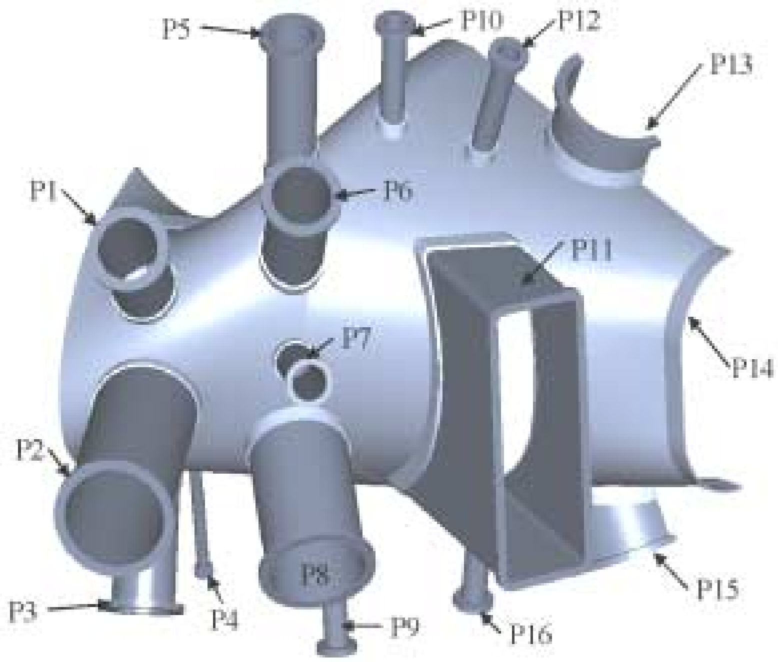
Access for tangential NBI

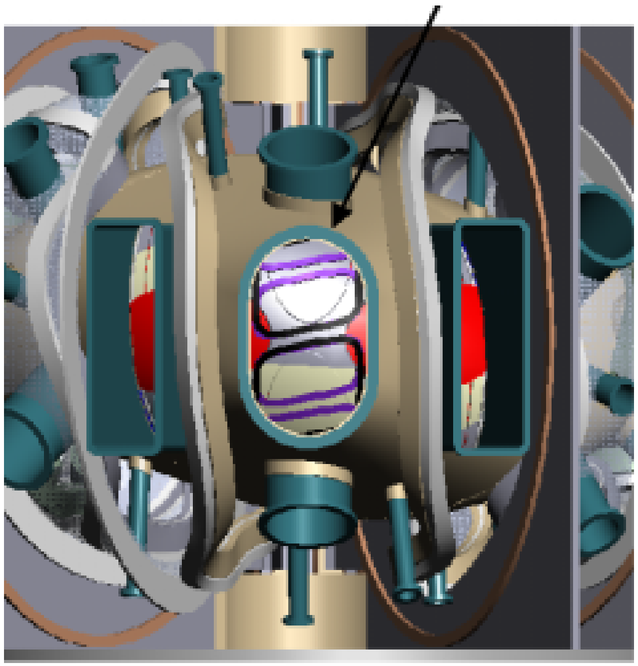
- **Up to 4 neutral beams in combinations of co- and counter-**
- **Vacuum pumping through NB ducts**



Diagnostic and personnel access

- **87 separate ports for ~100 different diagnostics**
  - **The number and sizes of ports appear to match diagnostic requirements**
  - **Geometric requirements for specific diagnostics will be addressed in more detail during conceptual design**
- **Personnel access available through NBI or adjacent large ports**



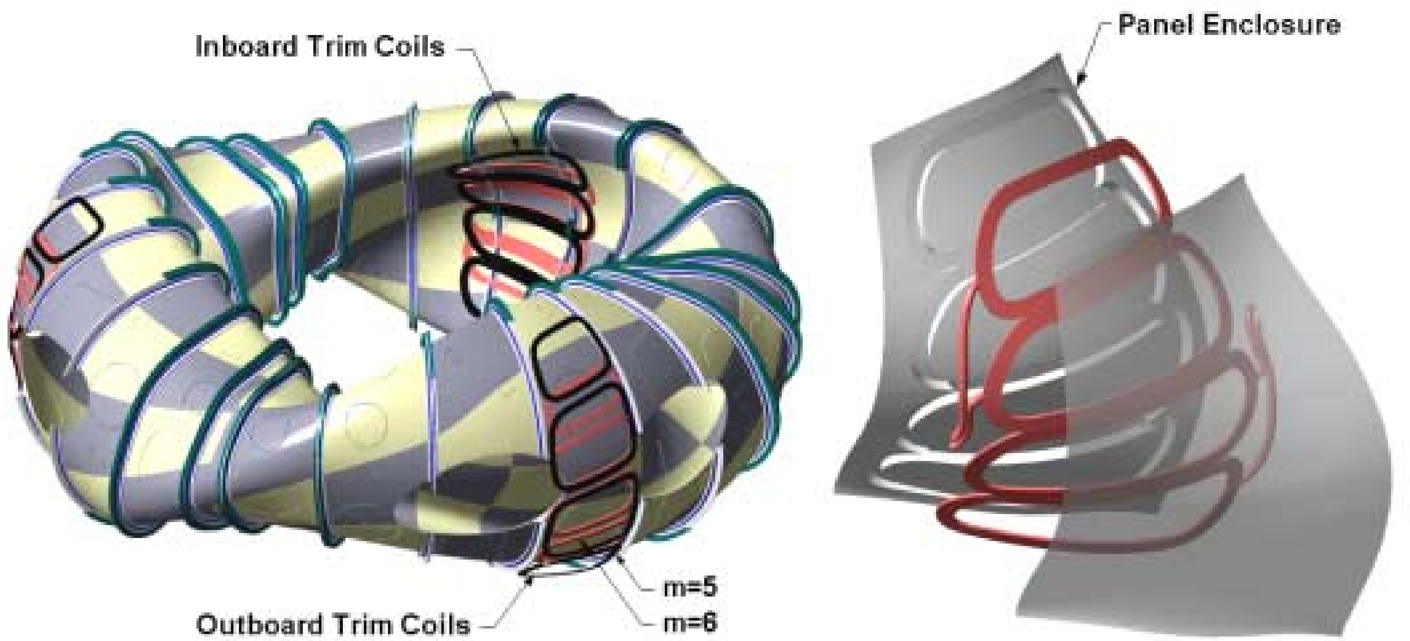


Vacuum vessel issues

Requirements	Design	Fab.	Ass'y
• RF launcher envelope • PFC / divertor envelope • Diagnostic views, incl. symmetry plane access • Maximum plasma current (greater than 175 kA?)	• smoother shape • port integration for diagnostics • segmentation • field joint flange envelope • stresses / buckling for disruption loads • mechanics of describing vessel shape to vendors	• Cost within est.? • Process and qualified vendors • Geometric tolerance • draft spec. for procure-ment	• sliding coils over vessel • distortion during and after port welding • personnel access for field joint • Leak checking

Trim coils – PVR requirements

- Provided to mitigate field errors on m=5 and m=6 resonant surfaces
- Located close to inboard and outboard midplane at v=0 cross-section
- Mounted off vacuum vessel, behind liner
- Canned for vacuum compatibility



Trim coil issues

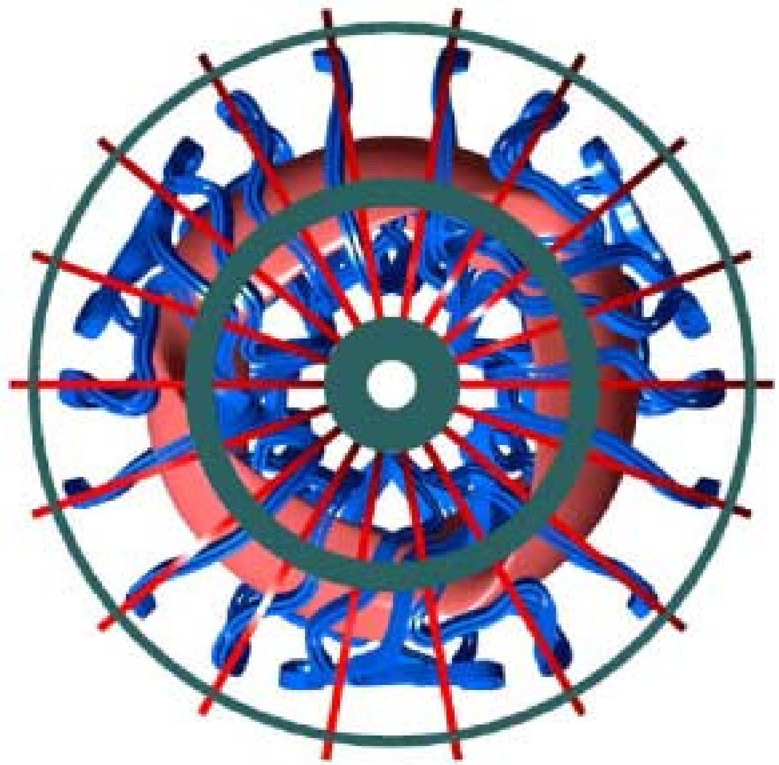
Requirements	Design	Fab.	Ass'y
• number / location of windings • winding geometry and accuracy • number of circuits • current waveforms	• NBI interface • support scheme • leads • cooling • mechanics of describing winding shape to vendors • fault conditions	• canned coils • draft spec. for procure-ment	• Personnel access for installation • measurement of coil location • Locational error correction

Modular coil requirements

- **Meet performance requirements**
  - **1.7 T scenario with 0.46s flattop**
  - **1.2 T scenario with 1.24s flattop**
  - **2.0 T with reduced external iota**
  - **15 minute rep rate (5 minute rep rate for short pulse)**
- **Provide flexibility**
  - **Independent control of modular and PF coils provided**
  - **Variable background TF field**
- **+/- 1 mm assumed for winding accuracy**
- **Coils must provide access for tangential NBI, RF, vacuum pumping, diagnostics, and personnel access**
- **Limit conductor current to ~ 24 kA peak to match with existing TFTR power supplies**

Modular coil configuration

- 18 coils, 3 field periods
- No coils at symmetry planes
- Coils wound with flexible cable conductor into cast-and-machined forms
- Coils pre-cooled to LN_2 temperature to allow high current density



Continuous shell forms robust structure

- **Shell consists of individual modular coil forms that are bolted together**
- **Penetrations for access are provided wherever needed**
- **Preliminary stress analysis of shell has been performed**
  - **Stresses are well within allowables except for a few localized "hot spots"**
  - **Local problems can be solved with minor changes in local thickness**

Modular coil winding issues

Requirements	Design	Fab.	Ass'y
• winding geometry definition, incorporating engr constraints • winding accuracy • current • current waveforms • Fault conditions	• coil twist • small bend radii, "squiggle" • local convergence / divergence of winding packs • leads • conductor R&D • fault conditions	• Dimension-al accuracy, inspection • Potting	• Clamp installation

Modular coil structure issues

Requirements	Design	Fab.	Ass'y
• maximum allow. deflection • time constants • Fault conditions	• shell surface shape - must be smoother • mechanics of describing winding form shape to vendors • analysis of coil electrical response, • reduce shell coverage via analysis (bigger holes, less wt.)	• casting accuracy, cost • machining vs grouting • draft spec. for procure-ment	• measurement of coil location • geometry error correction

Modular coil engr. constraints

- **Quantitative constraints**
  - **Bend radius**
  - **Rate of twist**
  - **Coil-coil separation, (current density, max coil temperature, max coil temp rise during pulse)**
  - **Plasma-coil separation**
  - **NBI access**
  - **Peak power**
  - **Current / turn**
  - **Cost**
- **Qualitative constraints**
  - **“shape” complexity**
  - **“manufacturability”**

TF Coils

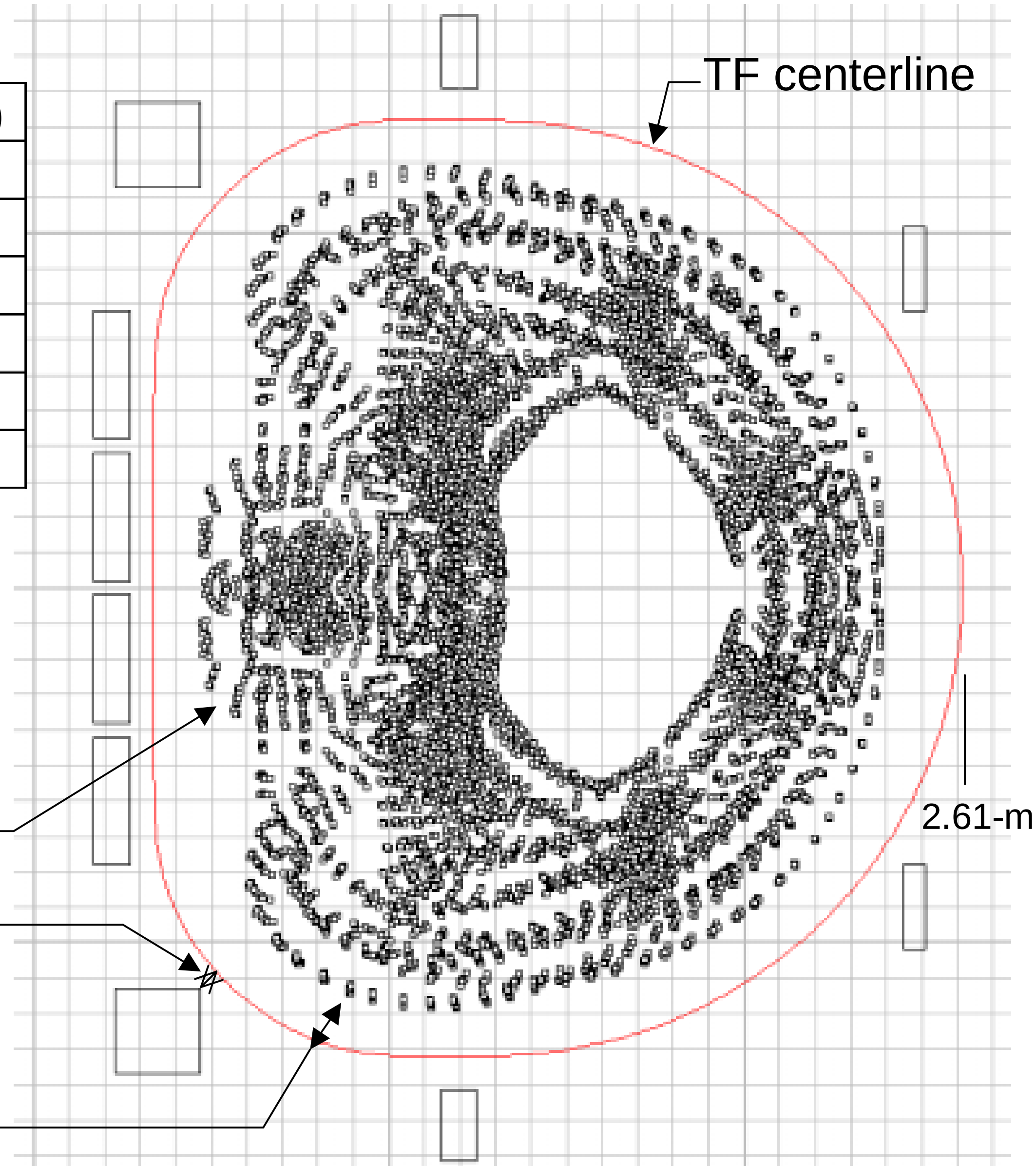
- **18 equally spaced coils provide +/- 0.3 T**
- **Pre-formed and mounted on modular coil shell structure. Additional plates should not be necessary**
- **Wound from hollow copper conductor**
- **Pre-cooled to LN_2 temperature (like modular coils)**

18 TF Coil Option – PF/TF Layout 10/05/01

	Rc	Zc	dR	dZ	I (kA)
PF1	0.22	0.20	0.10	0.36	0
PF2	0.22	0.60	0.10	0.36	0
PF3	0.35	1.25	0.24	0.24	650
PF4	1.20	1.52	0.12	0.24	47
PF5	2.48	0.90	0.06	0.24	9
TF	-	-	0.10	0.10	66

Coil current based on S3 state, Case 0918a17

TF one-turn length = 8.128-m
Bounding box (dR x dZ) = 2.285 x 2.649-m



TF coil issues

Requirements	Design	Fab.	Ass'y
• total field • max ripple • Accuracy • Fault conditions	• Optimize for access: at same plane as modular coils, between modular coils, ? • coils supported on plates or something else • fault conditions	• none *unless* coils are non-planar or if they must be wound onto modular coil structure • draft spec for procure-ment	• depends on shape

PF Coils

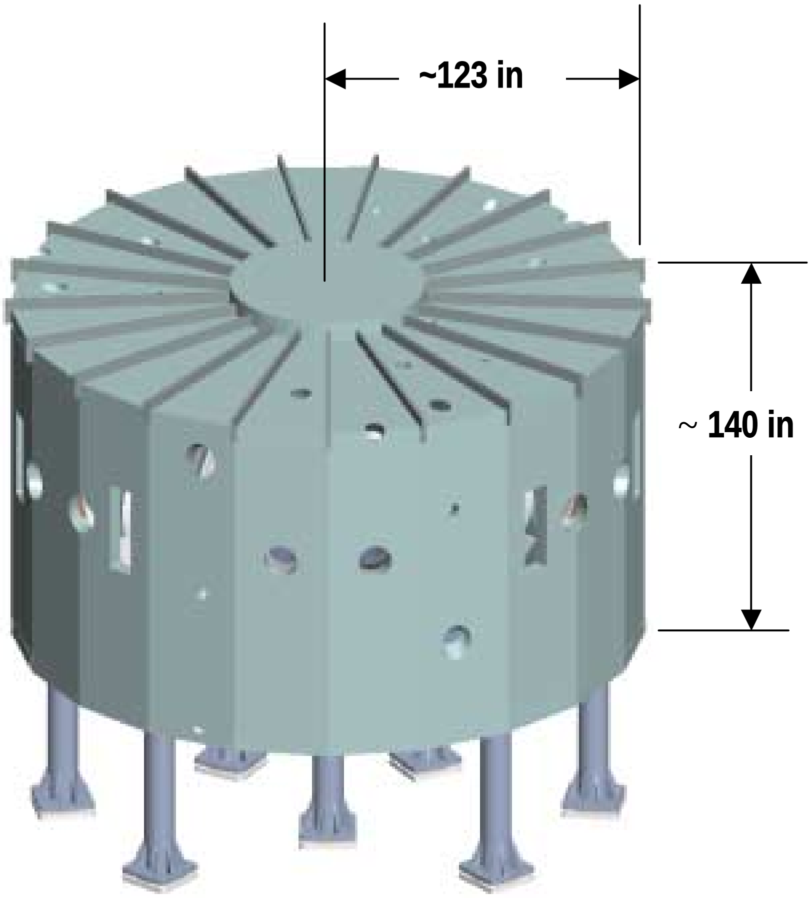
- 5 pairs of PF coils provide inductive current drive and plasma position and shape control
- 1.7T scenario requires 1Wb with a plasma current ramp rate of 3MA/s
- PF coils located outside modular and TF coils, supported off modular coil shell structure
- Wound from hollow copper conductor, glass-epoxy insulation
- Pre-cooled to LN_2 temperature (like modular and TF coils)

PF coil issues

Requirements	Design	Fab.	Ass'y
• current waveforms • Fault conditions	• location consistent with diagnostic access • fault conditions	• none *unless* coils are non-planar or if they must be wound onto modular coil structure • draft spec for procure-ment	• depends on shape

Cryostat

- Cryostat design uses commercial concept - substructure sprayed with urethane foam
- Inexpensive construction facilitates maintenance access
- Holes provided for all vacuum vessel port extensions
- Silicon rubber "Gortiflex" boots to seal between vessel port extensions and cryostat
- 8" thickness reduces heat leaks to 2kW but still will require local heaters/blowers to avoid condensation



Cryostat issues

Requirements	Design	Fab.	Ass'y
• **Are there any other requirements?**	• NBI interface • re-entrant duct design • thermal analysis • definition of heaters • Access to core for maintenance	• Spraying of poly-urethane insulation • draft spec for procure-ment	• Boot interfaces • Leak checking

Interfaces

- **Interfaces must be quantified among all WBS elements**
- **Propose spreadsheet on web to track**
- **WBS 1 has multiple interfaces**

WBS	System	21 Fueling	22 Vacuum pumping	23 Wall conditioning	24 RF heating	25 Neutral beams	3 Diagnostics	4 Electrical Power	5 Central I&C	61 Facility mods and test cell prep	62 Heating and cooling	63 LN2 systems	64 Utility systems	7 Machine assembly	82 Project engineering	9 Prep for ops
11	PFCs	●		●		●	●		●		●		●	●	●	●
12	Vacuum vessel	●	●	●	●	●	●		●		●		●	●	●	●
13	TF Coils							●	●		●	●		●	●	●
14	PF Coils							●	●		●	●		●	●	●
15	support structure	●			●	●	●		●	●				●	●	●
16	Cryostat	●			●	●	●		●		●	●		●	●	●
17	modular coils							●	●		●	●		●	●	●
18	trim coils							●	●		●			●	●	●