QOS Engineering Configuration Status

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QOS project meeting

Feb 28, 2001

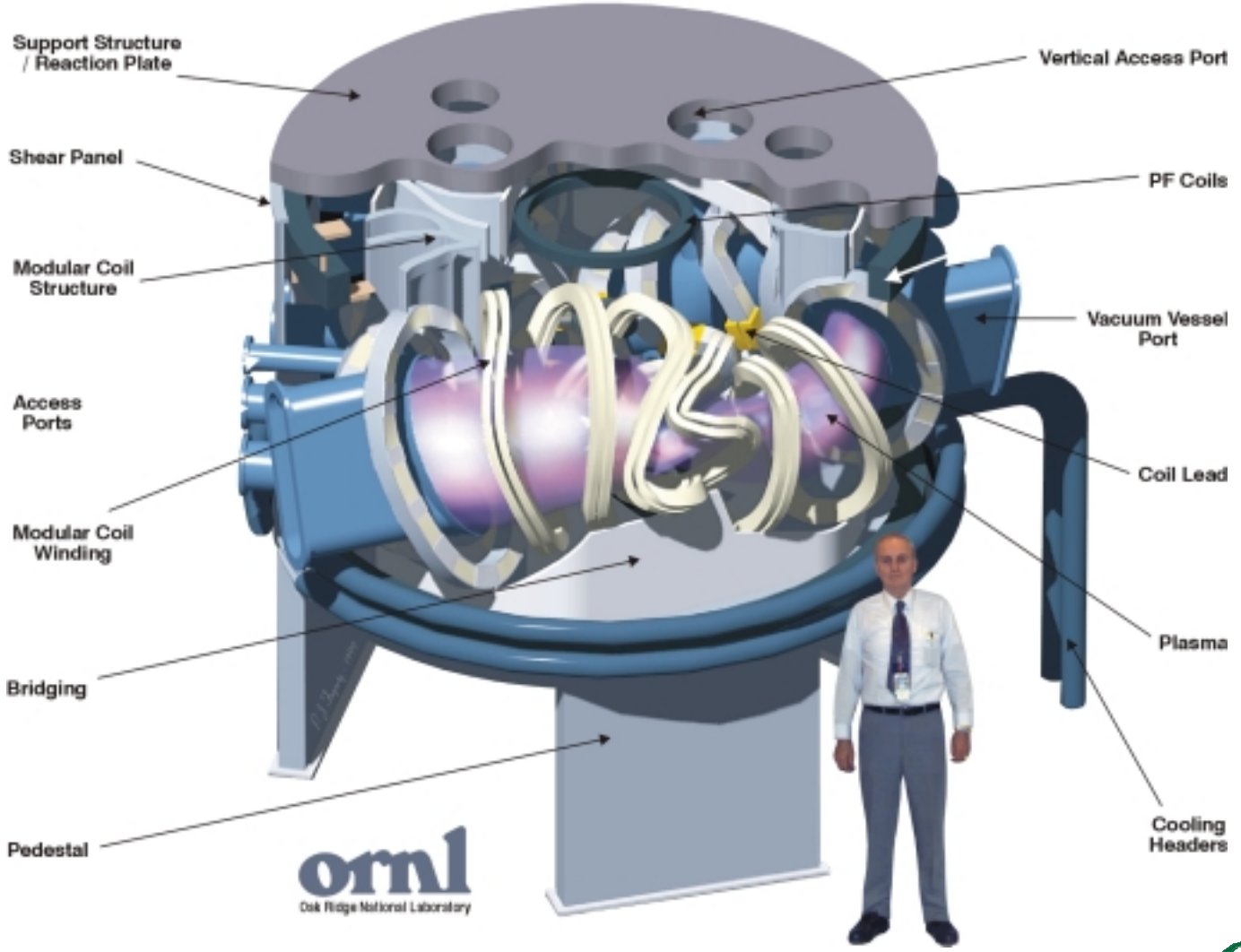
Presentation Outline

- **Baseline parameters and changes from last design**
- **Stellarator core configuration and evaluation**
  - **Modular coils, structure, vacuum tank**
  - **What is the design concept?**
  - **How do we build it?**
  - **Status, recent improvements**
- **Summary**

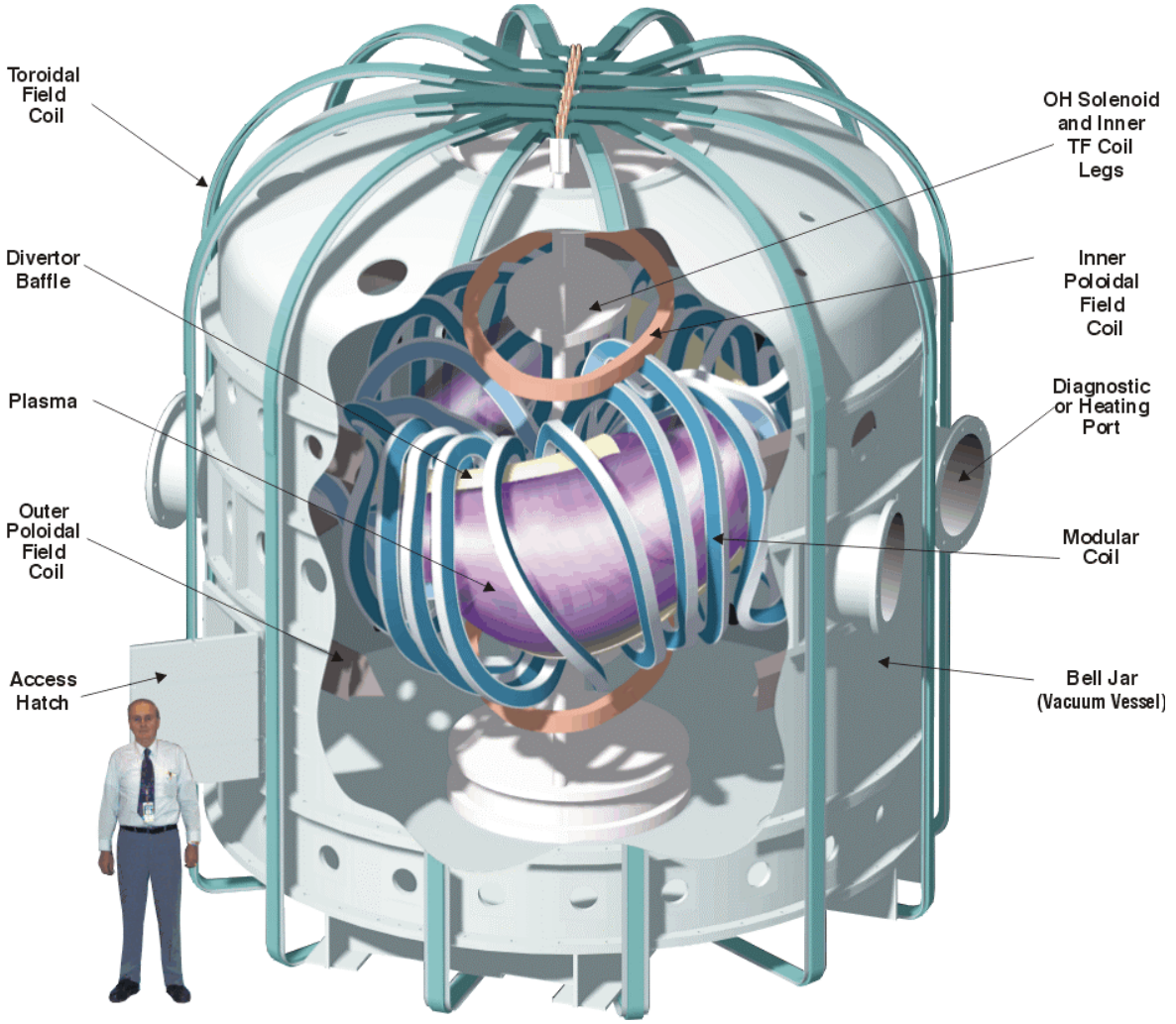
Baseline parameters for QOS design

- **Moderate size and field**
  - **<R0> ~ .95 m**
  - **<a> ~0.37 m**
  - **B0 = 1 T**
- **Factory assembled unit desired, consisting of modular coils, PF coils, and structure**
  - **Minimum cost is essential**
  - **Uses existing power supplies, cooling system, diagnostics, ICH antennas and power supplies, ECH system, etc.**
- **We have just begun refining engineering studies of our second two-period configuration**

Earlier 3 field period design



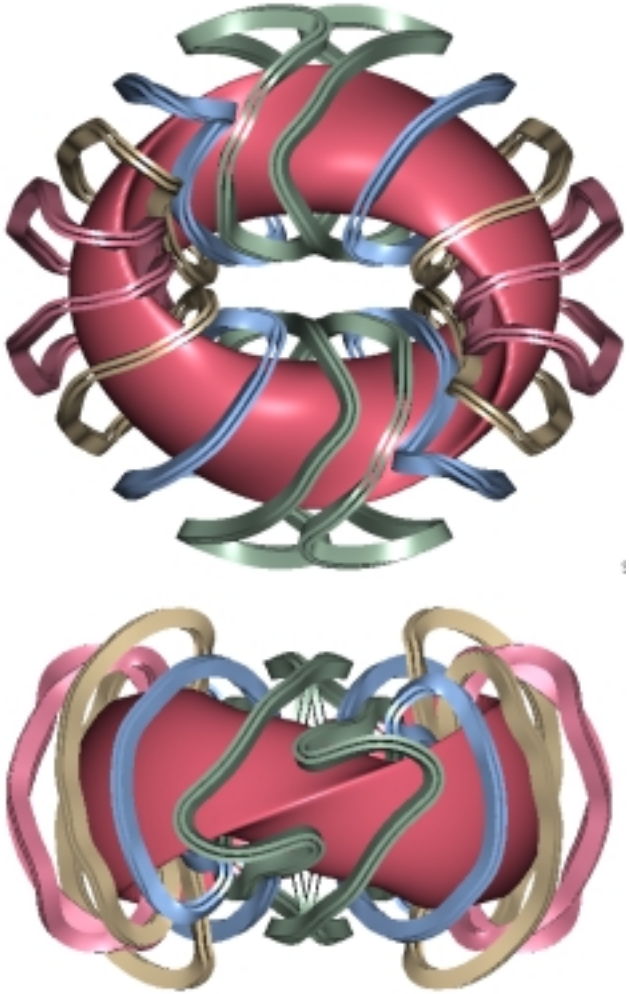
Configuration from Sept 00 through Jan 01



New coil set is more attractive

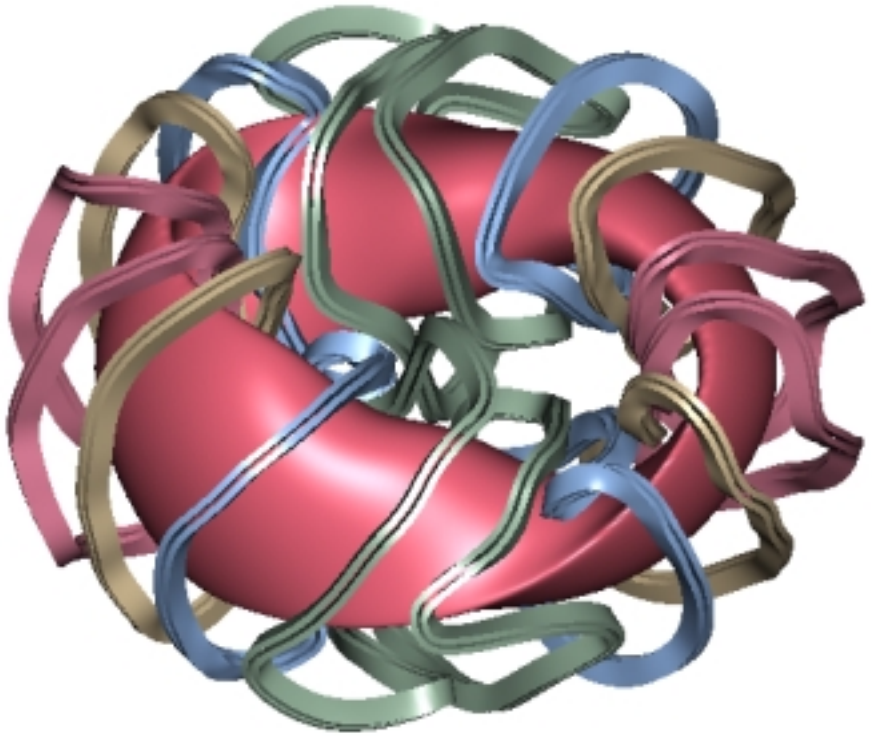
Feature	Sept 00 option	Current baseline
Configuration	2 period, A = 2.5	2 period, A = 2.5
Modular coils	22 coils, 6 coil types, 1T	*16 coils, 4 coil types, 1T*
TF coils	External set producing +/- 0.2 Tesla	External set producing +/- 0.15 Tesla
OH solenoid	4 m tall, oblong solenoid +/- 0.05 V-s	4 m tall, oblong solenoid ~ +/- 0.15 V-s
VF / trim coils	2 pairs	2 pairs
Vacuum config.	Bell jar	Bell jar
Access space	Limited by ports in external vessel and by modular coils / structure	Limited by ports in external vessel and by modular coils / structure

Modular coil configuration



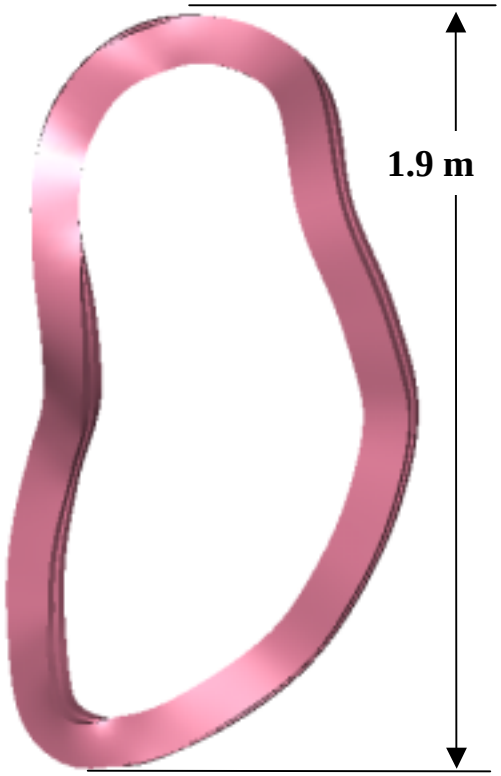
Coil set 0213A4 (as scaled)

R0 = .95 m, a = .37 m



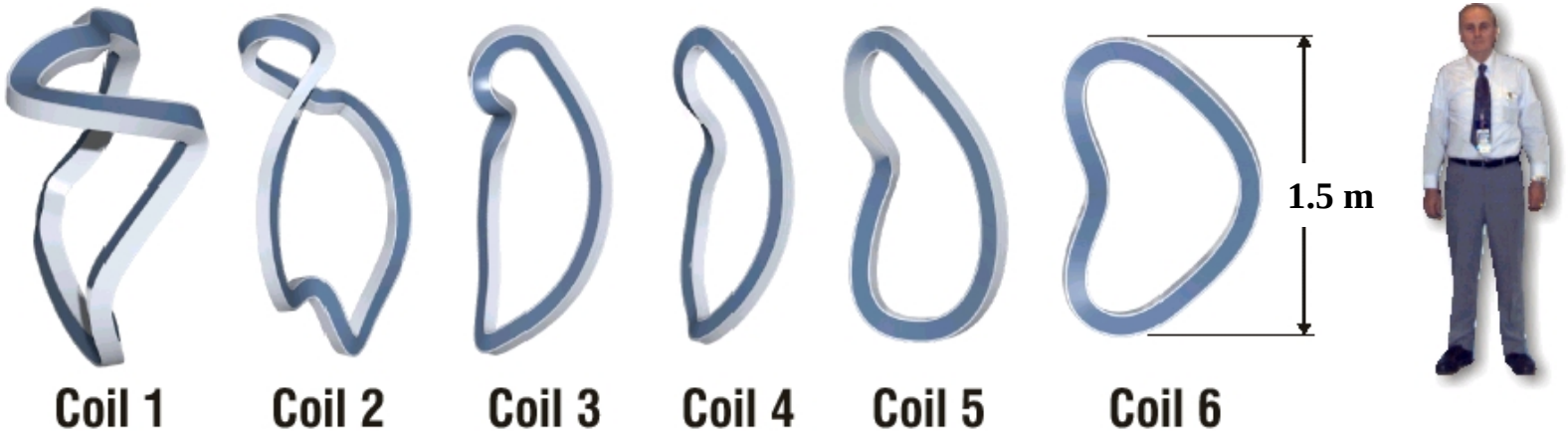
QOS modular coil parameters (as scaled)

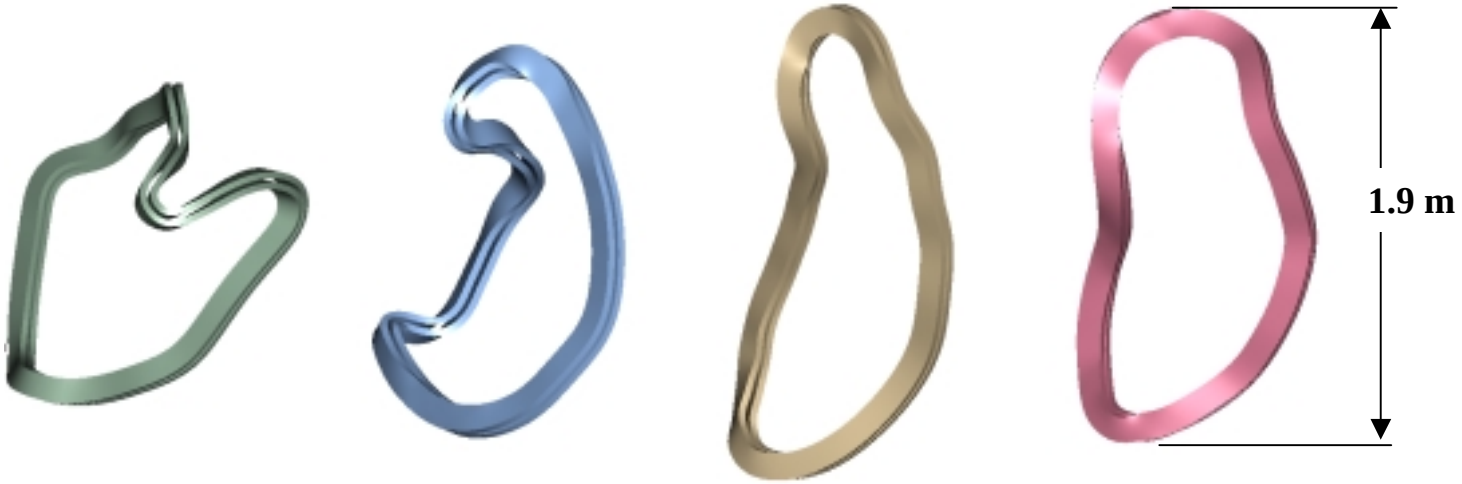
Coil set	0213b2
No. of field periods	2
No. of coils per period	8
No of coil types	4
Est. Current per coil, kA	356
Avg. length per coil, cm	535
Cross section, w x h, cm (including local structure)	8.5 x 12
Current density, gross, kA/cm^2	~ 3
Current density in Cu, kA/cm^2	~ 8
Scale factor used	0.95



Modular Coil Shapes - 0829b vs 0213b2

0829b





Modular Coil winding support concept

"I-Beam" provides accurate winding form and structural support

- Windings located on either side of I-Beam
- Loads transmitted to vertical webs, then to upper and lower reaction plates
- Coils can be pre-tested at full current
- Hard features can be used to measure and adjust coil position

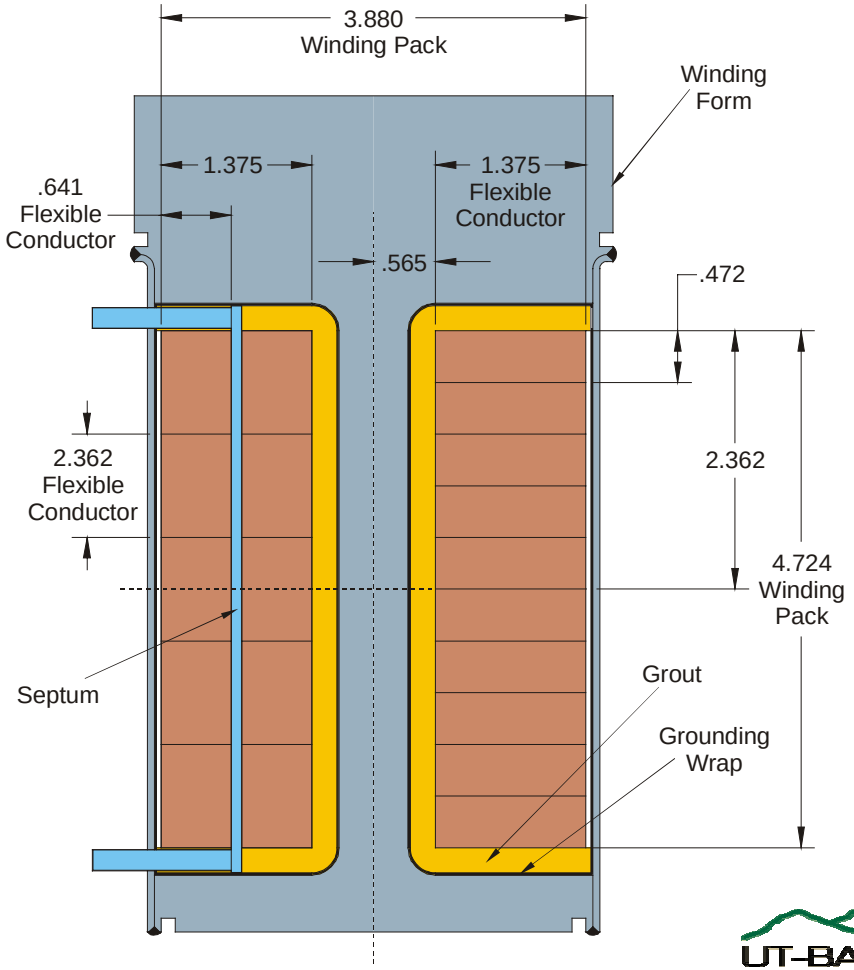
Exploded view

Assembled view

Modular coil winding concept

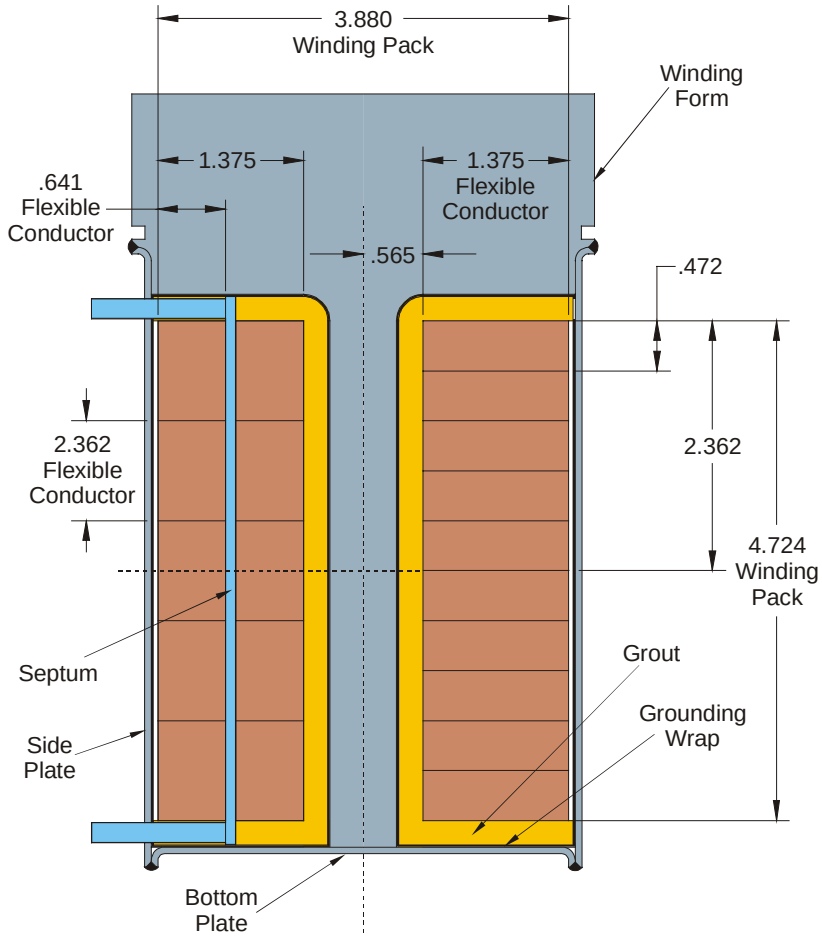
Molded winding cavity intended to minimize machining cost

- "I-Beam" structure can be weldment or casting
- Pattern made by stereolithography is positioned in structure
- Epoxy fills void between pattern and structure
- Pattern is removed
- Accurate cavity is left to receive conductor
- Cooling options include chill plate and "full can" cooling



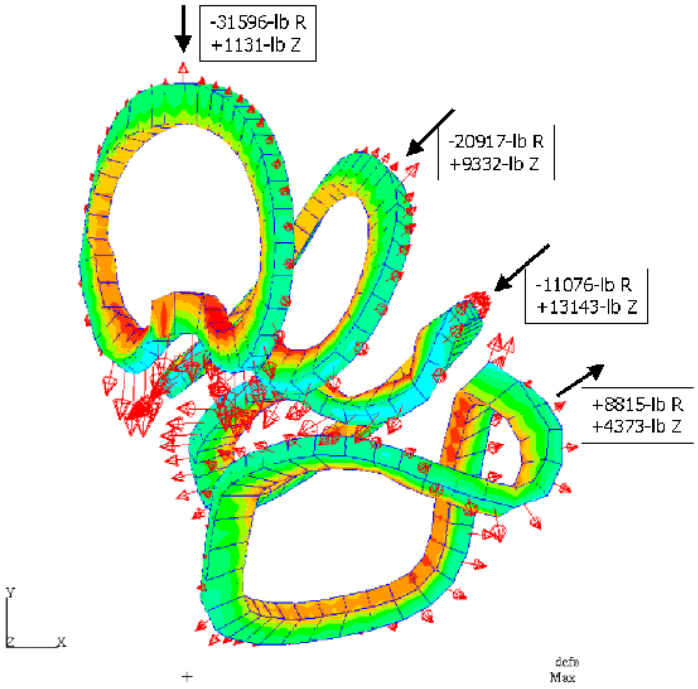
Winding cross section options

- **Use “tee” instead of “I-beam” for more open structure, increased winding space**
- **Requires additional formed strip for can closure**

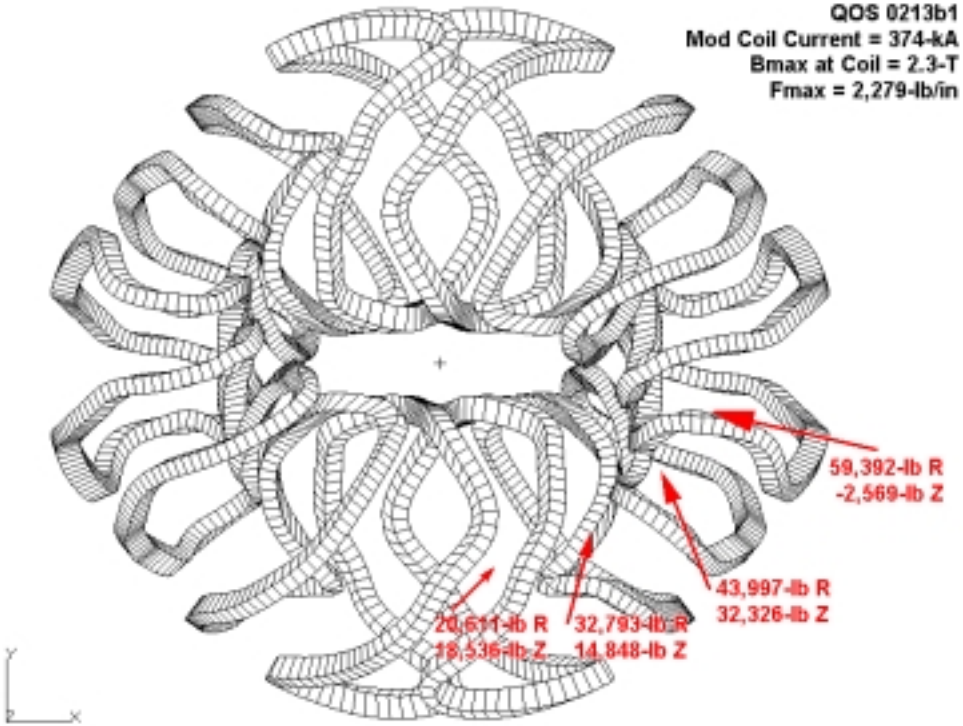


Modular coil forces and structure

- **Forces are higher than for 3-period case (59 vs 32 kips max)**
- **net load direction is always inward**



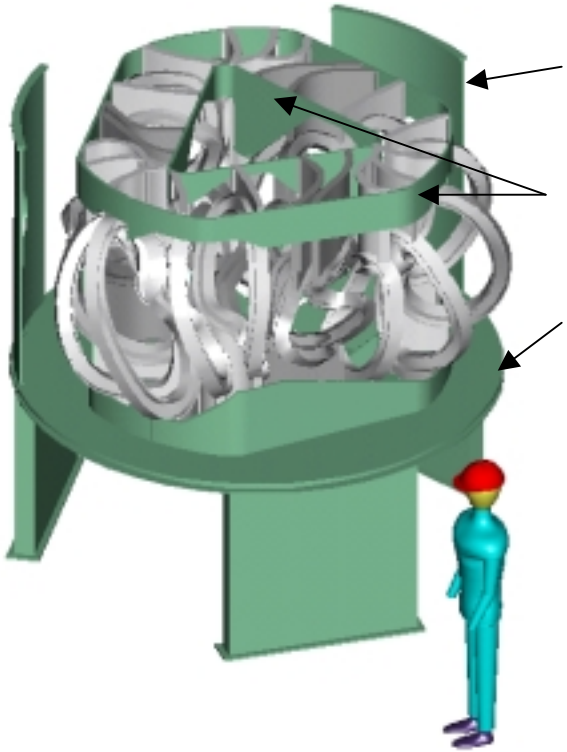
3-period case

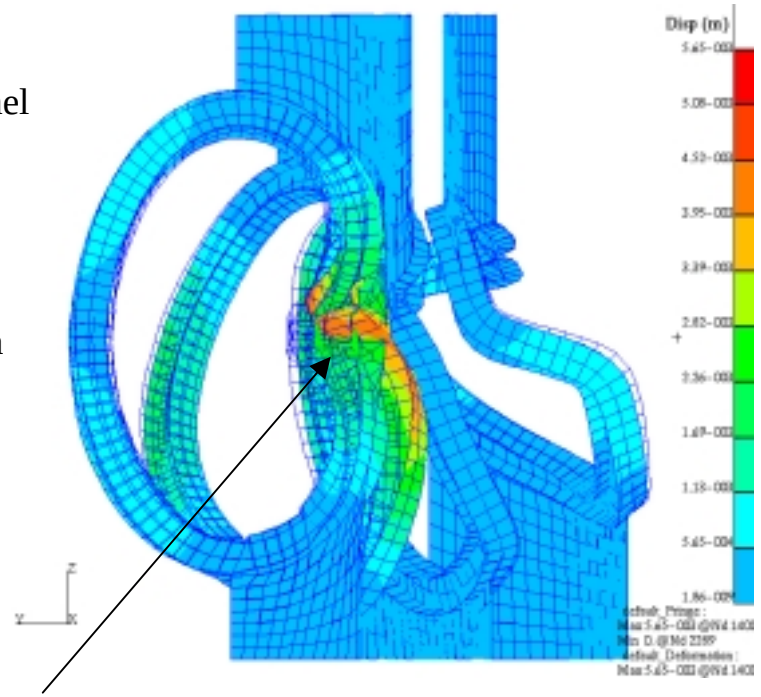


0213b2

Modular coil forces and structure (2)

- **3 field period design used reaction plates and bridging, analysis indicated reinforcement needed around tight bends**





Needs reinforcement

Modular Coils and Structure (3)

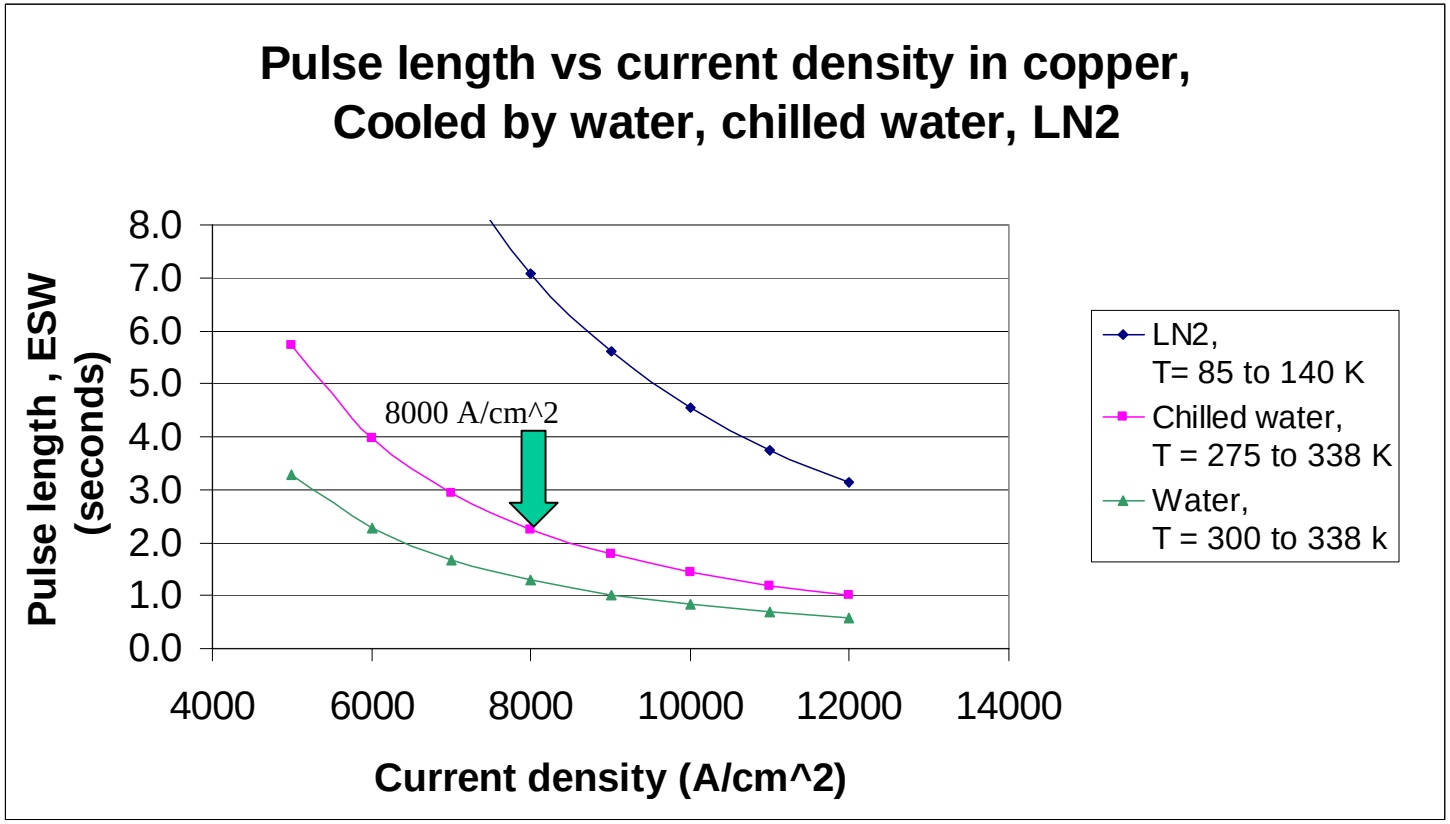
- **Concept evolving, not yet modeled**
- **Coil winding form and assembly structure will be integrated into coil castings**
  - **Sides of "I-Beam" provide winding form**
  - **Reinforcement and connection flanges integrated with "I-Beam"**
  - **Coil-to-coil connections and portions of winding pockets machined with common references, possibly common setup on 5-axis mill**
- **Coil assembly creates external shell structure**

Ramp rate and flat-top considerations

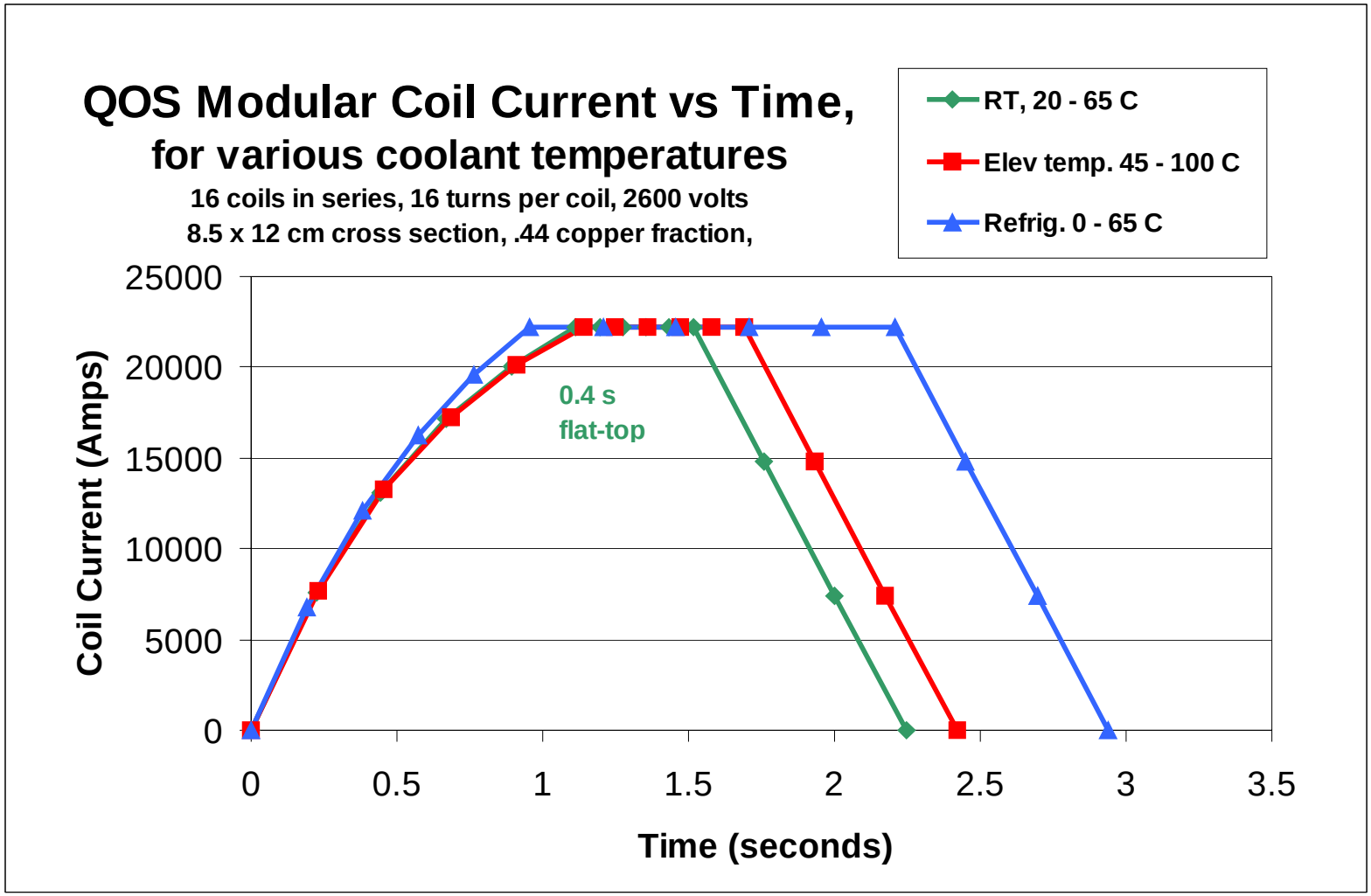
- **Temperature limits**
  - **Max temp depends on epoxy used, RT cure epoxy limited to ~ 65C**
  - **Min temp depends on thermal isolation of coils and compatibility with plasma vacuum**
- **Power supply limitations**
  - **4 solid state modules rated at 650 V, 30 kA pulsed (7.5 kA continuous)**
  - **3 solid state supplies rated at 625 V, 15 kA pulsed (~ 3 kA continuous)**
- **Eddy current decay time in structure**
  - **Error fields may not be completely symmetrical due to casting variations**
  - **"I-Beams" have 10-20 ms time constant**

Modular Coil Operating Temperature

- **Coil operating temperature not decided: can operate from 85 to ~340 K**
- **Room temperature coils may have marginal pulse length**



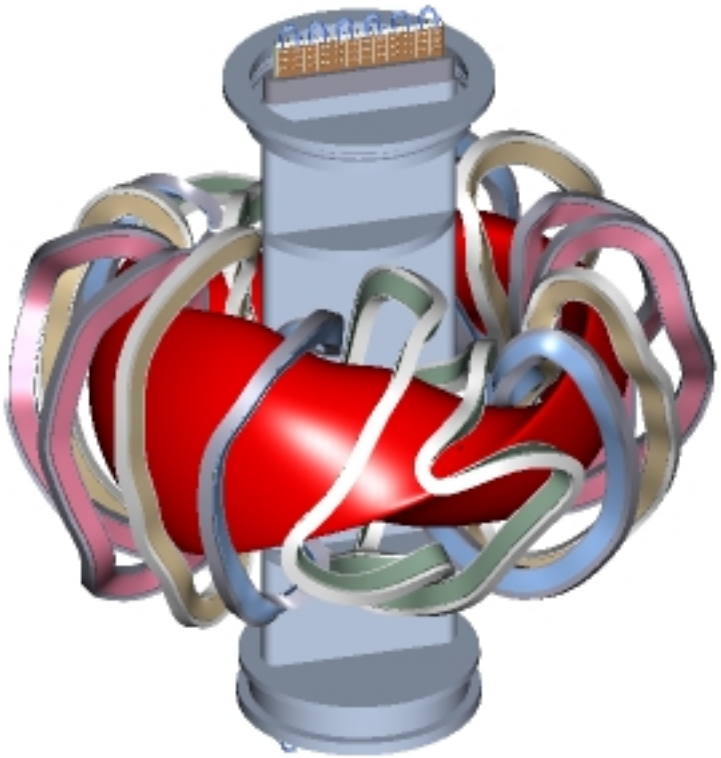
Coil parameters, power supply, cooling temp. determine pulse waveform and flat-top time

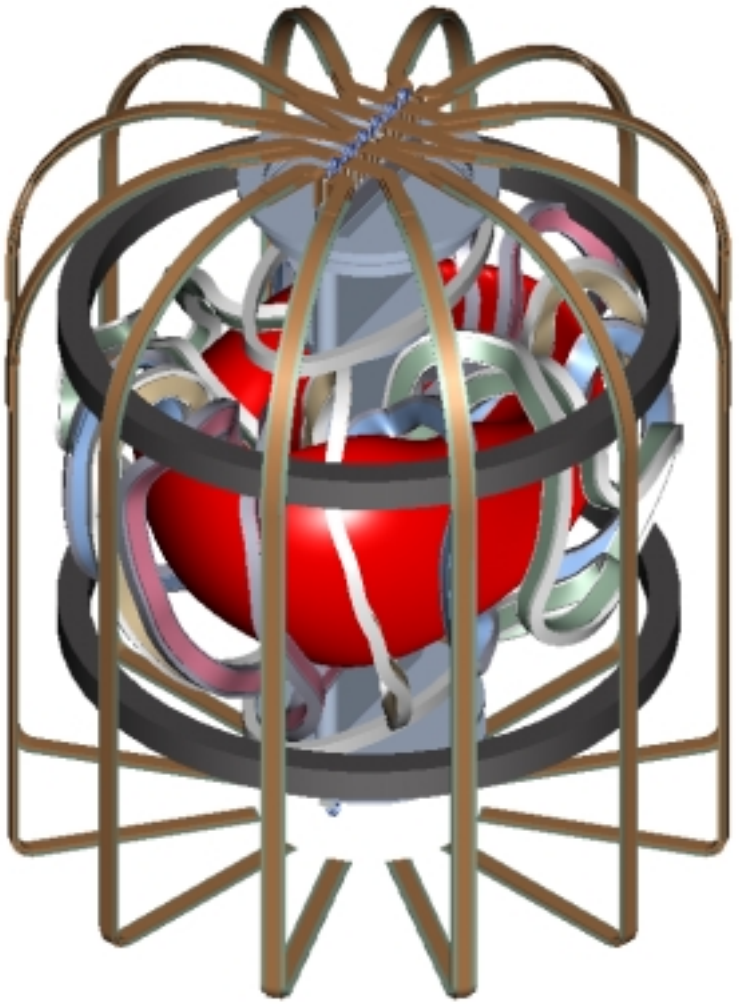


Modular coil issues

- **Geometry**
  - **Twist – What is optimum?**
  - **Increased distance between coils helps to reduce current density**
- **Structure configuration / modeling**
- **Conductor selection**
  - **Cable conductor, to pot or not to pot?**
  - **Bundled solid conductor (HSX, W7AS)**
- **Fabrication questions**
  - **Casting porosity – can we use cast coil forms in vacuum?**
  - **Cover plate welding – can we get it leak tight?**
- **Operating temperature**

TF and VF coils desired for flexibility

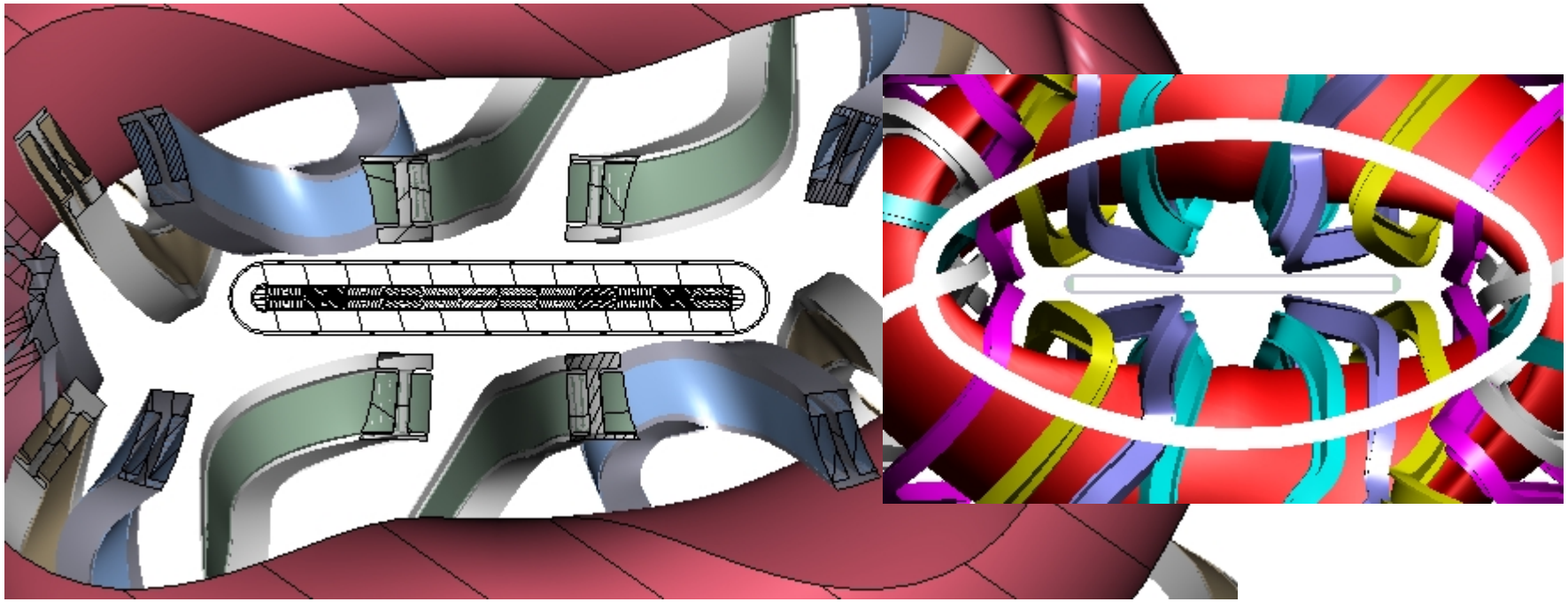




Centerstack assembly contains inner TF legs and solenoid

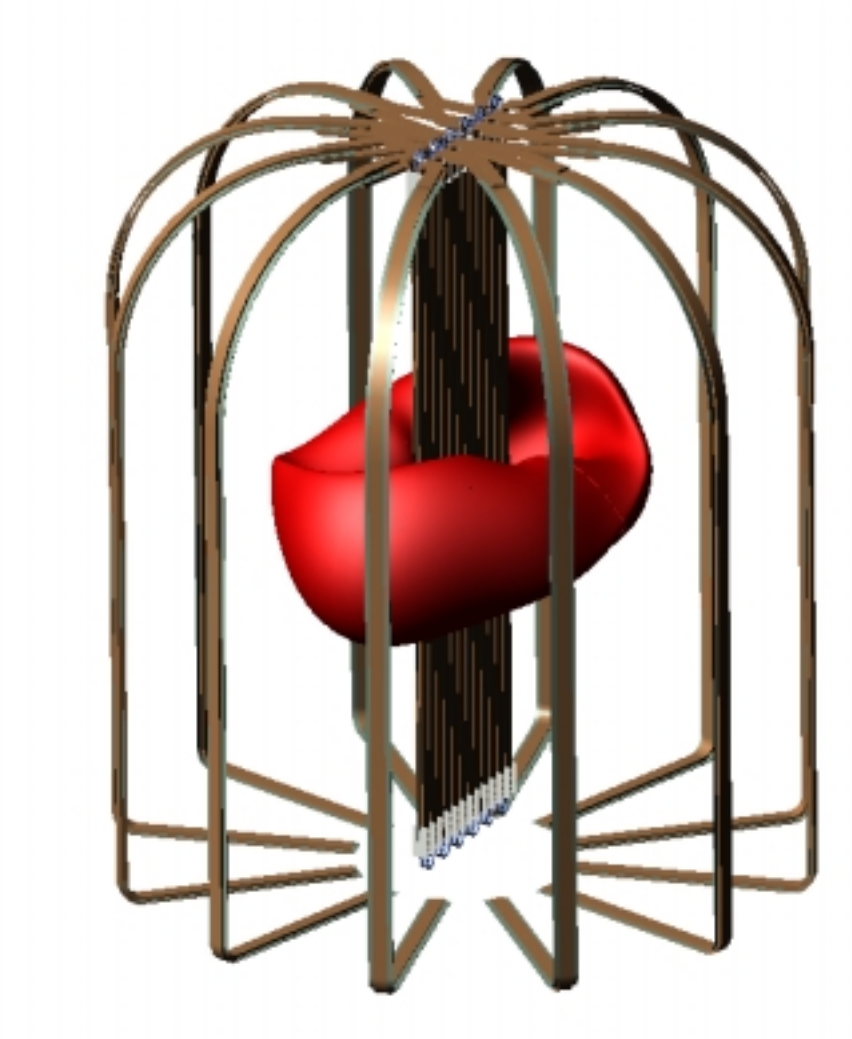
Now there is more room for centerstack

- **Room for TF coils, OH solenoid and casing**
- **Centerstack thickness increased > 50% to 15 cm**

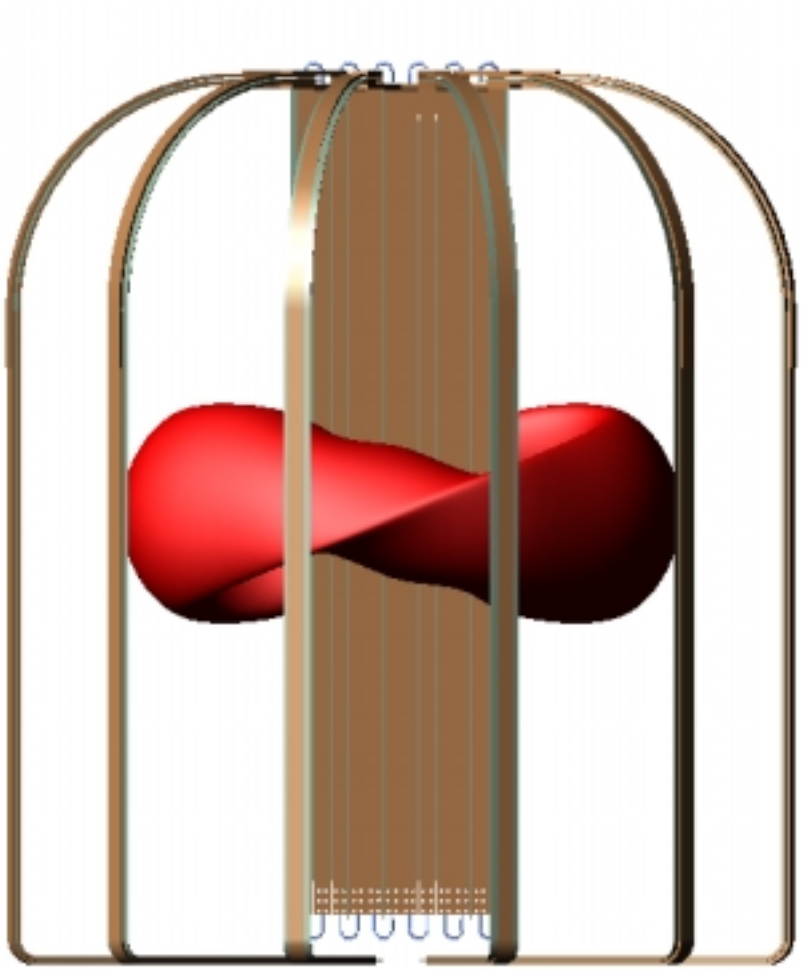


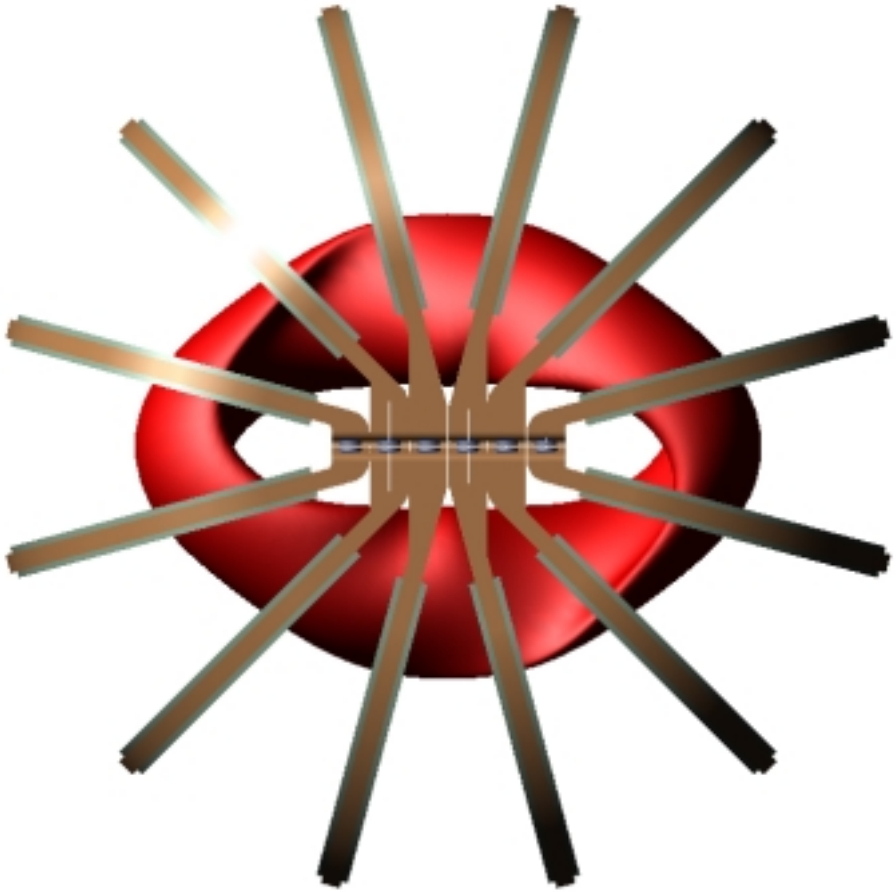
TF flexibility coils

- **48 turns, 1.5 x .75 in.**
- **~2000 A/cm^2**
- **12 return leg bundles**
- **Odd shape makes connections at center stack difficult**



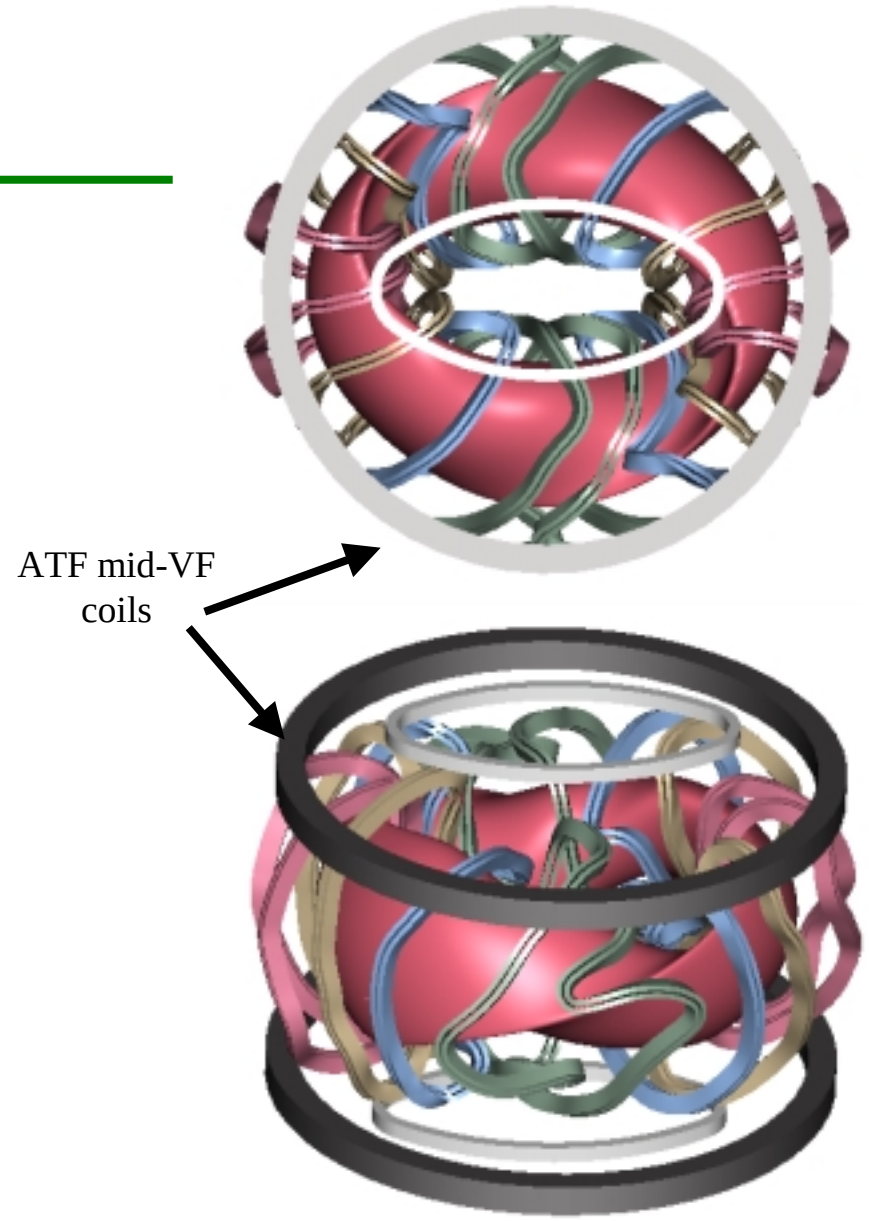
TF coil set





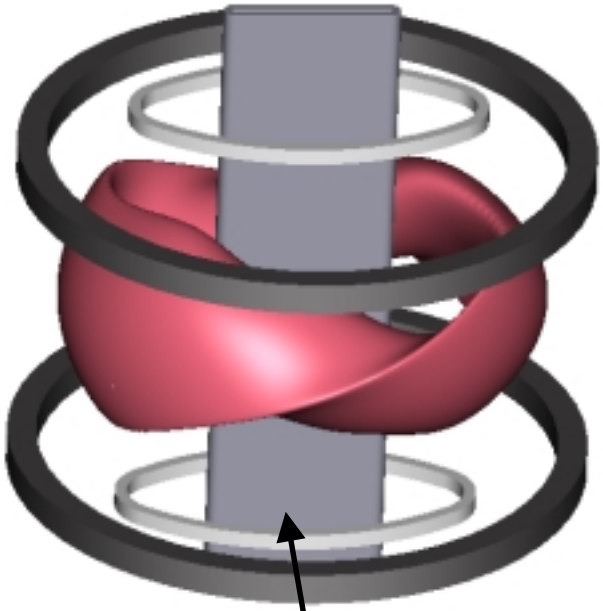
VF / Trim Coils

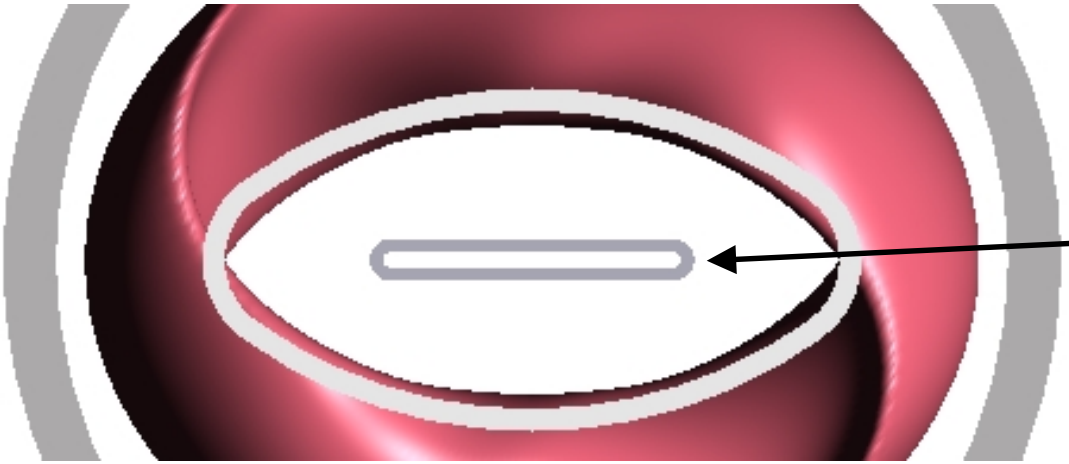
- **VF coil geometry still under study**
- **Planar coils are assumed**
- **Options include use of ATF coils, new coils, combination**
- **Elliptical shape for mid/inner VF coils is being considered**



OH solenoid / return coils

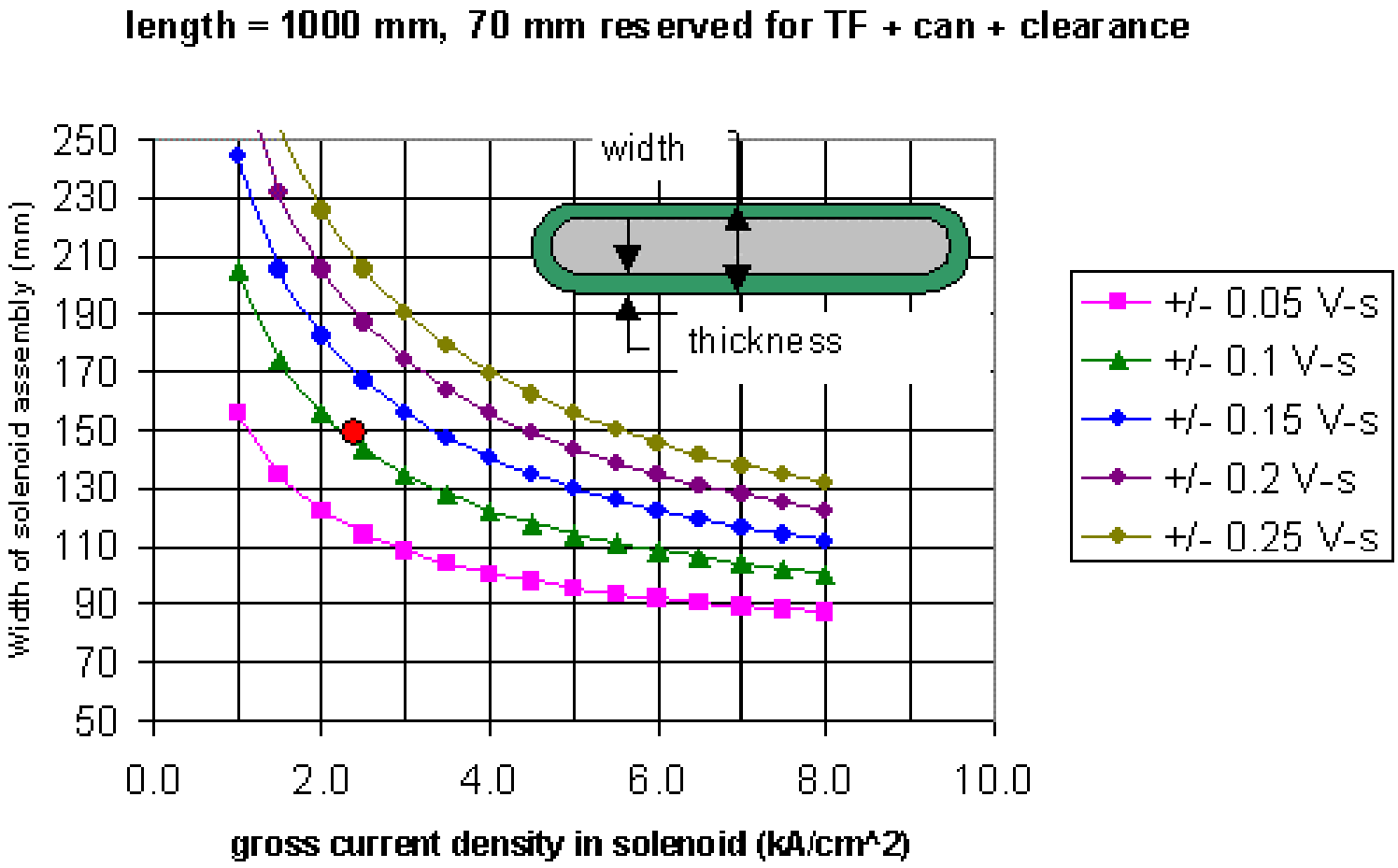
- **Central solenoid is limited to oblong shape by modular coils**
- **Plan to use VF / trim coils for outer return coils**
- **Present configuration limited to +/- 0.1 V-S by power supply**





OH solenoid

What space is needed for solenoid?

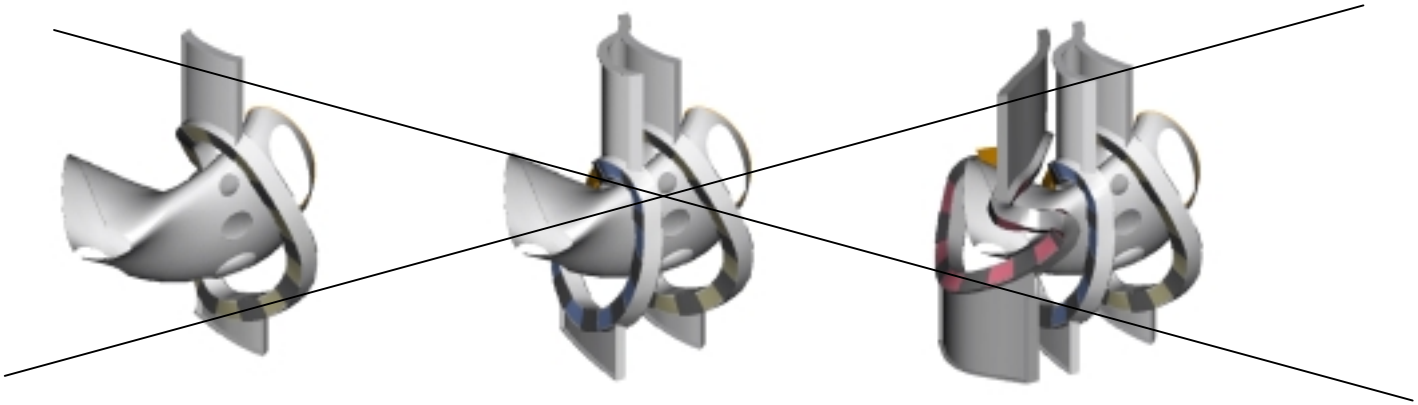


Coils match up with existing power supplies

Coil Set	Power Supply
Modular Coils, 4 groups of 4 coils	Existing ATF helical field power supplies, 4 each 650 V open circuit voltage, 30 kA pulsed current
OH solenoid 1 solenoid	Existing ATF VF coil power supply 625 V, 15kA pulsed
Mid PF coils 1 pair	Existing LCTF power supplies x 2 12 V, 25 kA
Outer PF coils 1 pair	Existing ATF VF coil power supply 625 V. 10 kA pulsed rating
TF coils 1 circuit, 48 total turns	Existing ATF VF coil power supply 625 V. 15 kA pulsed rating

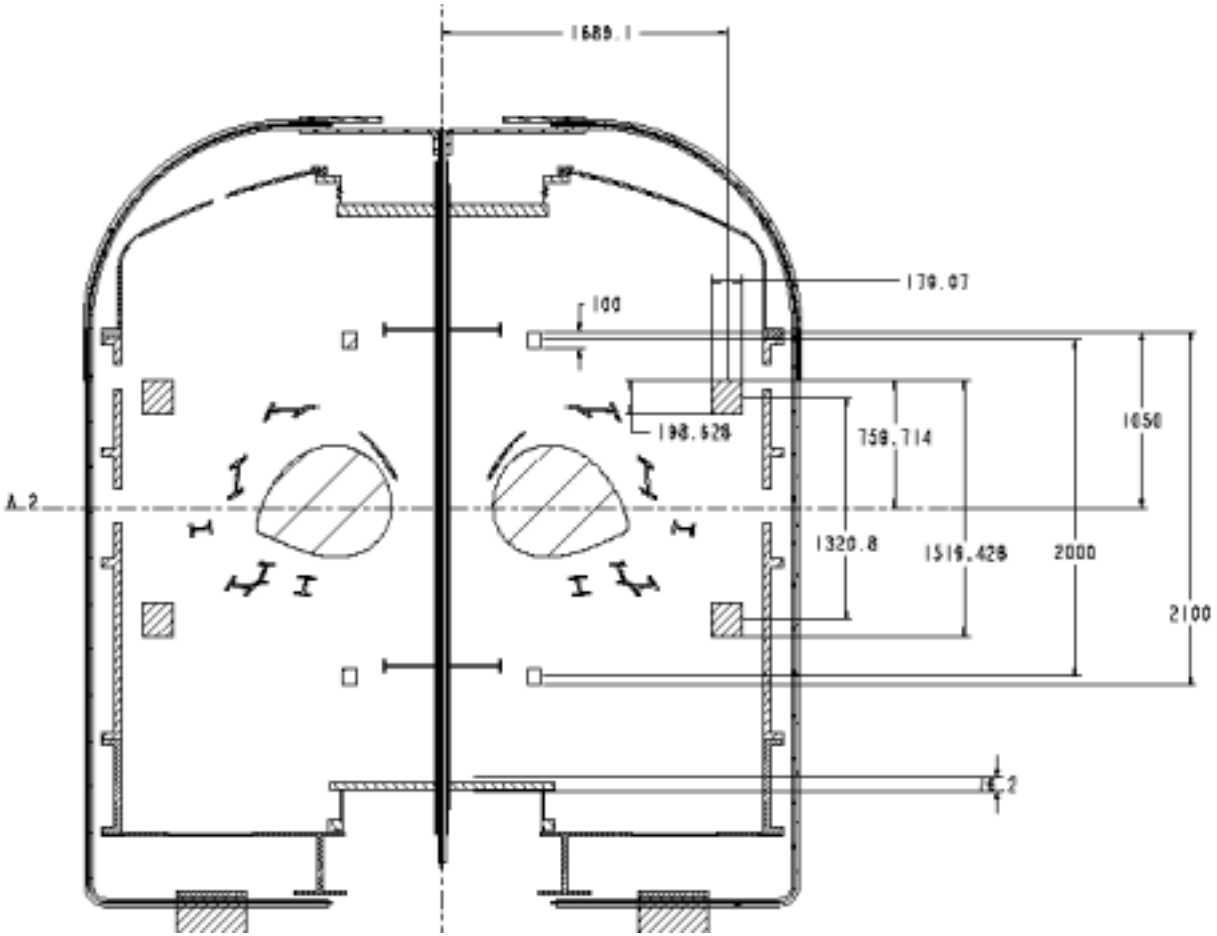
Bell jar favored over internal vacuum vessel

- **Provides possibility of operating coils below room temp.**
- **Eliminates complex vacuum vessel fabrication**
- **Provides more flexibility for structure, since coils do not have to be manipulated over internal vacuum vessel**

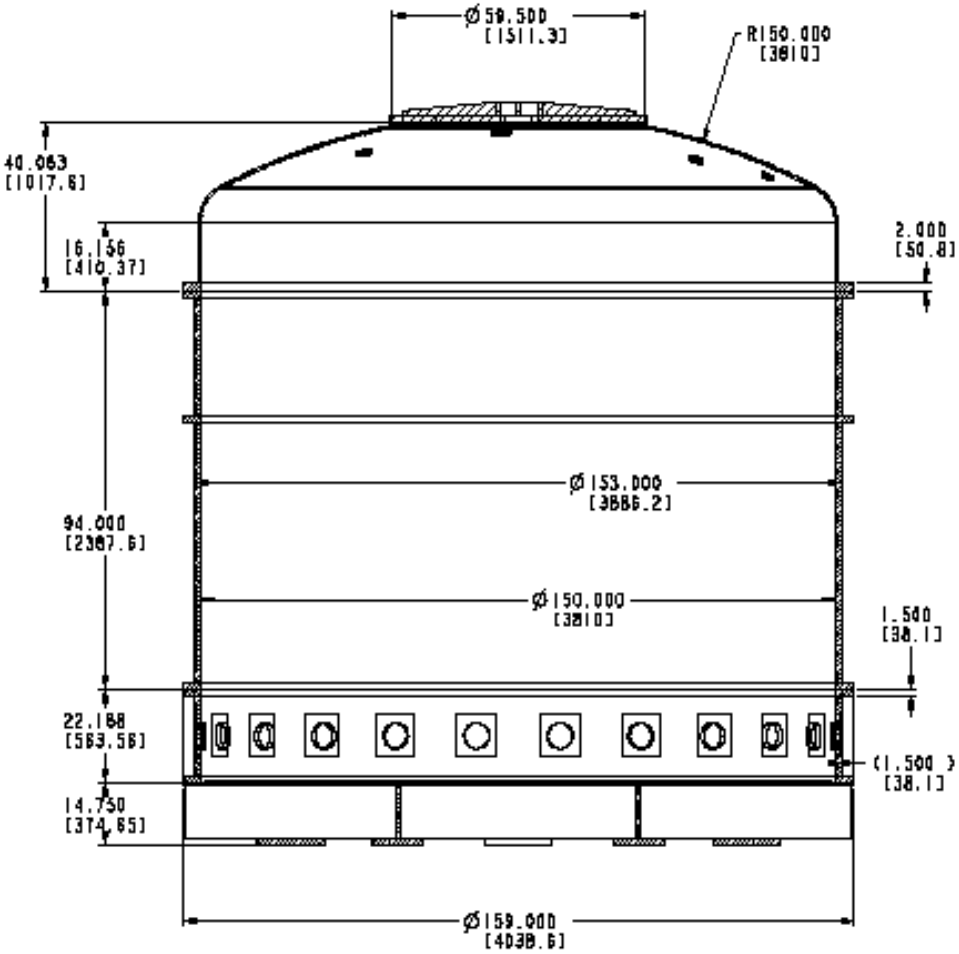


- **Bell jar already exists (old ORMAK tank)**

QOS coils fit well within ORMAK bell jar



ORMAK tank


Ø59.500
[1511.3]
R150.000
[3810]
40.063
[1017.6]
16.156
[410.37]
2.000
[50.8]
Ø153.000
[3886.2]
94.000
[2387.6]
Ø150.000
[3810]
1.500
[38.1]
22.188
[563.56]
(1.500)
[38.1]
14.750
[374.65]
Ø159.000
[4038.6]

Feasibility of re-using ORMAK tank

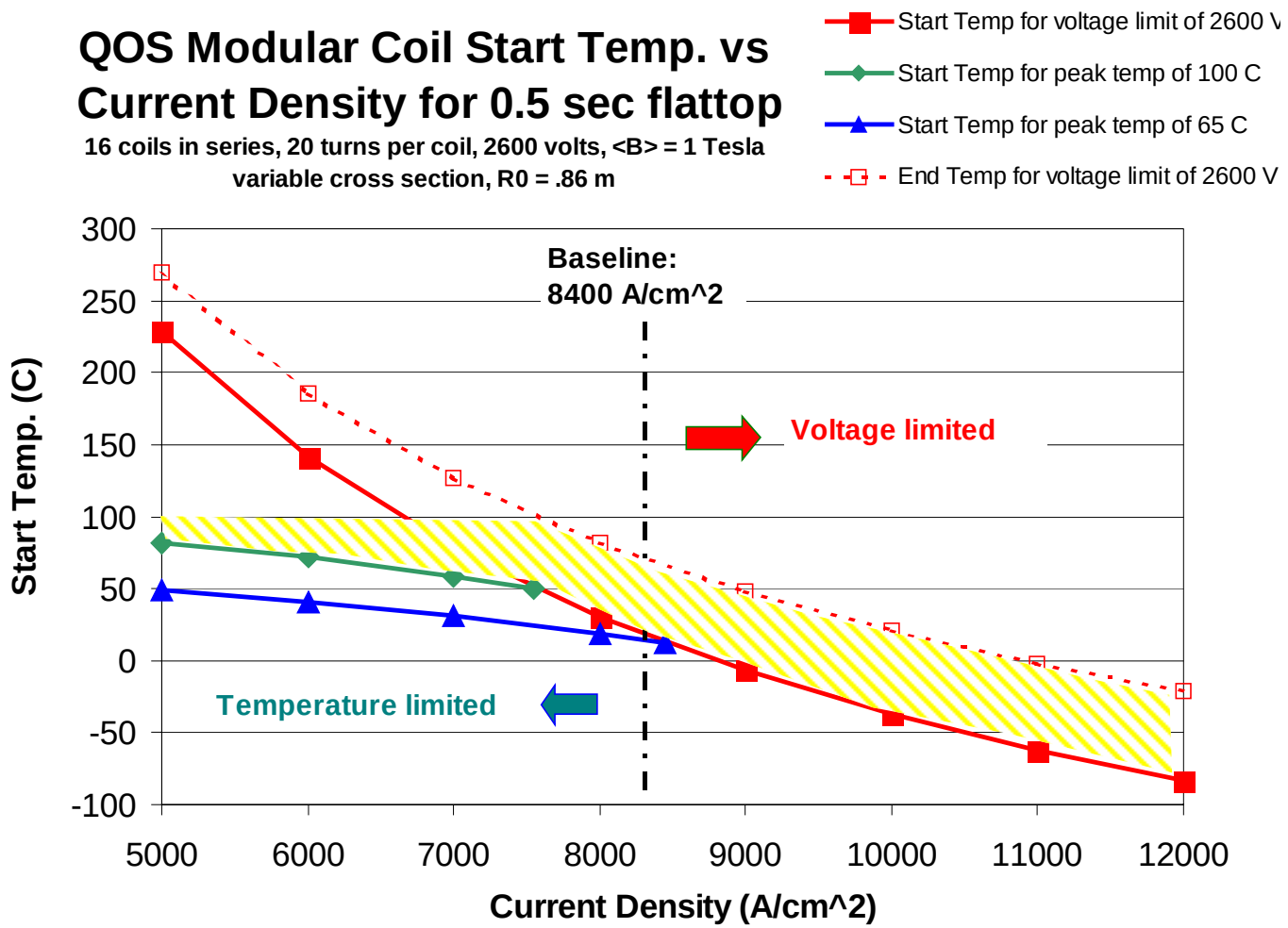
Requirements:

- **Clean:** **“bake-able” to 150 C (need double seals)**
  Minimum oxide buildup on inside of tank
- **No leaks:** **Integrated leak < 1e-7? (tbd) torr-l/s**
  Base pressure < 1e-9? (tbd) torr for all but H
  Base pressure < 1e-7 for H
- **Can be re-sealed “easily” after major opening**

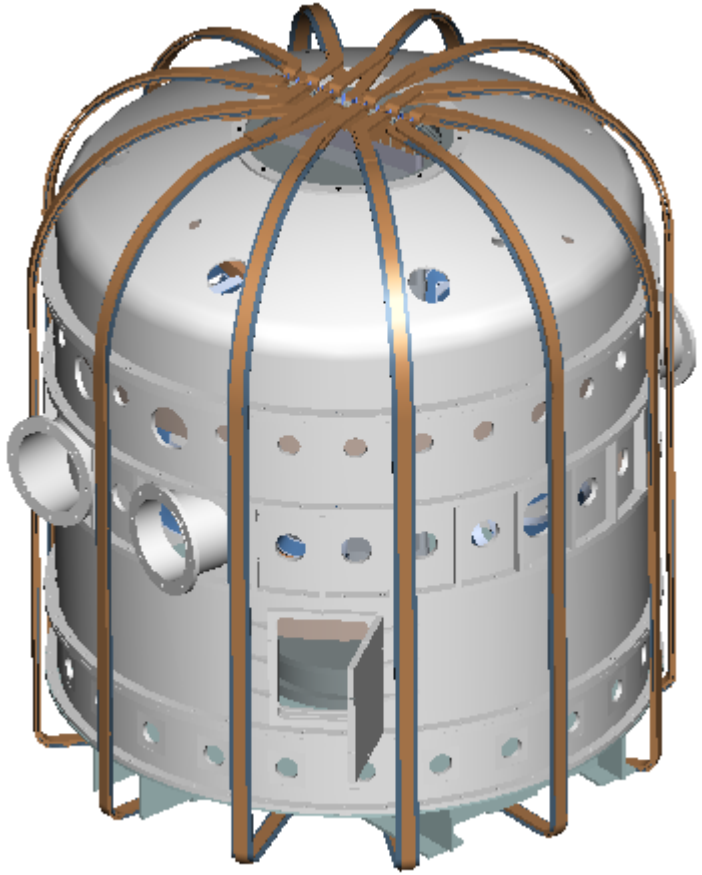
Status

- **Tank drawings retrieved**
- **Helico-flex contacted about seals**
- **Walker Stainless contacted about cost of new tank, new spool pieces**
- **Used tank broker contacted**

Coil oper. temp. depends on current density

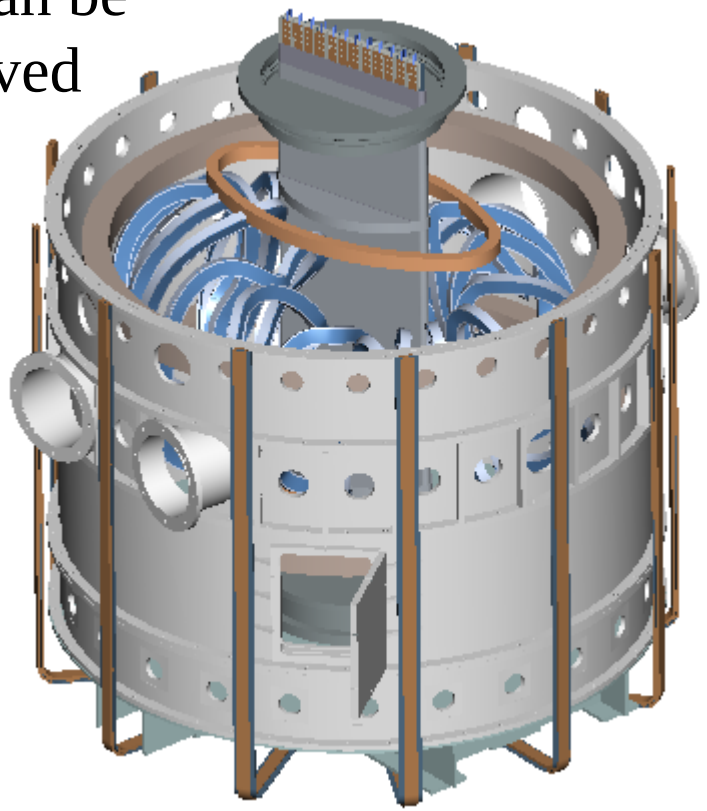


Access for maintenance

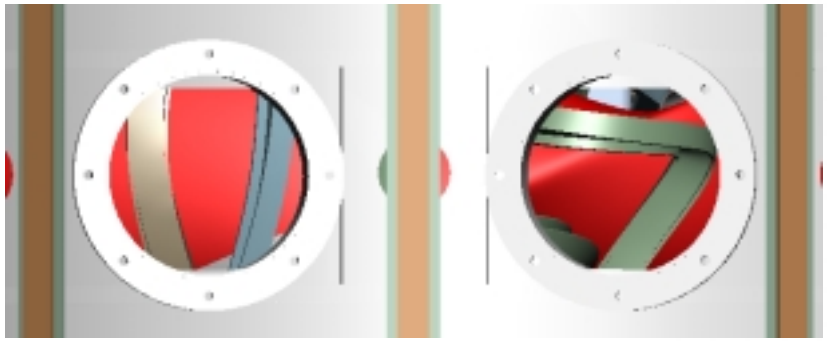


Large door

Lid can be removed



QOS Access for diagnostics, heating

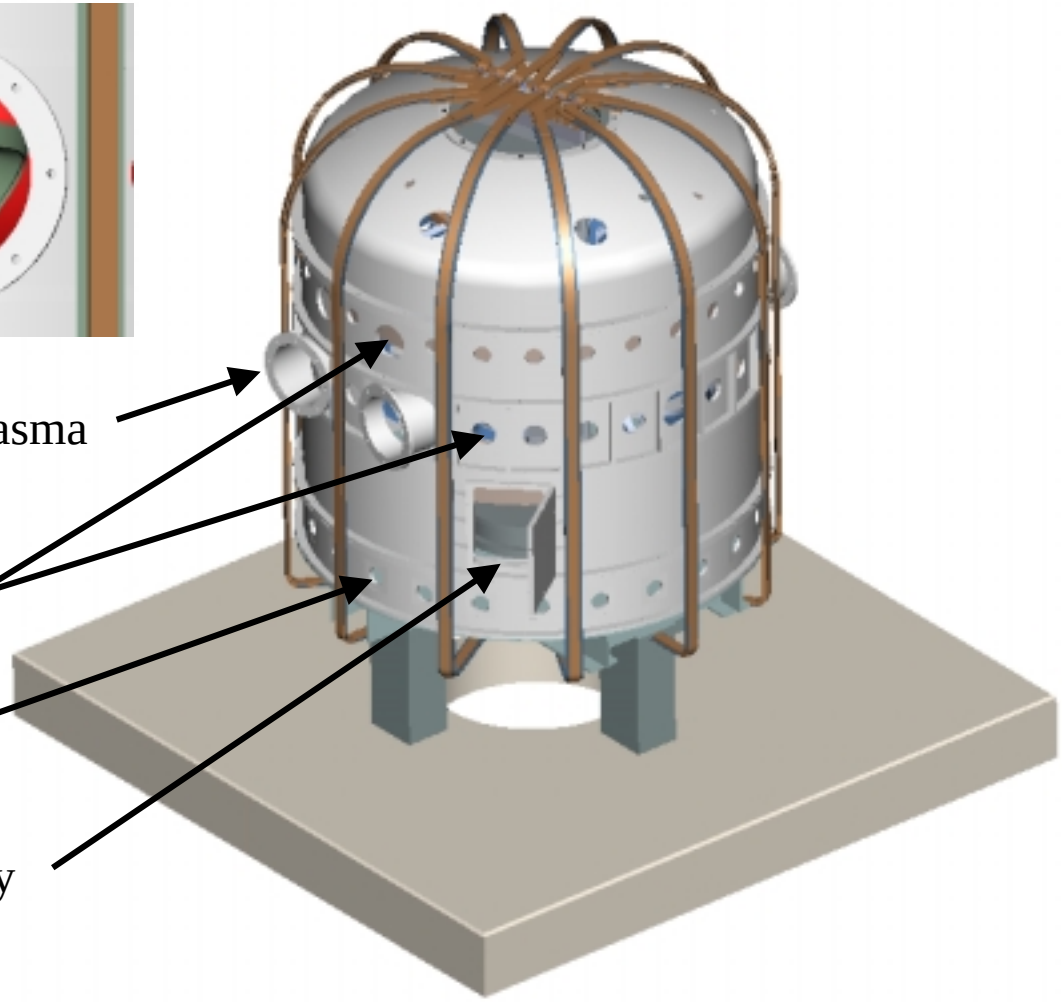


4 x 22” dia. ports, red (above) is plasma

18 x 8”, 6 x 12” , 23 x 6” ports

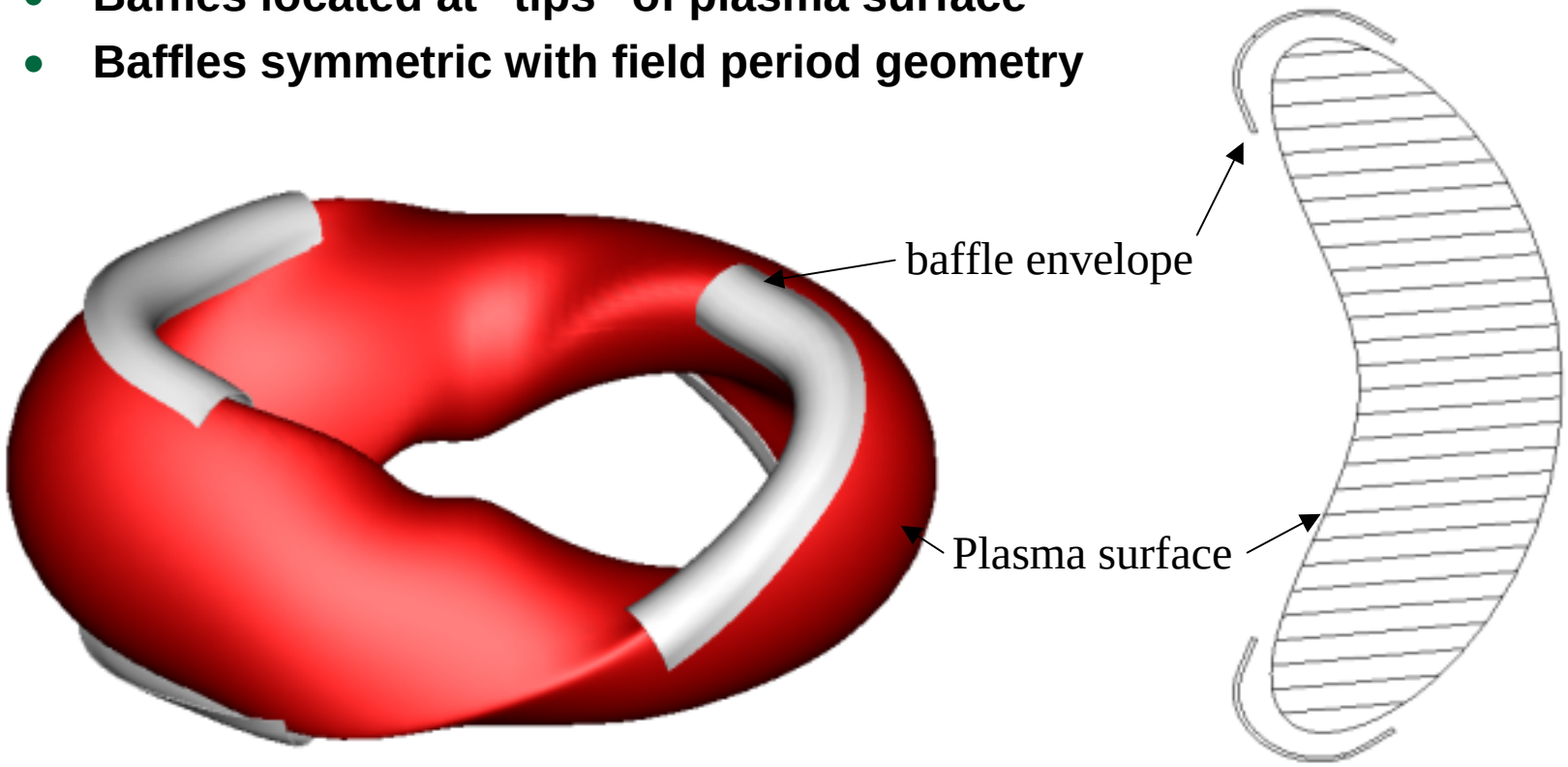
24 x 6” ports for coil leads,
coolant feeds, etc.

Manway

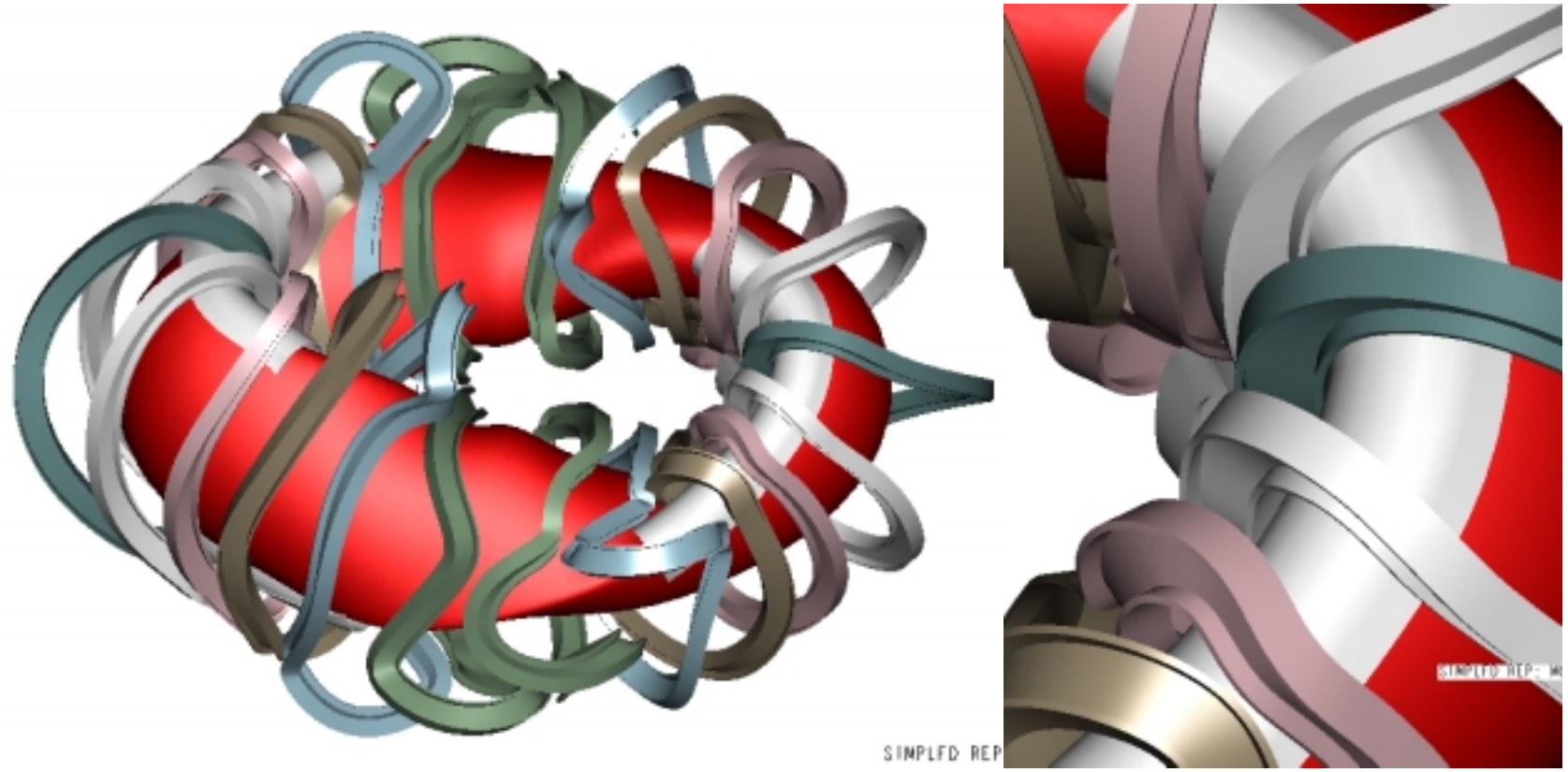


Possible baffle geometry

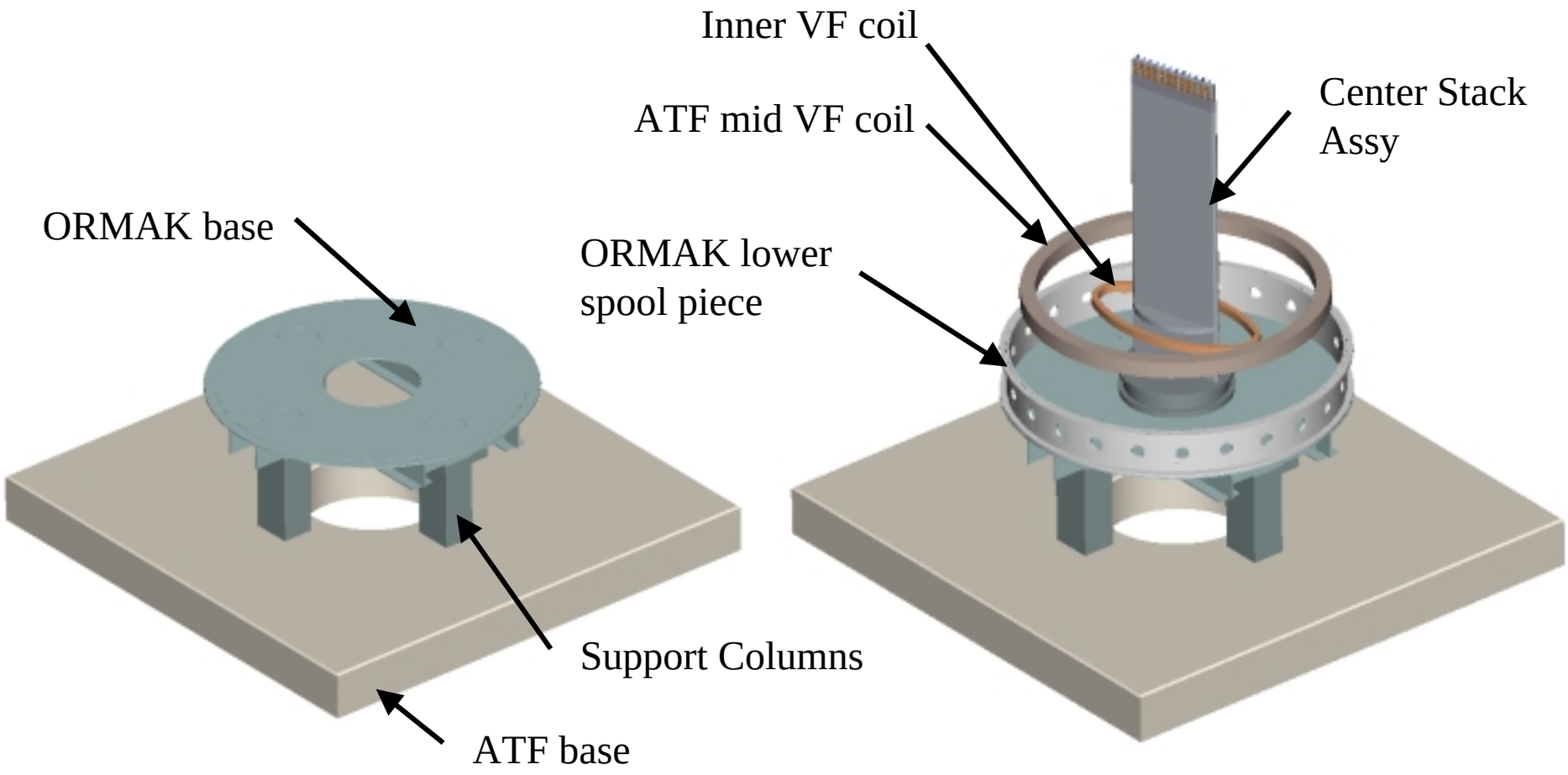
- **Baffles located at “tips” of plasma surface**
- **Baffles symmetric with field period geometry**



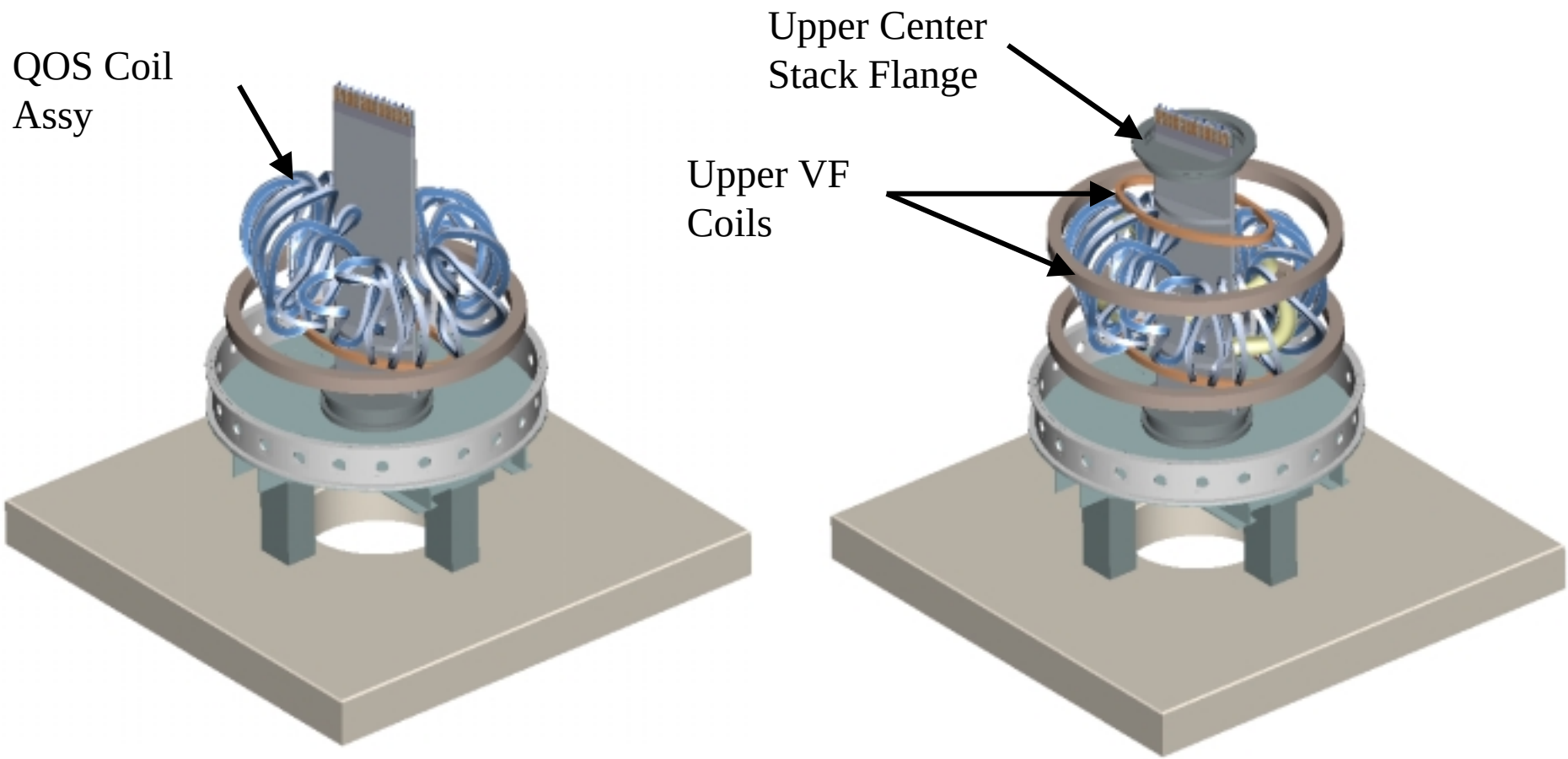
Baffles fit within modular coil structure



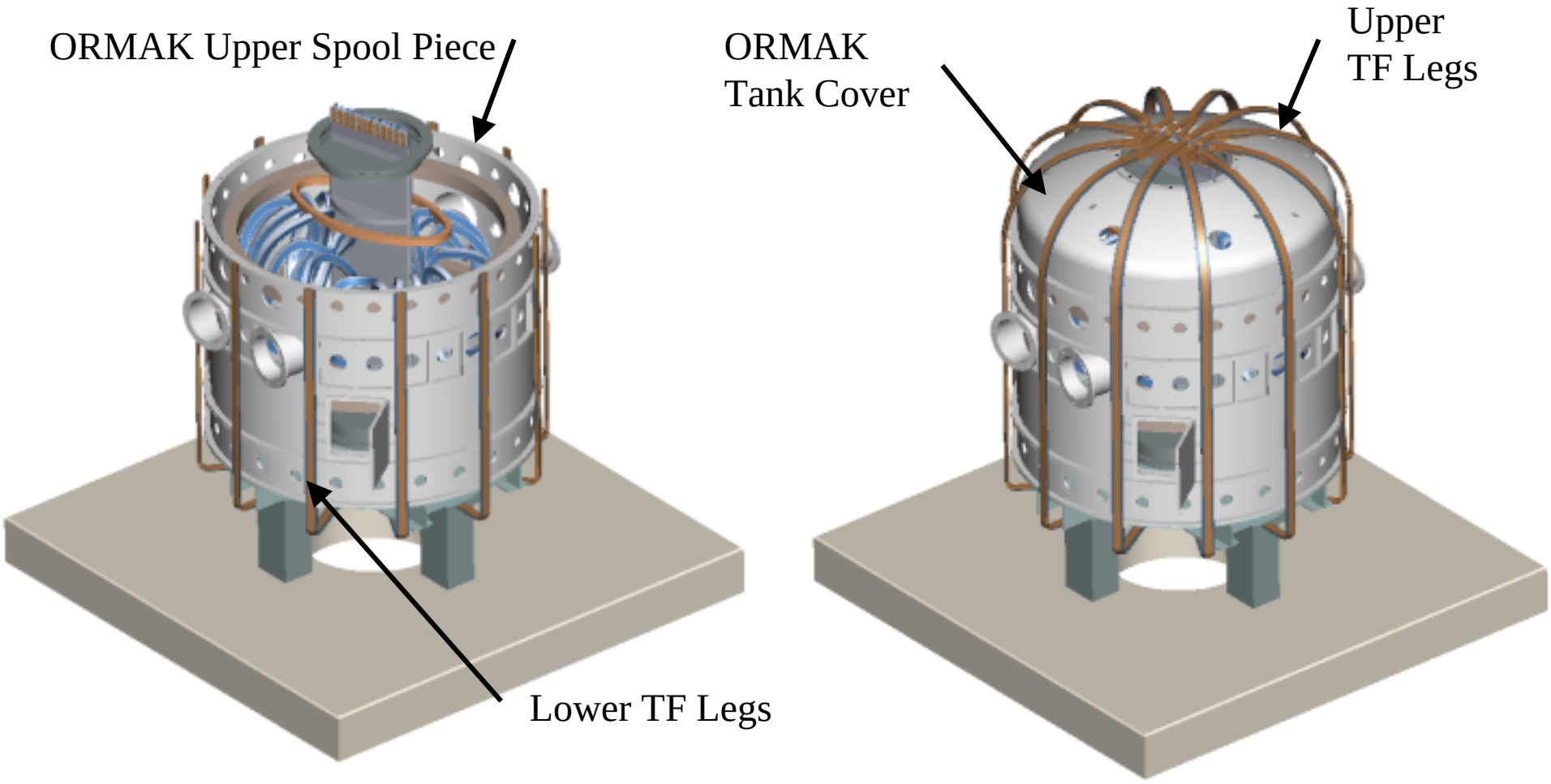
QOS Assembly sequence



QOS Assembly sequence (cont'd)



QOS Assembly sequence (cont'd)



Status of Engineering Activities
Issues addressed to some extent

- **Modular coils: Geometry, fields/forces/stresses (3 period), cooling/pulse length, structural support, power supply matching, fabrication ideas**
- **PF coils: Geometry, re-use of ATF coils**
- **Vacuum system, PFCs: ORMAK tank condition, seal re-work, baffle geometry**
- **Ancillary equipment : Use of existing equipment, power supplies**
- **Cost and schedule: ROM tabulation, schedule logic**

Status of Engineering Activities
Issues not yet addressed

- **Modular coils: Fields, forces, stresses (2 field period), fabrication tradeoffs, vacuum compatibility of castings, location accuracy, lead layout, optimized structure, fault conditions**
- **PF coils: Stresses, structural supports, fault conditions**
- **Vacuum system, PFCs : cost of tank rework, divertor options**
- **Ancillary equipment: diagnostic layout, magnetic loops**
- **Cost and schedule: vendor quotations, durations**

Summary and Conclusion

- **We have begun to investigate a new baseline design configuration**
  - **16 Modular coils instead of 22**
  - **Bell jar vacuum system with good port access**
  - **Maximum re-use of existing components and facilities**
- **Baseline design developed around A2.5 coils appears workable**
  - **~0.5 second flat-top at 1 Tesla**
  - **Structure needs development**
- **Coil set is still evolving**
  - **Coil geometry will evolve as engineering constraints are identified**
  - **Coil groups working to optimize coils for physics and engineering constraints**