# NCSX
# WBS 1.3 - Helical Coils
# In-PBX-Option Update

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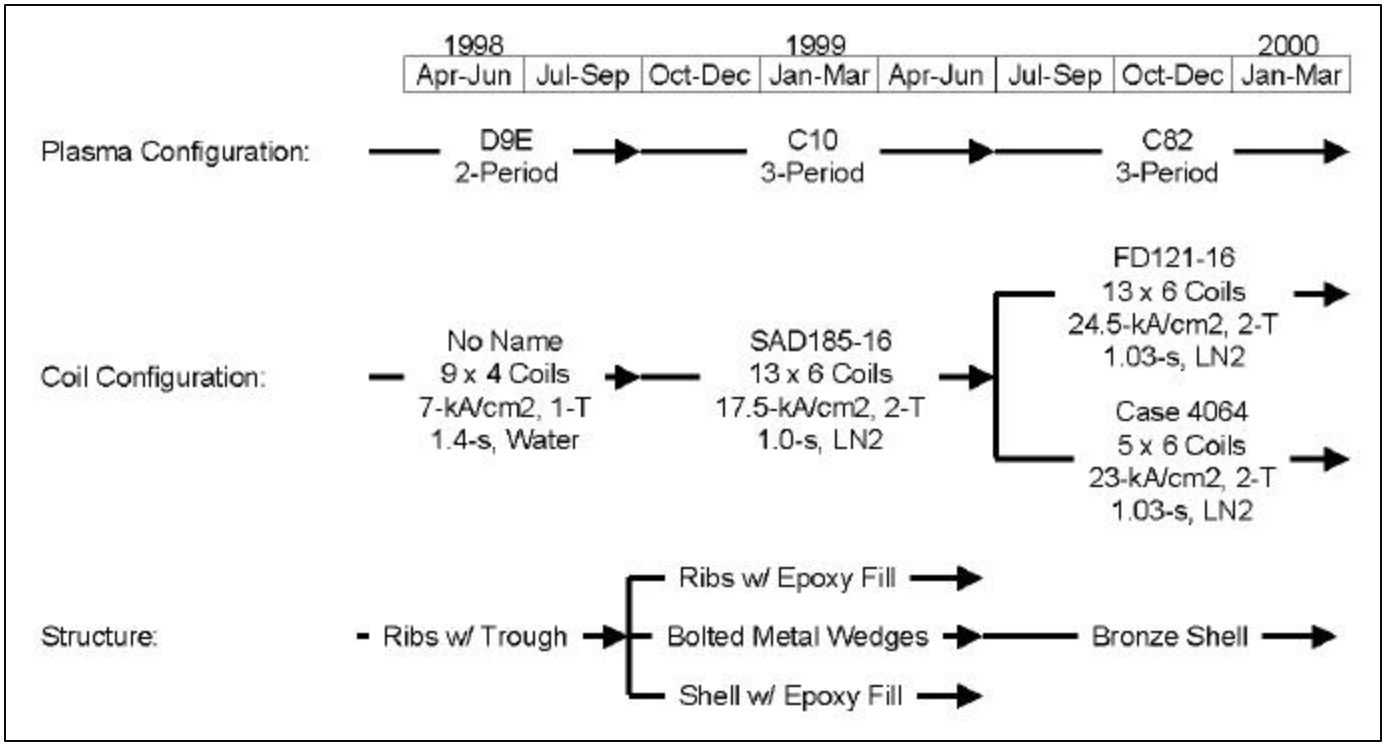
# Status of Helical Coils “In-PBX-Option”

- Pro/ENGINEER models have been updated to C82/FD121-16
- Radial build, access have been examined
- EM analysis has been updated to C82/4064
- Cost estimate has been updated (roughly) for both coil sets
- Draft System Design Description (SDD) is available



# Helical Coil Sets for C82 Plasma Configuration

Table 2.2 – Helical Coil Design Parameters and Requirements

| Parameter | Value | Value |
|---|---|---|
| Configuration | FD121-16 | Case 4064 |
| No. Coils / Half Period | 13 | 5 |
| Surface Offset | 18 cm | 18 cm |
| Nominal Dimensions | 13 x 70 mm | (16-22) x 70 mm |
| Current at 2-T | 91 kA | 115-184 kA |
| No. Turns / Coil | 10 | 10 |
| Coil Length | 0.4-19 m | 1.8-16 m |
| Total Length | 402 m | 214 m |
| Winding Accuracy | TP 1-mm dia | TP 1-mm dia |
| Field Error at Plasma | 1.E-4 T | 1.E-4 T |

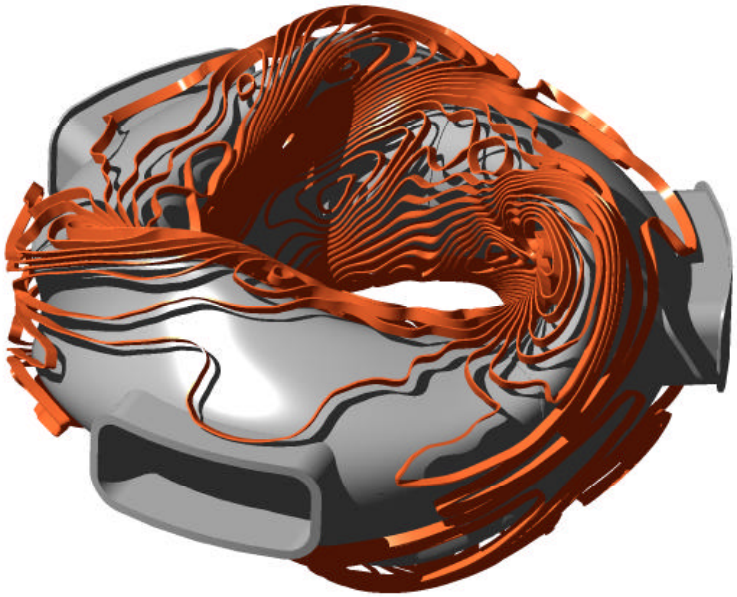


Fig. 2.1 – Helical Coil Set FD121-16

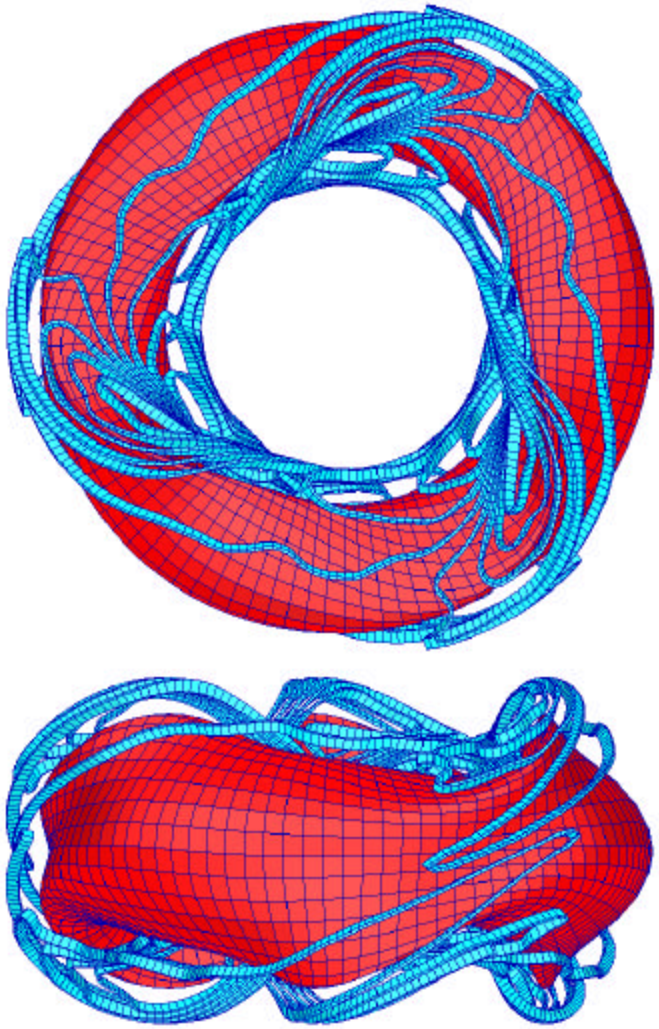
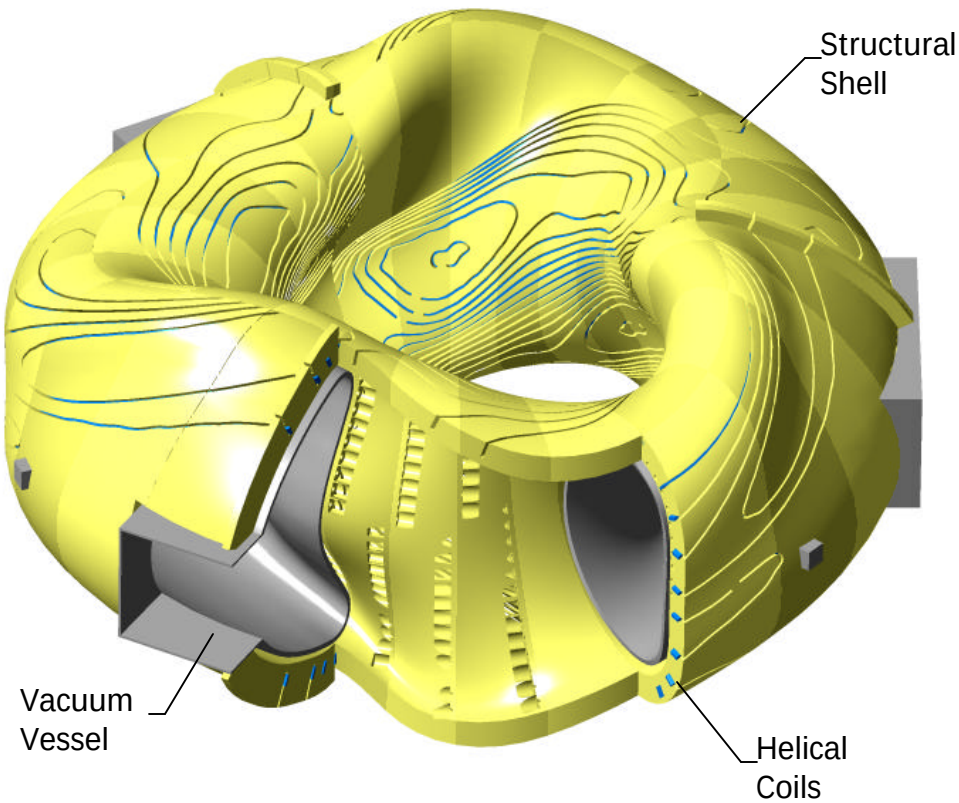


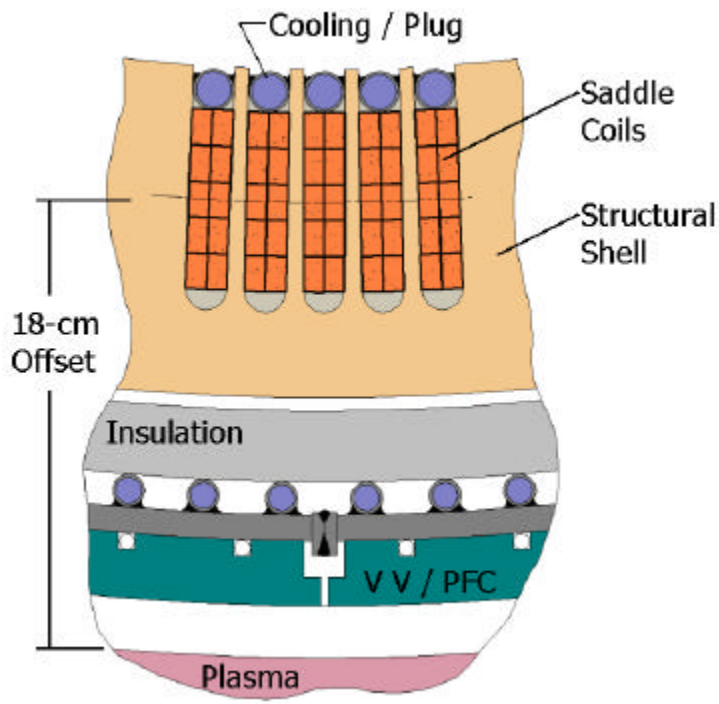
Fig. 2.2 - Helical Coils for Case 4064

# Structural Shell Configuration is Unchanged

- Nickel-Al-Bronze structure, 48 segments, ~0.5-in wide x 3.5-in deep slots



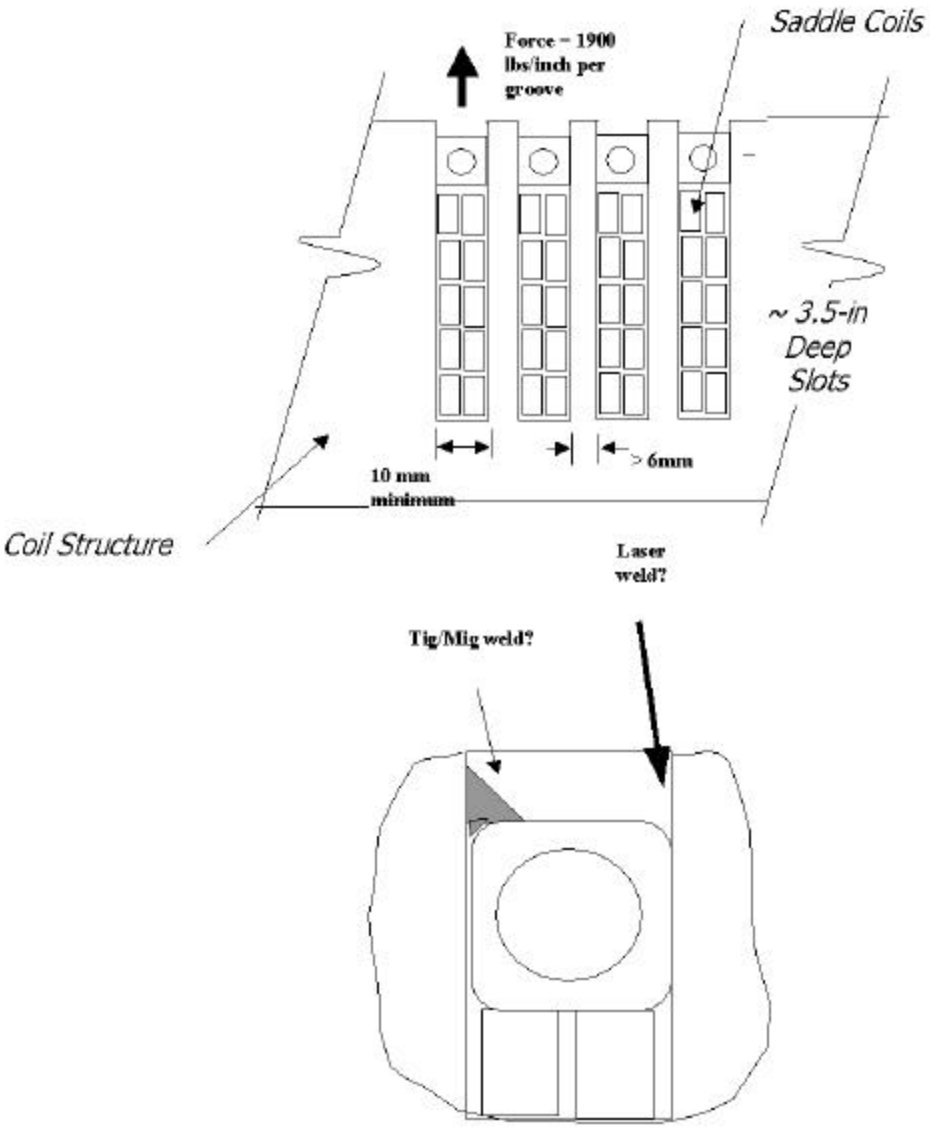

Core Assembly

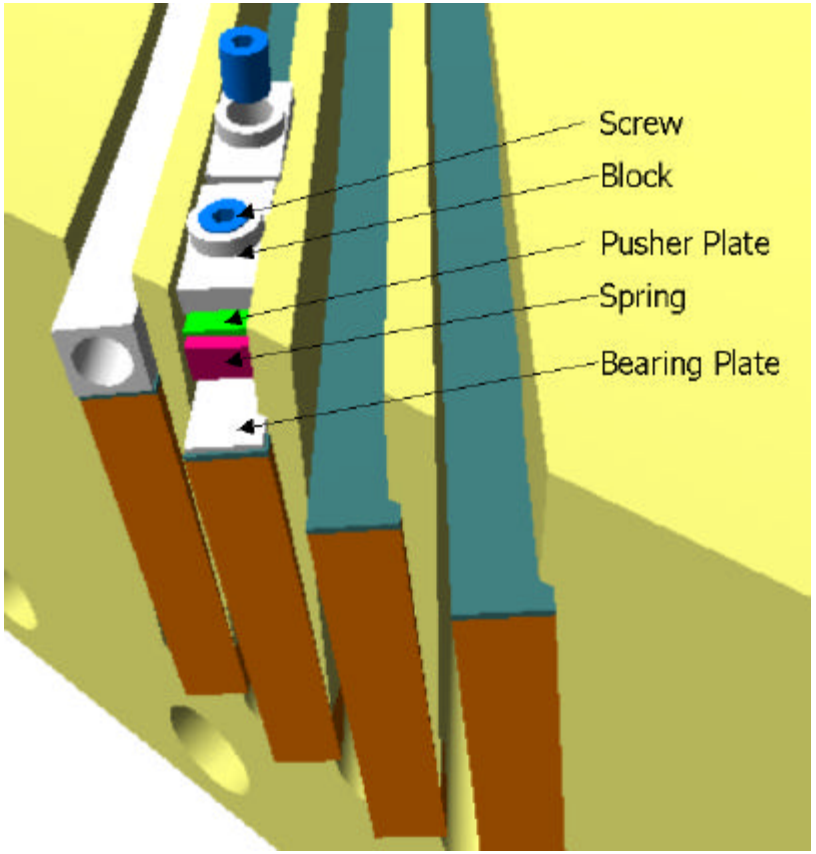



Typical Coil Cross-Section

# Two Options for Coil Slot Closure

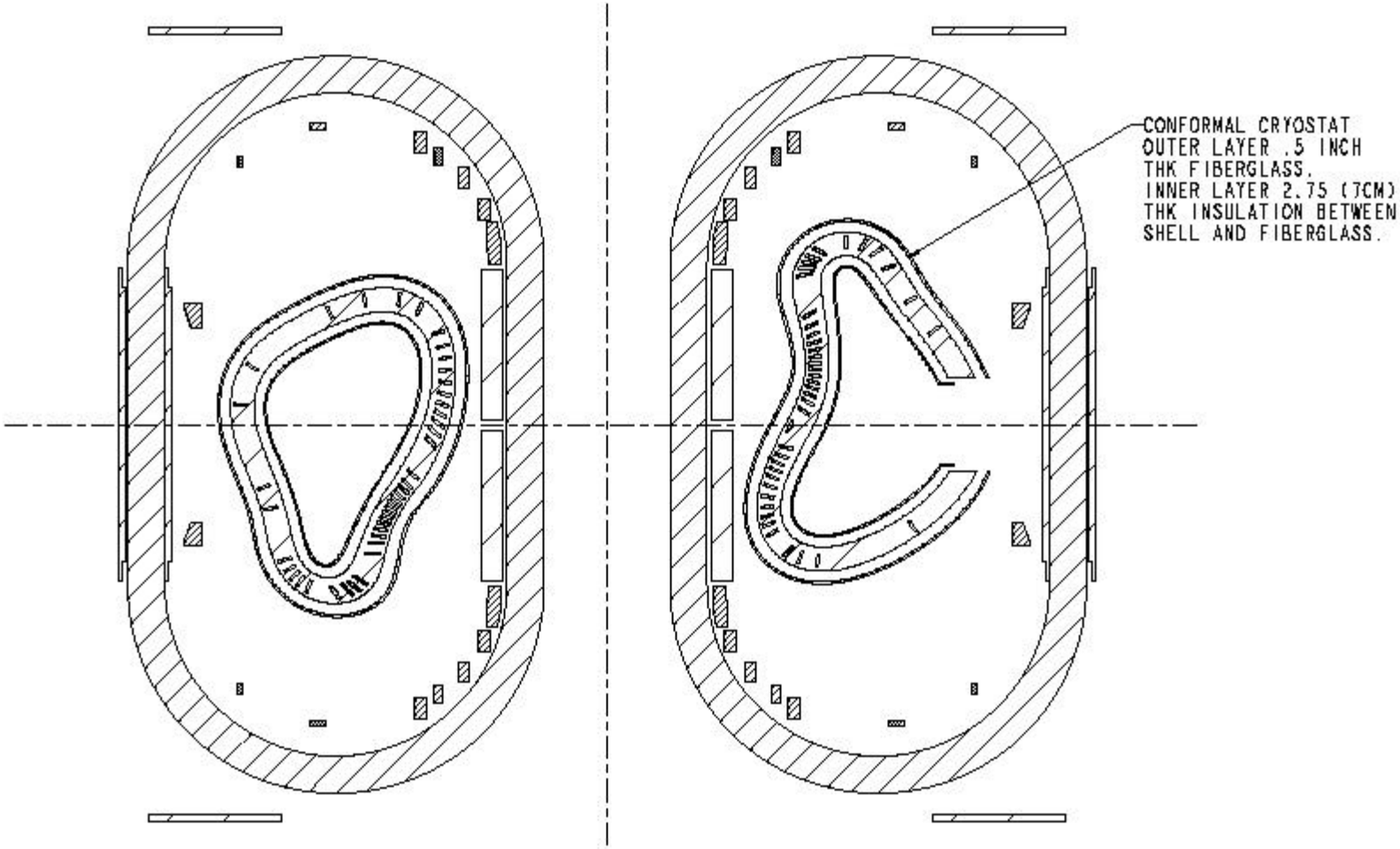
- Pre-formed, welded tubes or welded blocks with pre-load mechanism



# Conformal Cryostat is Better for Access

- Inner layer of 7-cm thick polyimide foam insulation, outer layer of 1.2-cm thick fiberglass, segmented for assembly
- Alternate concept would replace fiberglass with spray-on polyurethane



# Radial Build, Access Have Been Examined

## Radial Build Constraints:

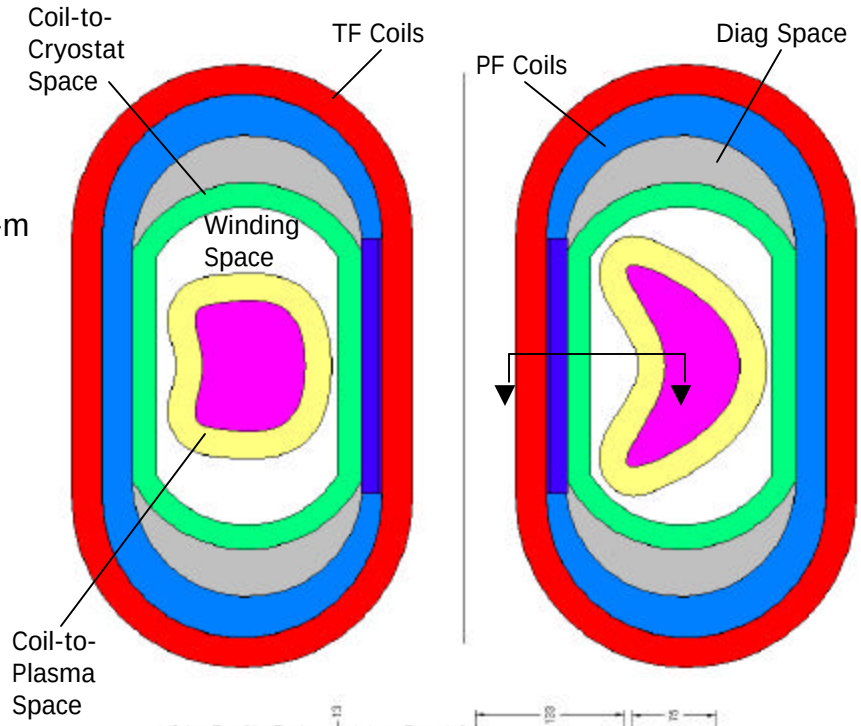
- Toroidal Field coils are located at r<0.55-m, r>2.43-m
- Central Solenoid is located at r<0.69-m
- PF coils and structure are located at r<0.69-m, r>2.23-m
- Diagnostics access space is located at z>1.2-m

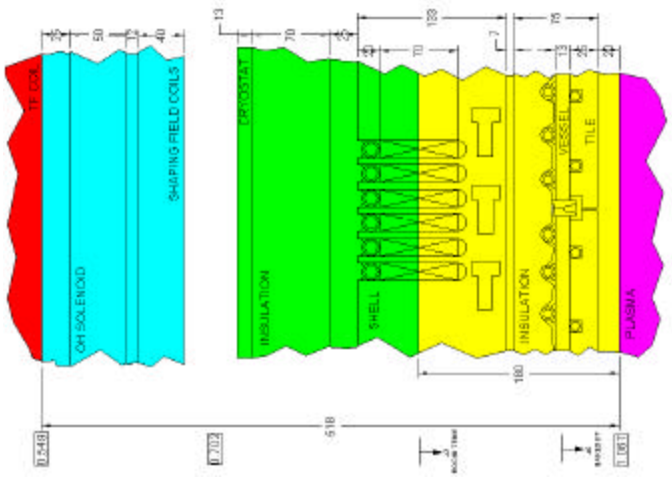
## Evaluation Method:

- Decide minimum space between plasma and winding center (18-cm), winding center and outside surface of cryostat (16-cm) based on machine design
- Split shell at winding center, move inner/outer parts to limiting boundary (plasma, PF structure, diag space)
- Space between shell parts is possible winding center location

## Conclusion:

- Winding surface can vary from
  18-21.5 cm outboard,
  18-21.8 cm inboard, and
  18-53 cm top / bottom



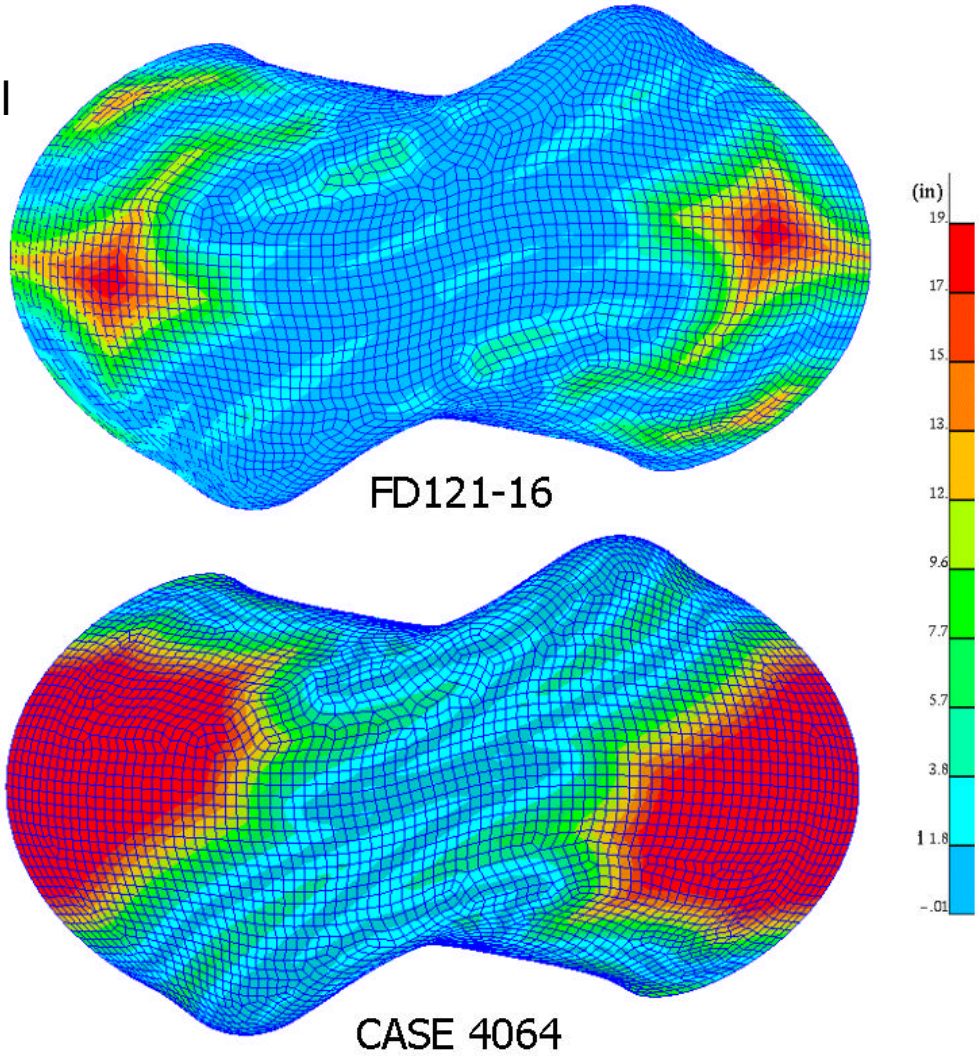




Section Through Core

# Radial Build, Access (Cont'd)

- Access potential compared by plotting distance to nearest coil over surface of structural shell

- Case 4064 can accommodate up to 35-in radius opening at outboard midplane, compared to 19-in for FD121-16



# EM Field/Force Calculation Has Been Updated

- Previous analysis based on C10/SAD185-16 (78 coils, 84-kA)
- Calculation includes TF at 2-T, two EF coil sets, and plasma

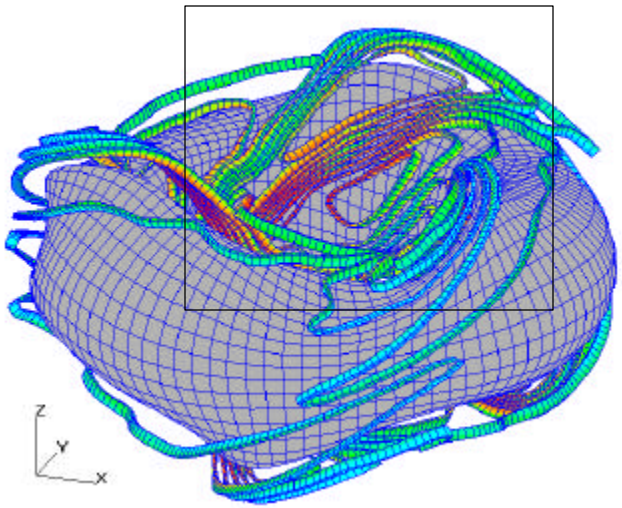
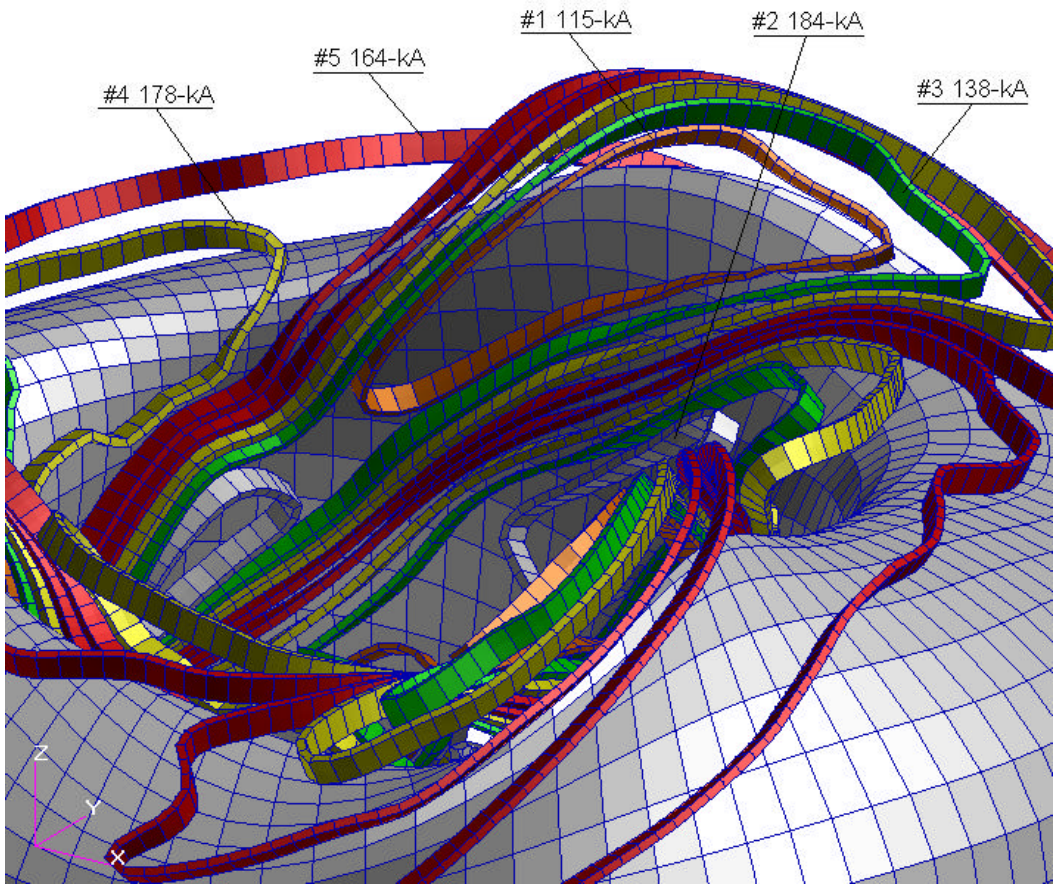


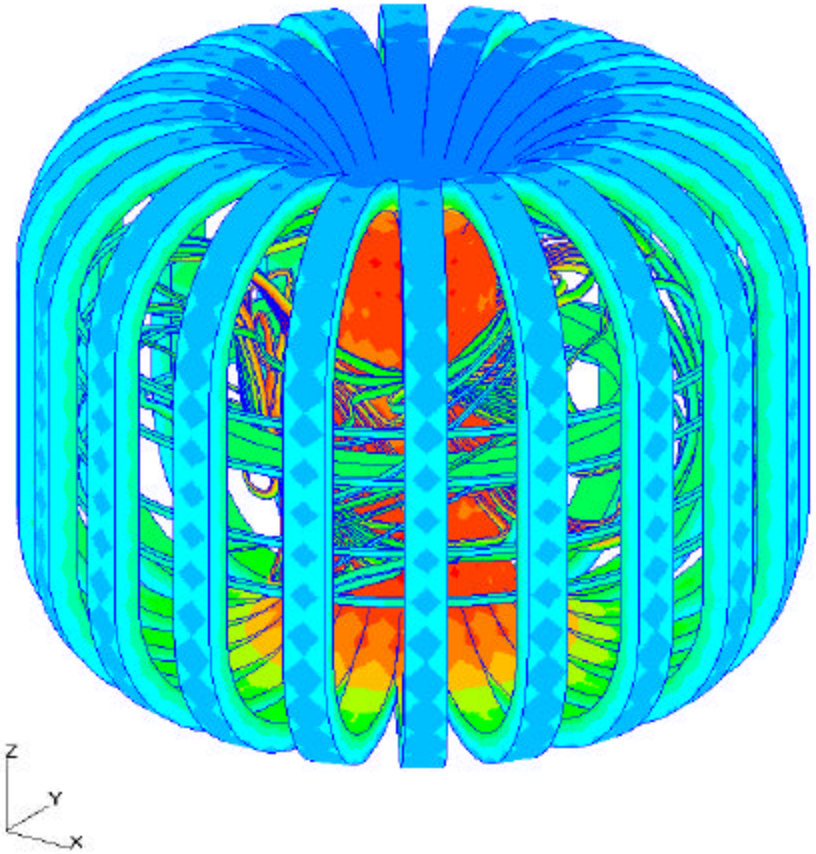

Table 4.1 – Coil Currents for Case 4064, 2-T

| Coil # | X-sec (mm) | Length (m) | Current (kA) | J in Cu (kA/cm2) |
|---|---|---|---|---|
| 1 | 16 x 70 | 3.0 | 115 | 22.9 |
| 2 | 22 x 70 | 1.8 | 184 | 23.6 |
| 3 | 18 x 70 | 6.5 | 138 | 23.2 |
| 4 | 22 x 70 | 8.6 | 178 | 22.9 |
| 5 | 20 x 70 | 16.0 | 164 | 23.9 |

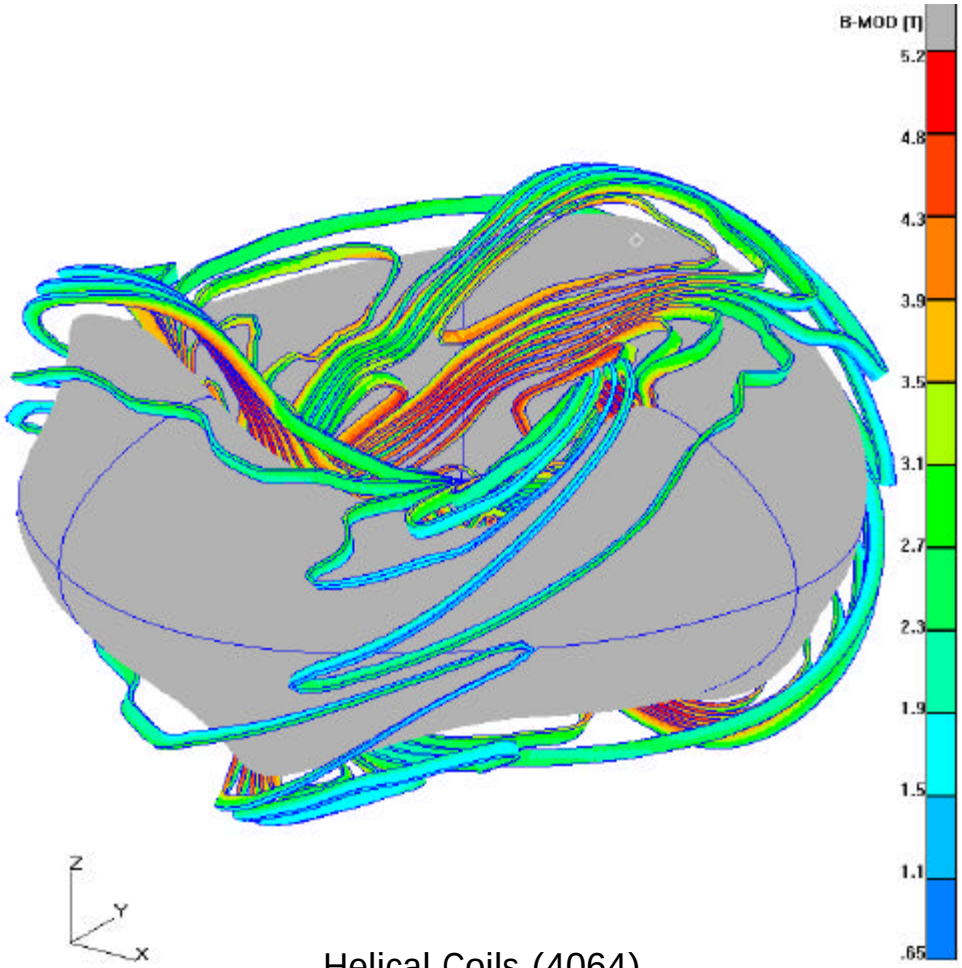


# Magnetic Field Results

- Maximum field at coil surface is 5.2-T (5.6-T previous)



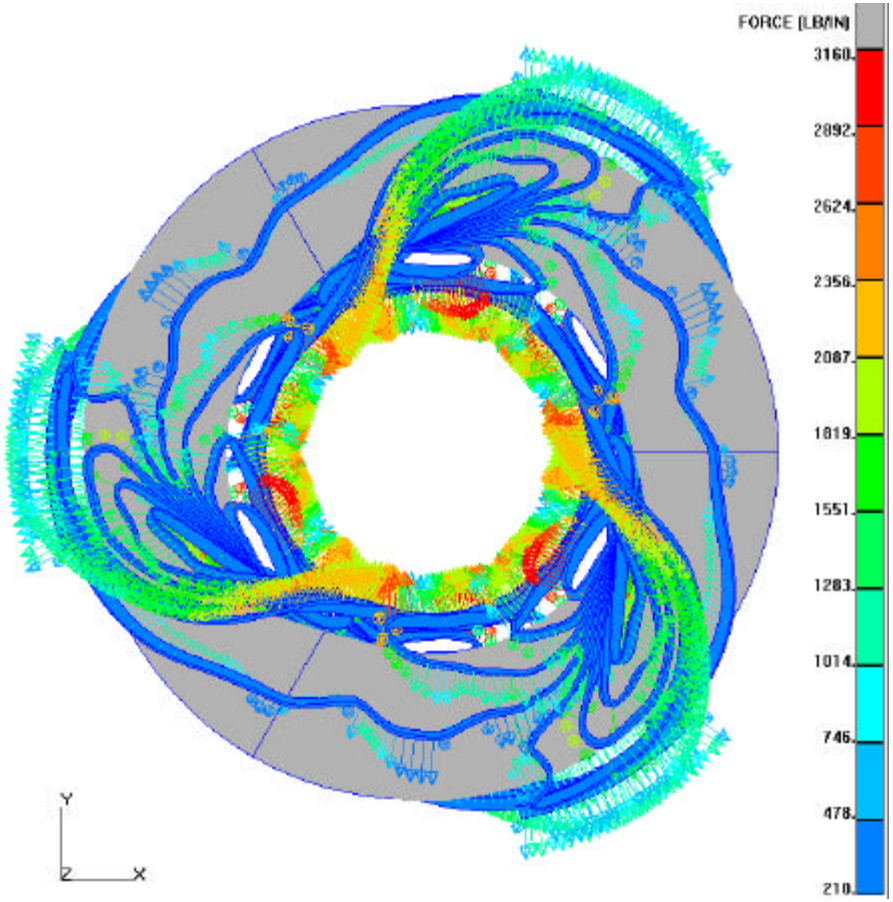

Electromagnetic Model

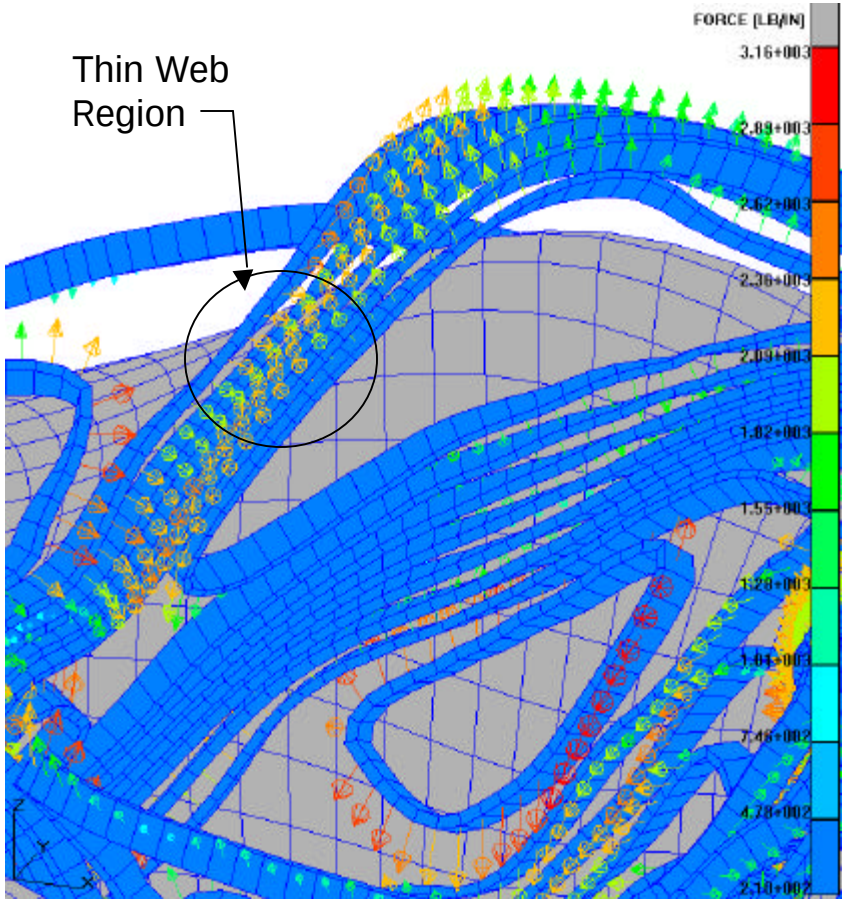



Helical Coils (4064)

# EM Force Results

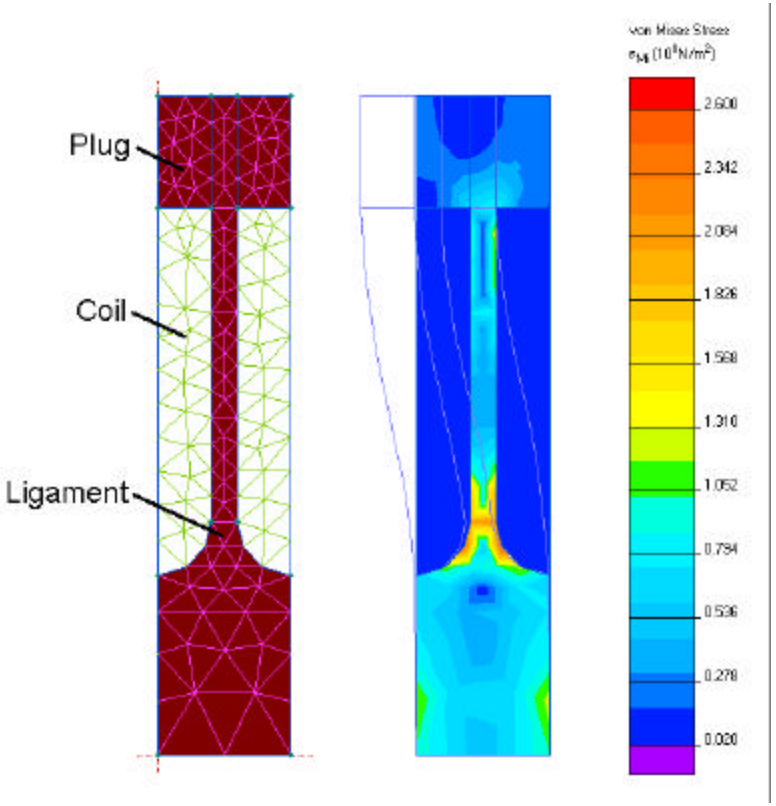
- Maximum running load varies from 2,474 to 3,159-lb/in (1,960-lb/in previous)
- Load variation is approximately linear with current



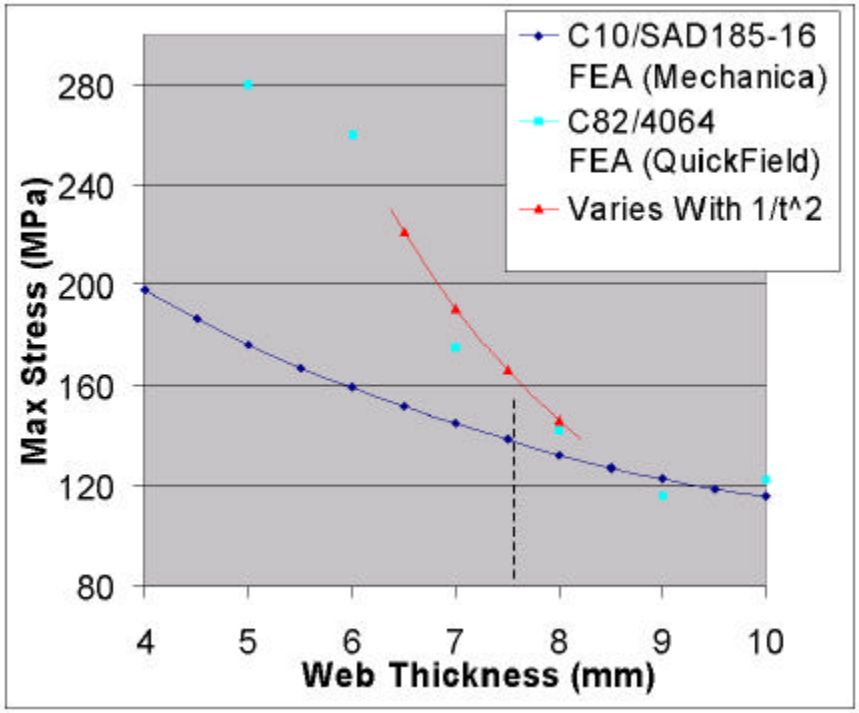



# Stress in Structural Shell Between Windings

- In thin web region, max load is 2,560-lb/in lateral, 1,200-lb/in normal
- 2D stress analysis indicates max VM stress is 260-MPa, >160-MPa limit
- Web thickness should be increased from 6- to 7.7-mm

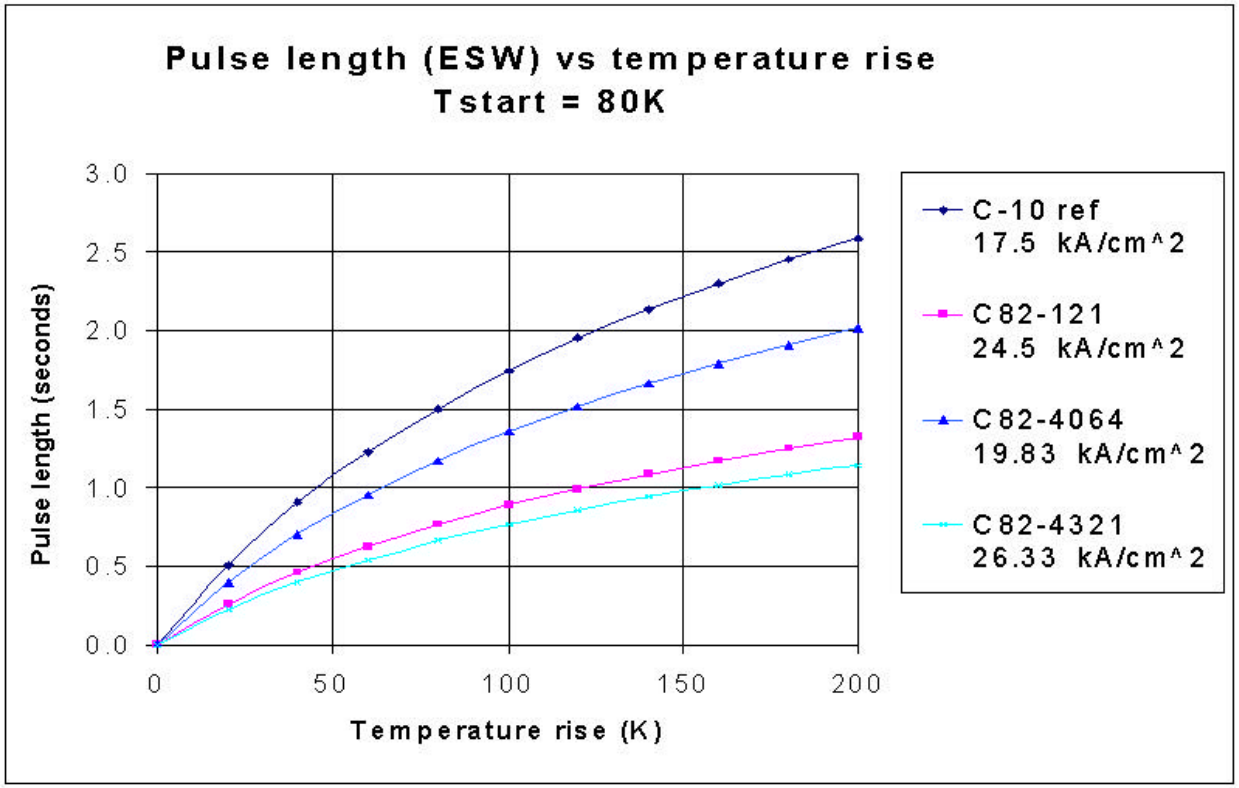



2D Web Stress Model



# Thicker Web Increases Current Density

- Current density with 7.7-mm thick web increases to ~27-kA/cm2
- Temperature rise increases to about 200-deg C



# Cost Estimate Has Been Updated

- Reflects C82 configuration, vendor input on manufacturing costs
- Driven by number of coils, size and length, and shell segmentation

Table 7.1 – Cost Estimate Parameters and Assumptions

| Date of Estimate | 6/98 | 12/98 | 6/99 | 3/00 | 3/00 |
|---|---|---|---|---|---|
| Plasma Configuration | D9E | C10 | C10 | C82 | C82 |
| Helical Coil Configuration | No Name | SAD185-8 | SAD185-16 | FD121-16 | Case 4064 |
| No. Plasma Periods | 2 | 3 | 3 | 3 | 3 |
| No. Coils per Half Period | 7 | 7 | 13 | 13 | 5 |
| Nominal Cross-Section | 37 x 87 mm | 30 x 53 mm | 16 x 70 mm | 13 x 70 mm | 20 x 70 mm |
| Total Coil Length | 200 m | 204 m | 408 m | 402 m | 214 m |
| No. Turns per Coil | 10 | 10 | 10 | 10 | 10 |
| Max Current Density | 8 kA/cm2 | 12 kA/cm2 | 17.5 kA/cm2 | 26 kA/cm2 | 23 kA/cm2 |
| Structure Concept | Plates and Troughs | Structural Shell | Structural Shell | Structural Shell | Structural Shell |
| Electrical Segmentation | N/A | 60 | 48 | 48 | 48 |
| No. Unique Patterns | N/A | 3 (cut up) | 8 | 8 | 8 |
| Pattern Dev Cost | N/A | 33 $/kg | 33 $/kg | 33 $/kg | 33 $/kg |
| Machining Rate | N/A | 10 in/min, .375 dia x .5 | 10 in/min, .375 dia x .5 | 10 in/min, .375 dia x .5 | 10 in/min, .375 dia x .5 |
| Matl Cost-Bronze | N/A | 6 $/kg | 6 $/kg | 6 $/kg | 6 $/kg |
| Matl Cost-SS | 8 $/kg | 8 $/kg | 8 $/kg | 8 $/kg | 8 $/kg |
| Matl Cost-Cu Cable | 150 $/m | 10 $/m | 3 $/m | 3 $/m | 3 $/m |
| Matl Cost-Epoxy Fill | 50 $/kg | 50 $/kg | 50 $/kg | 50 $/kg | 50 $/kg |
| Engr/Tech Rate | 100 $/hr | 100 $/hr | 100 $/hr | 100 $/hr | 100 $/hr |
| Outside Fab Rate | 65 $/hr | 65 $/hr | 65 $/hr | 65 $/hr | 65 $/hr |

Table 7.2 – Previous Cost Estimate Summary, k$

| Date of Estimate | 6/98 | 12/98 | 6/99 | 3/00 | 3/00 |
|---|---|---|---|---|---|
| Plasma Configuration | D9E | C10 | C10 | C82 | C82 |
| Helical Coil Configuration | No Name | SAD185-8 | SAD185-16 | FD121-16 | Case 4064 |
| Design & Analysis | 1850 | 1600 | 1600 | - | - |
| Outside Fabrication | 689 | 2000 | 1500 | - | - |
| Assembly Coil Install | 3410 | 1100 | 2400 | - | - |
| R&D Activities | 300 | 600 | 600 | - | - |
| Total w/o Contingency | 6249 | 5300 | 6100 | - | - |

# C82 Configuration Costs

- Costs for C82/FD121-16 configuration would be similar to the 6/99 estimate except shell fabrication costs were too low then. The error was corrected by incorporating data from a casting manufacturer and Y12 shops.

- Costs for Case 4064 are less than FD121-16 for the following reasons:
  - Fewer detail drawings (half as many coils, leads)
  - Slot machining reduced by 60% (total length reduced; fewer passes with wider cutter)
  - Coil installation time reduced ~50%

Table 7.3 – Cost Update for C82 Configuration, k$

| Coil Set | FD121-16 | Case 4064 |
|---|---|---|
| Design – | 1470 | 1013 |
| Pro/E Models | 192 | 121 |
| EM/Struct/Therm Analysis | 290 | 290 |
| Fabrication Drawings | 780 | 394 |
| Fab/Asm Oversight | 208 | 208 |
| Fabrication – | 3161 | 2585 |
| Castings | 1150 | 1150 |
| Part Machining | 1644 | 1160 |
| Pre-Asm/Final Machining | 367 | 275 |
| Assembly – | 2384 | 1426 |
| Shell Final Assembly | 336 | 336 |
| Coil Installation | 2048 | 1090 |
| R&D – | 600 | 600 |
| Total w/o Contingency | 7615 | 5624 |

# Cost Factors (Cont'd) and Conclusion

- In addition to coil size and total length, shell segmentation has a significant influence on cost. If the number of segments were reduced to 12 toroidal (~70-ms time constant), the cost of the C82/4064 configuration would be reduced by about $500k ($200k design, $120k fabrication, $180k assembly)

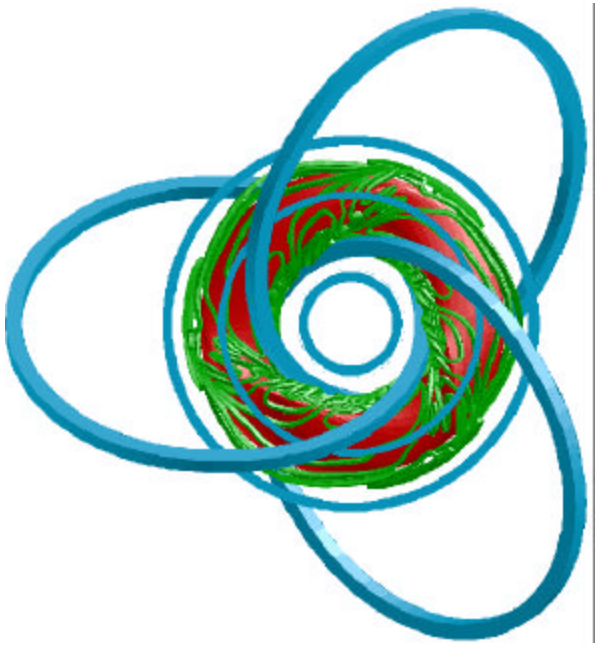
Conclusion:

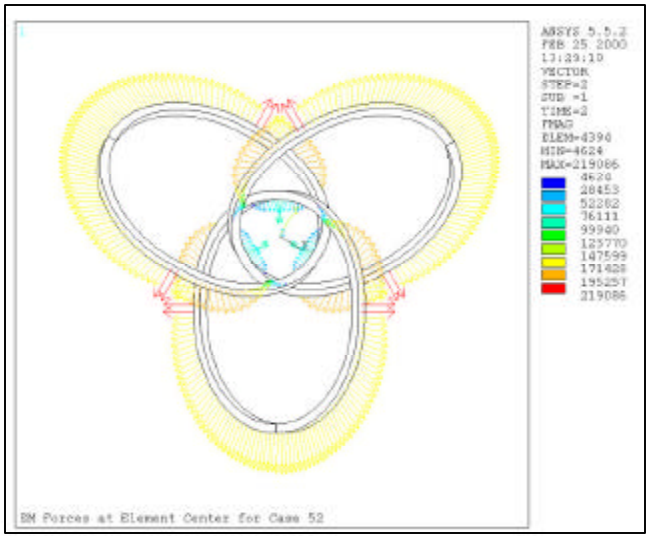
- Update of In-PBX-Option has not revealed any new problems
- C82/4064 configuration has some advantages (access, lower cost)
- Current density and shell local stress are high but OK

Actions:

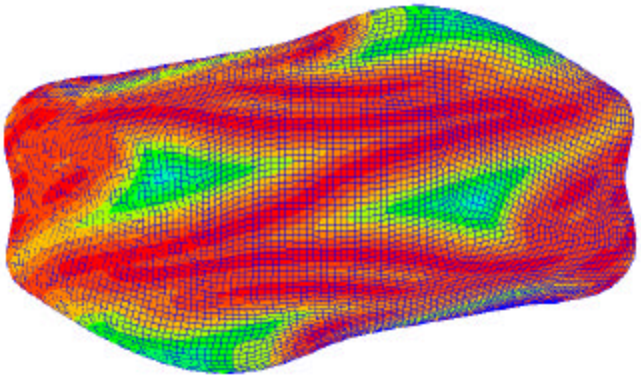
- Refine cost algorithm, integrate with WBS 1 master spreadsheet
- Incorporate comments to Design Description Document
- Evaluate alternate topology options (eg, Case 52)

# Case 52 - Tilted TF Concept

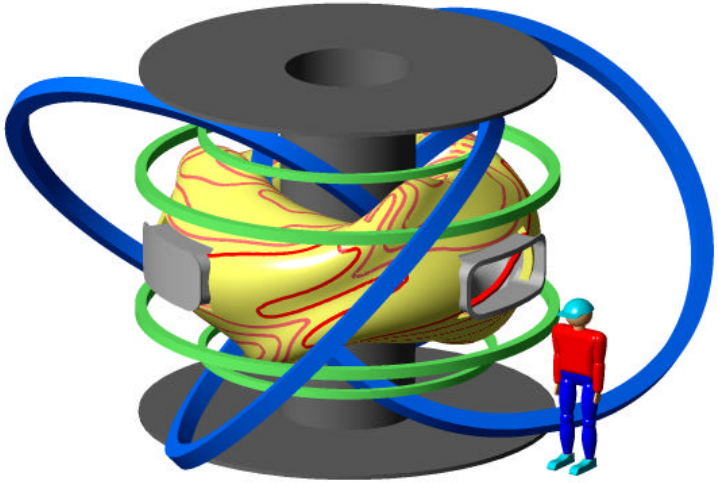





EM Analysis (H.M. Fan)



Access Evaluation



Structural Concept