# Status of Systems Code Studies

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UT-BATTELLE

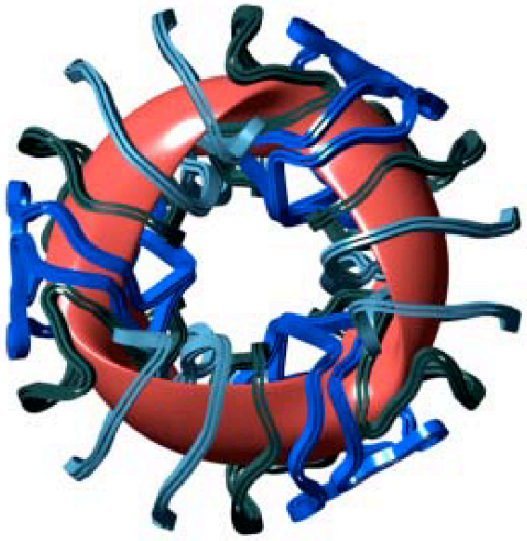
# Topics

- Revisions to Systems Code and component models
- NCSX-1 reference case results
- Comparison of NCSX-1 results with ARIES-AT, ARIES-RS and SPPS results
- Parameter scans and variations
- Detailed results for NCSX-1 reference case
- Next steps and questions

# Systems Code Changes since Feb. Meeting

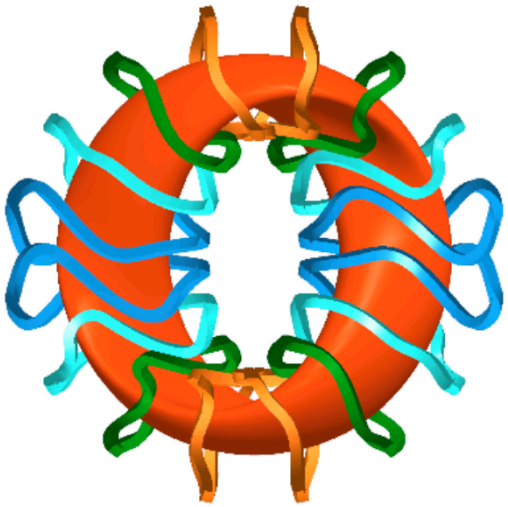
- **Code convergence to a solution much improved**
  - had been a significant problem
- **Coil parameters**
  - revised coil cost calculation
  - added 2 new NCSX and 3 new MHH2-16 coil configurations
- **Blanket/shield designs**
  - added (revised) manifolds, corrected back wall calculations
- **Output lists**
  - checked volumes, masses and costs for all components
  - revised some cost accounts, added new lists for components
- **Varied constraints on $\beta$, $\alpha$ loss, $B_{max}$, C & Fe %, $P_{elect}$**

# Five New Coil Configurations Were Added



**2 NCSX** **3 MHH2**

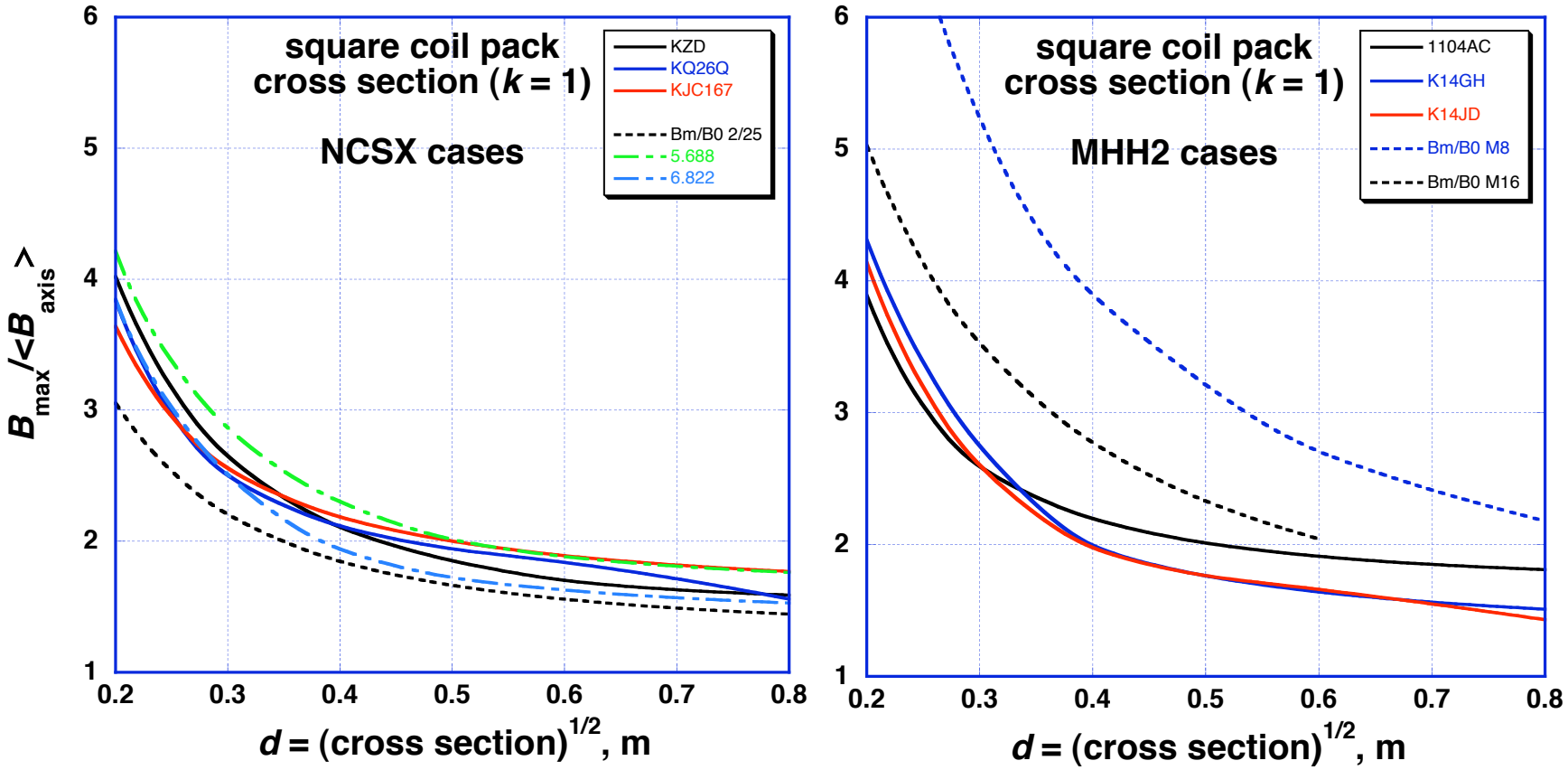
**all quasi-axisymmetric**



**old**

| Key Configuration Properties | NCSX-1: KZD | NCSX KQ26Q | NCSX KJC167 | MHH2 1104AC | MHH2 K14GH | MHH2 K14JD |
|---|---|---|---|---|---|---|
| Plasma aspect ratio $A_p = \langle R \rangle / \langle a \rangle$ | 4.48 | 4.62 | 6.00 | 2.65 | 2.69 | 2.69 |
| Wall (plasma) surface area/$\langle R \rangle^2$ | 11.74 | 10.89 | 8.99 | 17.60 | 18.20 | 17.64 |
| Min. pl-coil dist. ratio $A_\Delta = \langle R \rangle / \Delta_{min}$ | 5.89 | 5.80 | 6.02 | 5.34 | 5.40 | 5.54 |
| Min. coil-coil dist. ratio $\langle R \rangle$/(c-c) | 10.03 | 10.2 | 9.8 | 12.53 | 12.18 | 12.62 |
| Total coil length/$\langle R \rangle$ | 89.9 | 83.3 | 63.5 | 91.8 | 90.3 | 96.1 |
| $B_{max}/\langle B_{axis} \rangle$, 0.4 m x 0.4 m coil pack | 2.10 | 2.11 | 2.18 | 2.19 | 1.97 | 1.96 |

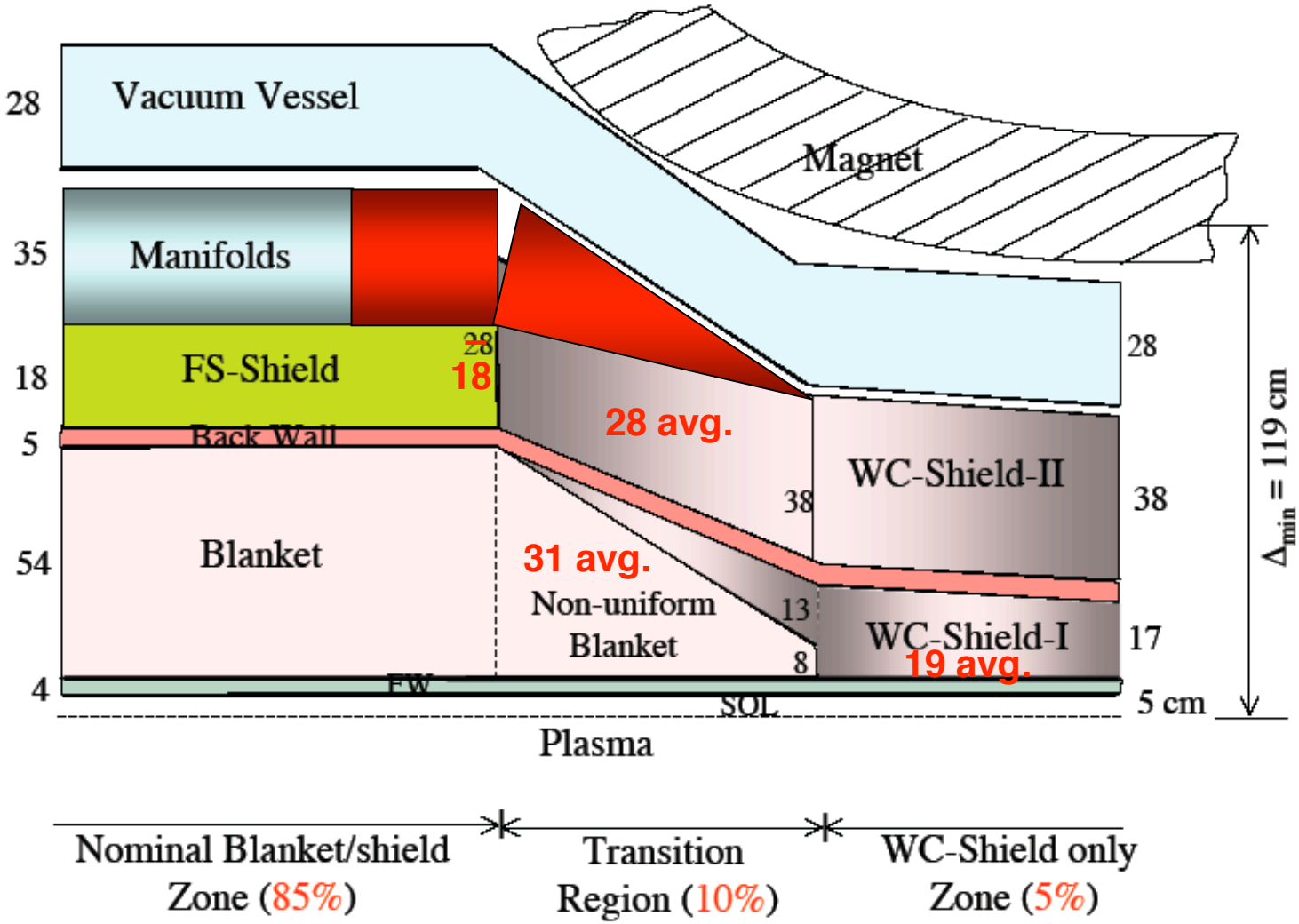
# Larger Change in $B_{max}/\langle B_{axis}\rangle$ for New MHH2 Cases




- Still only have $B_{max}(k)/B_{max}(1)$ curves from NCSX-2 (2/25/03) coil case to calculate $B_{max}(k)/B_{max}(1)$ for ***all*** plasma and coil cases

# Revised Radial Build Model

- **Incorporated blanket/transition model from Laila + manifold guidance from Xueren**
  - **added a manifold (extended and tapered)**

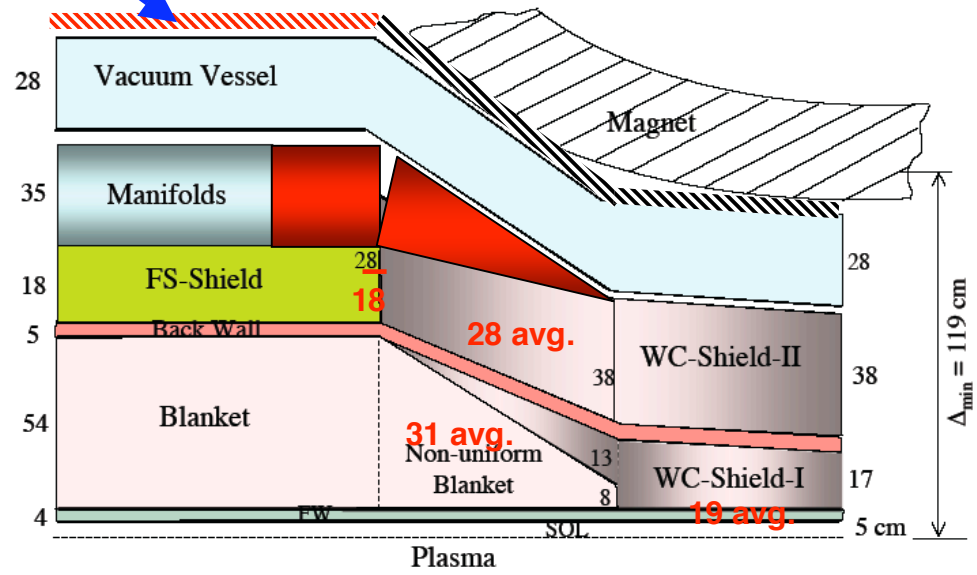


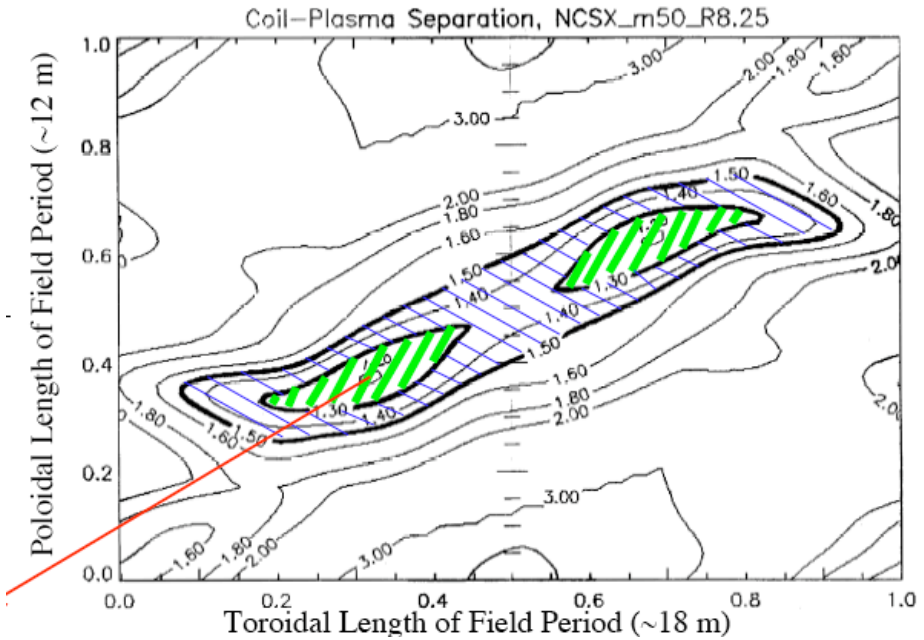
# All Volume Calculations are Approximate

- **3 approaches, all approximate due to poloidally elongated components (using #1, shift to #3 when available)**
  1. **mid-radius surface (scaled radially from plasma surface) x thickness -- underestimates**
  2. **difference in volumes from $r_{outer}$ and $r_{inner}$ (scaled radially from plasma volume) -- overestimates**
  3. **mid-radius surface normalized from CAD calculation (*but* for $R = 8.25$ m) x thickness -- overestimates**
- **All approaches should be close; need to do CAD for $R \sim 7.5$ m**

# Need to Check $\Delta(\phi,\theta)$ for Vacuum Vessel to Coil Winding Surface

- Only done so far for no-blanket region
- Is there sufficient clearance for other regions?
  - 59 cm difference
- OK for NCSX cases?



# Revised Calculation of Coil Costs

- **Earlier guidance**
  - coil cost = \$1.27/kA-m x 3 (for winding cost)

    cost = 3.81 x $I_{coil} l_{coil} = k_1 k_2 B_{axis} \langle R \rangle^2$ [3.81]
- **Revised guidance**
  - conductor cost varies rapidly with $B_{max}$: \$1.43/kA-m at 5 T, \$10.7/kA-m at 15 T (could be reduced factor of 3 by developing advanced manufacturing and increased billet size)
    - cost = $I_{coil} l_{coil} f(B_{max}) = k_1 k_2 B_{axis} \langle R \rangle^2 [f(B_{max})]$
  - cost of winding coil: mass of conductor x \$80/kg
    - cost = $80 \rho I_{coil} l_{coil} / j = k_1 k_2 B_{axis} \langle R \rangle^2 [80 \rho / j(B_{max})]$
- **Coil structure cost is unchanged**
  - volume = area of coil winding surface x 10-cm thickness (per Leslie Bromberg)
  - cost = volume x 7800 kg/m$^3$ x \$56/kg = $k_3 \langle R \rangle^2$

# Revised Calculation of Coil Costs

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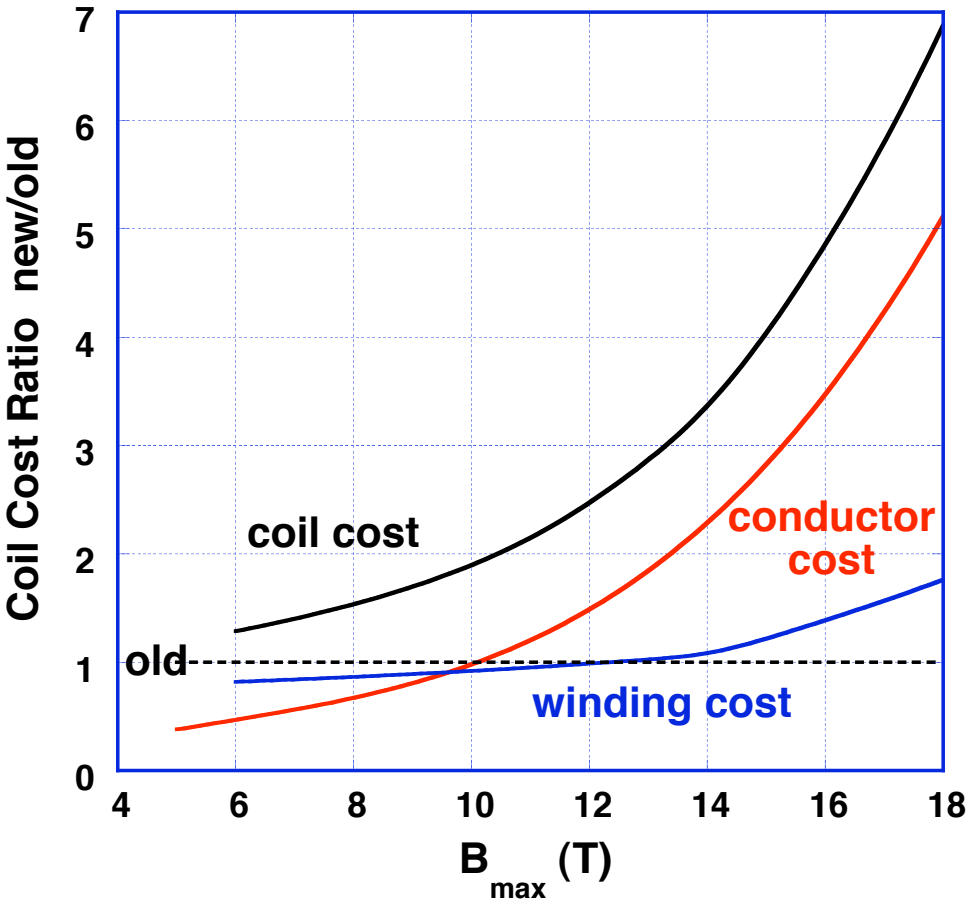
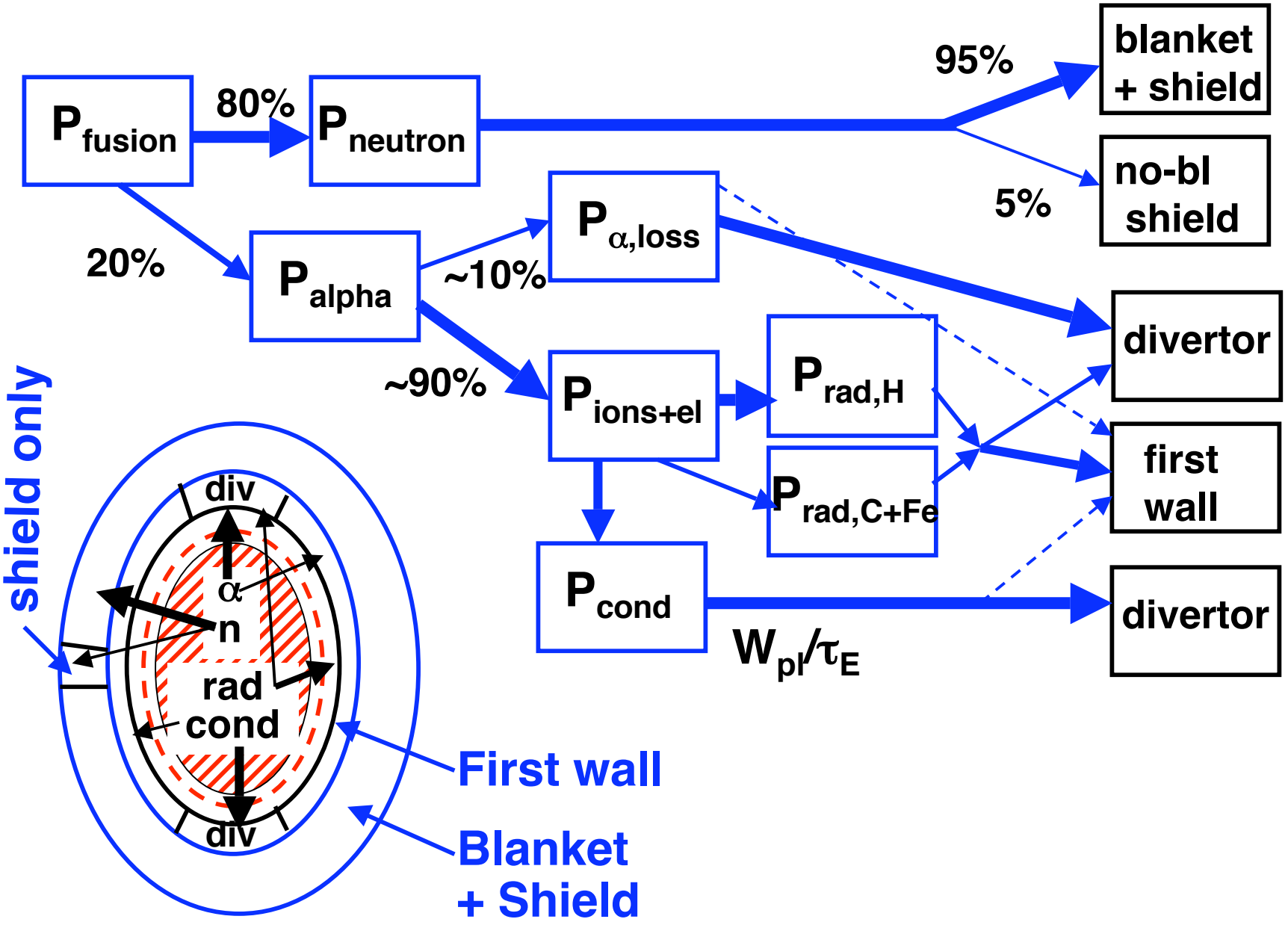
- **Revised guidance**
  - conductor cost = $I_{coil} l_{coil} f(B_{max})$ = $k_1 k_2 B_{axis} \langle R \rangle^2 [f(B_{max})]$
  - cost of winding coil = $80\rho I_{coil} l_{coil} / j = k_1 k_2 B_{axis} \langle R \rangle^2$ $[80\rho / j(B_{max})]$
  - coil cost = $k_1 k_2 B_{axis} \langle R \rangle^2$ $[f(B_{max}) + 80\rho / j(B_{max})]$



# Power Flows


P fusion
80%
P neutron
95%
blanket + shield
5%
no-bl shield
20%
P alpha
~10%
P α,loss
~90%
P ions+el
P rad,H
P rad,C+Fe
divertor
first wall
P cond
W pl/τE
divertor
shield only
div
α
n
rad
cond
div
First wall
Blanket + Shield

# System Code Convergence

**VARIABLES selected for iteration and ranges**

| | | | |
|---|---|---|---|
| major radius | 5.0 to 20.0 m; | field on axis | 3.0 to 10.0 T |
| ion density | 1.0 to 10.0 $10^{20}m^{-3}$; | ion temperature | 1.0 to 50.0 keV |
| half coil depth | 0.01 to 5.0 m; | calculated H-ISS95 | 0.1 to 9.0 |

| **CONSTRAINTS** | **value** | **target** |
|---|---|---|
| ignition margin | 0.9999 | 1.0 |
| electric power (GW) | 1.00 | 1.00 |
| volume averaged beta (%) | 6.00 | 6.00 |
| mag field at coil (T) | 16.00 | < 16.00 |
| ave neut wall load ($MW/m^2$) | 2.741 | < 3.086 |
| average/maximum density | 0.743 | < 1.0 |
| radial build margin $A_\Delta d_{min}/R$ | 1.00 | < 1.0 |
| confinement mult. H-ISS95 | 2.540 | < 6.00 |
| maintenance port width (m) | 2.546 | > 2.00 |
| $j_{coil}/j_{max}(B_{max})$ | 0.468 | < 1.0 |

- **convergence to a solution where all constraints were satisfied had been a problem for some cases**

# Typical Systems Code Summary

**MHHOPTNEW code NCSX-1 case (KZD)**

**modified LiPb/FS/He H2O-cooled internal vacuum vessel with SiC inserts and tapered blanket**

**inflation factor 2004 year**

**following CONSTRAINTS were selected:**

| | |
|---|---|
| ignition = 1 target | 1.00 |
| max. volume averaged beta | 0.06 |
| sufficient radial build | |
| max. magnetic field at coil | 16.00 |
| max. ave. neutron wall load | 3.09 |
| maximum density = 2 x nSudo | |
| Electric Power (GW) | 1.00 |
| max. confinement multiplier | 6.00 |
| min. port width | 2.0 |

**VARIABLES selected for iteration**

| | | |
|---|---|---|
| major radius | 5.00 | 20.00 |
| field on axis | 3.00 | 10.00 |
| ion density | 1.00 | 10.00 |
| ion temperature | 1.00 | 50.00 |
| coil width | 0.010 | 5.00 |
| confinement multiplier | 0.10 | 9.00 |

**FIGURE OF MERIT .....**

**70.4 Cost of Electricity**

**FINAL VALUES OF CONSTRAINTS:**

| | |
|---|---|
| ignition margin | 1.00 |
| volume averaged beta (%) | 6.00 |
| radial build margin | 1.00 |
| magnetic field at coil (T) | 16.00 |
| ave. neutron wall load ($MW/m^2$) | 2.74 |
| average/maximum density | 0.74 |
| Electric Power (GW) | 1.00 |
| ratio of tauE to conf. multiplier | 4.24 |
| maintenance port width (m) | 2.55 |
| jcoil/jmax | 0.47 |

**FINAL DESIGN**

| | |
|---|---|
| major radius (m) | 7.38 |
| field on axis (T) | 5.03 |
| volume avg. density ($10^{20}$ $m^{-3}$) | 2.36 |
| density averaged temp (keV) | 8.26 |
| coil dimensions (m x m) | 0.41 x 0.72 |
| current density ($MA/m^2$) | 39.0 |

# Typical Systems Code Summary

## Plasma Parameters

| | |
|---|---|
| central ion temp (keV) | 12.44 |
| central ion density ($10^{20}$ $m^{-3}$) | 4.97 |
| central elec. density ($10^{20}$ $m^{-3}$) | 5.34 |
| fraction fuel to electrons | 0.88 |
| confinement time, taue (sec) | 1.14 |
| stored plasma energy (MJ) | 358 |
| volume averaged beta (%) | 6.00 |
| beta star (%) | 9.85 |
| fraction carbon impurity | 0.5 % |
| fraction iron impurity | 0.022 % |
| fraction helium | 4.09 % |
| Z effective | 1.27 |

## Mass Summary

| | |
|---|---|
| total nuclear island (tonnes) | 7,171 |
| mass LiPb coolant (tonnes) | 3,840 |
| total mass (tonnes) | 11,011 |

## Power Balance

| | |
|---|---|
| net electric power (MW) | 1000 |
| gross electric power (MW) | 1054.9 |
| fusion power (MW) | 2258.5 |
| thermal power (MW) | 2511.6 |
| $\alpha$ heating power (MW) | 450.9 |
| power in neutrons (MW) | 1807.6 |
| radiated power (MW) | 177.1 |
| fuel bremsstrahlung (MW) | 129.1 |
| carbon radiation (MW) | 25.9 |
| iron radiation (MW) | 21.0 |
| synchrotron radiation (MW) | 1.2 |
| conduction power (MW) | 138.5 |
| fusion power to plasma (MW) | 315.6 |
| fraction alpha power lost | 30.0 % |
| radiated power fraction | 56.1 % |
| neutron wall load ($MW/m^2$) | 2.43 |
| radiated wall load ($MW/m^2$) | 0.27 |

# CoE Components for CS, AT, RS & SPPS

| mills/kW$_e$h | CS | AT | RS | SPPS |
|---|---|---|---|---|
| CoE (in 1992 $) | 57.41 | 56.61 | 75.66 | 74.92 |
| Cap. Return | 47.62 | 43.95 | 61.34 | 63.34 |
| O & M | 8.18 | 8.34 | 9.16 | 9.16 |
| FW/Bl replace. | 0.96 | 3.79 | 4.63 | 1.90 |
| Decomm. | 0.50 | 0.50 | 0.50 | 0.50 |
| Fuel costs | 0.03 | 0.03 | 0.03 | 0.03 |

- Largest CoE component is Capital Return
- Cap. Return $\alpha$ Total Cap. Cost $\alpha$ Total Direct Cost

# Comparison of General Plant Costs (1992 $)

| Parameter | CS | AT | RS | SPPS |
|---|---|---|---|---|
| $\langle R \rangle$, m | 7.38 | 5.20 | 5.52 | 13.95 |
| $\langle B_{axis} \rangle$, T | 5.03 | 5.86 | 7.98 | 4.94 |
| $\langle \beta \rangle$, % | 6.0 | 9.2 | 5.0 | 5.0 |
| FPC Mass, tonnes | 7,170 | 5,226 | 12,679 | 21,430 |
| CoE, mills/kW$_e$h (1992 $) | 57.4 | 56.6 | 75.7 | 74.9 |
| 90 Total Direct Cost (M$) | 1902 | 1757 | 2189 | 2261 |
| 20 Land | 10.4 | 10.6 | 10.4 | 10.4 |
| 21 Structure | 318.0 | 335.5 | 331.0 | 332.5 |
| *22 Reactor Plant Equip.* | *999.3* | *900.3* | *1386* | *1487* |
| 23 Turbine Plant Equip. | 259.9 | 243.0 | 284.4 | 254.0 |
| 24 Electric Plant Equip. | 103.6 | 110.3 | 110.6 | 103.6 |
| 25 Misc. Plant Equip. | 51.9 | 50.1 | 56.2 | 51.9 |
| 26 Special Materials | 159.4 | 83.8 | 11.1 | 21.1 |
| Heat Rejection System | | +23.3 | | |
| 22+26 Reactor Plant + LM | 1159 | 984.1 | 1397 | 1508 |

- Only Reactor Plant Equip. contains stellarator costs

# Comparing % Costs with AT, RS & SPPS

| % of Total Direct Cost | CS | AT | RS | SPPS |
|---|---|---|---|---|
| 20 Land | 0.5 | 0.6 | 0.5 | 0.5 |
| 21 Structure | 16.7 | 19.1 | 15.1 | 14.7 |
| 22 Reactor Plant Equip. | 52.5 | 51.2 | 63.3 | 65.8 |
| 23 Turbine Plant Equip. | 13.7 | 13.8 | 13.0 | 11.2 |
| 24 Electric Plant Equip. | 5.4 | 6.3 | 5.1 | 4.6 |
| 25 Misc. Plant Equip. | 2.7 | 2.9 | 2.6 | 2.3 |
| 26 Special Materials | 8.4 | 4.8 | 0.5 | 0.9 |

- Reactor Plant Equipment is largest part of Total Direct Cost, but structure and turbine plant equipment are also significant

# Comparison of General Plant Costs (1992 $)

| Cost (M$) | CS | AT | RS | SPPS |
|---|---|---|---|---|
| 21 Structure | 318.0 | 335.5 | 331.0 | 332.5 |
| 21.2 reactor building | 129.1 | n. a. | n. a. | 141.6 |
| 21.6 misc. buildings | 112.6 | n. a. | n. a. | 112.7 |
| 22 Reactor Plant Equip. | 999.3 | 900.3 | 1386 | 1487 |
| *22.1 reactor equipment* | *656.8* | *519.9* | *966.4* | *1115* |
| 22.2 heat transport | 192.8 | 209.9 | 258.3 | 217.8 |

- **While the reactor equipment is the largest cost component, the costs of structure (buildings) and heat transport are also large**

# Comparing Costs with AT, RS & SPPS

| Cost (M$) | CS | AT | RS | SPPS |
|---|---|---|---|---|
| 22.1 Reactor Equipment | 656.8 | 519.9 | 966.4 | 1115 |
| Cost of stellarator parts | 448.5<br>68% | 274.9<br>53% | 516.3<br>53% | 750.9<br>67% |
| 22.1.1 blanket & 1st wall | 54.1 | 67.9 | 74.3 | 71.5 |
| 22.1.2 shield, BW, man. | 233.1 | 73.3 | 168.0 | 289.8 |
| 22.1.3 coils | 161.3 | 133.7 | 274.0 | 389.6 |
| 22.1.4 heating | 53.7 | 41.0 | 164.2 | 54.2 |
| 22.1.5 primary structure | 52.3 | 29.8 | 53.4 | 152.9 |
| 22.1.6 vacuum systems | 46.9 | 109.2 | 159.2 | 85.4 |
| 22.1.7 power supplies | 55.3 | 56.1 | 55.3 | 55.3 |
| 22.1.8 impurity control | 0 | 4.5 | 13.6 | 12.0 |
| 22.1.10 ECH startup | 0 | 4.4 | 4.3 | 4.3 |

# Comparing Masses with AT, RS & SPPS

| Mass (tonnes) | CS | AT | RS | SPPS |
|---|---|---|---|---|
| FW/Blanket/BW | 898 | 255 | 585 | 251 |
| Shield, BW, man. | 2360 | 882 | 4235 | 9453 |
| Coils | 3049 | 1525 | 3280 | 4191 |
| Structure | 1148 | ---- | 1627 | 5365 |
| Vacuum Vessel | 1287 | 1415 | 1357 | 2171 |
| Fusion Power Core | 7,170 | 5,226 | 12,679 | 21,430 |
| LM Coolant | 3,840 | 5,269 | 223 | 175 |
| FPC + Coolant | 11,010 | 10,495 | 12,902 | 21,605 |

# Weak Variation of Reactor Parameters with $\beta$

| NCSX-1 $\langle\beta\rangle$, % | $\langle R\rangle$ m | $\Gamma_{n,wall}$ MW/m$^2$ | $\langle B_{axis}\rangle$ T | CoE | H-ISS95 |
|---|---|---|---|---|---|
| 2.5 | 7.85 | 2.43 | 7.45 | 74.73 | 1.82 |
| 3 | 7.67 | 2.54 | 6.90 | 73.18 | 1.92 |
| 4 | 7.53 | 2.64 | 6.11 | 71.85 | 2.24 |
| 5 | 7.44 | 2.70 | 5.48 | 70.96 | 2.37 |
| 6 | 7.38 | 2.74 | 5.03 | 70.37 | 2.54 |
| 8 | 7.30 | 2.80 | 4.39 | 69.58 | 2.84 |
| 10.1 | 7.25 | 2.84 | 3.97 | 69.08 | 3.26 |

- Increasing $\langle\beta\rangle$ allows reduced $\langle B_{axis}\rangle$ and $\langle R\rangle$ but requires larger H-ISS95
- Relatively small change in CoE for $\langle\beta\rangle$ = 4-8%

# Typical Cost Summary (2004 $)

| COST SUMMARY (M$) | | | % of 99 | % of 22.1 |
|---|---|---|---|---|
| 20 | Land | 12.822 | 0.284 | |
| 21 | Structure | 390.613 | 8.663 | |
| 22.1.1 | Bl. & 1st wl. | 66.516 | 1.475 | 8.245 |
| 22.1.2 | Shield | 286.334 | 6.350 | 35.492 |
| 22.1.3 | Magnets | 198.160 | 4.395 | 24.563 |
| 22.1.4 | Supp. Heating | 65.915 | 1.462 | 8.171 |
| 22.1.5 | Primary Str. | 64.288 | 1.426 | 7.969 |
| 22.1.6 | Reactor Vac. S | 57.579 | 1.277 | 7.137 |
| 22.1.7 | Power Supply | 67.954 | 1.507 | 8.423 |
| 22.1.8 | Impurity Cont | 4.523 | 0.125 | 1.043 |
| 22.1.9 | Direct En. Conv | 0.000 | 0.000 | 0.000 |
| 22.1.1 | ECH breakdown | 0.000 | 0.000 | 0.000 |
| 22.1 | Total | 806.747 | 17.891 | 100.00 |
| 22.2 | Heat transport | 236.882 | 5.253 | |
| 22 | Reactor Plant Eq. | 1227.446 | 27.221 | |
| 23 | Turbine Plant Eq. | 319.188 | 7.079 | |
| 24 | Electric Plant Eq. | 127.284 | 2.823 | |
| 25 | Misc. Plant Eq. | 63.770 | 1.414 | |
| 26 | Special Material | 195.851 | 4.343 | |

# Typical Cost Summary (2004 $)

| | | | | |
|---|---|---|---|---|
| Cost 90 | Total Dir Cost | 2336.975 | 51.827 | percentages |
| Cost 91 | Construction | 280.437 | 6.219 | of total |
| Cost 92 | Home office | 121.523 | 2.695 | |
| Cost 93 | Field office | 140.218 | 3.110 | |
| Cost 94 | Owner's costs | 431.873 | 9.578 | |
| Cost 96 | Proj. Contingency | 558.771 | 12.392 | |
| Cost 97 | Constr Interest | 639.936 | 14.180 | |
| Cost 98 | Constr Escalation | 0.000 | 0.000 | |
| Cost 99 | Total Capital | 4509.193 | 100.000 | |

| | | |
|---|---|---|
| [90] | Unit direct cost, UDC | 2336.975 |
| [94] | Unit base cost, UBC | 3869.797 |
| [99] | Unit total cost, UTC | 4509.193 |
| | Capital return | 58.500 |
| [40-47,51] | O&M costs | 10.045 |
| [50] | B/FW replacement | 1.174 |
| | Decomissioning allow. | 0.614 |
| [02] | Deuterium fuel | 0.037 |

Cost of Electricity, COE 70.369 in 2004$, 57.288 in 1992$

# Component Cost Summary (2004$)

| | |
|---|---|
| **total mod coil + str cost** | **198.16** |
| mod coil SC cost | 91.29 |
| rest mod coil pack cost | 42.58 |
| coil structure cost | 64.29 |
| total VF coil cost | 0.00 |
| divertor coil cost | 0.00 |
| total coil cost | 198.16 |
| bucking cylinder cost | 0.00 |
| **total blanket, first/back wall** | **66.52** |
| first wall cost | 6.92 |
| front full blanket cost | 29.00 |
| front blanket back wall cost | 28.75 |
| second blanket cost | 0.00 |
| transition blanket cost | 1.84 |
| **total vacuum vessel cost** | **57.58** |
| full blanket vac vessel cost | 49.64 |
| shield-only vac vessel cost | 2.43 |
| transition vac vessel cost | 5.50 |
| **shield cost and back wall** | **115.11** |
| ferritic steel shield cost | 39.18 |
| 1st shield-only WC shield cost | 3.04 |
| shield-only back wall cost | 24.36 |
| 2nd shield-only WC shield cost | 7.50 |
| 1st transition WC shield cost | 2.54 |
| trans shield back wall cost | 26.73 |
| 2nd transition WC shield cost | 11.77 |
| **cost of manifolds** | **171.22** |
| full manifold cost | 115.40 |
| transition manifold cost | 55.82 |
| **cost of liquid metal coolant** | **195.85** |

# Component Mass Summary (tonnes)

| | |
|---|---|
| **total modular coil mass** | **3276.99** |
| conductor mass | 1064.50 |
| rest winding pack mass | 1064.50 |
| coil structure mass | 1148.00 |
| total VF coil mass | 0.00 |
| divertor coil mass | 0.00 |
| total coil mass | 3276.99 |
| bucking cyl mass | 0.00 |
| **total blanket, first, back wall** | **897.63** |
| first wall mass | 67.22 |
| front full blanket mass | 557.80 |
| front blanket back wall | 237.25 |
| second blanket mass | 0.00 |
| transition blanket mass | 35.36 |
| **total vacuum vessel mass** | **1287.38** |
| full blanket vac vessel mass | 1109.94 |
| shield-only vac vessel mass | 54.43 |
| transition vac vessel mass | 123.01 |
| **shield mass and back wall** | **1720.33** |
| ferritic steel shield mass | 1008.85 |
| 1st shield-only WC shield mas | 94.80 |
| shield-only back wall mass | 11.82 |
| 2nd shield-only WC shield mas | 204.55 |
| 1st transition WC shield mass | 79.39 |
| trans shield back wall mass | 25.95 |
| 2nd transition WC shield mass | 320.92 |
| **mass of manifolds** | **1329.17** |
| full manifold mass | 1257.61 |
| transition manifold mass | 71.56 |
| **total nuclear island** | **7170.52** |
| mass of liquid metal coolant | 3840.22 |
| **mass of nuclear island + coolant** | **11010.74** |

# Component Volumes Summary ($m^3$)

| | | |
|---|---|---|
| **total modular coil volume** | | **534.27** |
| conductor volume | | 193.54 |
| rest winding pack vol | | 193.54 |
| coil structure volume | | 147.18 |
| **total FW, blanket, BW volume** | | **445.31** |
| first wall volume | 25.35 | 1.717 |
| front full blanket volume | 359.18 | 2.007 |
| front blanket back wall vol | 38.02 | 2.303 |
| second blanket volume | 0.00 | 2.328 |
| transition blanket volume | 22.77 | 1.891 |
| **total vacuum vessel volume** | | **541.22** |
| full blanket vac vessel vol | 364.78 | 2.683 |
| shield-only vac vessel vol | 176.44 | 2.596 |
| transition vac vessel vol | 30.92 | 2.843 |

$r_{mid}$(m) in blue

| | | |
|---|---|---|
| **total shield + back wall volume** | | **203.25** |
| ferritic steel shield volume | 143.71 | 2.418 |
| 1st shield-only WC shield vol | 6.76 | 1.831 |
| shield-only back wall volume | 1.89 | 1.951 |
| 2nd shield-only WC shield vol | 15.99 | 2.166 |
| 1st transition WC shield vol | 5.66 | 2.081 |
| trans shield back wall vol | 4.16 | 2.141 |
| 2nd transition WC shield vol | 25.08 | 2.306 |
| **volume of manifolds** | | **323.63** |
| full manifold volume | 279.02 | 3.018 |
| transition manifold volume | 13.68 | 2.516 |
| **volume of liquid metal in core** | | **431.63** |

# Cost Element Breakdown

**COST COMPONENTS in 2004 year M$**

| | | |
|---|---|---|
| Cost 20 (Land) = | 12.822 | constant |
| Cost 21.1 (site improvements) = | 22.651 | constant |
| Cost 21.2 (reactor building) = | 158.606 | $V_{\text{reactor building}}^{0.62}$ |
| Cost 21.3 (turbine building) = | 38.997 | $(\eta_{th} P_{th})^{0.75}$ + constant |
| Cost 21.4 (cooling system) = | 9.708 | $(\eta_{th} P_{th})^{0.3}$ |
| Cost 21.5 (PS building) = | 12.269 | constant |
| Cost 21.6 (misc. buildings) = | 138.299 | constant |
| Cost 21.7 (vent. stack) = | 2.424 | constant |
| Cost 21 (Structure) = | 390.613 | |

$P_{th} = P_n \times \text{gloem} + P_\alpha$

# Cost Element Breakdown

**COST COMPONENTS**

| | | |
|---|---|---|
| Cost 22.1.1.1 (FW) | 6.923 | |
| Cost 22.1.1.3 (BL + BW) | 59.593 | |
| Cost 22.1.1 (Bl/BW & 1st wl.) | 66.516 | 8.245% |
| Cost 22.1.2 (Sh/BW/man) | 286.334 | 35.492% |
| Cost 22.1.3 mod coils + str | 198.160 | |
| Cost 22.1.3 VF coils | 0.000 | |
| Cost 22.1.3 divertor | 0.000 | |
| Cost 22.1.3 (coils + str) | 198.160 | 24.563% |
| Cost 22.1.4 (Heating) | 65.915 | constant 20 MW |
| Cost 22.1.5 (Primary Str.) | 64.288 | coil winding surface |
| Cost 22.1.6 (Vac. Sys.) | 57.579 | vacuum vessel only |
| Cost 22.1.7 (Power Sup.) | 67.954 | constant |
| Cost 22.1.8 (Imp. Control) | 0 | divertor area |
| Cost 22.1.9 (Dir. Ener. Conv. | 0 | |
| Cost 22.1.10 (ECH) = | 0 | |
| Cost 22.1 (Core) = | 806.747 | |

# Cost Element Breakdown

| | | |
|---|---|---|
| Cost 22.2.1 prim. coolant | 236.882 | $P_{th}^{0.55}$ |
| Cost 22.2.2 interm. coolant | 0.000 | |
| Cost 22.2.3 sec. coolant | 0.000 | |
| Cost 22.2 (Heat transport) | 236.882 | |
| Cost 22.3 aux. cooling | 3.190 | $P_{th}$ |
| Cost 22.4 rad. waste | 5.684 | $P_{th}$ |
| Cost 22.5.1 fuel injection | 14.017 | constant |
| Cost 22.5.2 fuel processing | 16.453 | constant |
| Cost 22.5.3 fuel storage | 7.009 | constant |
| Cost 22.5.4 atm T recover. | 3.325 | constant |
| Cost 22.5.5 H2O T recover. | 7.009 | constant |
| Cost 22.5.6 BL T recover. | 7.009 | constant |
| Cost 22.5 fuel handling | 54.821 | constant |
| Cost 22.6 other plant equip | 51.865 | $P_{th}$ |
| Cost 22.7 I&C | 44.189 | constant |
| Cost 22 (Reactor Plant) | 1227.446 | |

# Cost Element Breakdown

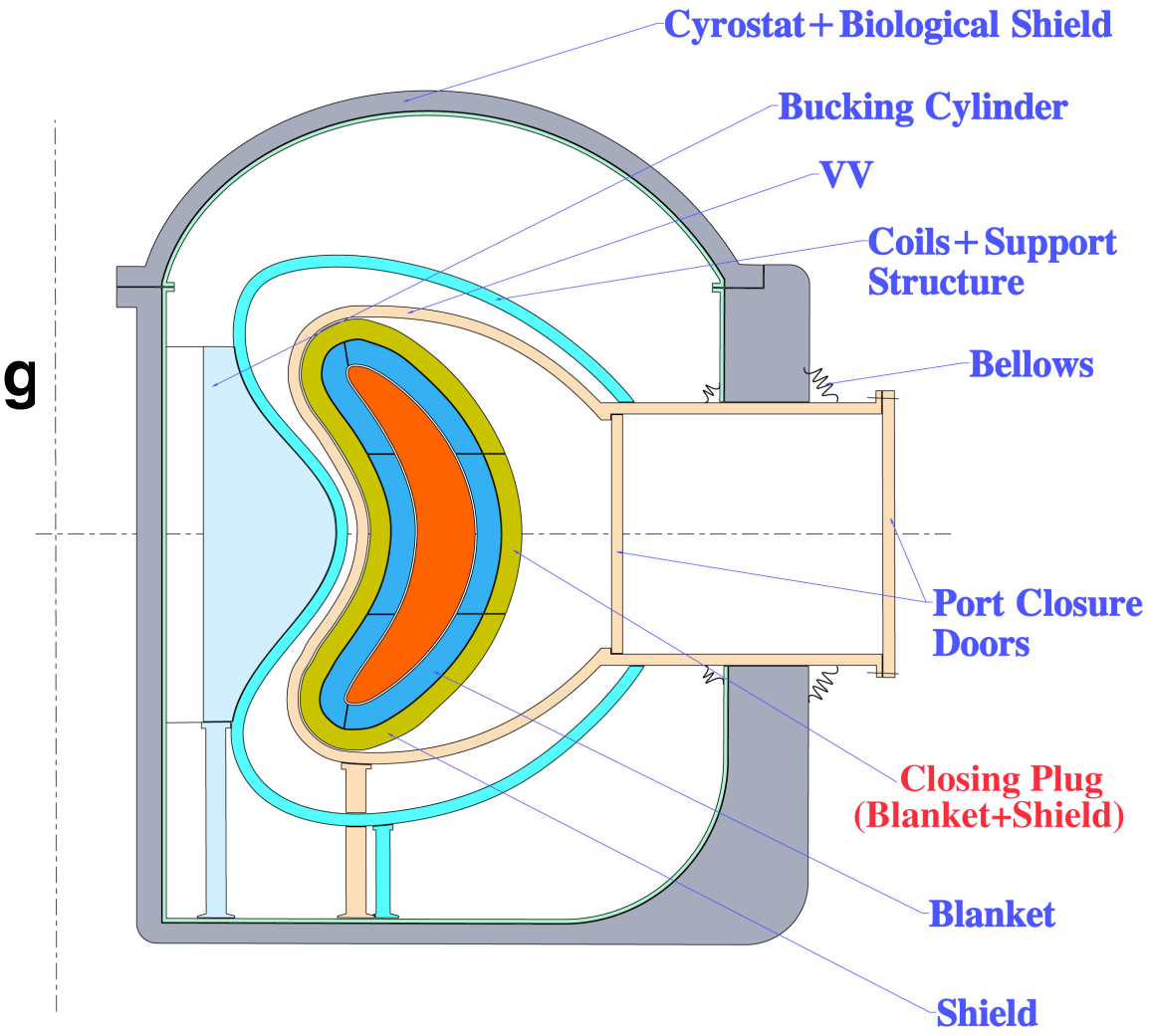
| | | | |
|---|---|---|---|
| Cost 23 (Turbine Plant) | | 319.188 | $(\eta_{th}P_{th})^{0.83}$ + constant |
| 23.3 heat reject. | 47.752 | | $P_{th} - (\eta_{th}P_{th})$ |
| Cost 24 (Electric Plant) | | 127.284 | $(\eta_{th}P_{th})^{0.49}$ |
| Cost 25 (Misc. Plant Eq.) | | 63.770 | $(\eta_{th}P_{th})^{0.59}$ |
| 26.4 other materials | 192.011 | | $V_{LiPb}$ |
| Cost 26 (Spec. Matls.) | | 195.851 | |

# Remaining Code Improvements

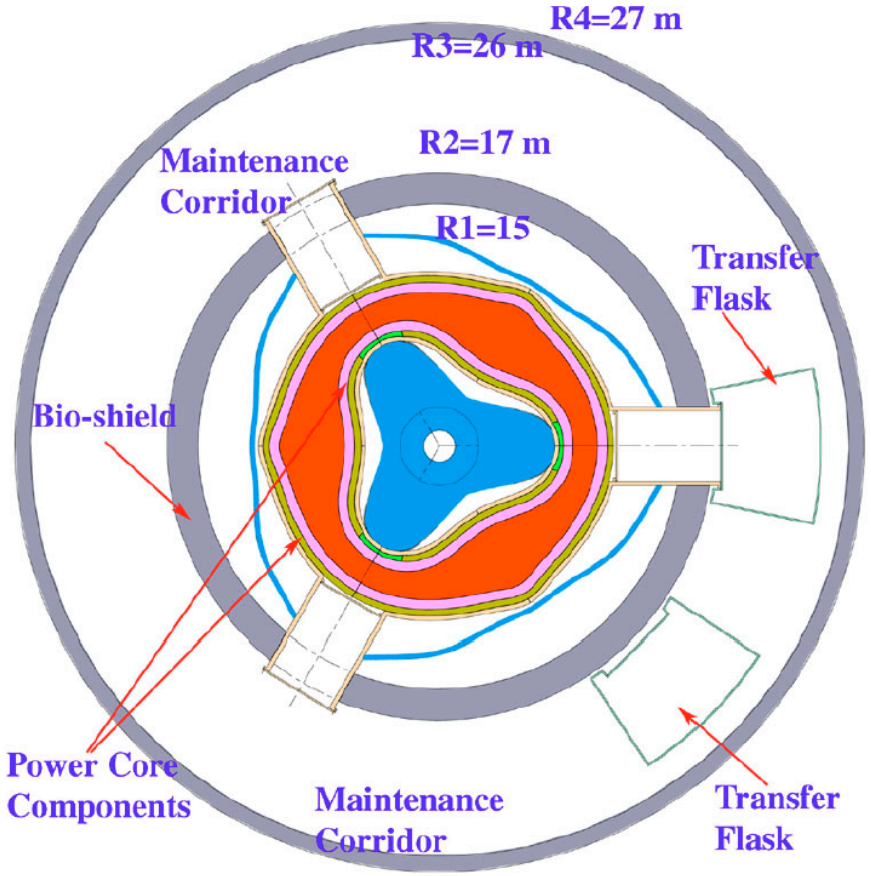
- Divertor treatment
  - areas, thicknesses, costs not included yet
- Need better calculation of coil support structure?
  - 10-cm-thick shell, no bucking cylinder
- Need to improve vacuum systems (22.1.6) cost
  - only includes vacuum vessel cost; need to include other systems (pumping, gas useage/day)
- Need to add $\ln(p_{wall}/2)$ correction to shield thickness
- No vertical field or control coils
  - needed for flexibility and startup
- Cryostat, vacuum vessel & port values for port maintenance approach
- Shield/vacuum vessel geometry for field period maintenance approach
- External vacuum vessel approach?

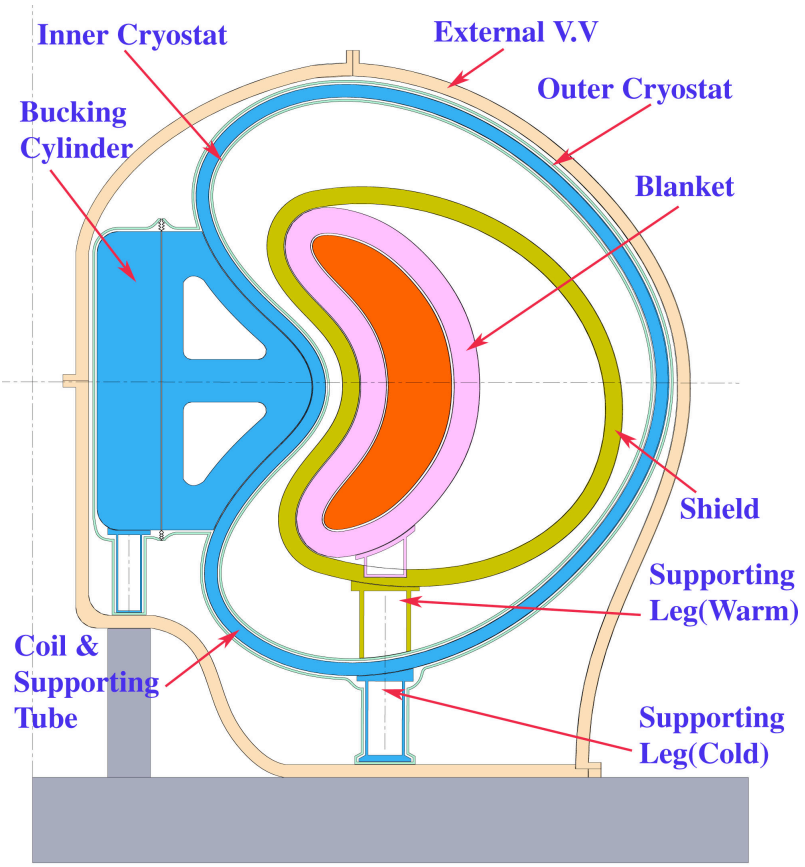
# Need to Refine Treatment of Port Maintenance Approach

- Dimensions of cryostat and biological shield
- Volume of bucking cylinder
- Refine shape of vacuum vessel and add ports?

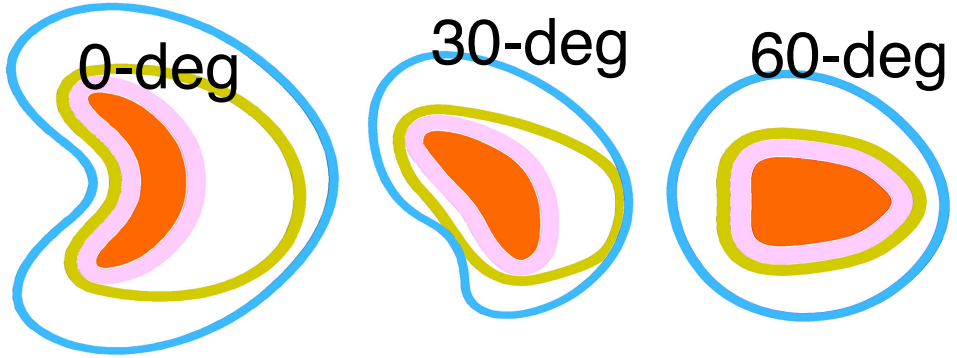


# Field Period Maintenance Approach




- **Requires area of shield surface and external vacuum vessel**



# Summary

- Added 2 new NCSX and 3 MHH2 coil configurations
- Modified blanket/shield model
  - added modified manifolds
- Checked costing algorithms
- Added more output information
- CoE is relatively insensitive to assumptions for a plasma/coil configuration; variation is in H-ISS95
- Need data to analyze sector maintenance approach

  $\Rightarrow$ essential for September selection process