Plasma Power Handling Parameters and Issues

May 1-3, 2000

M. Ulrickson

Presented at the FIRE Physics Workshop

Outline

- Power Distribution
- Divertor Heat Loads
- Divertor Conceptual Design

Power Distribution

- Heating Power - 30 MW
- Fusion Power - 200 MW (9 MW/m^3)
- Alpha Power - 40 MW
- Thermal Power - 70 MW
- Assume:
  - 30% power radiated in core
  - 30% power radiated in the scrape-off layer
- Divertor Power - 34 MW

Power Distribution

- Assume:
  - Inner divertor gets 20%
  - Equal up/down split for double null divertor
- Divertor power distribution
  - Inner - 7 MW (3.4 each)
  - Outer - 27 MW (14 each)

Divertor Heat Loads

- The plasma edge has been modeled using the UEDGE code
- The inner divertor is easily detached assuming no impurity content
- The heat loads for an attached plasma in the outer divertor are 20-25 MW/m^2
- Beryllium and/or neon must be added to the outer divertor to attain detachment
- The heat loads for a detached outer case are less than 5 MW/m^2

Divertor Heat Loads

- For a tungsten thickness of 7 mm the peak surface temperature is 1840C (for 5 mm it is 1400C
- Steady-state temperatures are reached in about 1-2 sec for the cooling parameters assumed.

Peaking Factors On The Heat Flux

- Misalignments are of three types
  - Eccentricity of the TF and the divertor surface (m=1)
  - Misalignments between modules (TF coil period)
  - Accuracy of divertor module fabrication (high frequency)

Misalignment Peaking Factors

- For the m=1 eccentricity the peaking factor is typically 1.2 for a 5 mm displacement
- For module to module in the divertor (n=16) the key decision is whether four quadrant operation is desired
  - If yes, both leading edges will have to be recessed (like the TFTR bumper limiter)
  - If no, only one leading edge needs to be protected (a 5 mm step height yields a peaking factor of 1.09)

Disruption Heat Loads

- Thermal Quench Phase
  - 33 MJ stored thermal energy
  - Loss time 0.2 ms
  - Heated area in the divertor
    - Inner - 9.35 l_E m^2
    - Outer - 10.9 l_E m^2
  - Energy Scrape-off length 1.8-2.3 cm
  - Angle of incidence: outer - 30º and inner - 90º
  - Ratio of heated length: 1 to 3
  - In/out ratio: 1/2
  - Toroidal peaking: 2:1

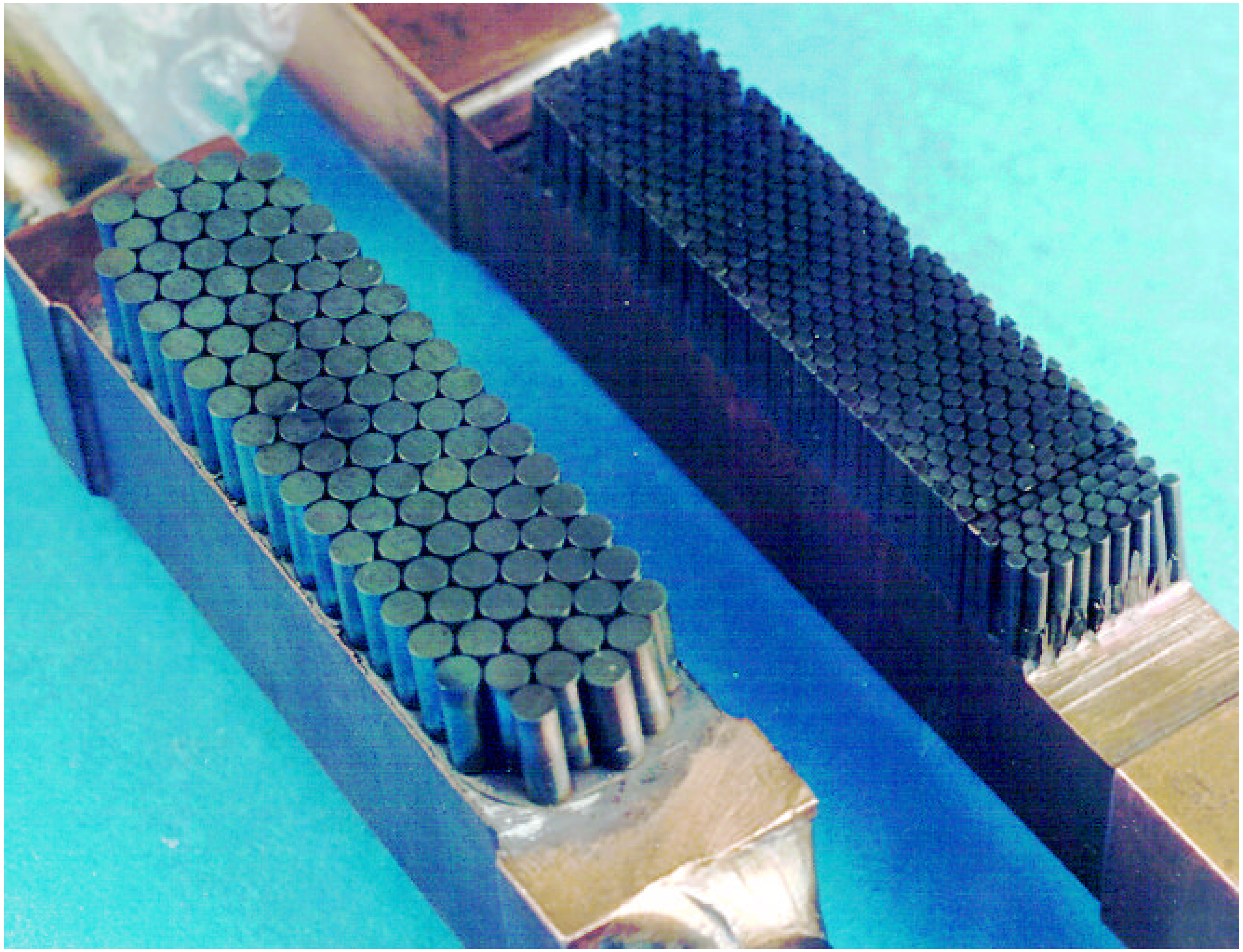
Disruption Heat Loads

- Thermal Quench
- Energy deposition on the divertor plates
  - Inner: 8.5 to 21.8 MJ/m^2 or 42.5 to 109 GW/m^2
  - Outer: 7.3 to 18.7 MJ/m^2 or 36.5 to 93.5 GW/m^2
- These heat fluxes will cause the tungsten surface to melt in about 50 ns after the start of the disruption

Materials Capabilities

- Both the first wall and inner divertor can be passively cooled for a 10 sec pulse
- Recent results from the ITER R&D program have shown that both W and CFC can be used for actively cooled components up to 30 MW/m^2
- These designs use either a monoblock or rod type configuration on a copper alloy heat sink that is water cooled.

Tungsten Rod PFC Mockup



Tritium Issues

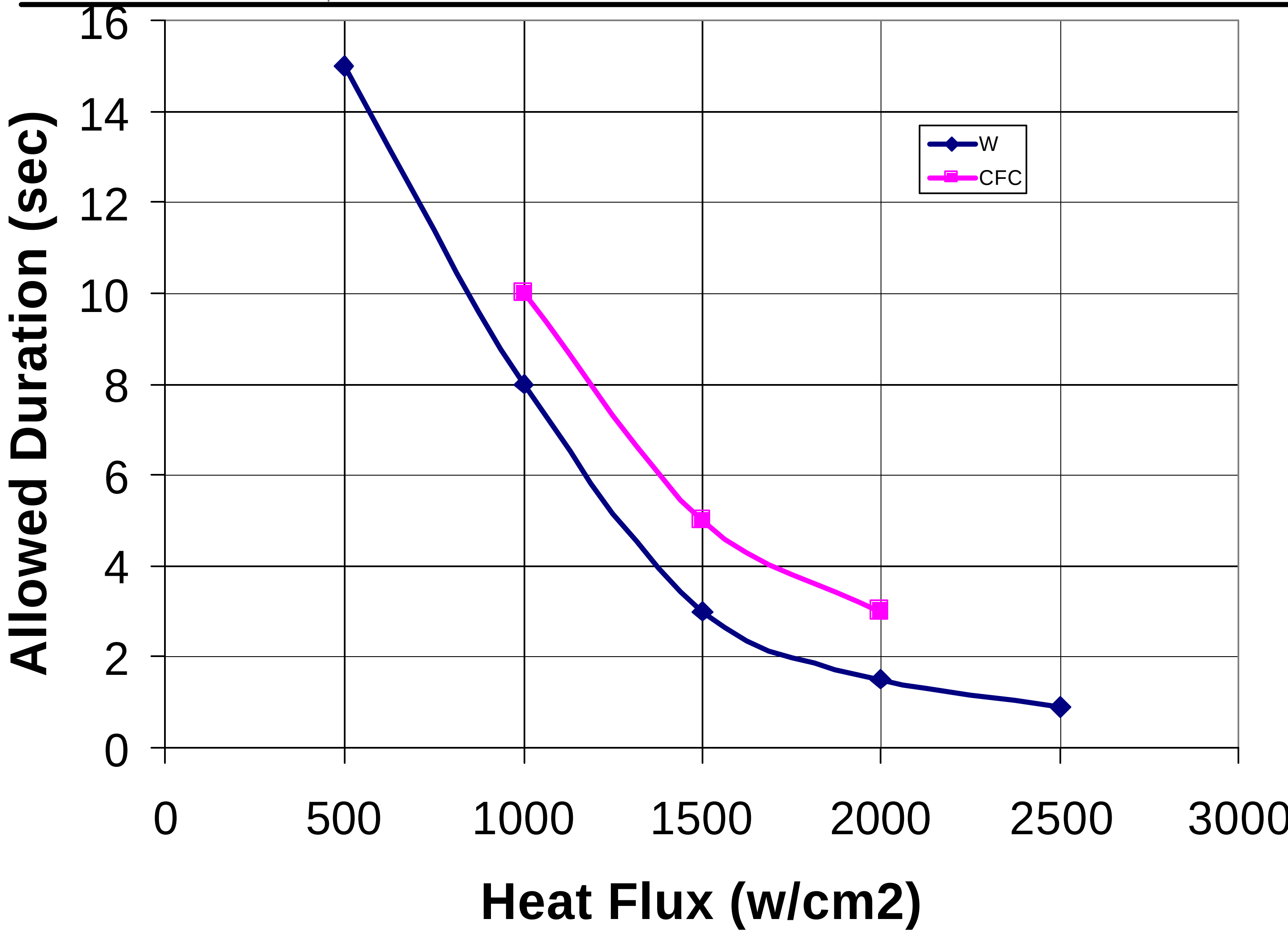
- Both TFTR and JET have found that about 50% of the tritium injected into the machine is trapped in layers of redeposited carbon
- There is no acceptable method for removing such trapped tritium
- This has been identified as a major R&D issue for the continuation of ITER
- Recommendation: DO NOT use carbon based materials in FIRE

Sandia National Laboratories

Materials Selection

- For the divertor
  - Inner divertor: W rods passively cooled
  - Outer divertor: W rods actively cooled
- For the First Wall: Be plasma sprayed on cooled copper passive plates

Allowed Pulse Duration for Passive Cooling



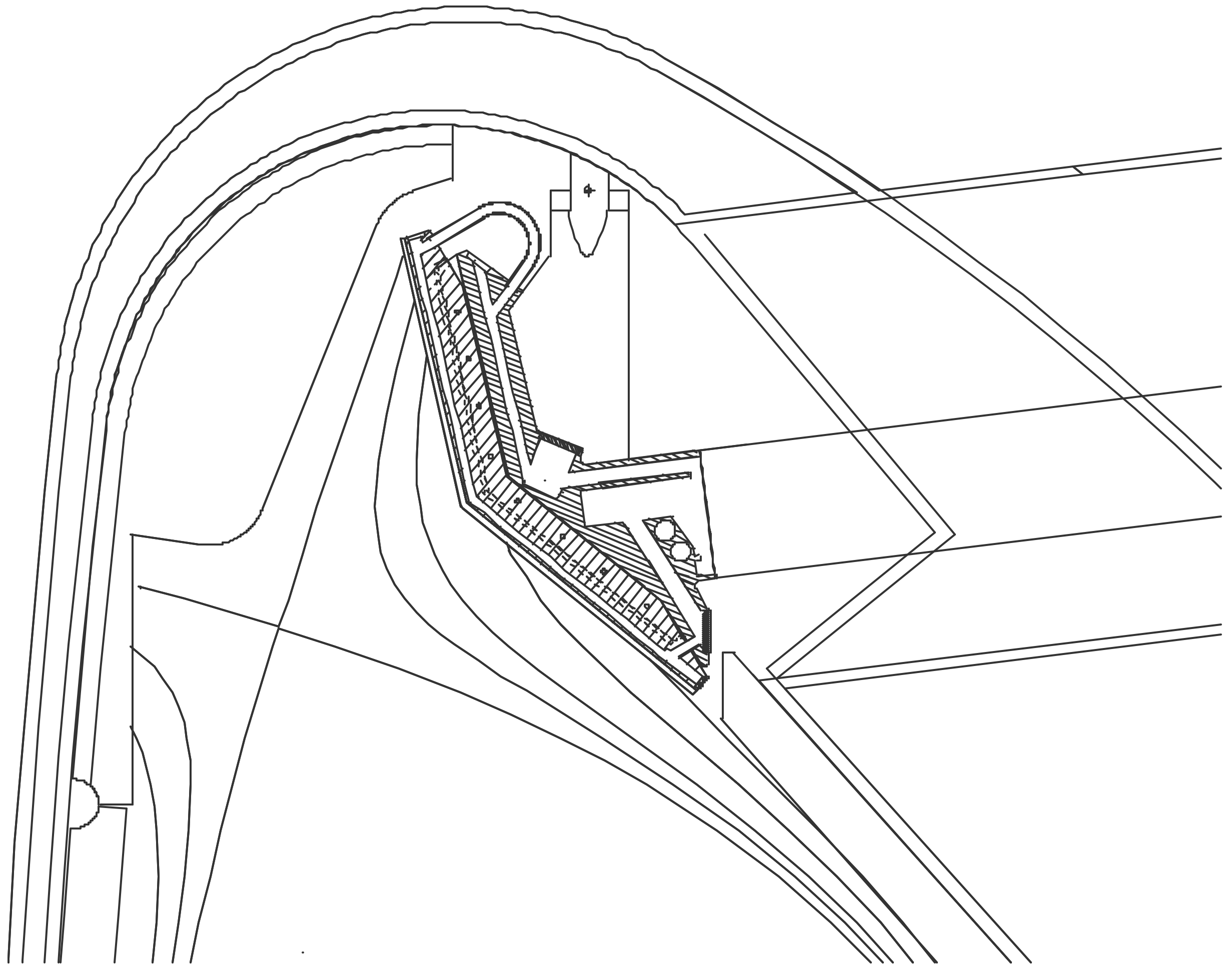
Divertor Conceptual Design

- Modular construction for remote maintenance
- Actively cooled outer divertor
- Passively cooled baffle and inner divertor for baseline case (longer pulses or radiative outer solution will require active cooling of the baffle)
- Analysis of disruption forces is not complete

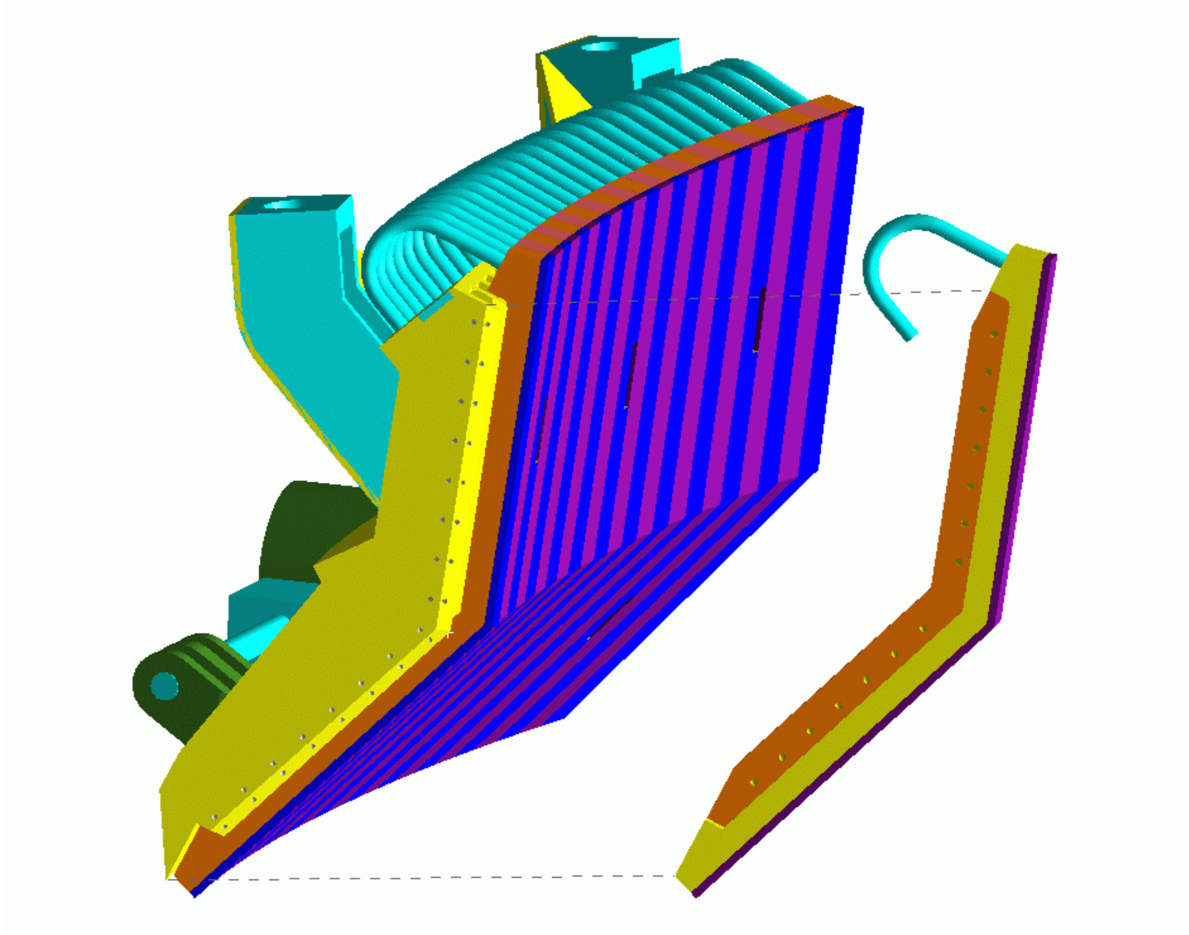
Component Layout

- Relatively open configuration is forced by the proximity of the x-point
- Flux surface spreading is about X6
- The x-point to plate distances are 300 mm outside and 150 mm inside
- The outer divertor plate is at about 60 degrees to the field lines
- The inner divertor plate is nearly perpendicular to the field

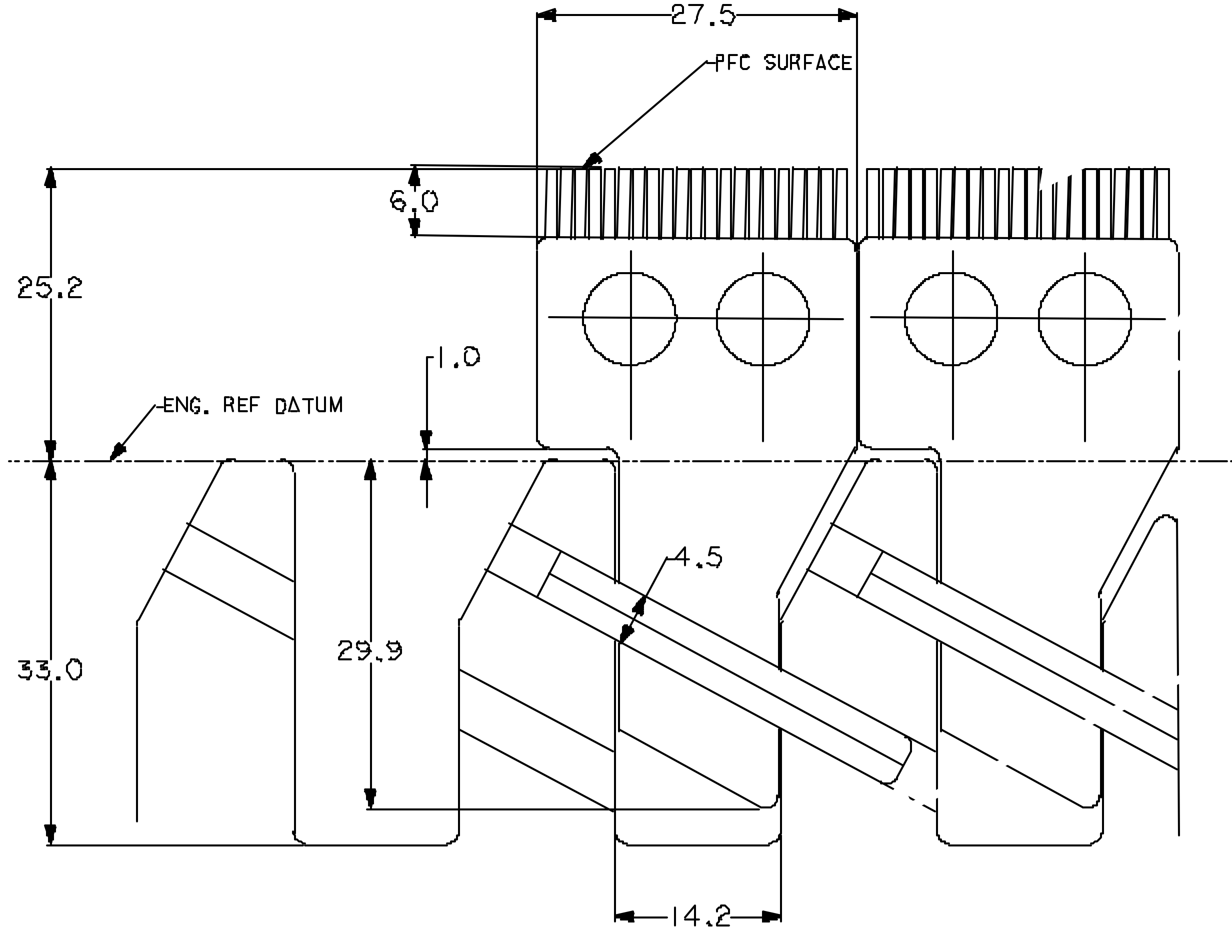
FIRE Divertor Design



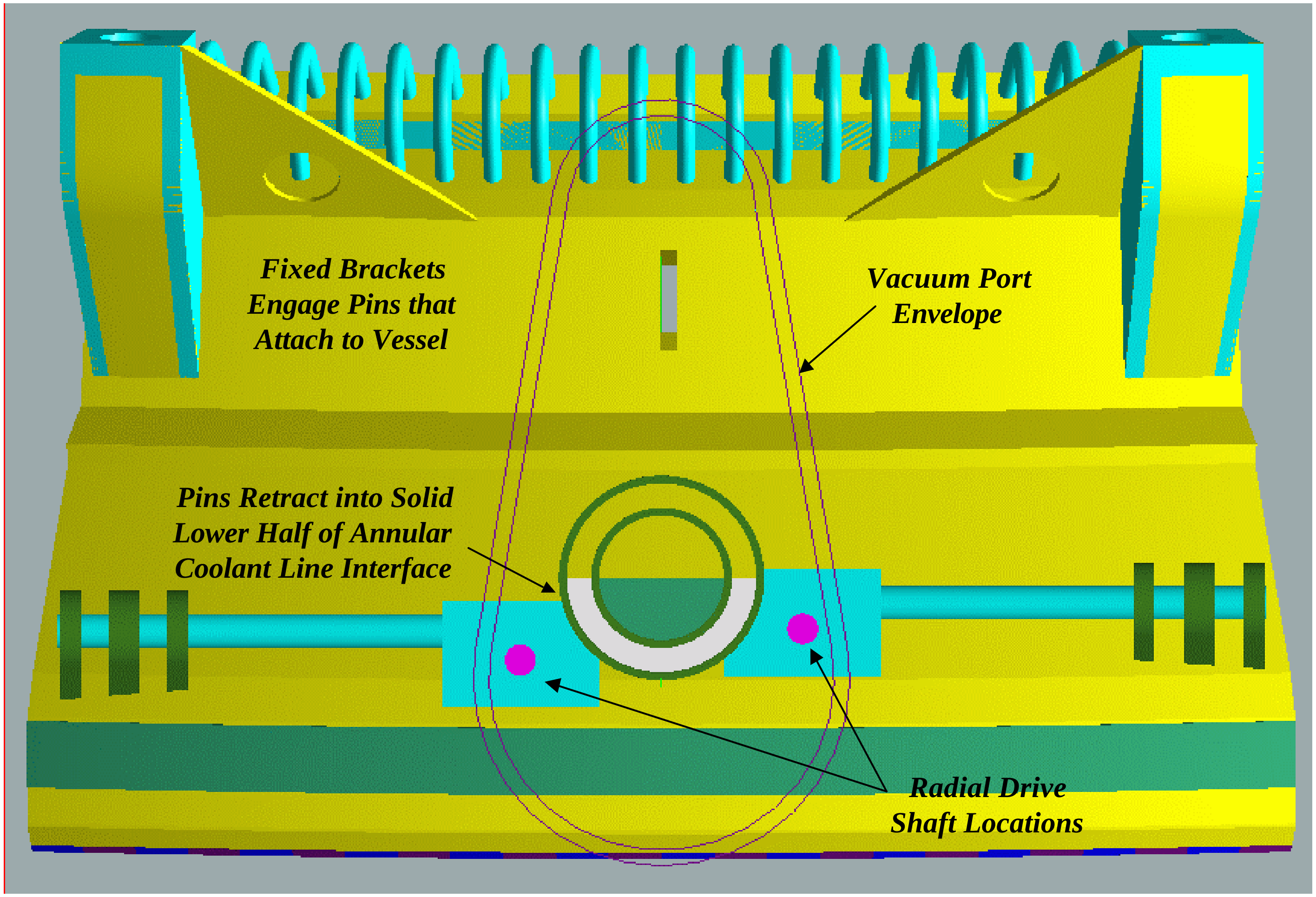
Outer Divertor Module



Divertor Module Construction



Outer Divertor Module



Conclusions

- The physics requirements for the FIRE divertor are challenging.
- Solutions have been found for the design of the plasma facing components
- It is recommended that the divertor be tungsten rods on a copper backing plate with active cooling on at least the outer divertor
- Further analysis of disruption effects is needed

Halo Currents

- Taking either a peaked or a uniform distribution gives the same halo current in the worst location.
- For 16 divertor modules the maximum halo current is 200 kA.
- Module size
  - Inner poloidal length: 0.58 m current path: 0.14 m
  - Outer poloidal length: 0.68 m current path: 0.41 m
- The force exerted on a module is
  - Inner: 0.3 MN
  - Outer: 0.77 MN

Eddy Currents

- The force on the edge of an outer plate is about 1.9 MN
- The force on the edge of an inner plate is about 2.8 MN
- This is a 2.5 times the halo load for the outer and 8.5 times the inner halo load
- Mitigating factors
  - The copper surface is not continuous
  - The stainless steel backing will need to be slotted
  - The convoluted path will add resistance

Sandia National Laboratories

Particle Pumping Requirements

- Loss of particles from the plasma:
  - Number of particles in the plasma 1×10^{22}
  - Energy confinement time 0.5-0.8 s (use 0.65 s)
  - Particle confinement time 2-10 t_E
  - Fueling rate required 3.1×10^{21}/s ($1.25\text{-}10 \times 10^{21}$/s)
  - Assuming the fueling efficiency is 50% implies 6.2×10^{21}/s (23 Pa m^3/s; range 10-75 Pa m^3/s)
- **Recommendation 75 Pa m^3/s maximum fueling rate (net equal D and T)**

Particle Pumping Requirements

- Particle pumping rate required for He removal
  - Fusion burn rate 1 x 10^{20}/s (200 MW)
  - He fraction in the divertor 0.02
  - Wall recycling coefficient 0.5
  - Required divertor pumping is 1.4-2.7 x 10^{22}/s (50-100 Pa m^3/s)
  - Very similar to the previous estimate
- Recommendation provide pumping for up to 100 Pa m^3/s