Design of the FIRE Plasma Facing Components

Presented at the UFA Burning Plasma Workshop II

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Presented By
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Participants

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- C. Baxi, J. C. Wesley, General Atomics
- J. Brooks, A. Hassenein, Argonne National Laboratory
- D. Driemeyer, Boeing Corp.
- C. E. Kessel, Princeton Plasma Physics Lab.
- B. E. Nelson, Oak Ridge National Laboratory
- T. Rognlein, Lawrence Livermore National Laboratory

Outline

- Divertor hardware designs
- Actively cooled outer divertor and baffle design
- First wall and inner divertor design
- Disruption effects
- Benefits for technology development
- Important results for disruption mitigation
- Summary

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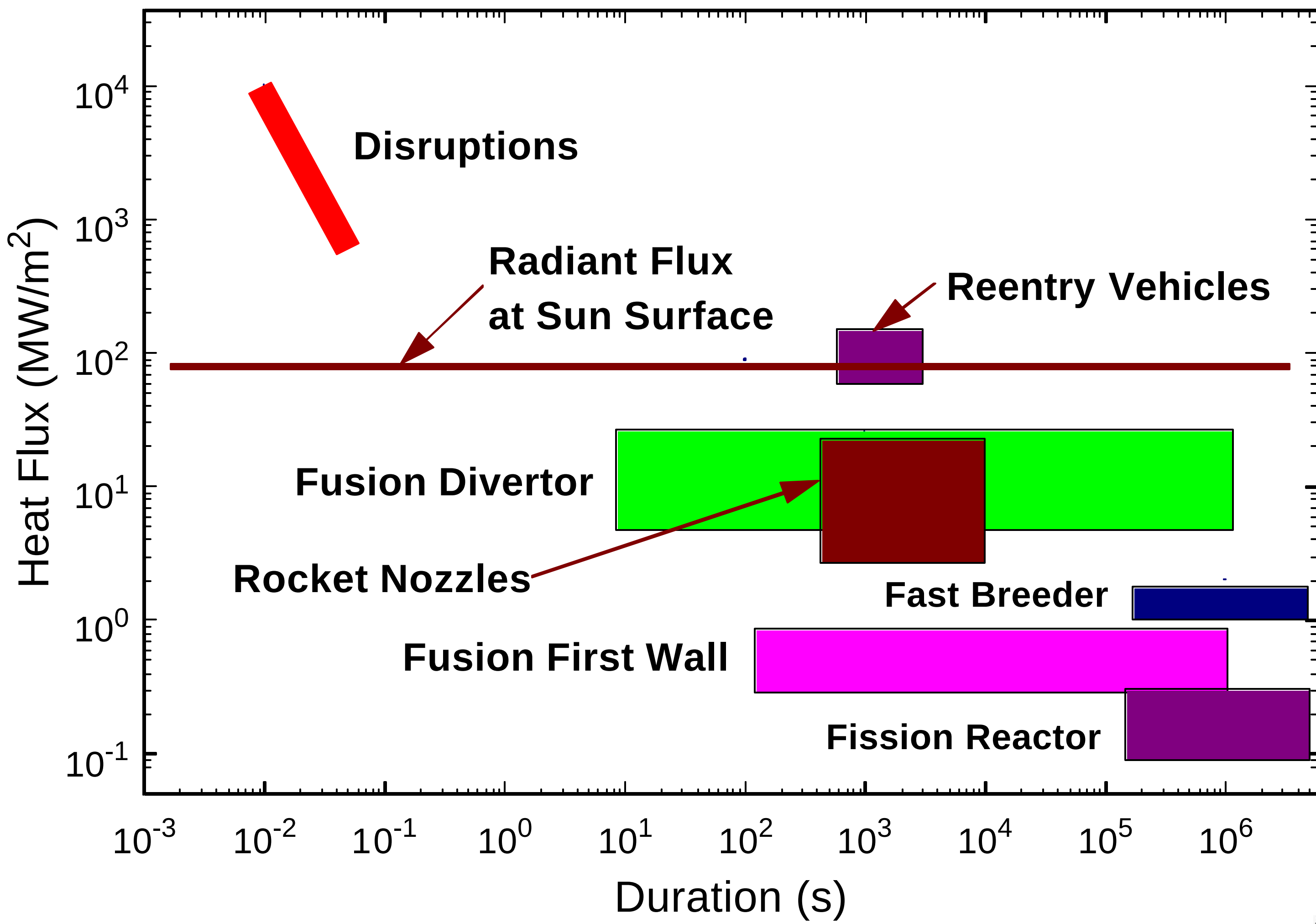
Comparison of Heat Fluxes



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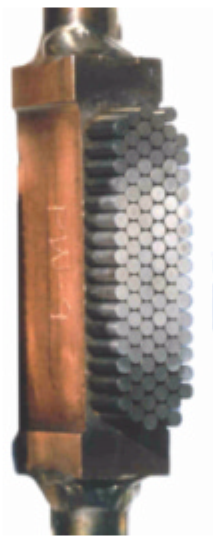
Divertor Design Requirements

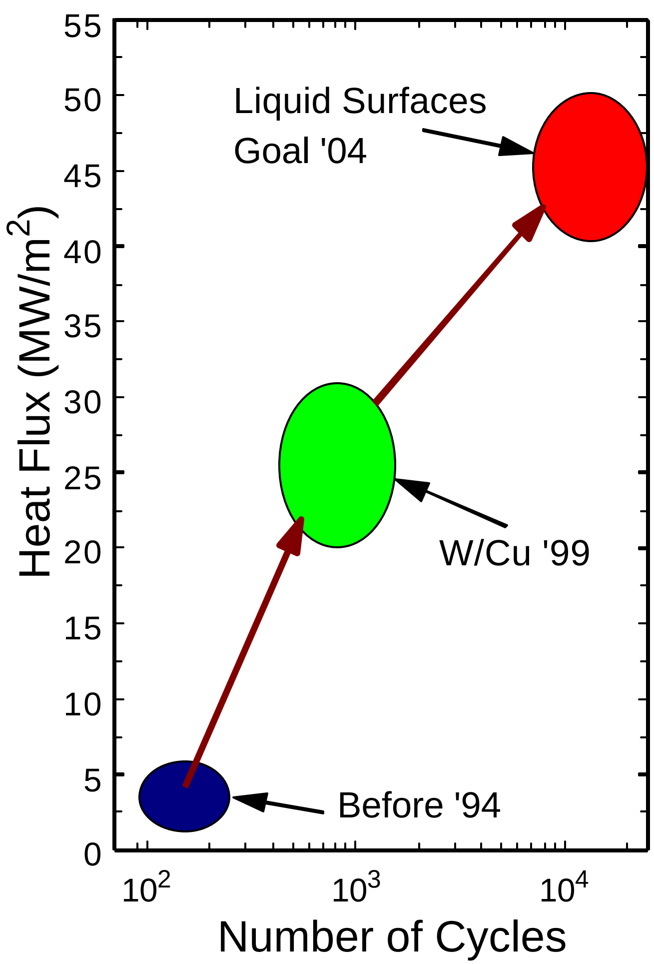
- All PFCs remotely maintained
- Materials selection
  - Divertor W rod surface
  - Water cooled copper alloy heat sinks
  - First wall plasma sprayed Be surface
- First wall and inner divertor attached to cooled copper skin on vacuum vessel
- Eddy current forces determine the strength of attachments and back plates

Progress in PFCs For Burning Plasmas



Tungsten rod component tested at 30 MW/m² (SNL)

Progress in Heat Removal Capability



Plasma interaction with liquid Li (UCSD)

Progress:

- **Reduction of stress using rods on the surface**
- **Low temperature joining**
- **Improved heat transfer enhancement**

Why Choose W Surface for the Divertor?

- Both TFTR and JET have observed large amounts of T retention in redeposited carbon layers and dust (substantial amounts far from the divertor)
- Mechanisms involving hydrocarbon radical transport were presented at PSI
- There is no effective method for removing these layers
- Predicted tritium inventories are mg per burn second

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Why Choose W Surface for the Divertor?

- Tungsten or Molybdenum have been successfully used on ASDEX-U and C-Mod
- The results of the ITER development program have shown W on Cu can withstand up to 25 MW/m^2 without damage
- High Z materials have very low predicted erosion and low T retention

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Thermal Analysis of PFCs

- Driemeyer (Boeing) and Baxi (GA) have performed thermal analysis of the divertor design
- The outer divertor is actively cooled with a swirl tape in the cooling channel in the copper heat sink
- The baffle is actively cooled but there is no heat transfer enhancement in the cooling channel
- The inner divertor and first wall are attached to the cooled copper liner in the vacuum vessel

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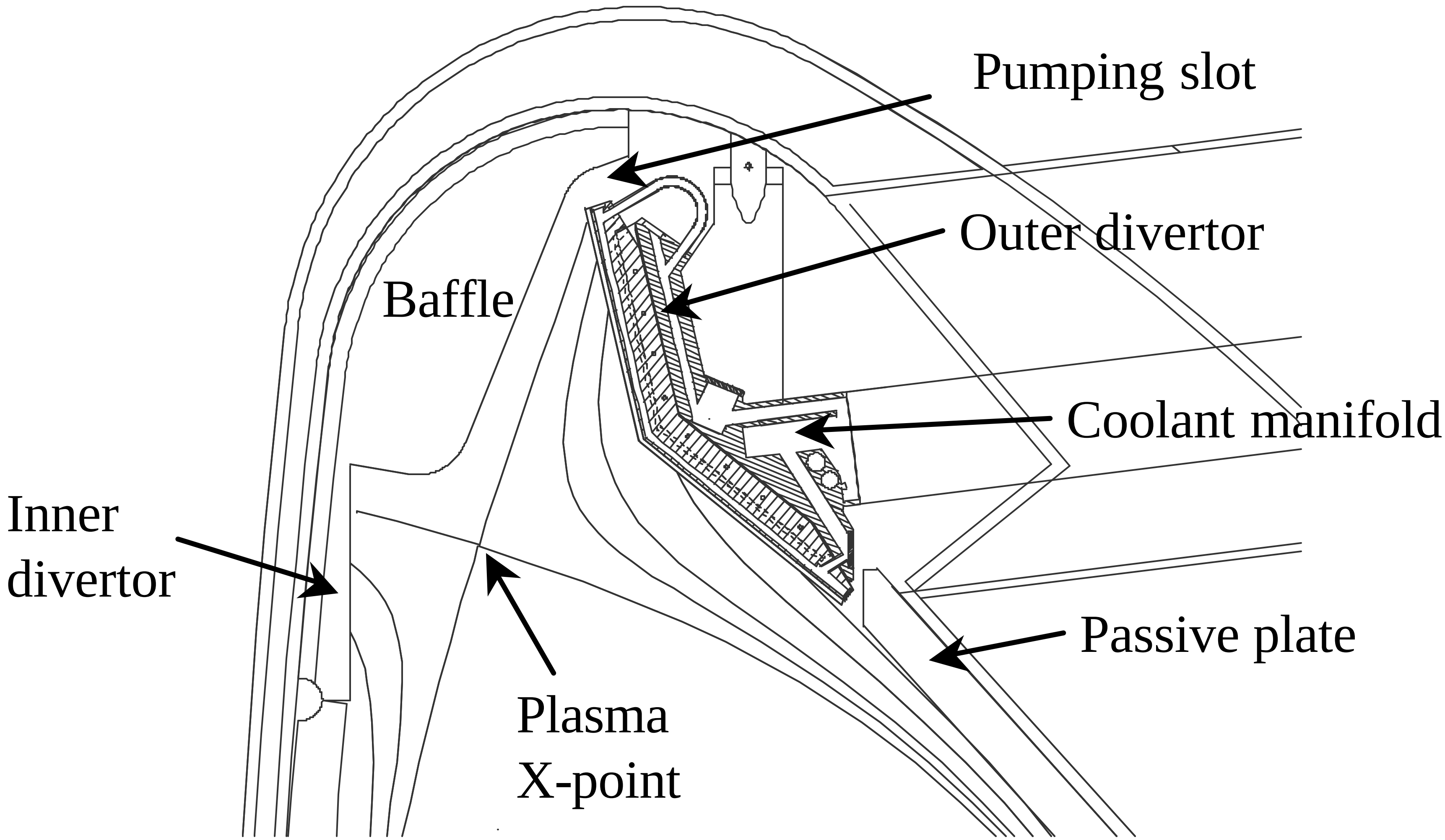
FIRE Divertor Design



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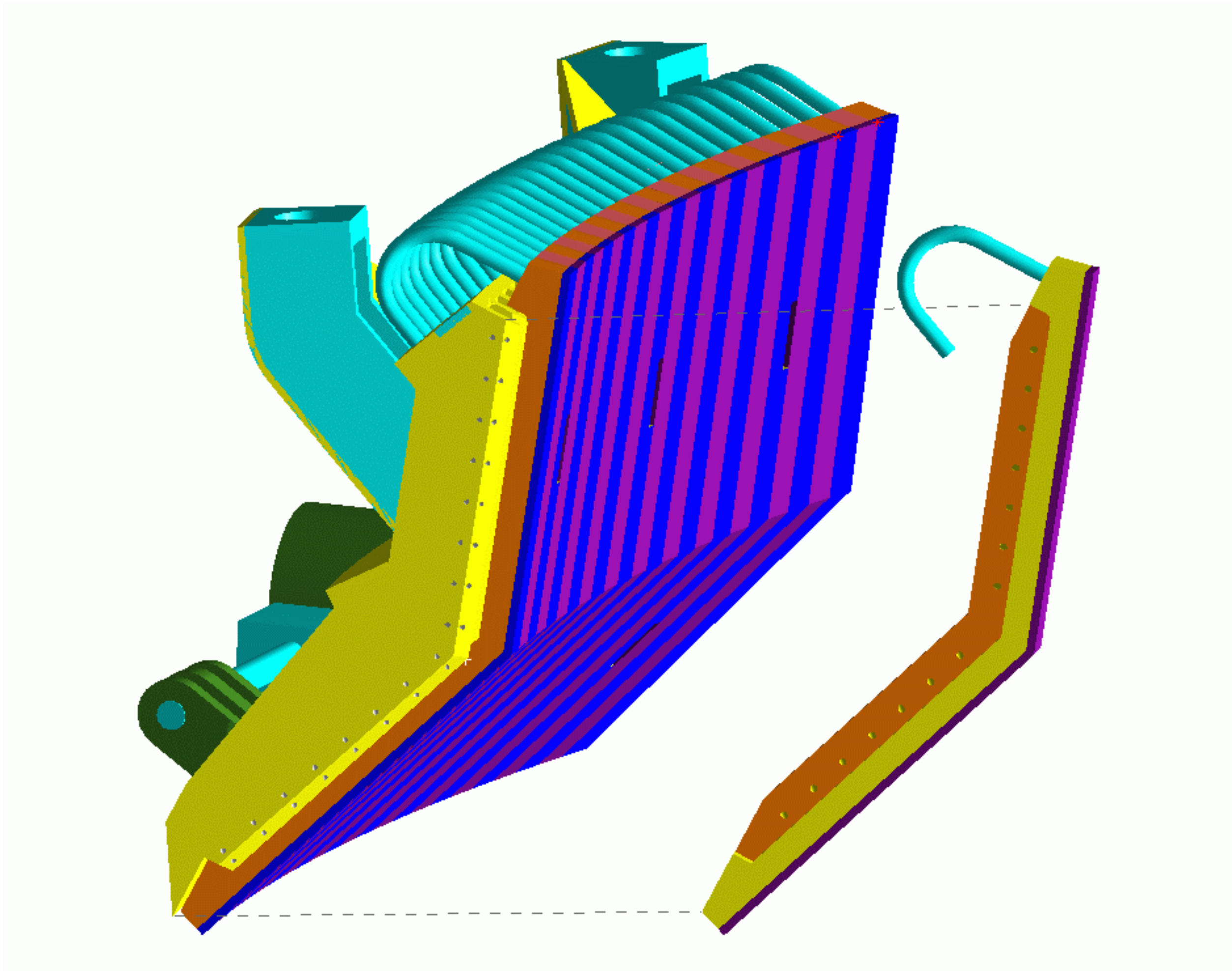
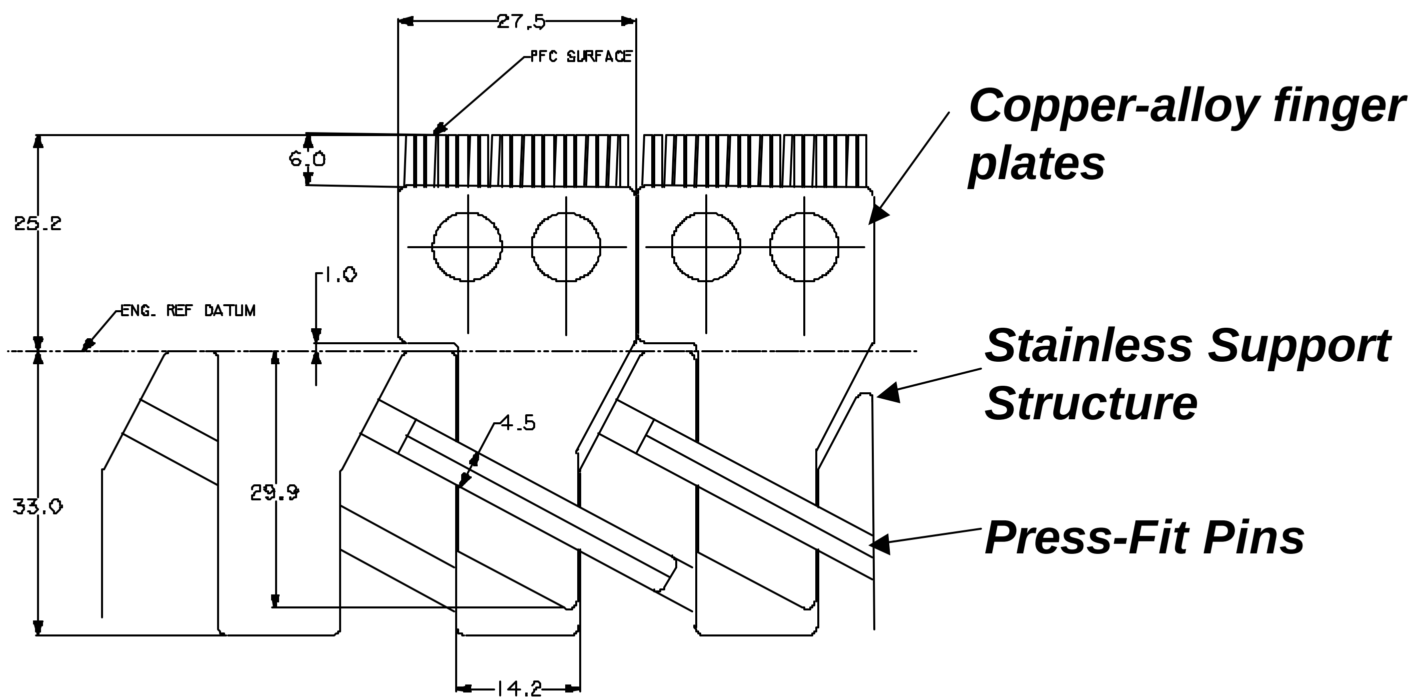
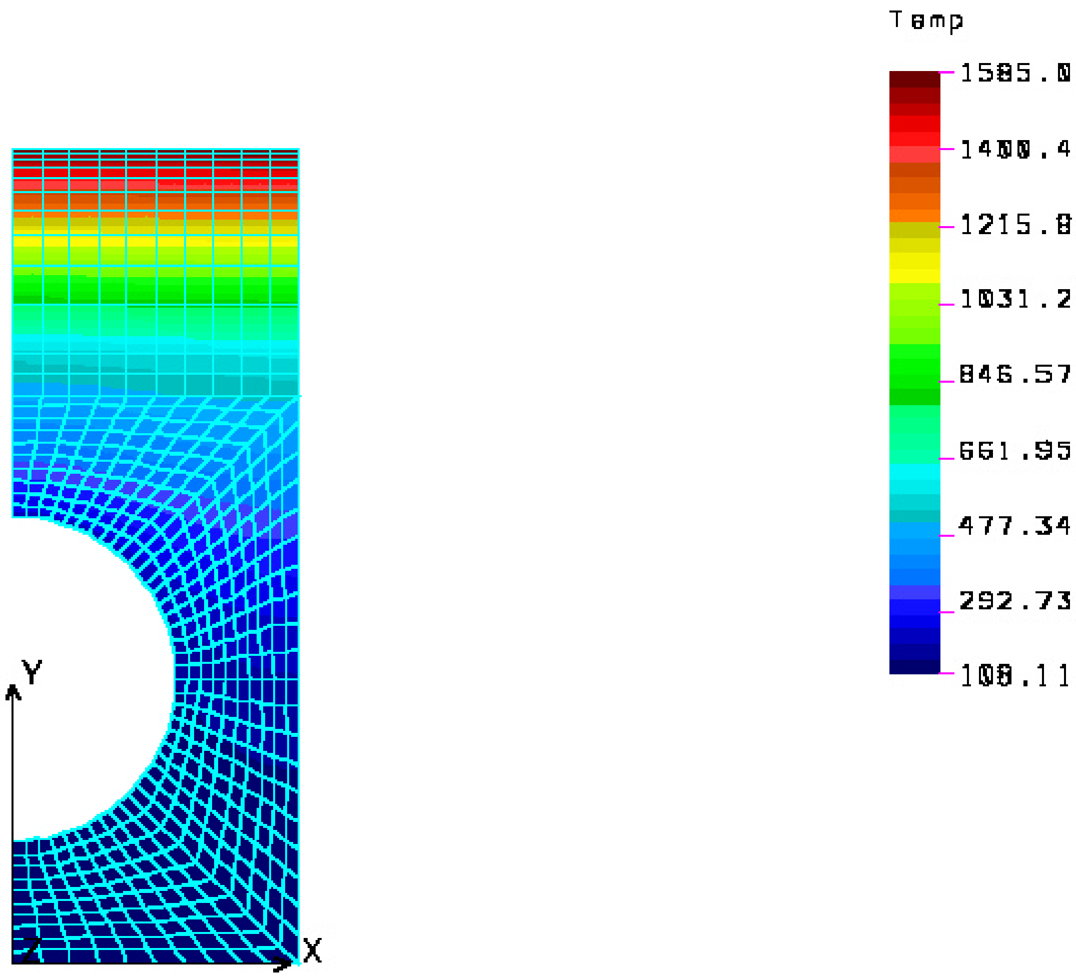
Outer Divertor Design



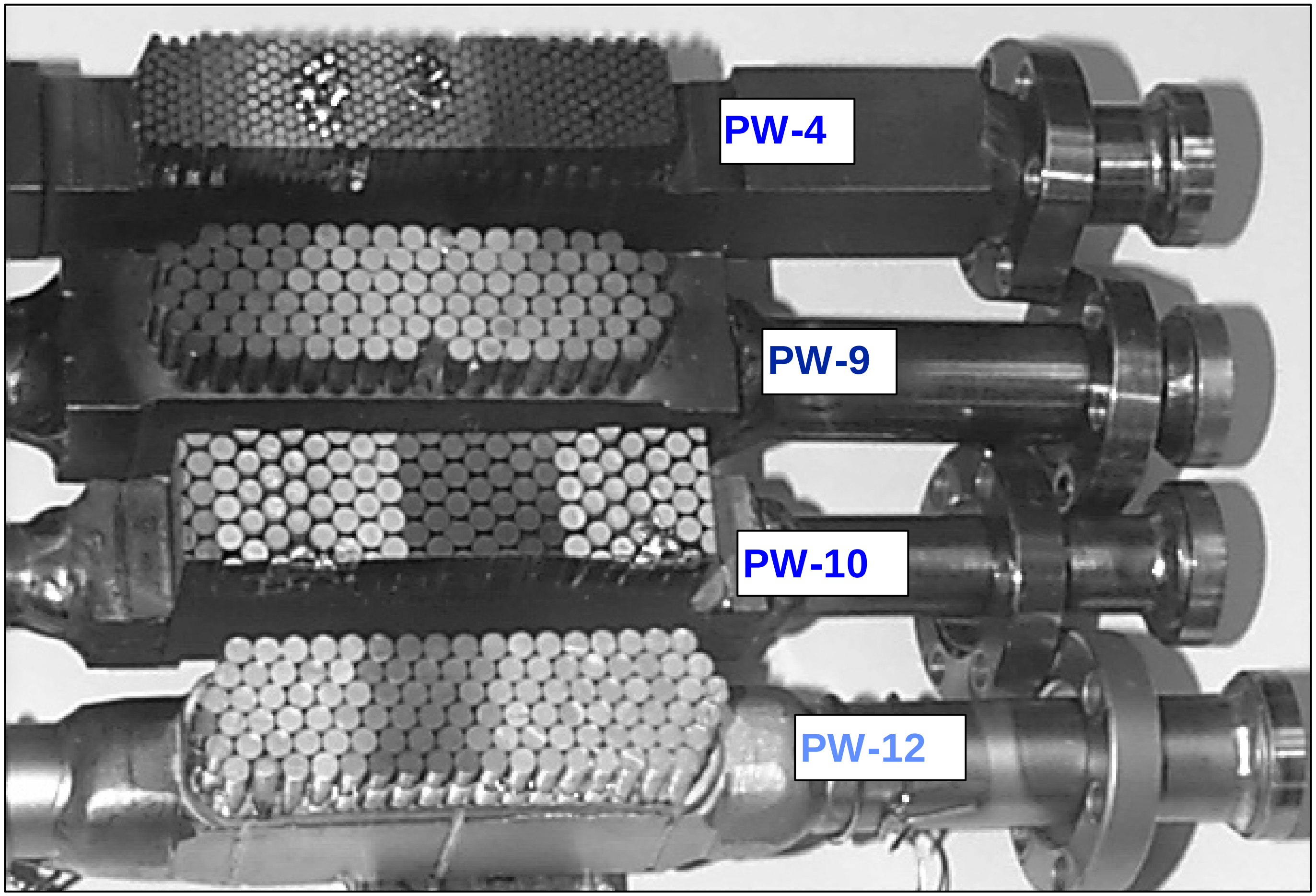
Outer Divertor Design



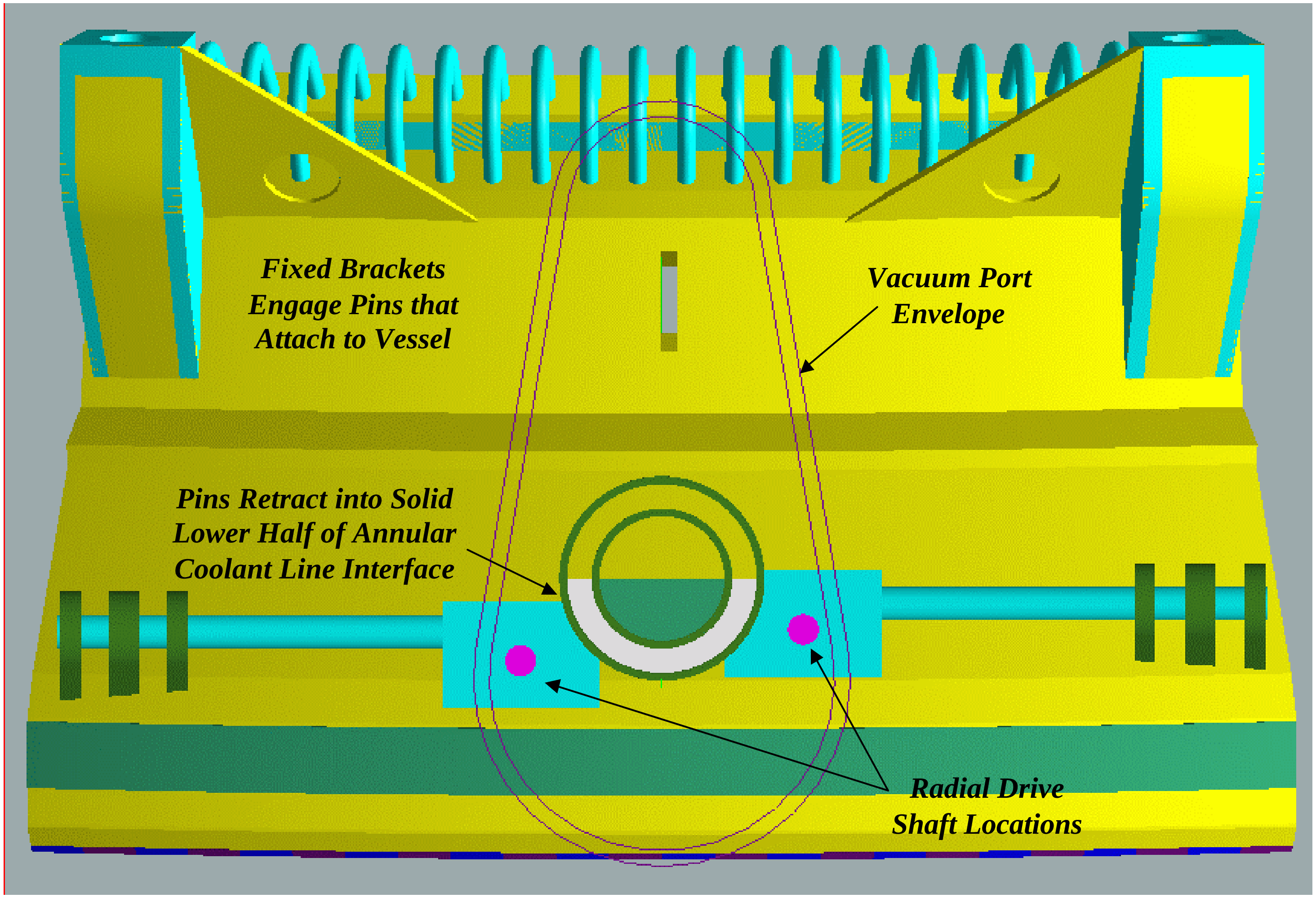
Thermal Analysis of PFCs



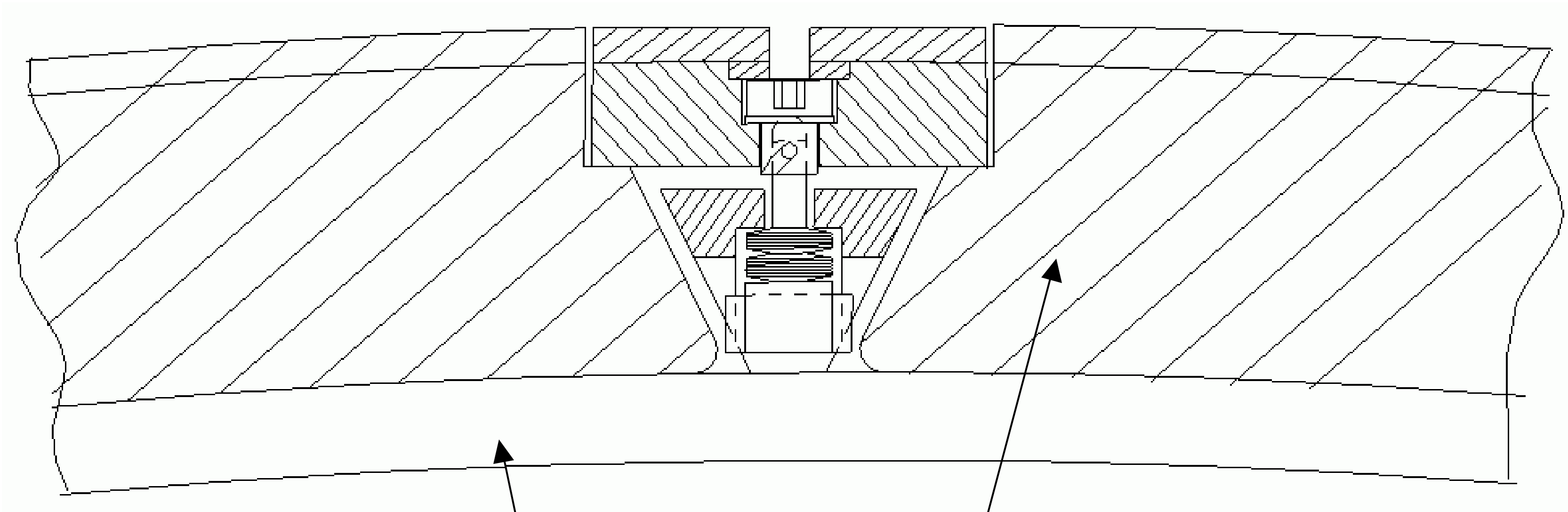
W Rod Test Articles



Backside of Outer Divertor



Design of 1st Wall and Inner Divertor



PFC tiles

Cu shell on VV

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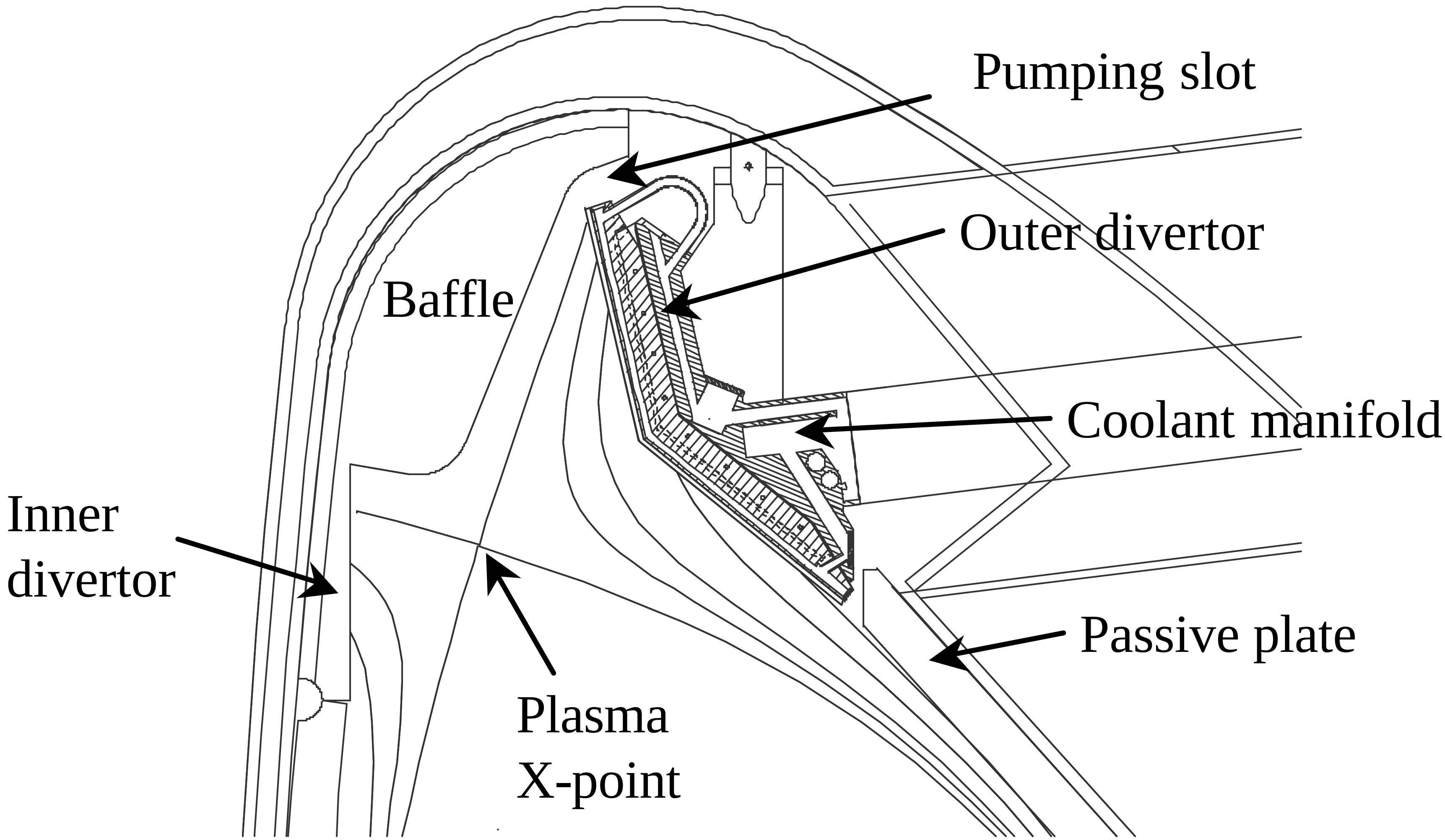
FIRE Divertor Design



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Particle Pumping Requirements

- **Loss of particles from the plasma:**
  - **Number of particles in the plasma 1 x 10^{22}**
  - **Energy confinement time 0.5-0.8 s (use 0.65 s)**
  - **Particle confinement time 2-10 $?_E$**
  - **Fueling rate required 3.1 x 10^{21}/s (1.25-10 x 10^{21}/s)**
  - **Assuming the fueling efficiency is 50% implies 6.2 x 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

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Analysis of Disruption Thermal Loads

- **Hassanein (ANL) used the A*Thermal code to determine the melting and vaporization of W due to thermal loads during disruptions**
- **Energy deposition was taken from Wesley's analysis**
- **Melting begins 10?s after the disruption begins**
- **Vaporization begins 15 ?s later than melting**
- **The amount of vaporized material is limited by vapor shielding**

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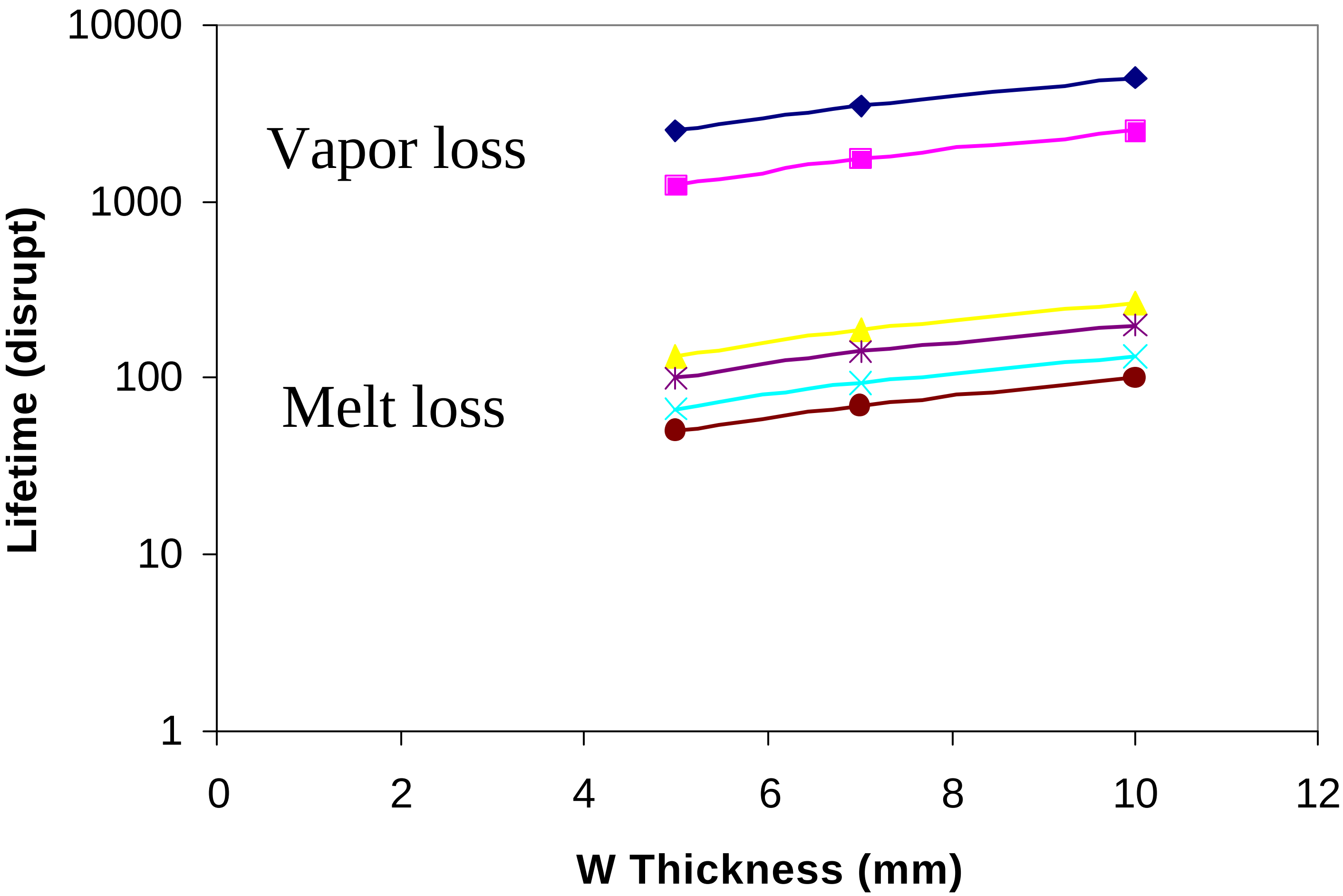
PFC Lifetime Due To Disruption Erosion



Benefits for Technology Development

- Heat flux typical of all burning plasma designs being considered
- Pulse long enough to test active cooling
- Substantial data on PMI and tritium effects
- Remote maintenance required
- Full neutron effects not present (advantage and disadvantage)
- Excellent platform to prove disruption mitigation
- Steady state fueling and pumping

Recent Results on Disruption Mitigation

- At the PSI Meeting in May there were several important papers concerning disruption prediction
  - The ASDEX group has developed a neural network that predicts the time before a disruption
    - the network has predicted disruptions with 50 ms warning and an accuracy >90% with <5% false alarms
  - A similar technique has been used on JET with good results
- This is sufficient warning to take action to mitigate the effects of a disruption

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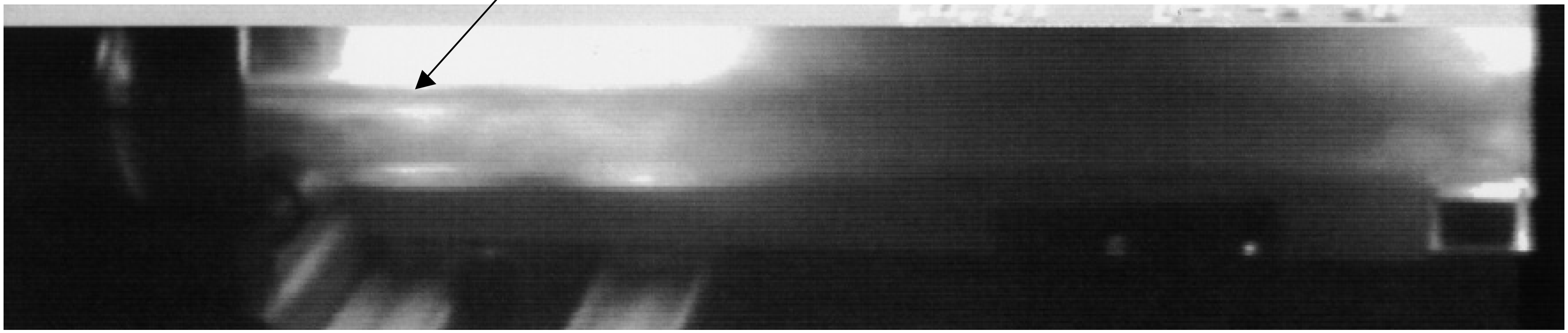
Liquid Jets for Disruption Mitigation

The liquid core of the jet is clouded by mist that surrounds the jet. This jet is traveling in air, but the next phase of the work will be into a vacuum.

Parameter	DIII-D Goal	Achieved to Date
Reynolds No.	**1.2E6**	**8.2E5**
Weber No.	**7.6E6**	**3.7E6**
Jet L/D	**2000**	**1000**

360 m/s Water Jet



Summary

- A pre-conceptual design has been completed for the FIRE PFCs
- The outer divertor and baffle are actively cooled
- The first wall and inner divertor are attached to a cooled copper skin on the vacuum vessel
- Disruptions are the strongest driver in the PFC design
- A new technique for predicting disruptions has been developed that offers the potential for mitigation of disruption effects

Summary

- The divertor design is sufficient for all proposed operating modes for FIRE
- The life limiting events for the PFCs are disruptions
- Disruptions also determine the design of the backplates and mounting features
- Important benefits for technology development
- New results suggest disruptions may be able to be mitigated