FIRE Plasma Facing Components

Pre-Conceptual Design

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Outline

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- **Why Choose Double Null?**
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- **FIRE Divertor Design**
- **ELMs on FIRE**
- **Disruption Specifications & Analysis**
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Participants

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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 on Cu
- First wall and inner divertor attached to cooled copper skin on vacuum vessel
- Eddy current forces determine the strength of attachments and back plates
- Double null configuration

Why Choose Double Null?

- There are results that indicate vertical stability can be improved by operating the single null plasmas slightly off center vertically. Double null plasmas should be even better.
- Since the PFCs are actively cooled, we can use the power in the coolant to monitor or control up/down ratio. The time constant of the plates is < 1s.
- The average power loading is lower in a double null configuration. We are near the power handling limit.

Operating Scenarios

Case	P_{fusion}	P_{heat}	$P_{divertor}$	Duration
Baseline	150 MW	20 MW	28 MW	20 s
D-D	5	16	8	214
AT Mode	200	45	22	20

UEDGE Modeling Results

Case	Te_m (eV)	λ_m (cm)	Te_p (eV)	Ne_p ($10^{21}/m^3$)	Q_p (MW/m^2)	λ_p (cm)
A	106	0.8	1.5	61	5.7	6.5
B	152	0.6	15	44	25	1.8
C	138	0.7	14	43	23	2.3
D	138	0.7	13	52	19	2.5

UEDGE Modeling Results

- The inner divertor is easily detached.
  - Particle flux ~ 1 MW/m^2
  - Radiated power flux 1.8 MW/m^2
- Addition of Be (2%) to the outer divertor cases increases the radiated power to about 6 MW/m^2 and decreases the particle power to 20 MW/m^2
- Addition of Ne to the outer divertor causes partial to full detachment (~12 Mw/m^2 to ~6 MW/m^2)

FIRE Divertor Capability

- Outer divertor
  - Maximum power load 20-25 MW/m^2
  - Pulse length unlimited (actively cooled)
- Inner divertor and baffle
  - Maximum power load 1-5 MW/m^2
  - Pulse length 10-50 s with passive cooling
- First Wall
  - Power 0.3-0.6 MW/m^2 for up to 50 s passive cooling

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 τ_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)

Sandia National Laboratories

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

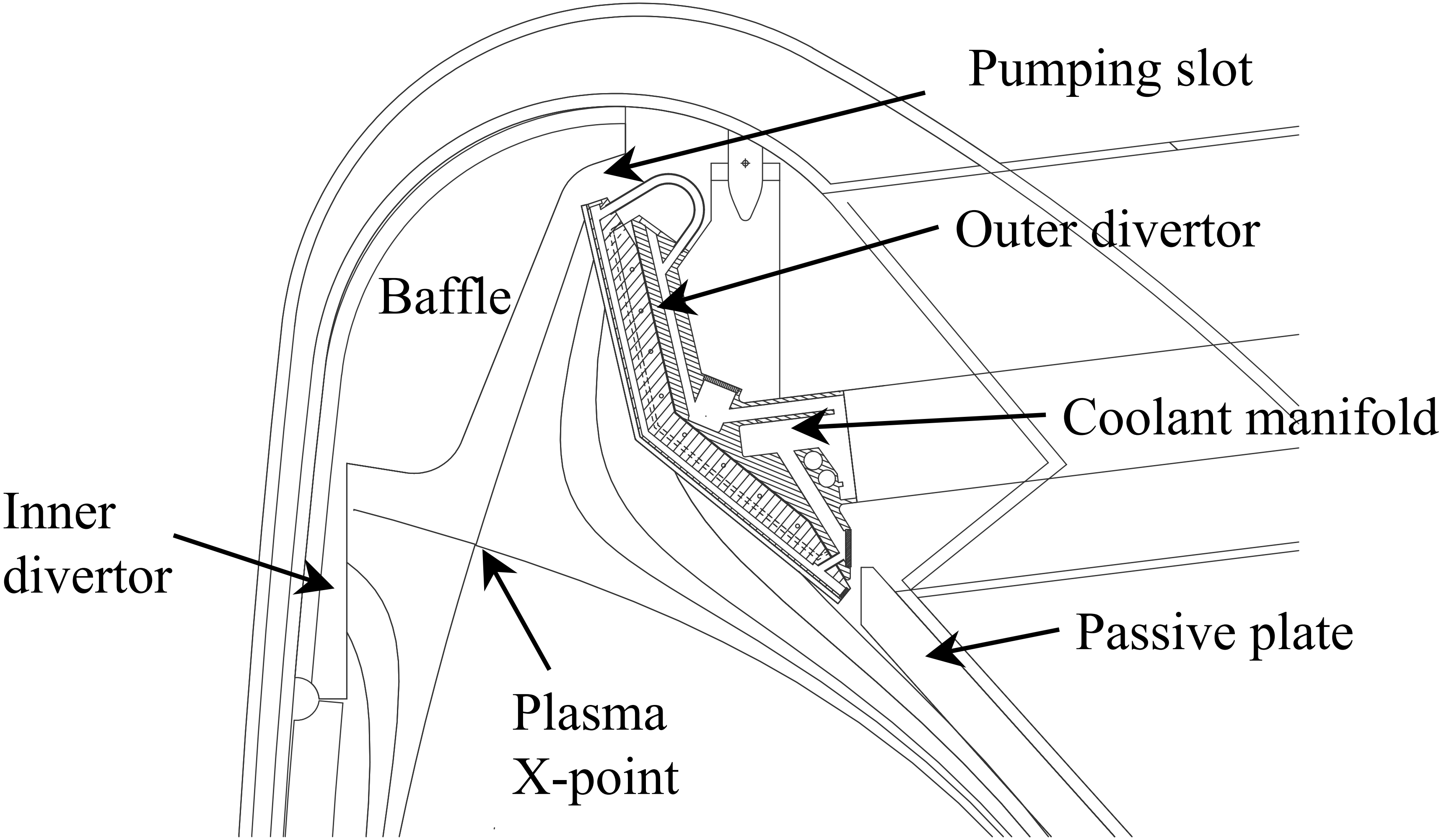
Why Choose W Surface for the Divertor?

- 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

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

FIRE Divertor Design



Pumping slot

Outer divertor

Baffle

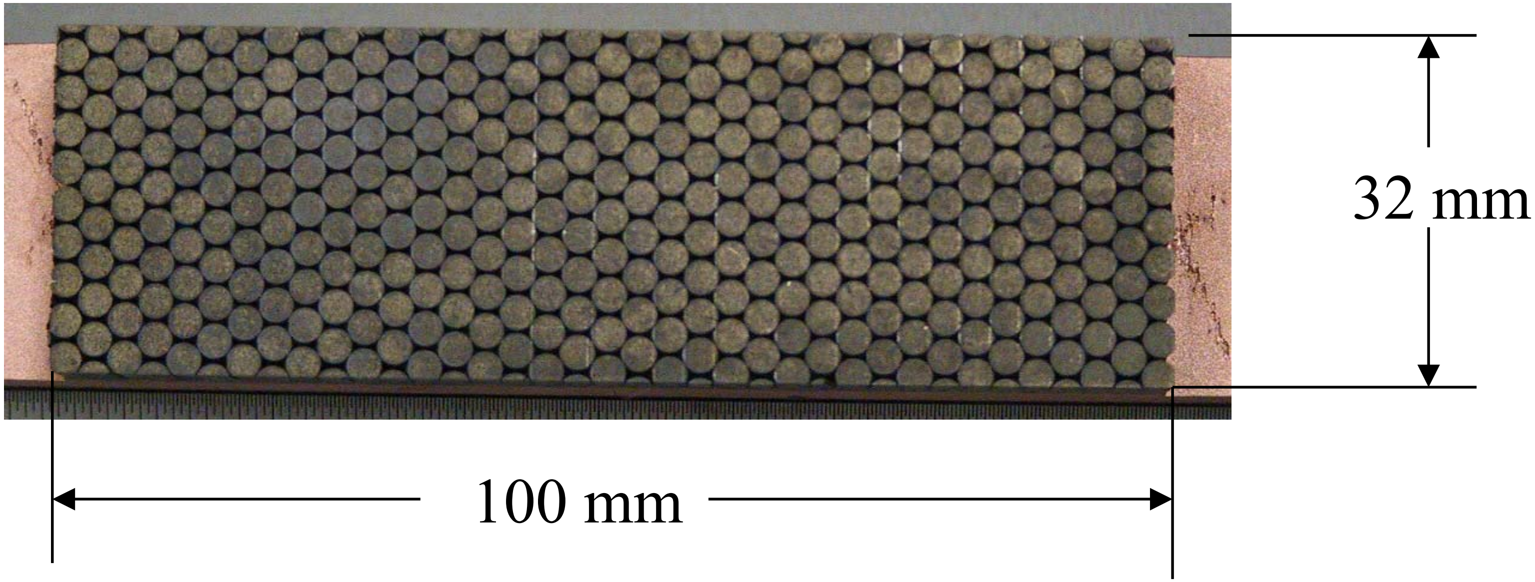
Coolant manifold

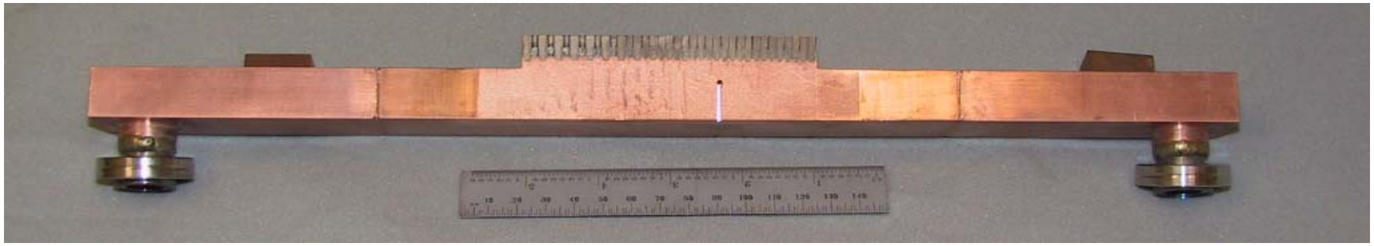
Inner divertor

Passive plate

Plasma X-point

Tungsten Rod PFC Design





Rods 7 mm long

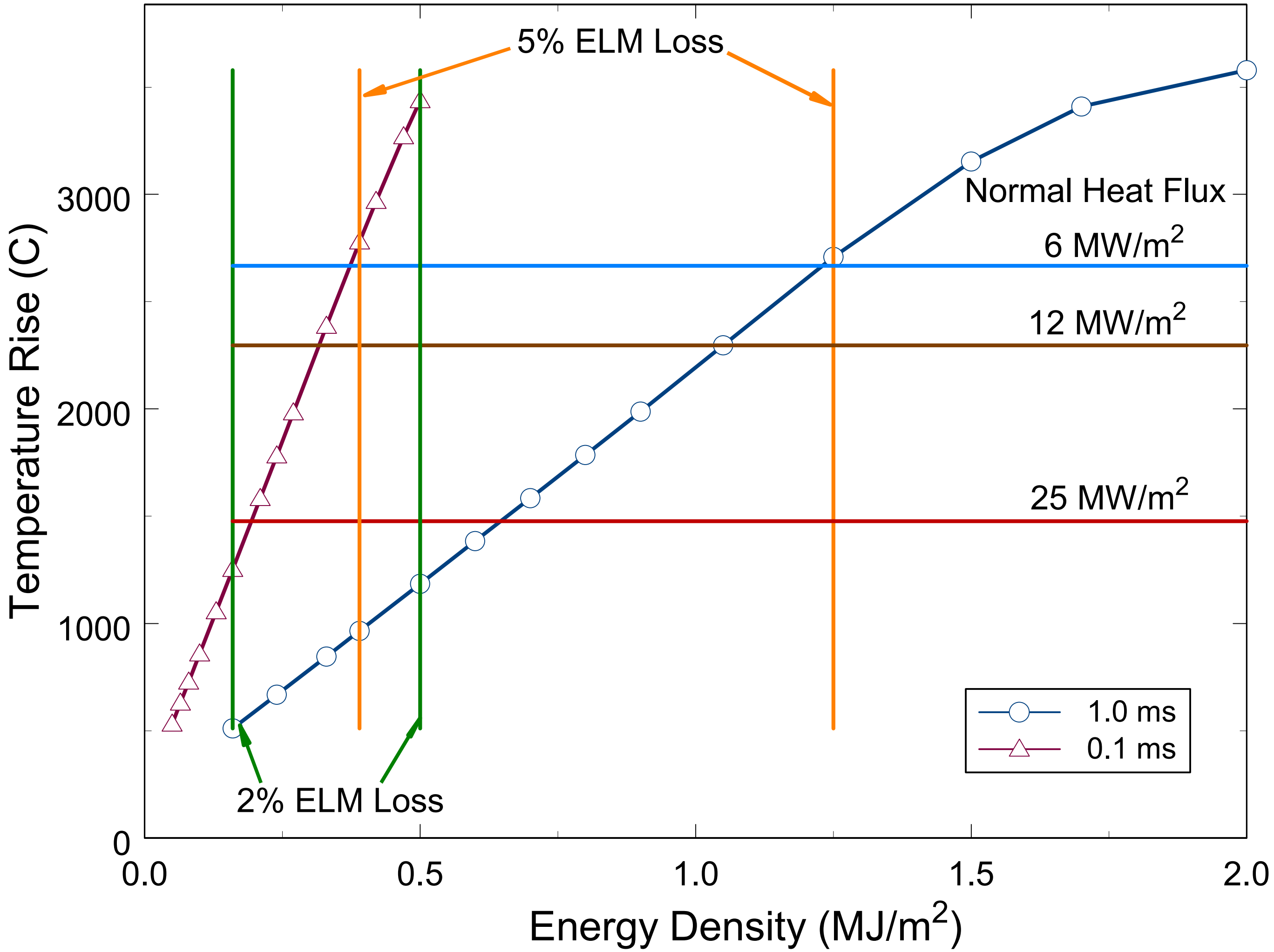
ELMs on FIRE

- ELM Energy Deposition on the FIRE Divertor Plates assumed
  - Either 2% or 5% of stored energy lost
  - Energy deposited over either the same footprint as normal operation or a greater area up to three times larger
  - The duration of the ELM was between 0.1 and 1 ms
- ELMS are no problem if no surface melting occurs

ELMs on FIRE

- Melting will not occur if the energy deposition is less than the intersection of the temperature rise curve and the normal operating line
- Most of the 2% cases are acceptable, few of the 5% cases are acceptable
  - Limit for 0.1 ms duration is about 0.3 MJ/m^2 (partially detached operation, 12 MW/m^2)
  - Limit for 1.0 ms duration is about 1.0 MJ/m^2 (partially detached operation, 12 MW/m^2)
- We must reduce the magnitude of ELMs

ELM Analysis For FIRE



Possibilities for ELM Mitigation

- Report - G Saibene – EFPW 2001
- At high density (nped >70% nGR), ELMs losses can become purely convective (particle ELMs), with ∇TELM~0: minimum Type I ?
- Total suppression of Type I ELMs in JT-60U, AUG & DIII-D QDB, partial in JET & DIII-D. C-Mod is a special case (no Type I ELMs!)
  - Conditions of access vary: high δ is required (possibly q95 >3.5)
  - High βp (JT60-U) and proximity to DN (ASDEX-U, JT60-U?)
  - Key requirement : high edge shear!!

Disruption Specifications

- **Current Quench Phase**
  - **Magnetic stored energy 35 MJ**
  - **Current decay time 2-6 ms**
  - **Average energy deposition to first wall 0.5 MJ/m^2**
  - **Toroidal peaking factor 2:1**
  - **Thermal modeling predicts <0.1 mm melting of Be per disruption.**

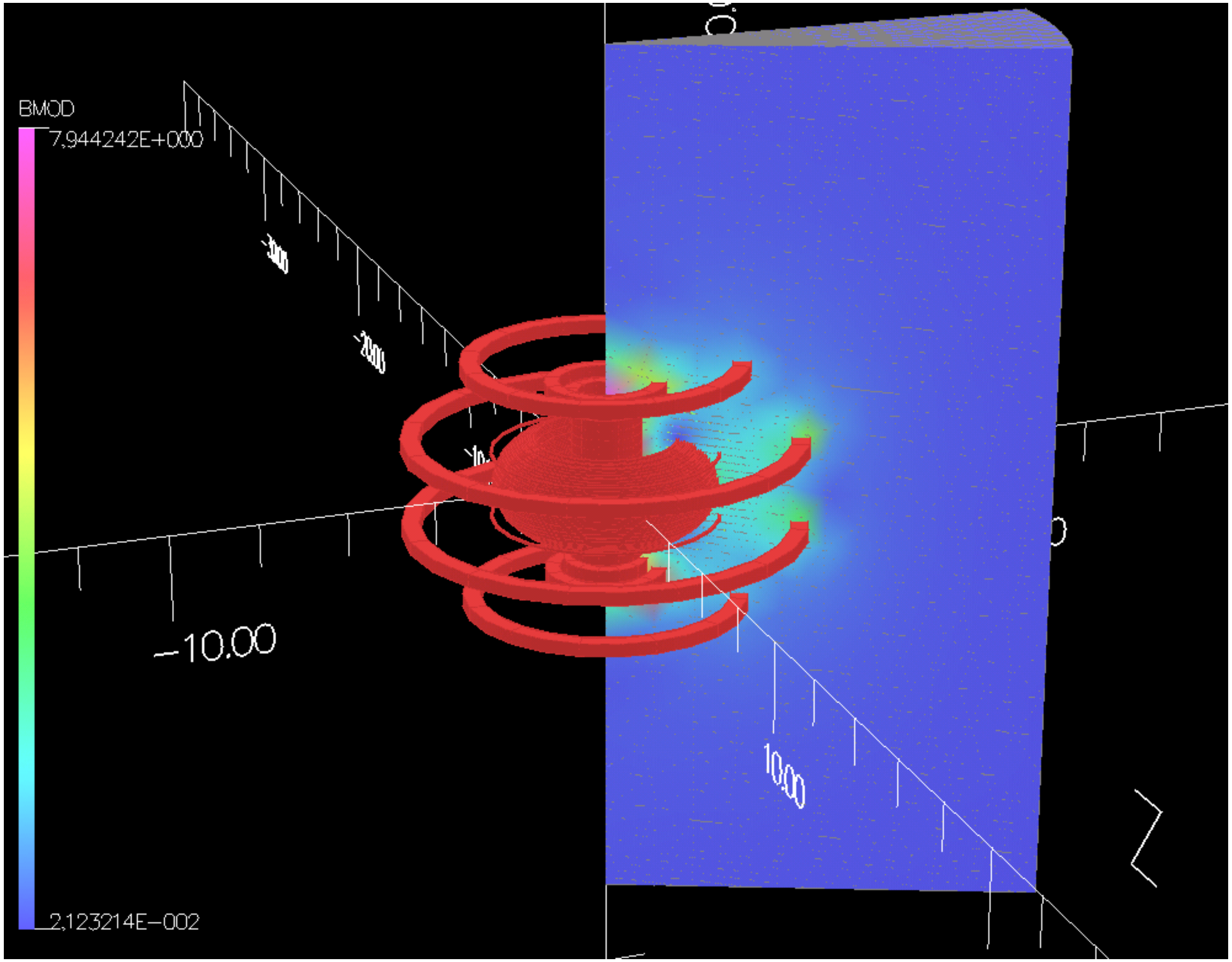
Halo Currents

- 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

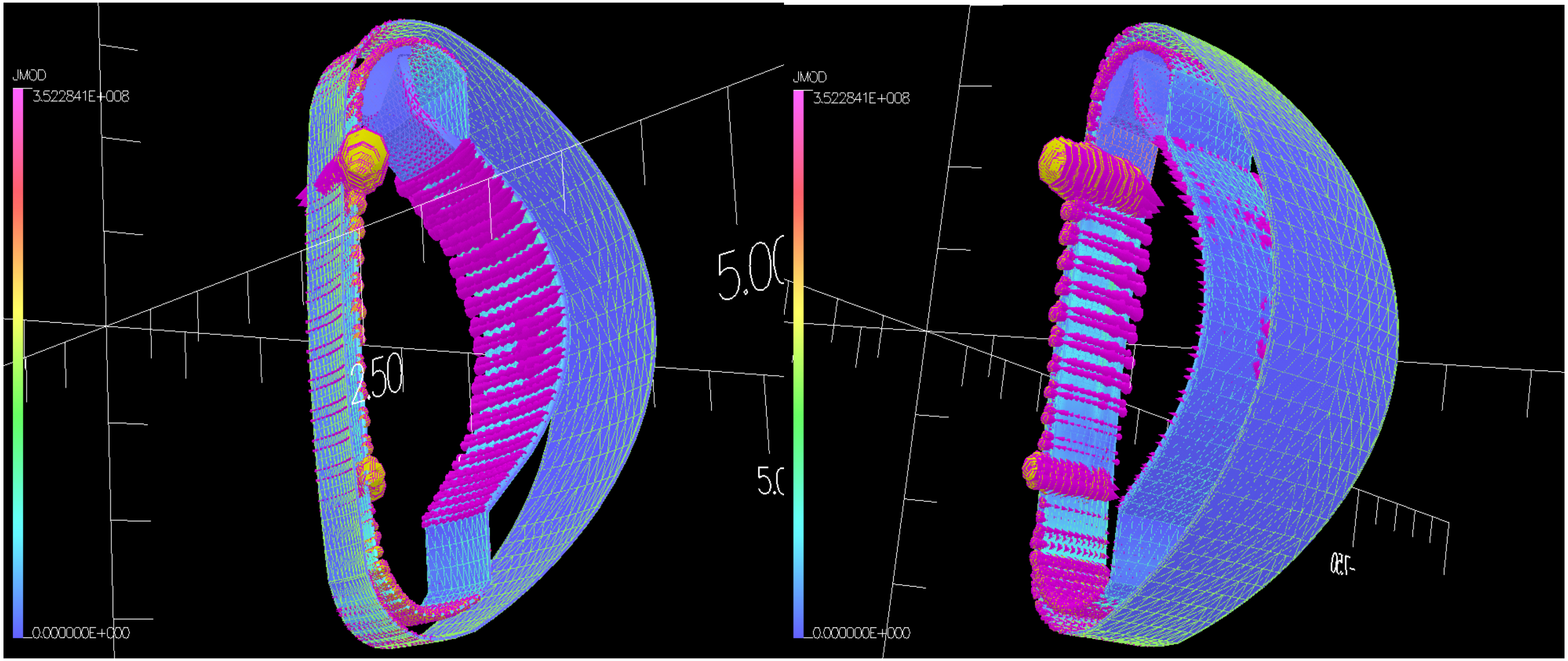
PC-Opera Capabilities

- Calculates the vector potential given an array of current carrying filaments and materials (including magnetic materials)
- Fully 3-D version
- The TSC model of VDE has about 1400 current filaments
- The FIRE geometry requires about 15,000 elements for a proper description
- Time dependent current drive capability used.

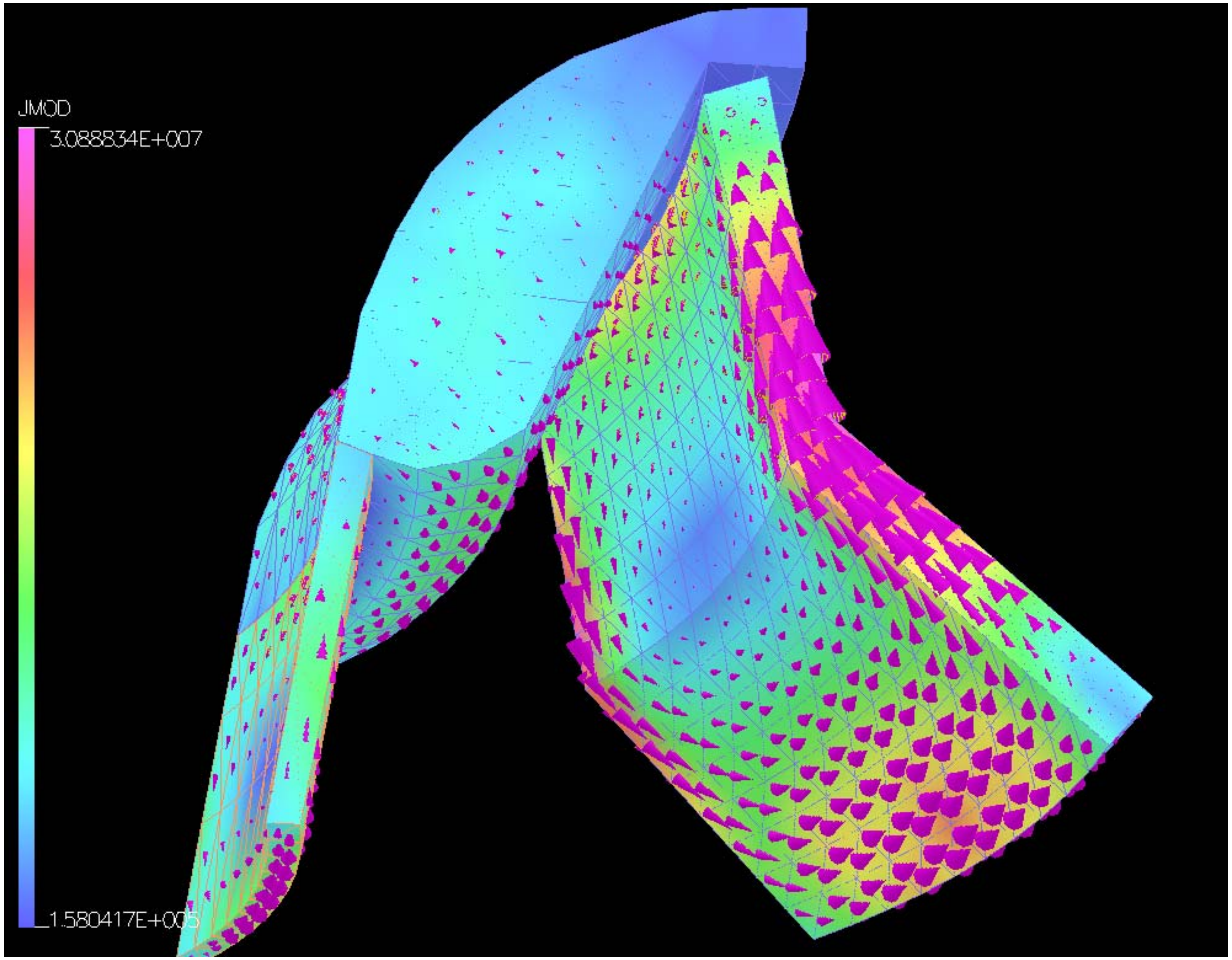
PC Opera Model



t=0.303 s, Passive Plates

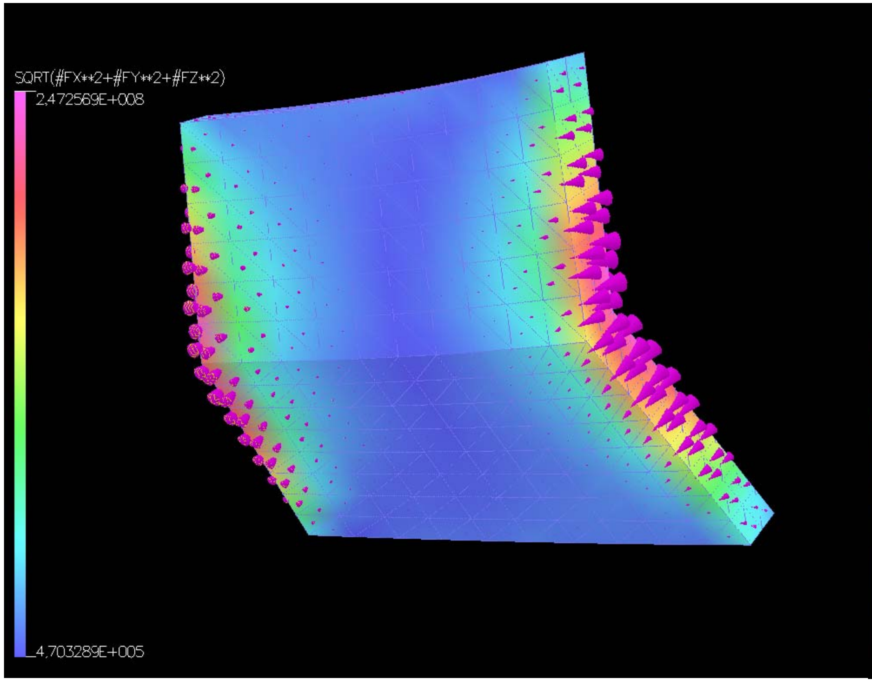


PFCs VDE t = 0.303 s

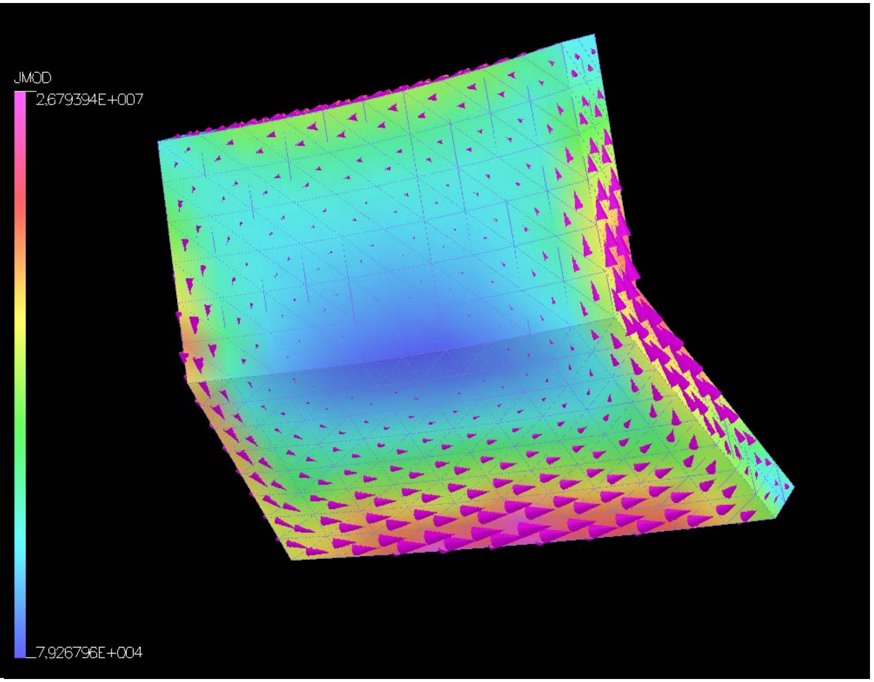


Outer Divertor Plate VDE

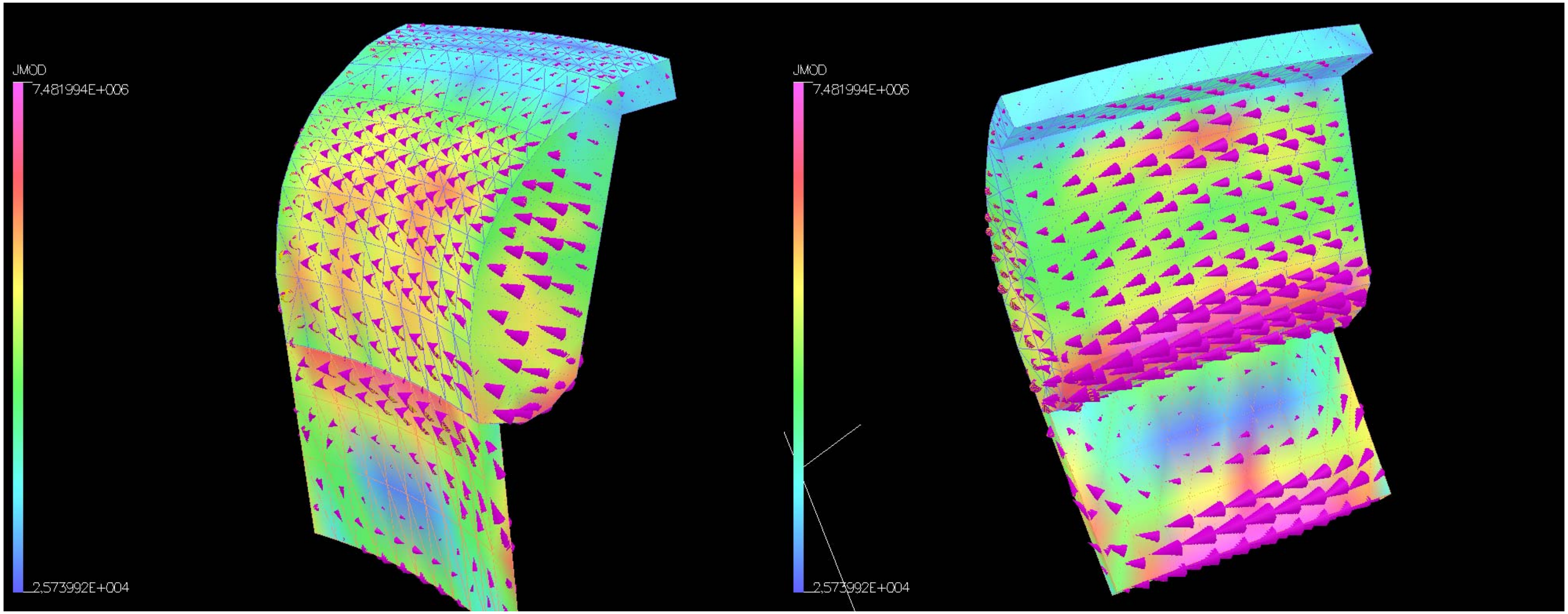
Force



Eddy Current



Inner Divertor & Baffle t = 0.302



Note current loops through thickness.

Disruption Mitigation

- There have been several important developments concerning disruption prediction in the last ~4 yrs
  - Several groups have developed a neural network that predicts a disruption is about to occur
    - the networks have predicted disruptions with 50 ms warning and an accuracy >90% with <5% false alarms
  - The networks require training to properly use the diagnostics available
  - This is sufficient warning to take action to mitigate the effects of a disruption
- Massive gas puff has mitigated disruptions on DIII-D

Summary

- Addition of neon to the outer divertor channel can help control divertor heat loads
- Type I ELMs are a life limiting phenomenon for the outer divertor. Additional R&D on mitigation methods is needed.
- Highly radiative disruptions (i.e., mitigated with gas puff) are likely to cause slight melting of the Be first wall.
- At the pre-conceptual design level the stresses in the divertor structure are acceptable.