Sandia National Laboratories Overview

Transient EM Analysis of ITER Plasma-facing Components

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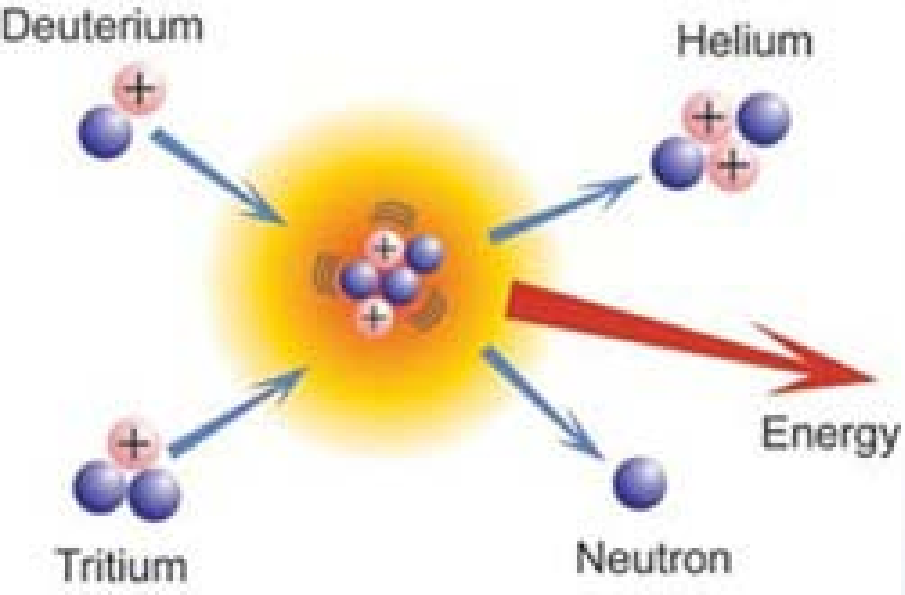
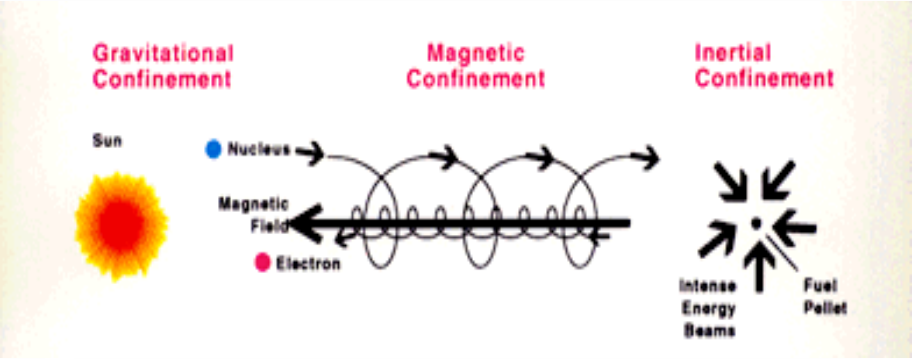
Deuterium-Tritium Fusion Reaction

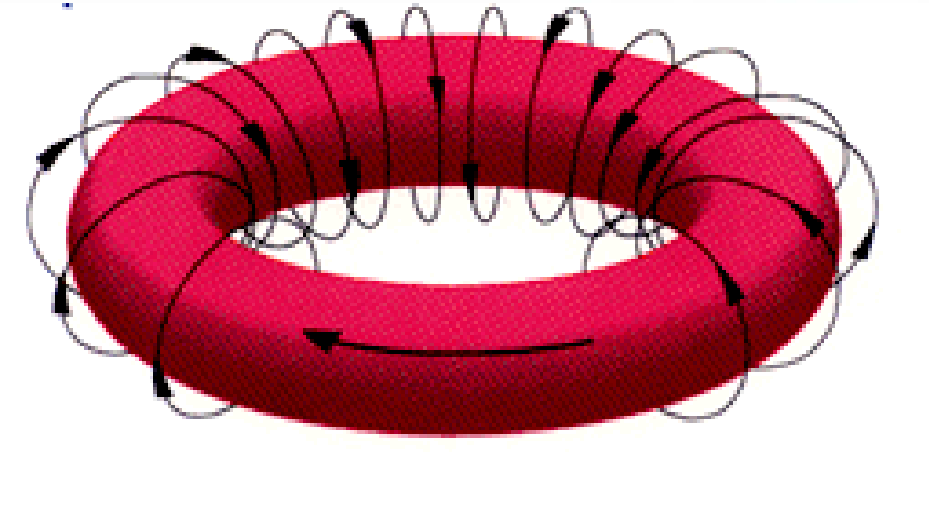
The Fusion Reaction

- The peak DT reactivity is about 200 keV but a plasma temperature of about 20 keV (~100 MK) has a sufficient reaction rate
- The reaction products are a 3.5 MeV alpha and a 14 MeV neutron
- Deuterium is found in all water
- Tritium is bred from lithium using fusion neutrons



Plasma Confinement

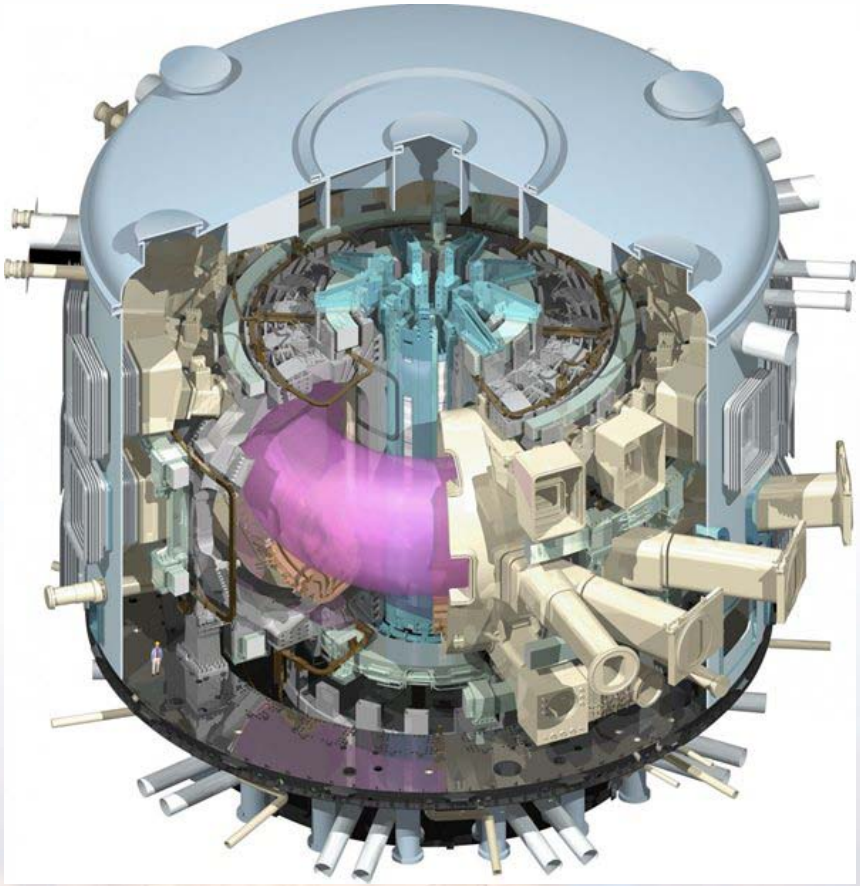




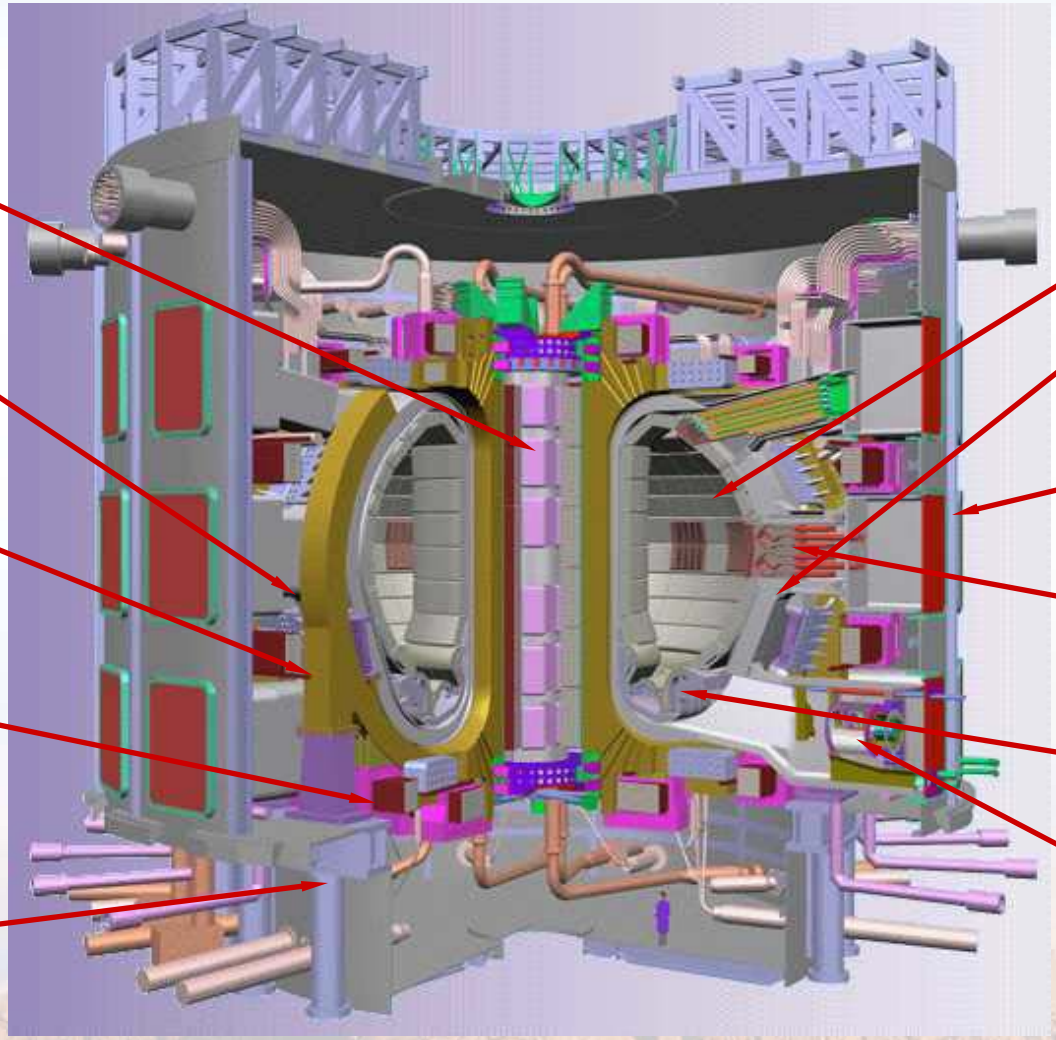
- Stars are confined by gravity.
- Terrestrial plasmas are confined by either magnetic fields (many configurations) or inertially (inward momentum confines the plasma long enough for reactions to take place)
- The most common magnetic scheme is the tokamak (bottom figure).

ITER

- **Largest tokomak device to be built**
- **“The way”**
- **Prove the feasibility of fusion technology, not produce power**
- **First plasma to ignite in 2018**
- **Collaboration of 7 National Entities**
  - United States, Russian Federation, China, South Korea, Japan, European Union, India



ITER – The Device



Characteristics of ITER

Total fusion power	500 MW
Additional heating power	50 MW
Q - fusion power/ additional heating power	≥ 10
Average 14MeV neutron wall loading	≥ 0.5 MW/m^2
Plasma inductive burn time	300-500 s *
Plasma major radius (R)	6.2 m
Plasma minor radius (a)	2.0 m
Plasma current (I_p)	15 MA
Toroidal field at 6.2 m radius (B_T)	5.3 T

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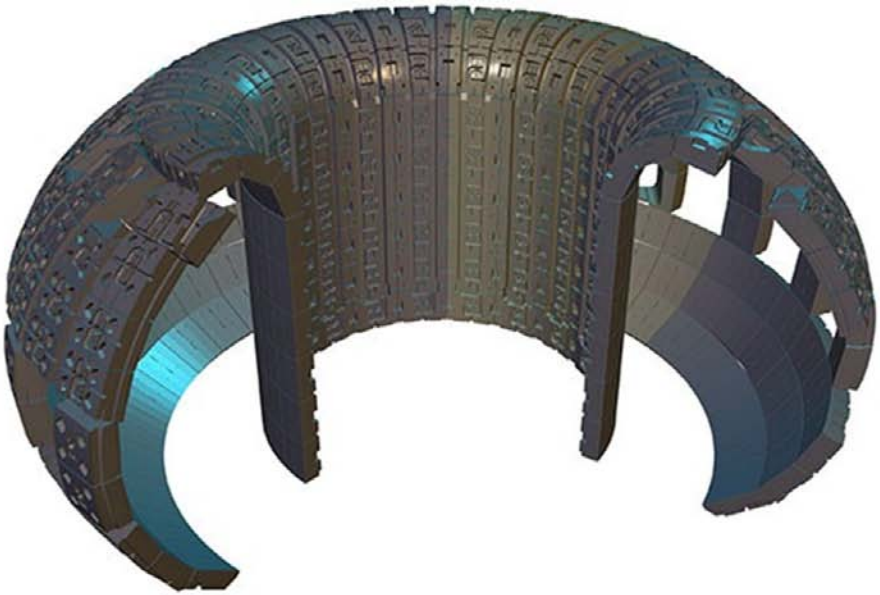
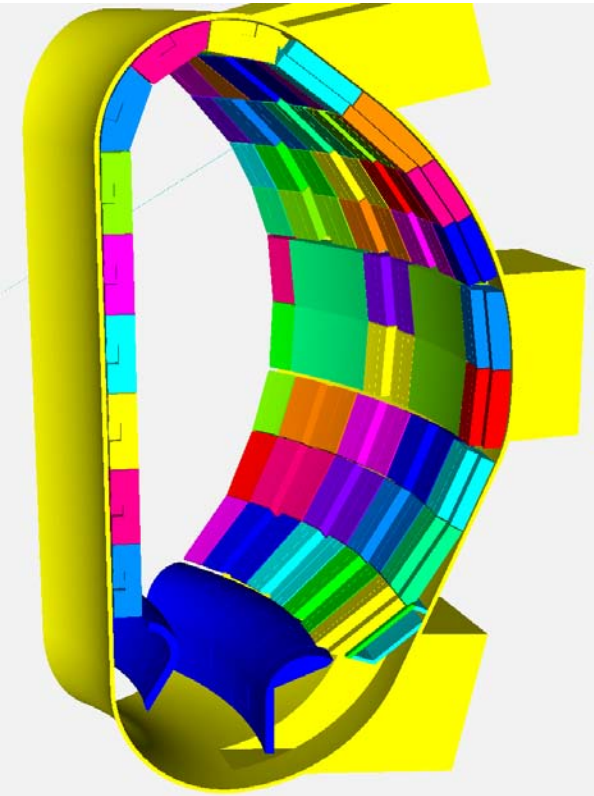
ITER - Blanket

- Covers the interior of the vacuum vessel and magnets
- Modular - 440 individual segments, 1x1.5 m
- Thermal shielding, Nuclear Shielding
- weighing up to 4.6 tons

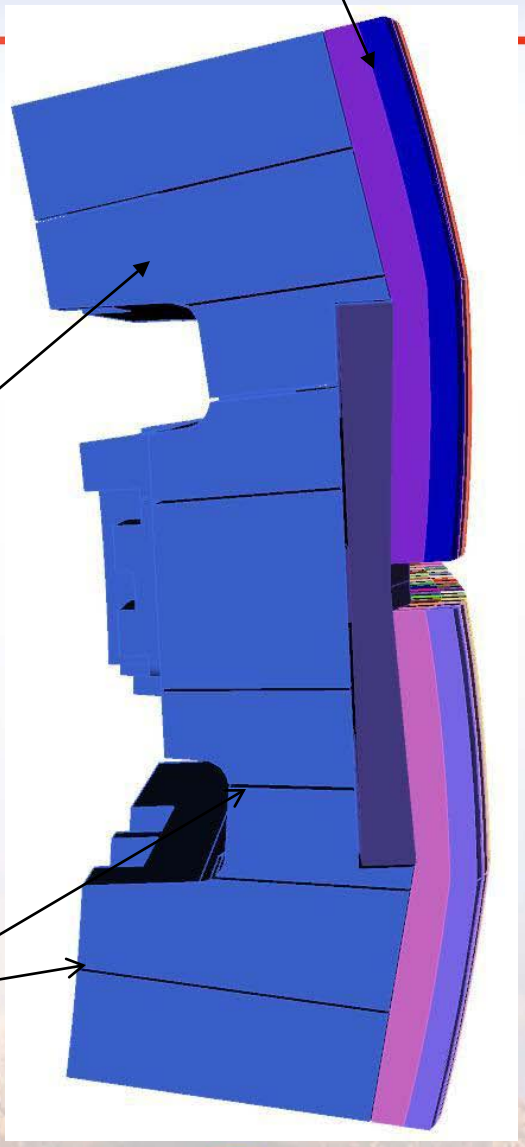




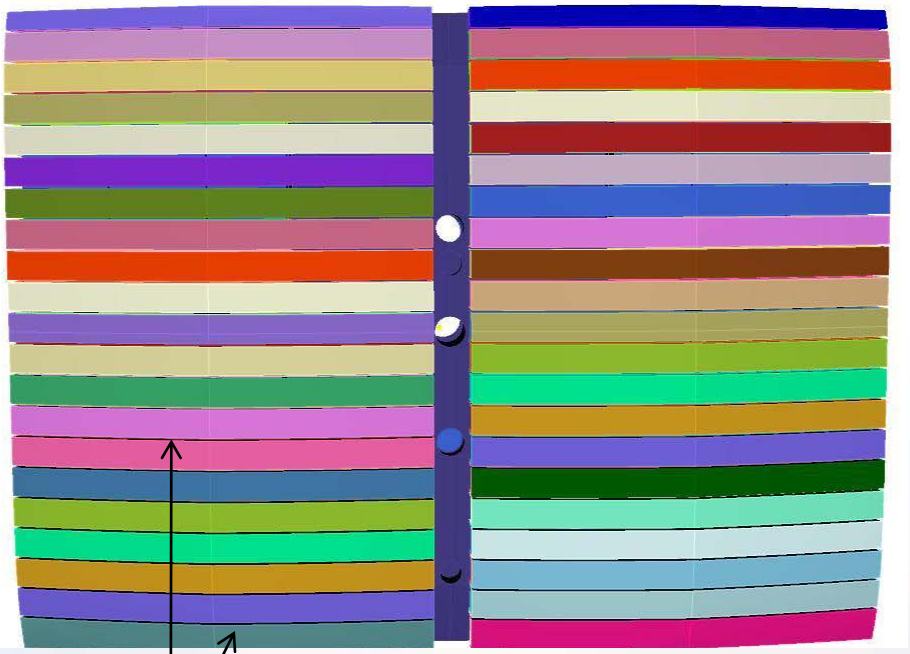
Courtesy of J. Kotulski

First Wall and Shield

- **Blanket comprised of thin PFC First Wall and thicker Shield Block**
- **First Wall serves as heat sink**
- **Shield Block serves as neutron shield**



First Wall and Shield - Continued



First wall comprised of
“fingers” to mitigate currents

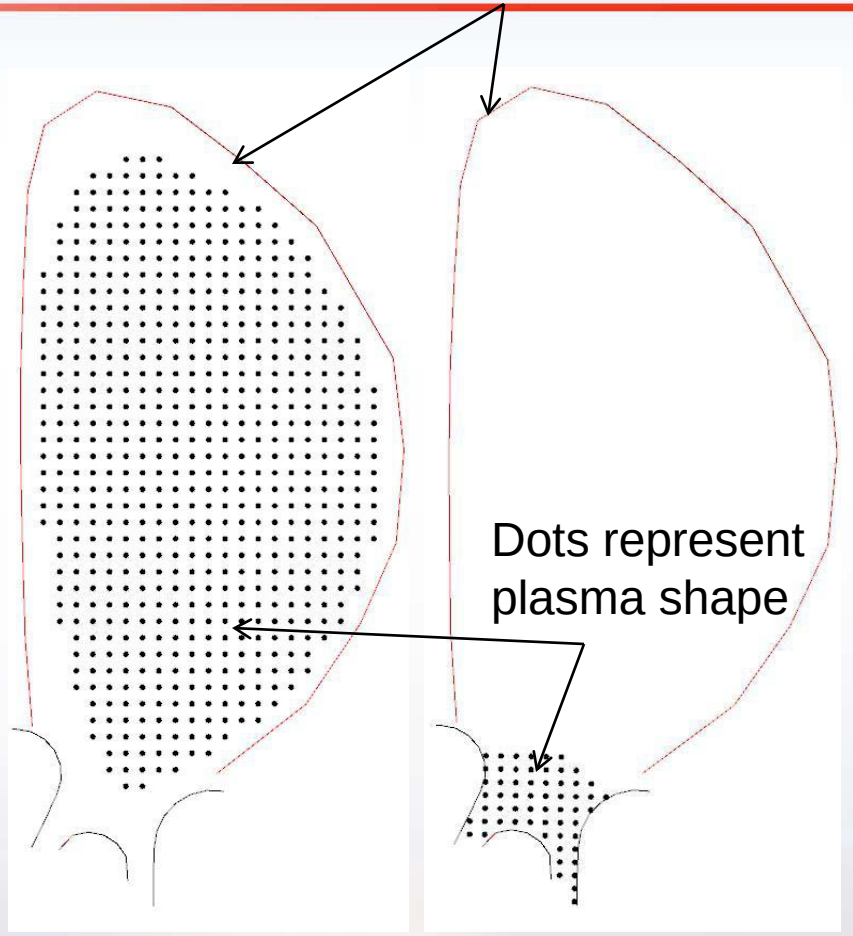
Slits in shield block to
mitigate eddy currents

Pivot Point

Courtesy of J. Kotulski

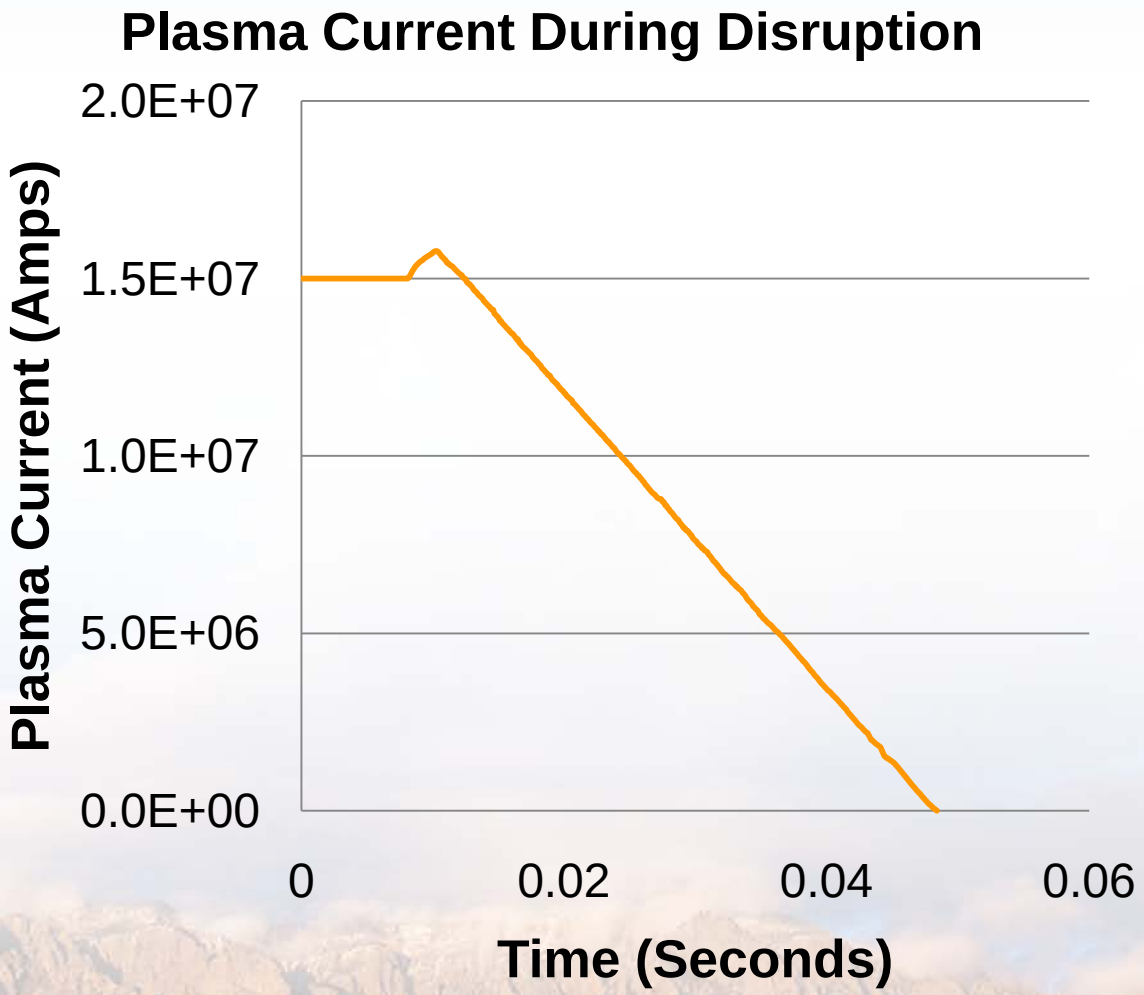
Plasma Disruptions

- Plasma dissipates in milliseconds
- Numerous causes
  - Loss of Temperature
  - Loss of Control
- Change in plasma current or magnetic fields causes plasma to move, eventually hitting the walls of the vessel



Plasma Disruptions

- Rapid loss of current in plasma induces current in other structures
- Induced current in a magnetic field creates JxB forces and torques on objects
- Extreme current magnitudes mean extreme forces are possible



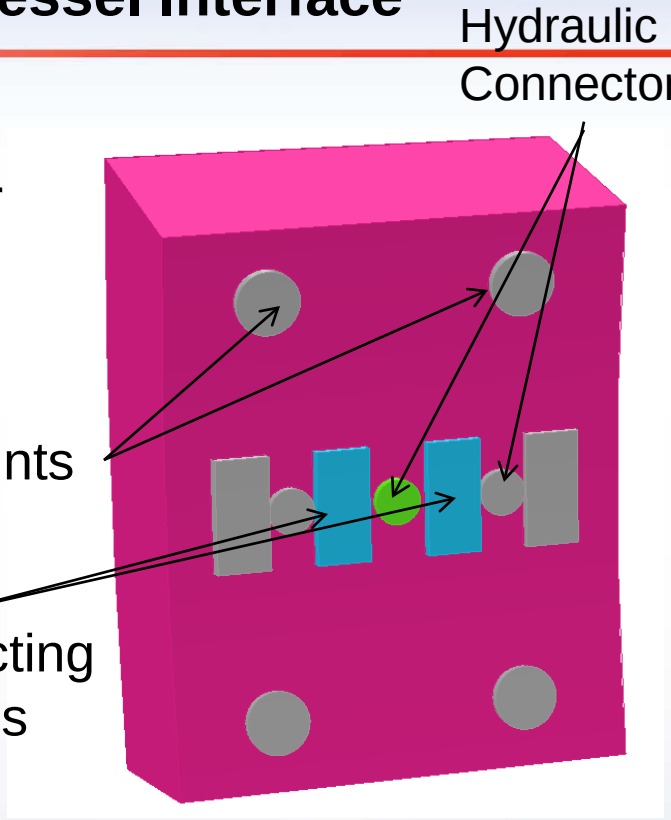
Electromagnetic Analysis of Current Induced in ITER Blanket Modules

Tim Burke

Sandia National Laboratories

Blanket Module – Vacuum Vessel Interface

Different configurations
- Center/off center Hydraulic Connector
- Different Mount shorting scenarios
- Different impedances/conductivity
- Different Strip counts
- Different Strip positions



All of these have the potential to carry current to and from the vacuum vessel

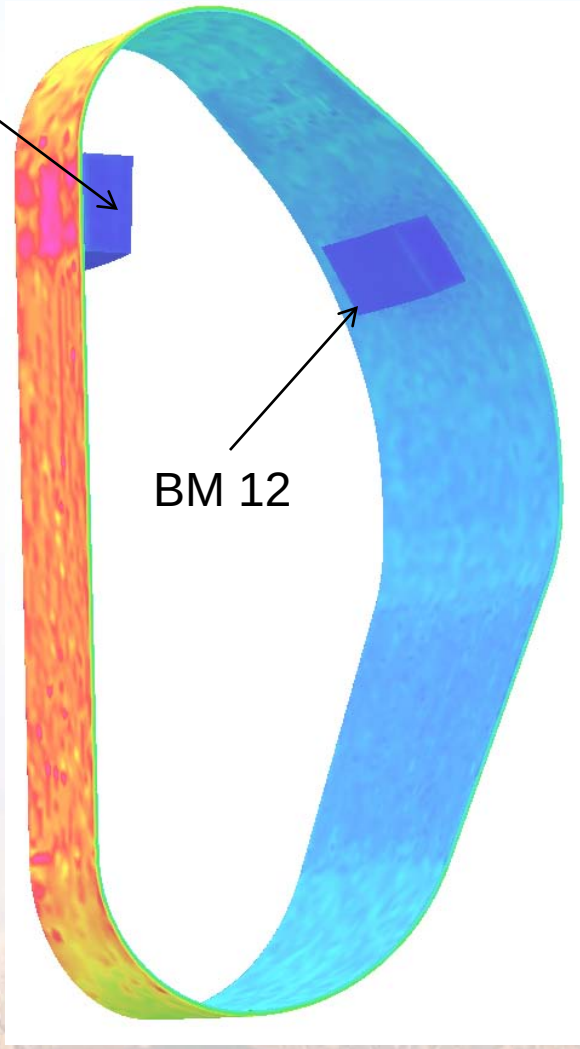
Goal is to minimize current path through vacuum vessel as well as current magnitude

The Model

- Simple, imperfect model in design and properties
- Designed for time efficiency
- 4 hours of run-time compared to days or weeks of run-time
- Designed to see if the problem warrants further investigation

Pink = 450 A/mm²

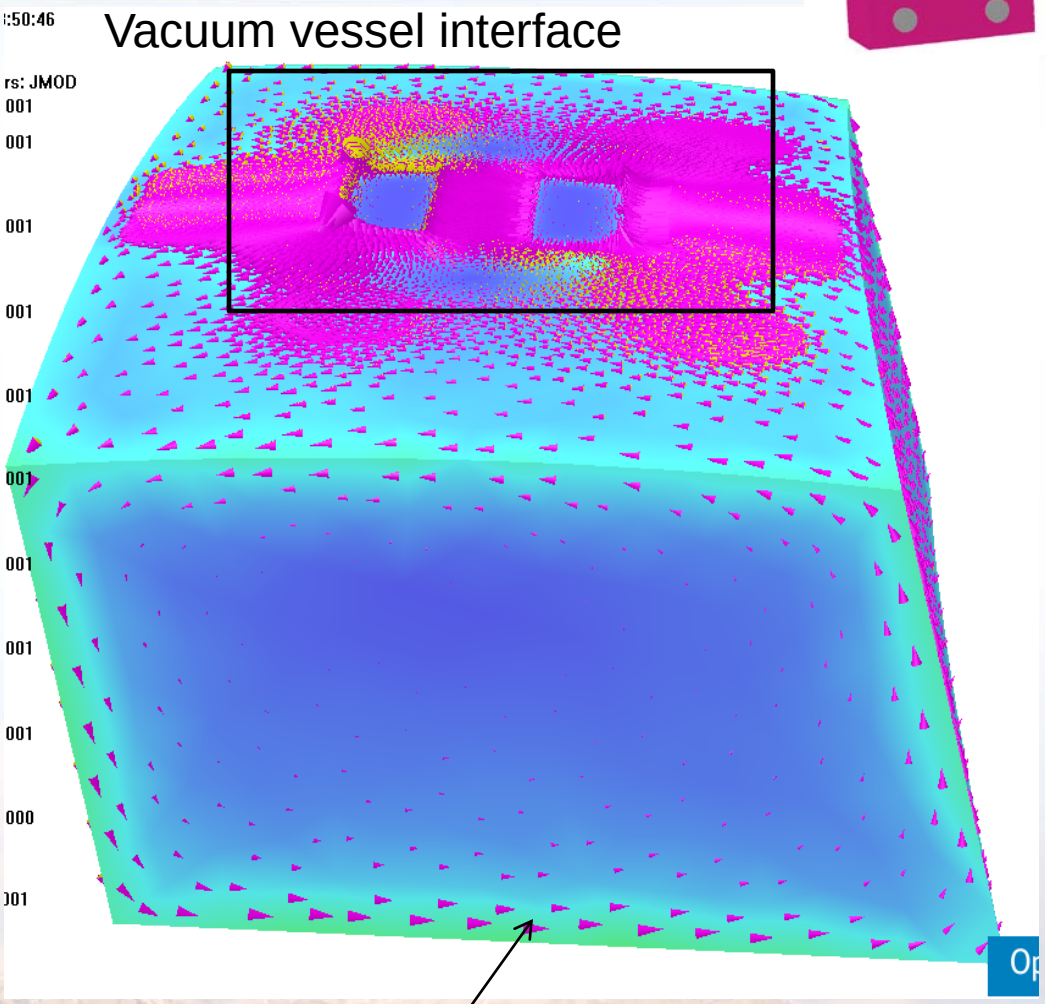
Blue = 0 to 50 A/mm²



Currents in Blanket Module 12

- Disruptions cause current to flow through blanket module
- Currents can impart JxB forces on module
- Currents become un-balanced due to connections between shield block and vacuum vessel

Note: size and direction of arrows indicate direction and magnitude of current.

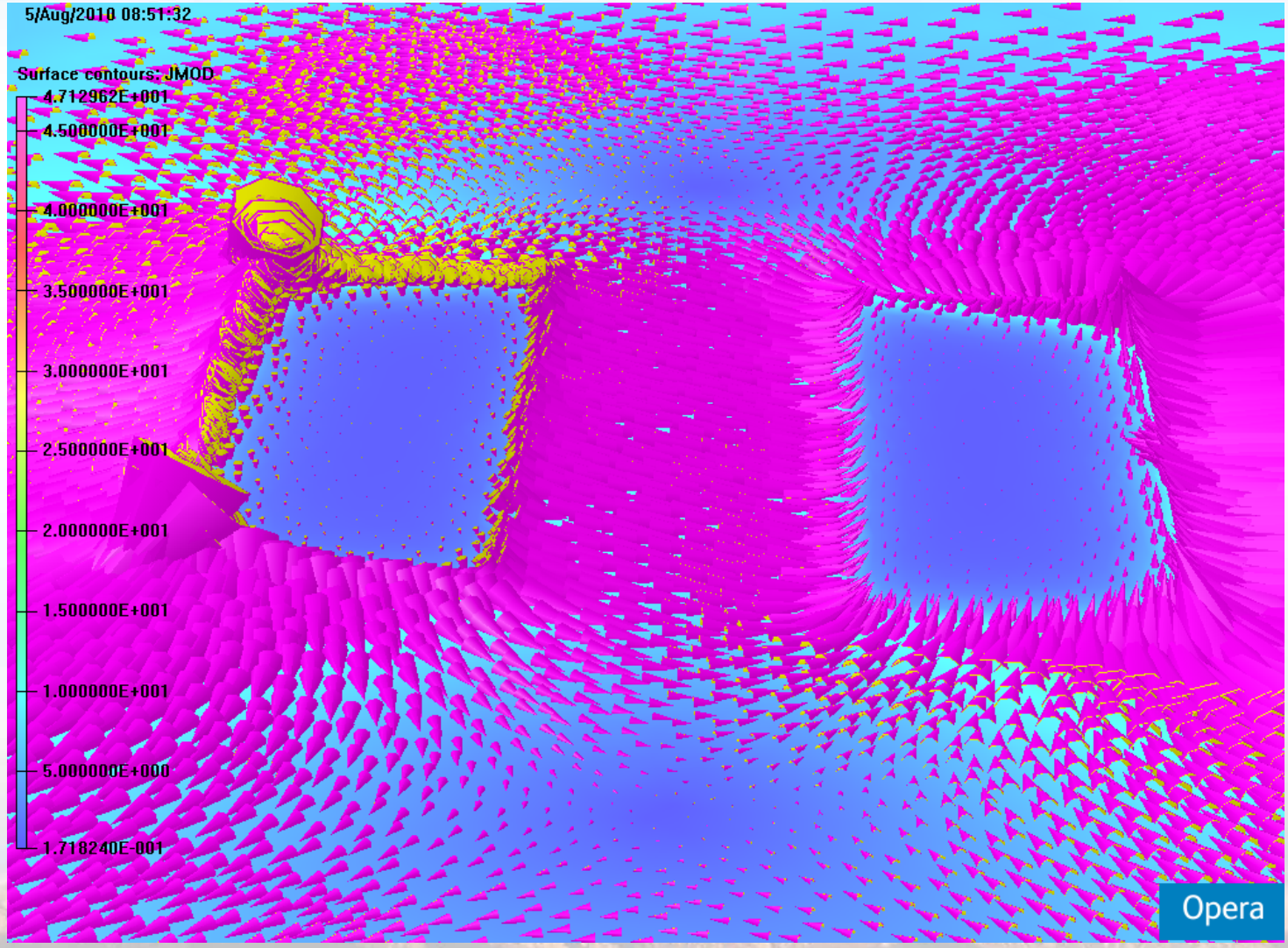


Currents in Blanket Module 12

Interface between shield block and vacuum vessel

Blue areas are conducting strips (Not shown)

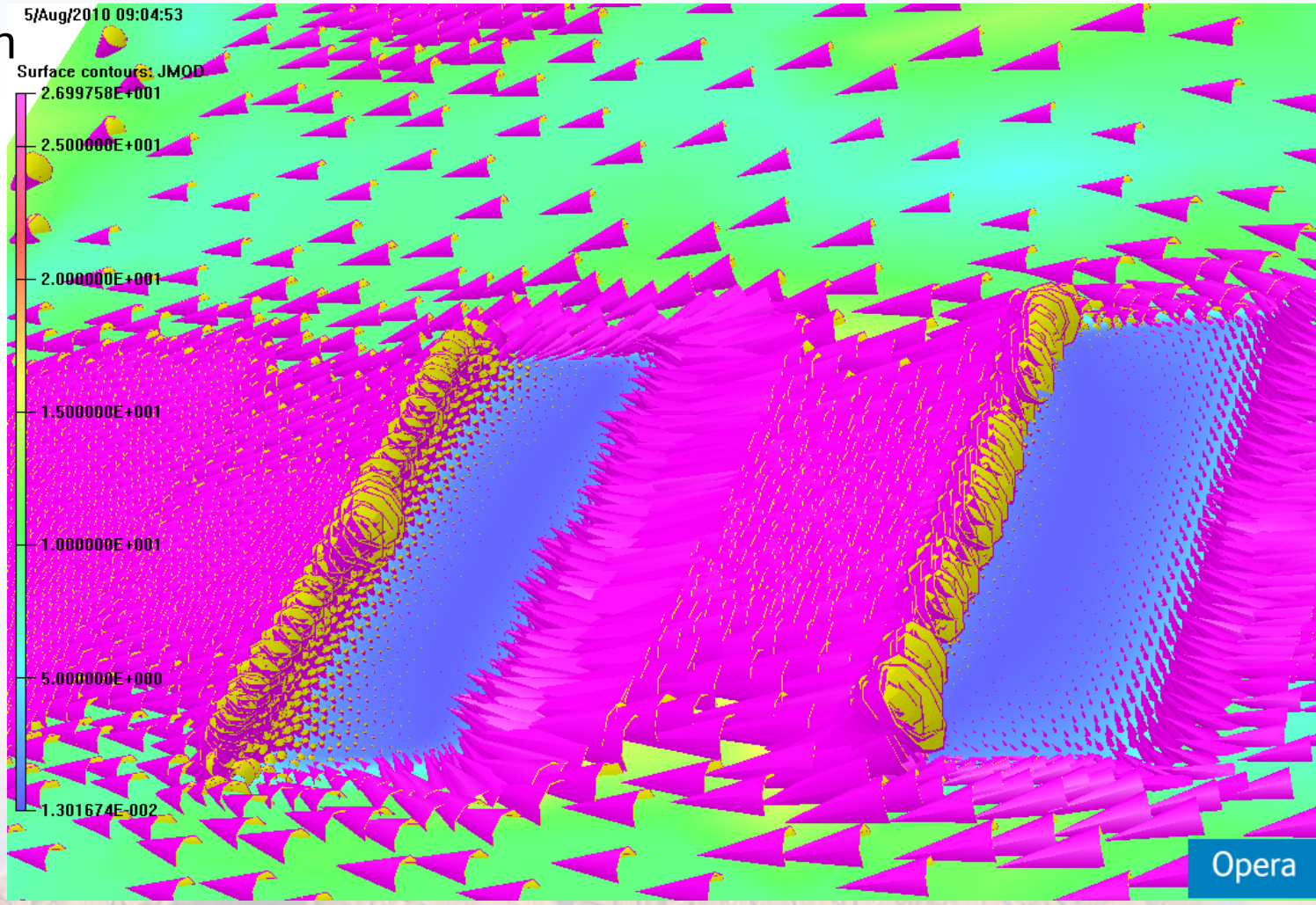
Arrows indicate magnitude and direction of current



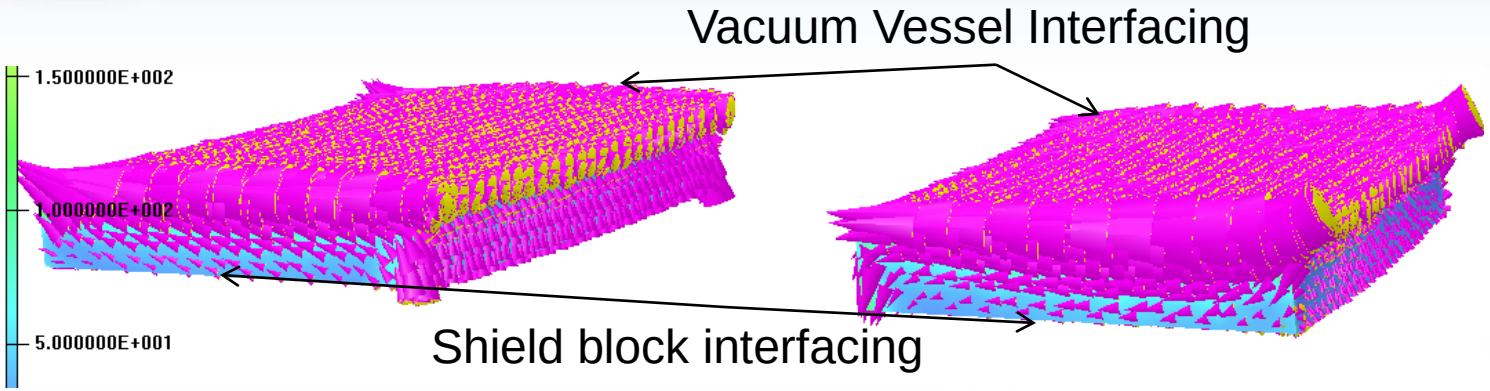
Currents in Blanket Module 6

Interface between shield block 6 and Vacuum Vessel

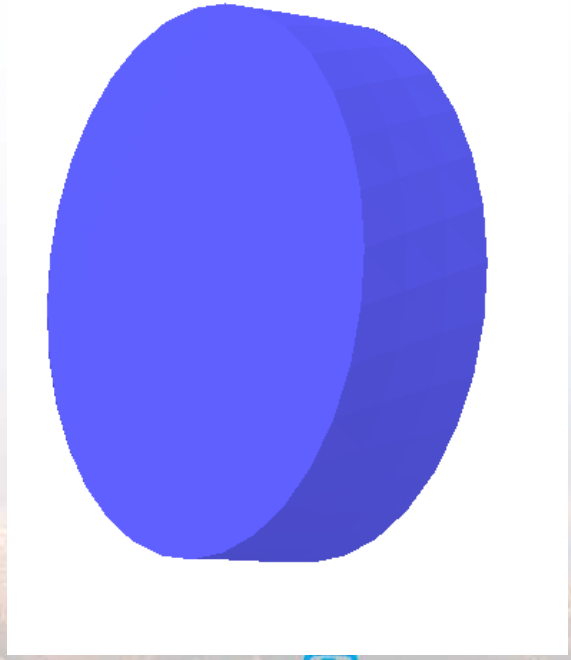
Blue areas are conducting strips (Not shown)



Currents in Blanket Module 6 Components

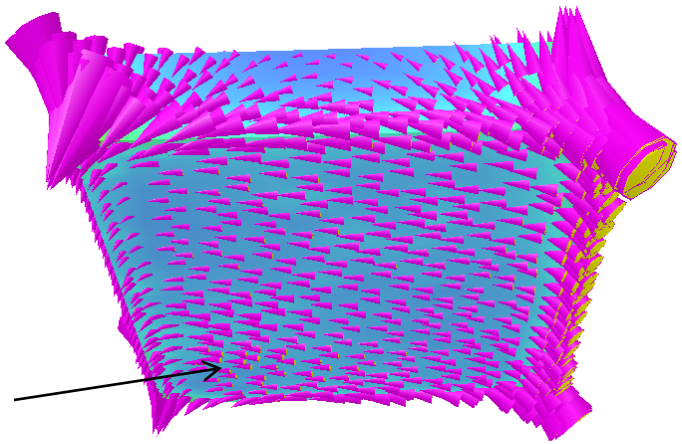


- Major currents flowing from vessel, to strips, through shield block, through strips, then back to vessel
- Unexpected current flow
- Merits further investigation
- Current density of 150 A/mm² in strips
- Minimal current in hydraulic connector

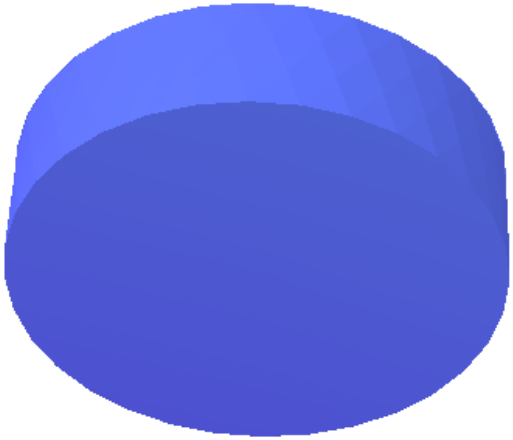


Current with one conducting strip

- Current flowing in to and out of the same conducting strip from shield block
- Unexpected results
- Merits further investigation
- Minimal current flowing through hydraulic connector

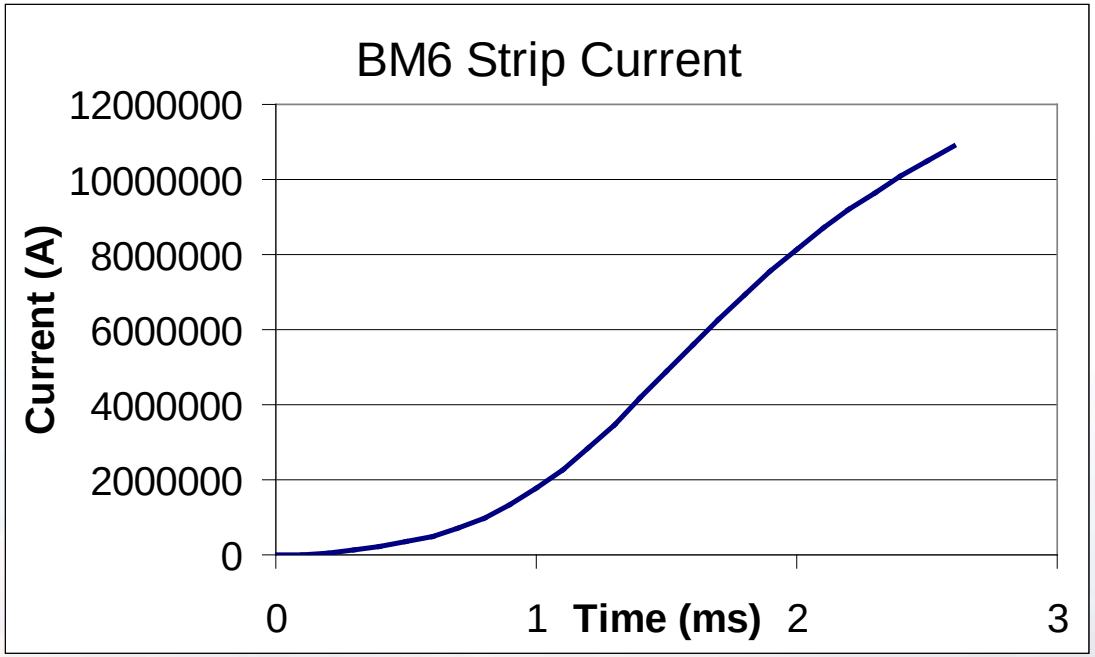


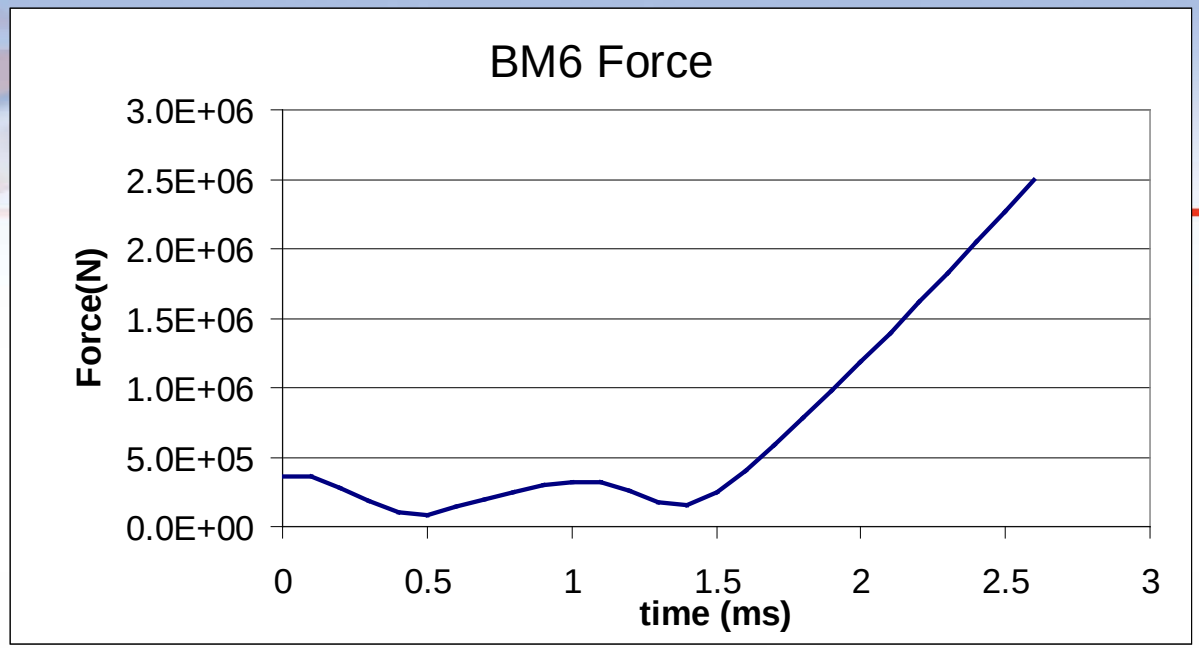
Shield-block interfacing side

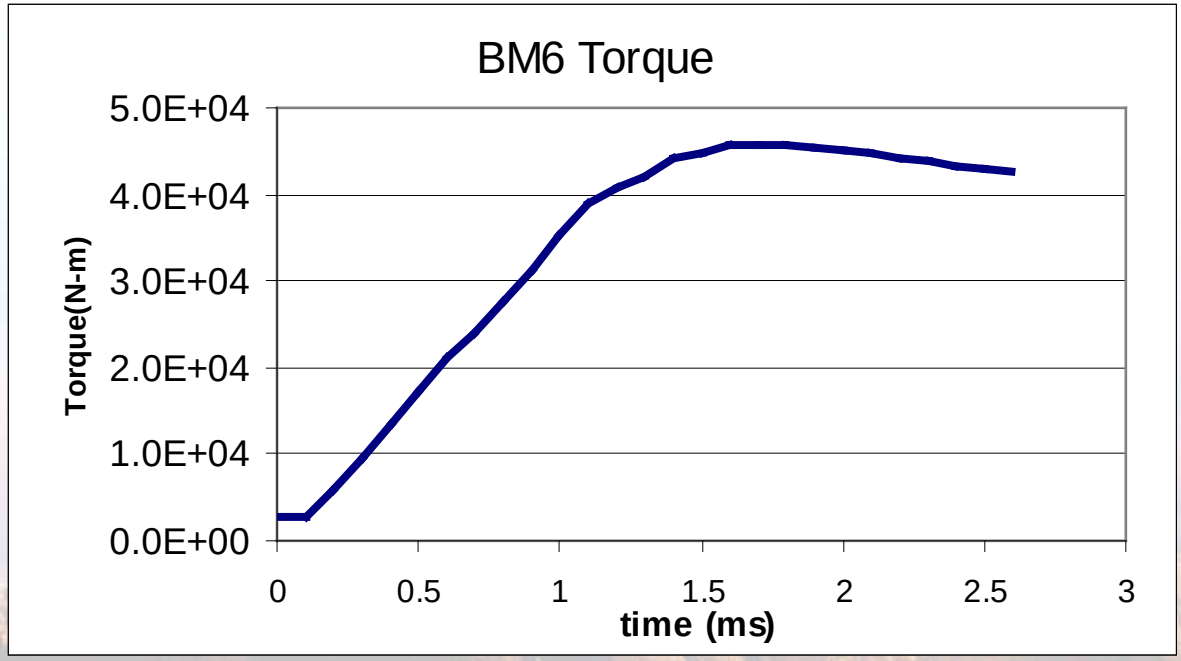


Current in BM 6 Conducting Strips

- Current ramps up to 11MA in milliseconds
- Potential to generate massive forces




BM6 Force
3.0E+06
2.5E+06
2.0E+06
1.5E+06
1.0E+06
5.0E+05
0.0E+00
Force(N)
0
0.5
1
1.5
2
2.5
3
time (ms)


BM6 Torque
5.0E+04
4.0E+04
3.0E+04
2.0E+04
1.0E+04
0.0E+00
Torque(N-m)
0
0.5
1
1.5
2
2.5
3
time (ms)

Conclusion

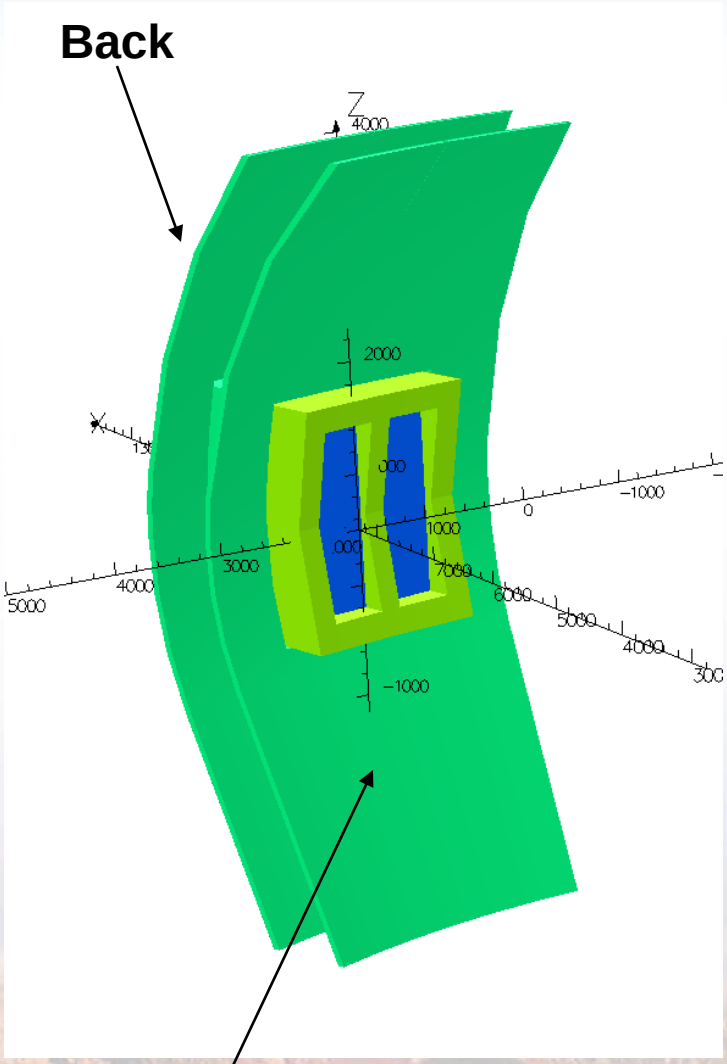
- **Interesting results**
- **Problem warrants further investigation**
- **Next steps**
  - Properly model B-field inside vacuum vessel
  - Analyze different current paths thoroughly
  - Include components with more intricate design

Electromagnetic Analysis of Test Blanket Module

Tommy Holschuh

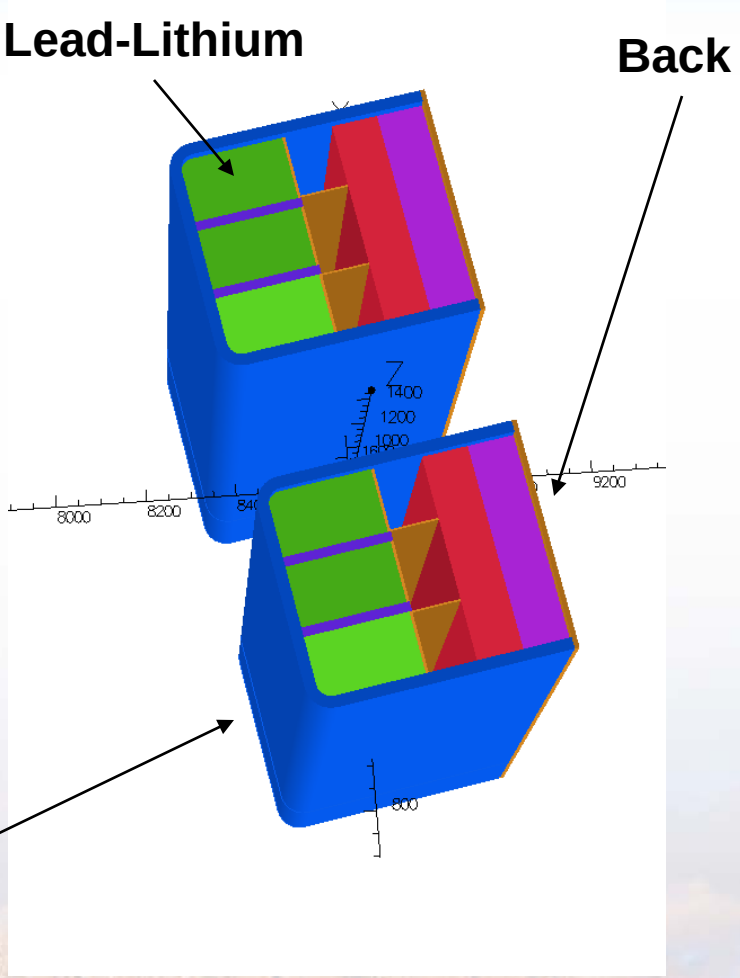
Test Blanket Module

- The Test Blanket Module is designed to produce tritium.
- Deuterium is easy to get.
- Tritium is needed for the fusion reaction, but harder to find.



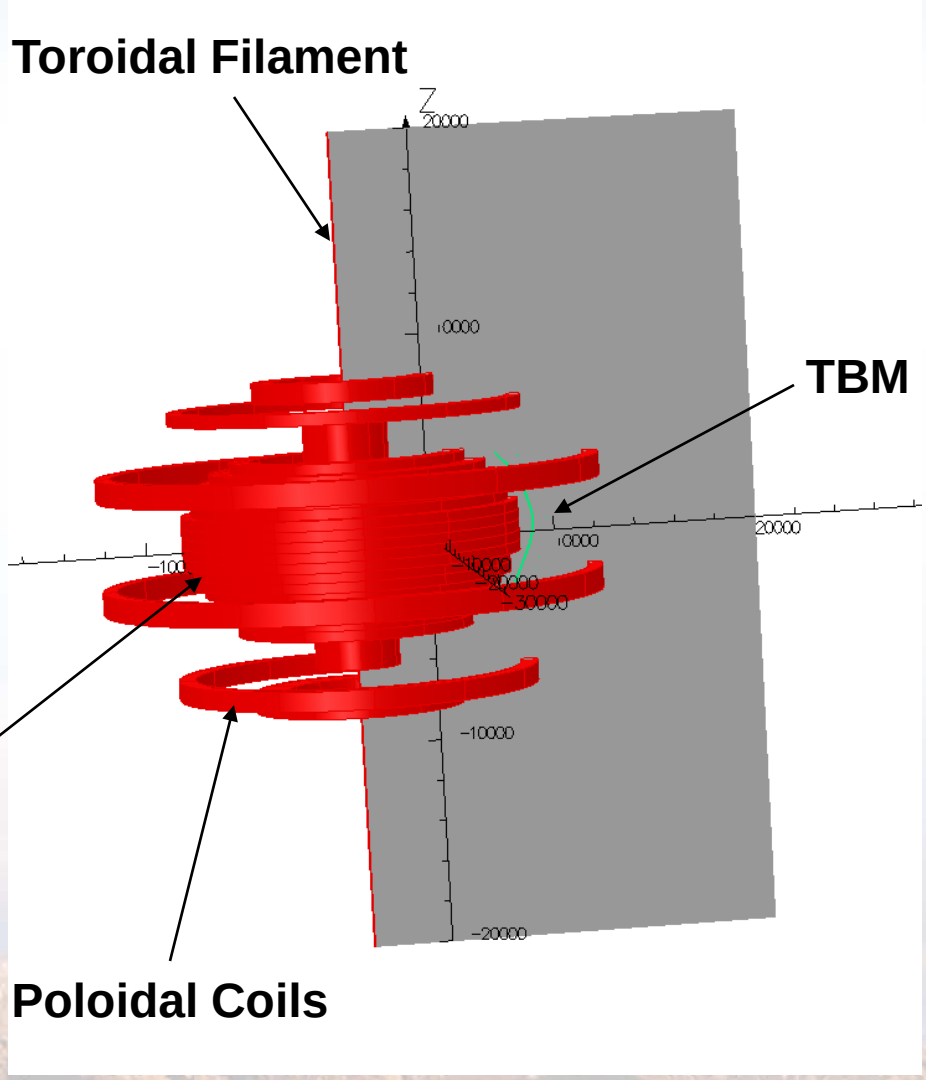
Test Blanket Module

- The TBM contains PbLi as a liquid metal.
- Neutrons interact with Lithium, produce tritium.
- Elaborate system behind module to extract tritium.

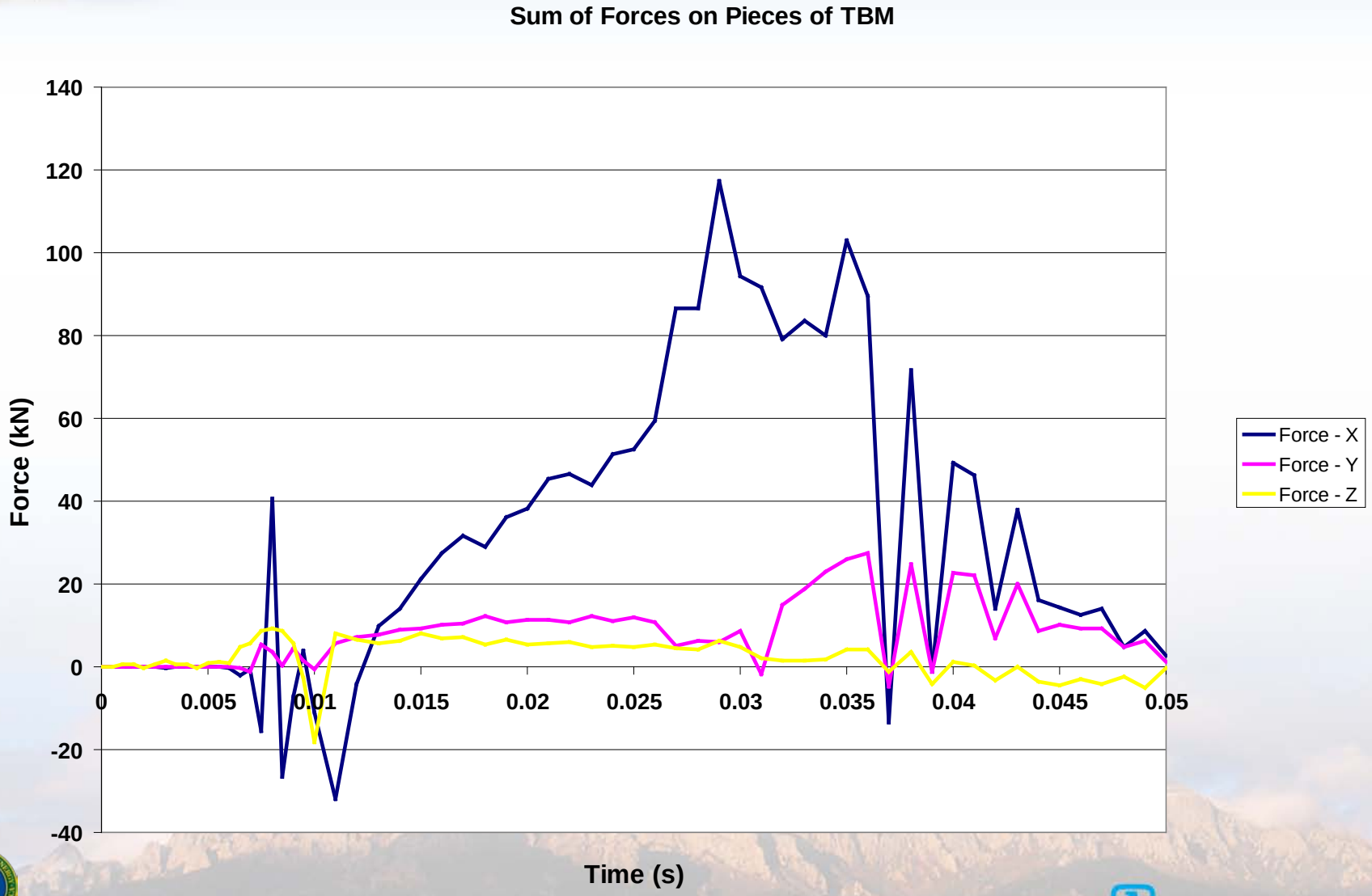


Test Blanket Module

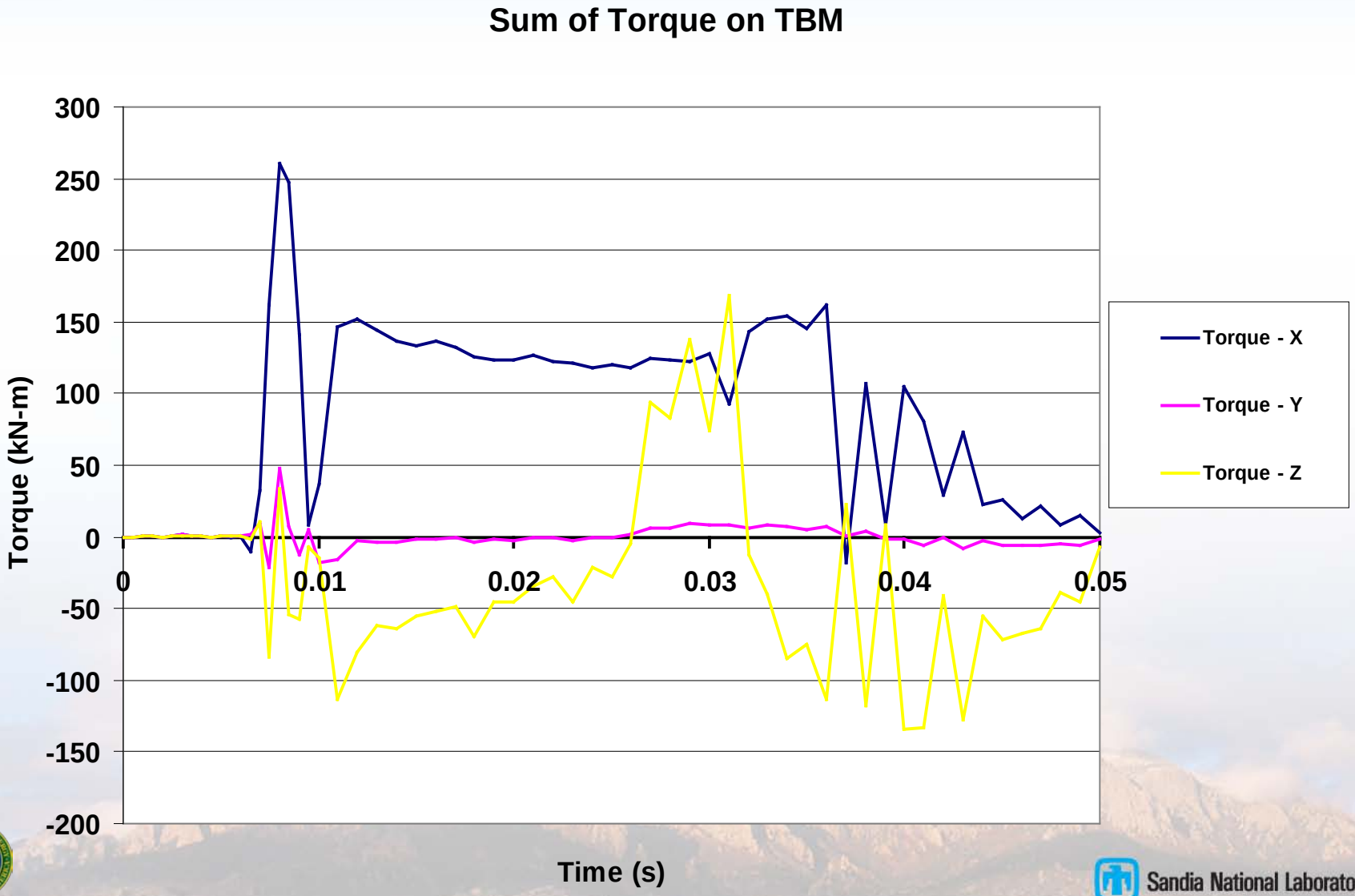
- During a disruption, the change in current produces forces on pieces of tokamak.
- Need to model forces and torque on TBM
- Use OPERA-3D to do Elektra E&M Transient Analysis



Elektra Analysis

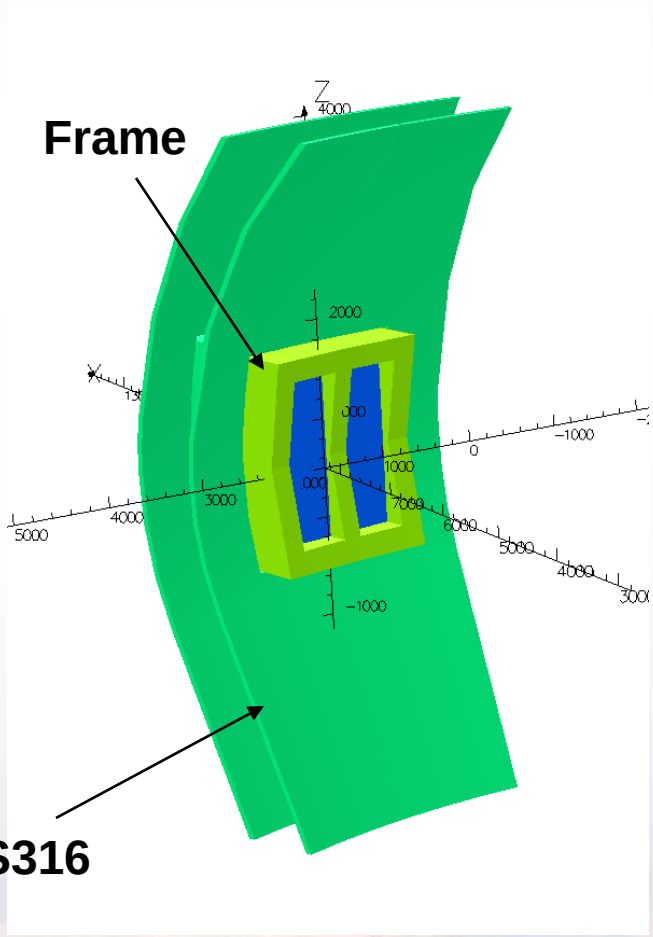


Elektra Analysis

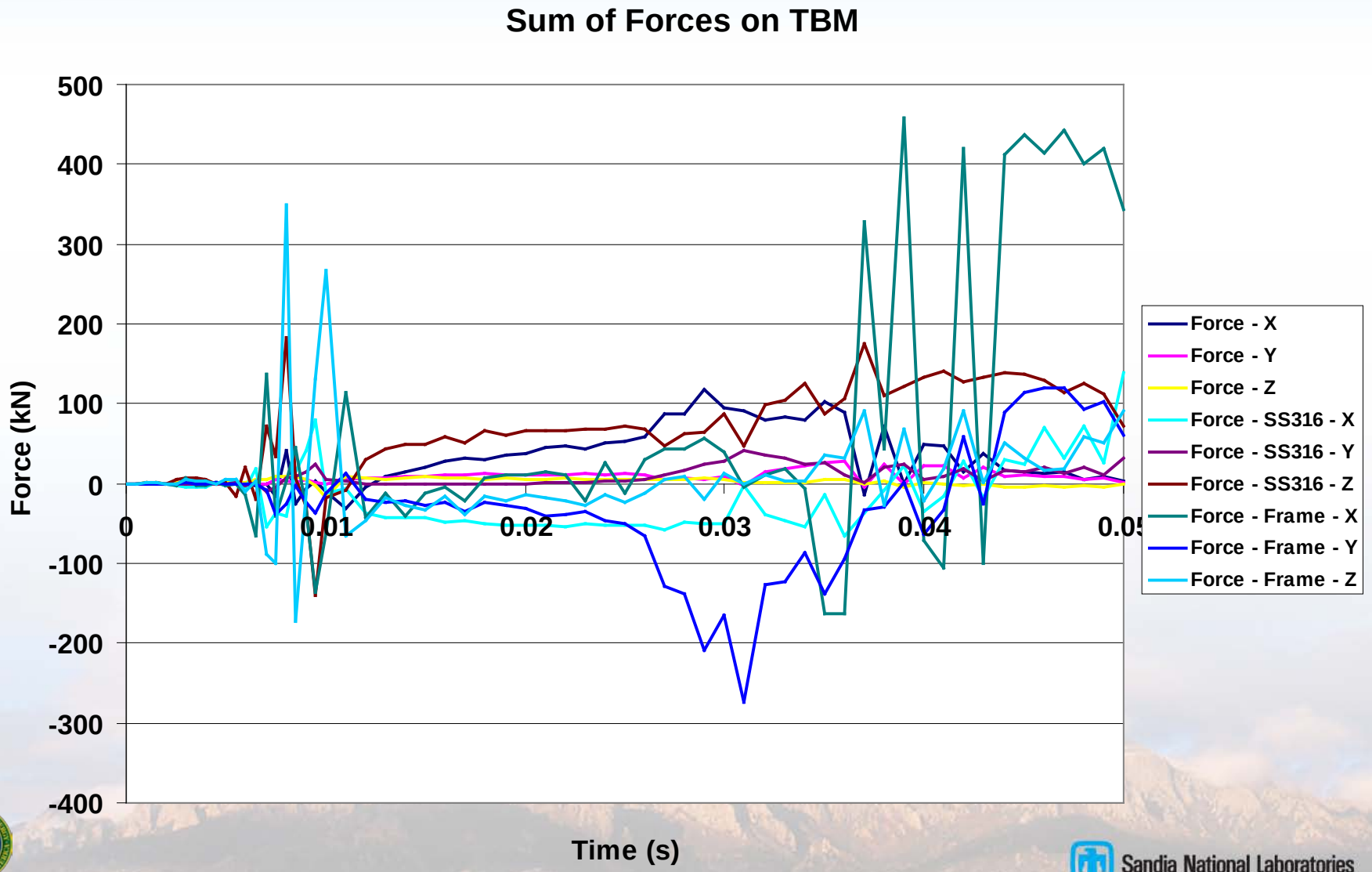


Elektra Analysis

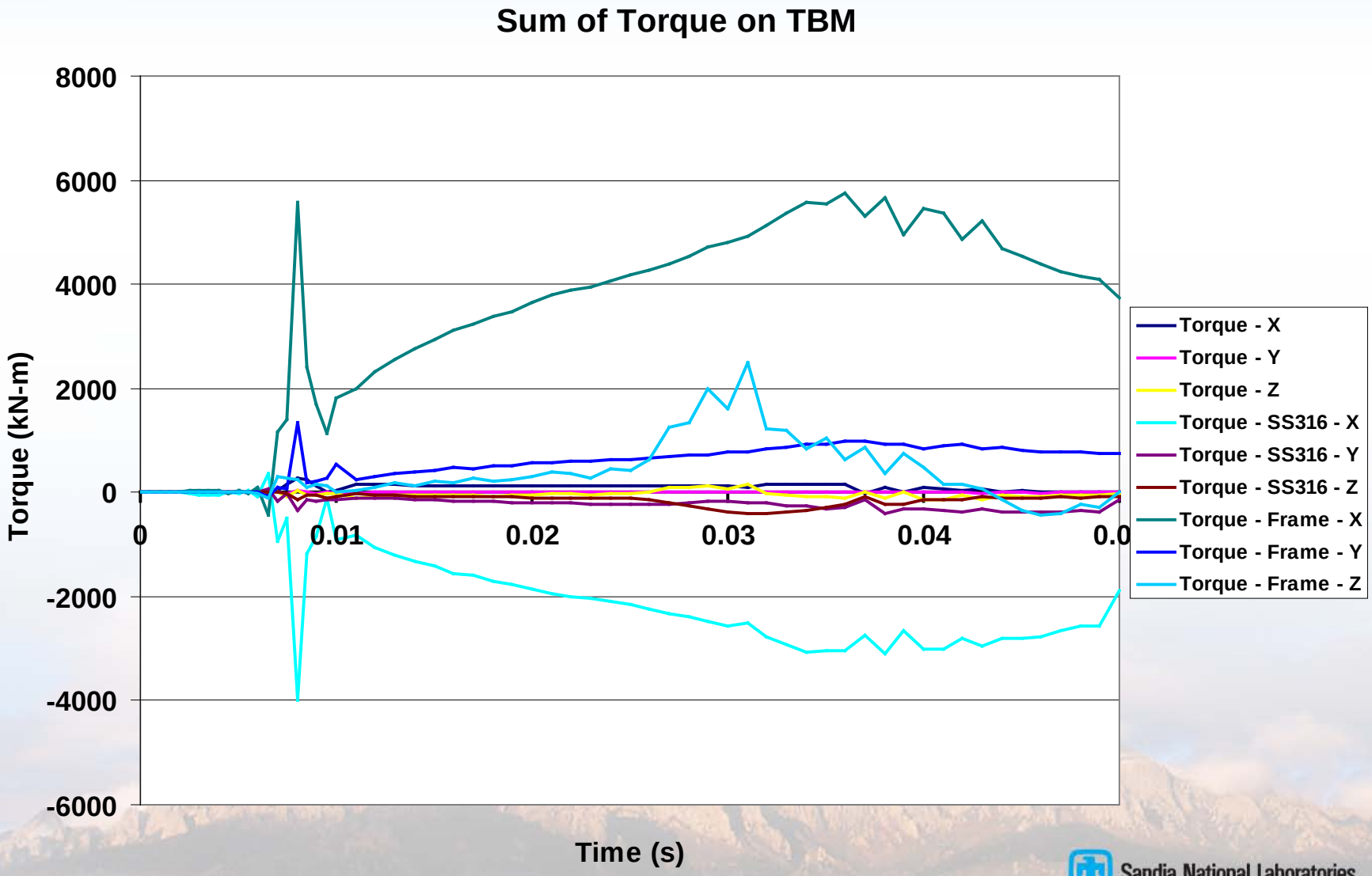
- Sum is a little high, but near expected values.
- This is the sum of Force and Torque on every piece of the Test Blanket Modules (blue-colored).
- These do not include frame (light green) and SS plate (green).



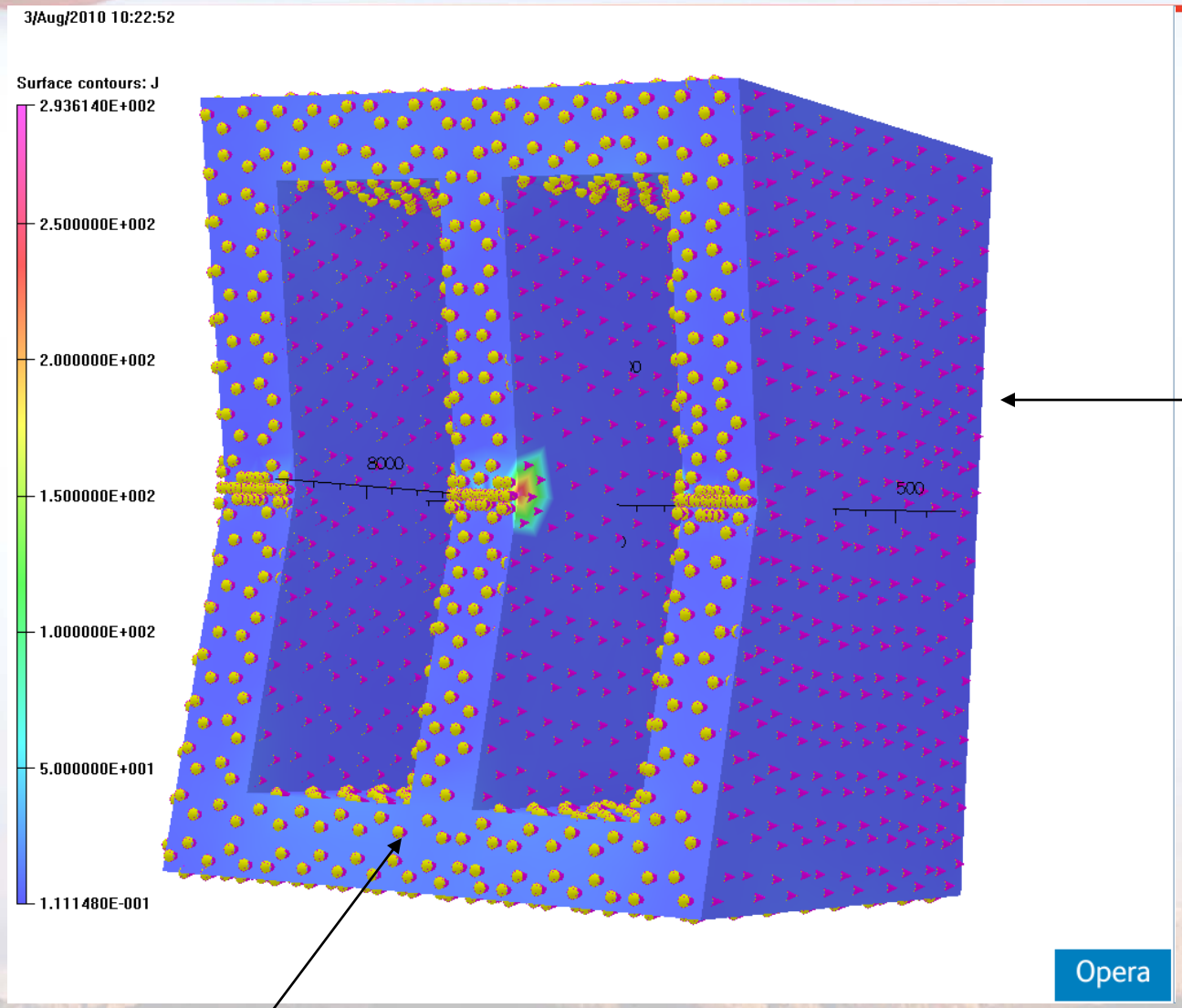
Elektra Analysis – Frame and Plate



Elektra Analysis – Frame and Plate



Elektra Analysis



Back

Plasma-Facing Side

Future

- Since then, conductor properties were checked.
- It was found that initial current densities were incorrect.
- Toroidal filament was several orders of magnitude larger than correct value.
- Solenoid coils were several orders of magnitude smaller than correct value.
- This was adjusted.
- OPERA is currently re-running analysis

- Correct simulations, pictures, and data will be finished by end of this week.