ITER Neutronics Challenges for Upper Port 14

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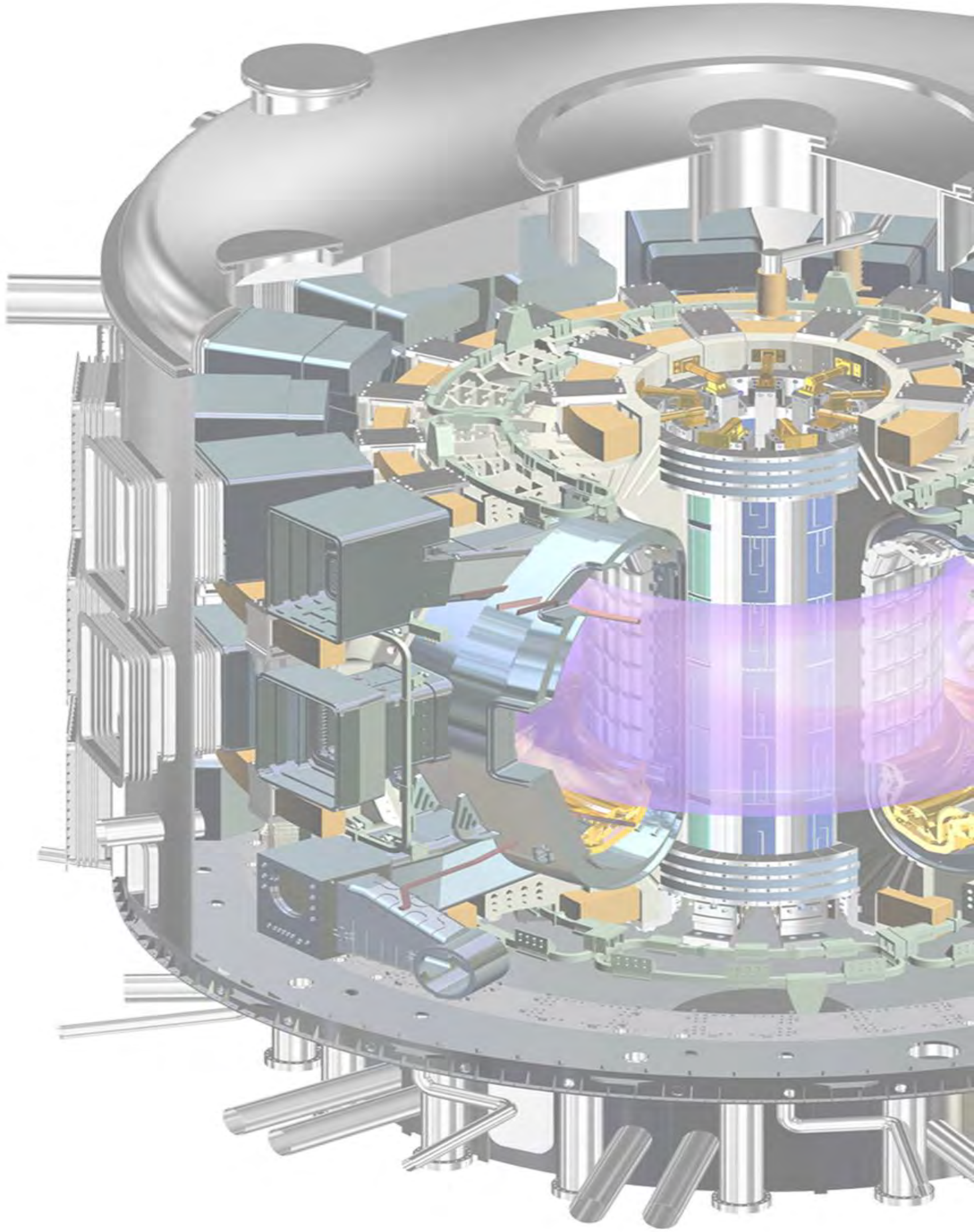
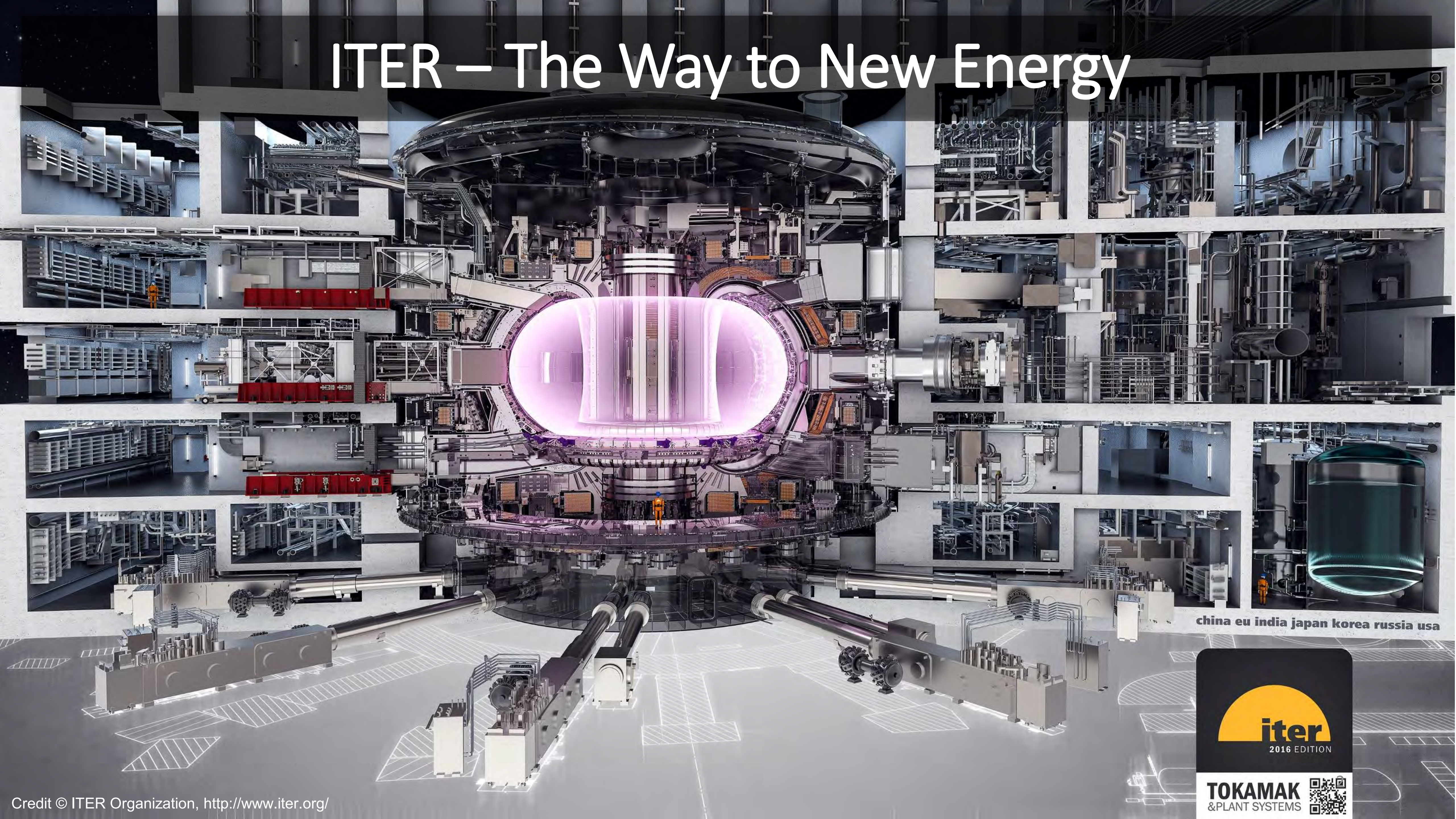
ANS Annual Meeting

June 14, 2017



ITER – The Way to New Energy

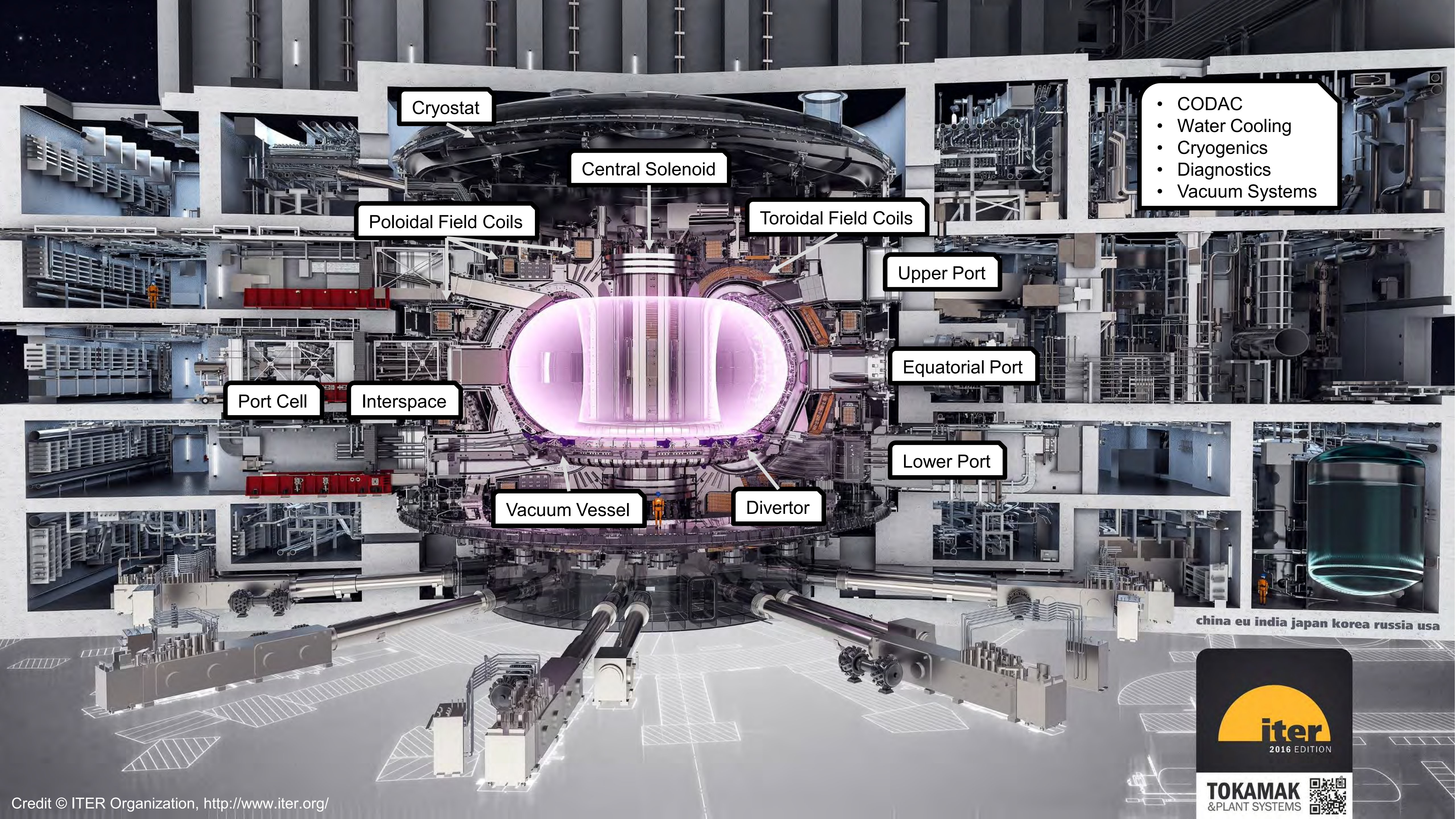


Credit © ITER Organization, http://www.iter.org/

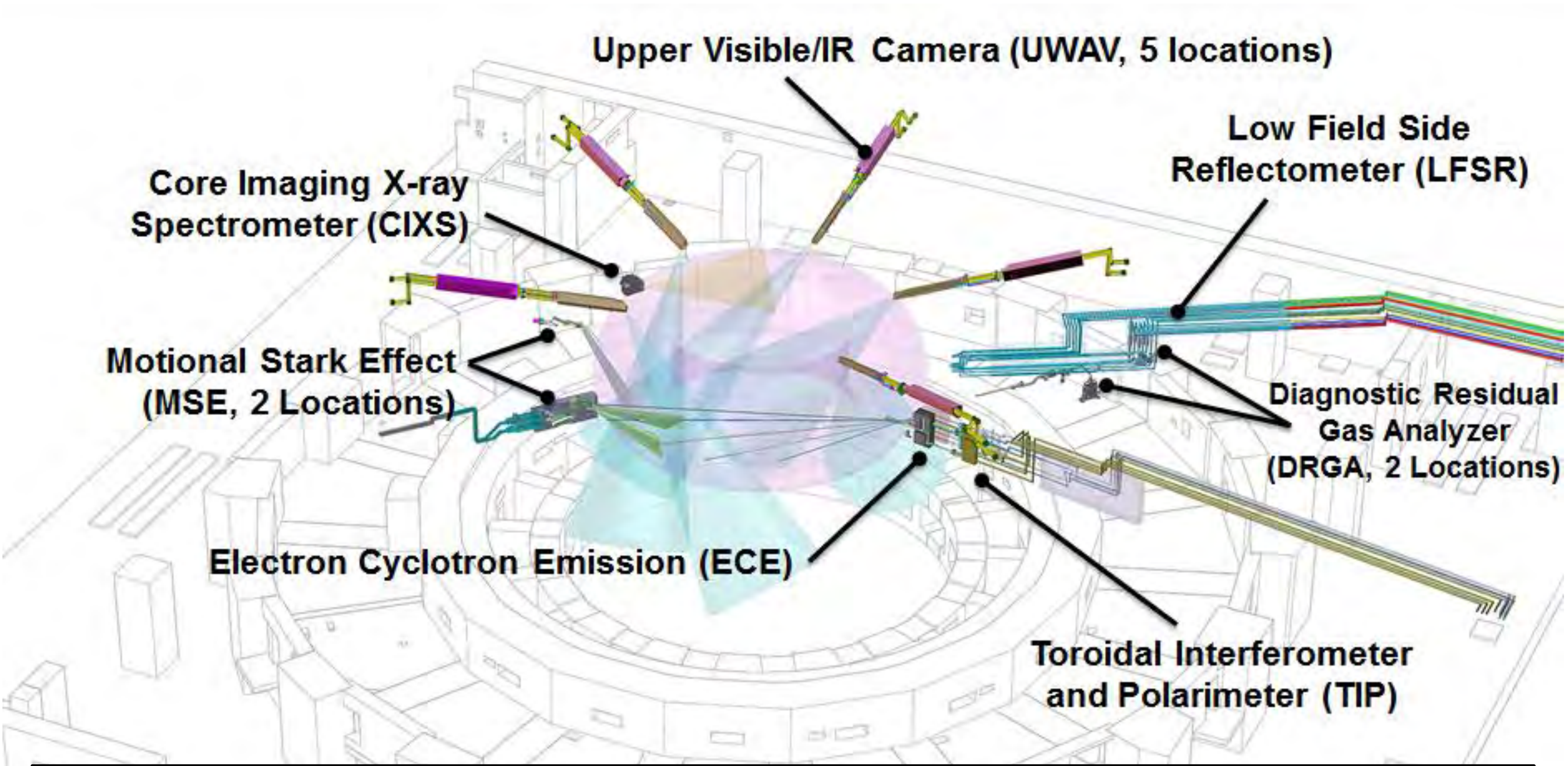
ITER – The Way to New Energy

- Worlds largest tokamak being built in southern France
- Bringing the power of the sun down here to earth
- 7 ITER Members
  - China, EU, India, Japan, Russia, and the US
- Nothing on this scale has ever been done before
  - Achieve a DT "burning plasma"
  - Produce 500 [MW] fusion energy (10 fold return on energy!)
  - Demonstrate the feasibility of Tritium breeding
  - Integrate wide range of current device components and diagnostics

Credit © ITER Organization, http://www.iter.org/

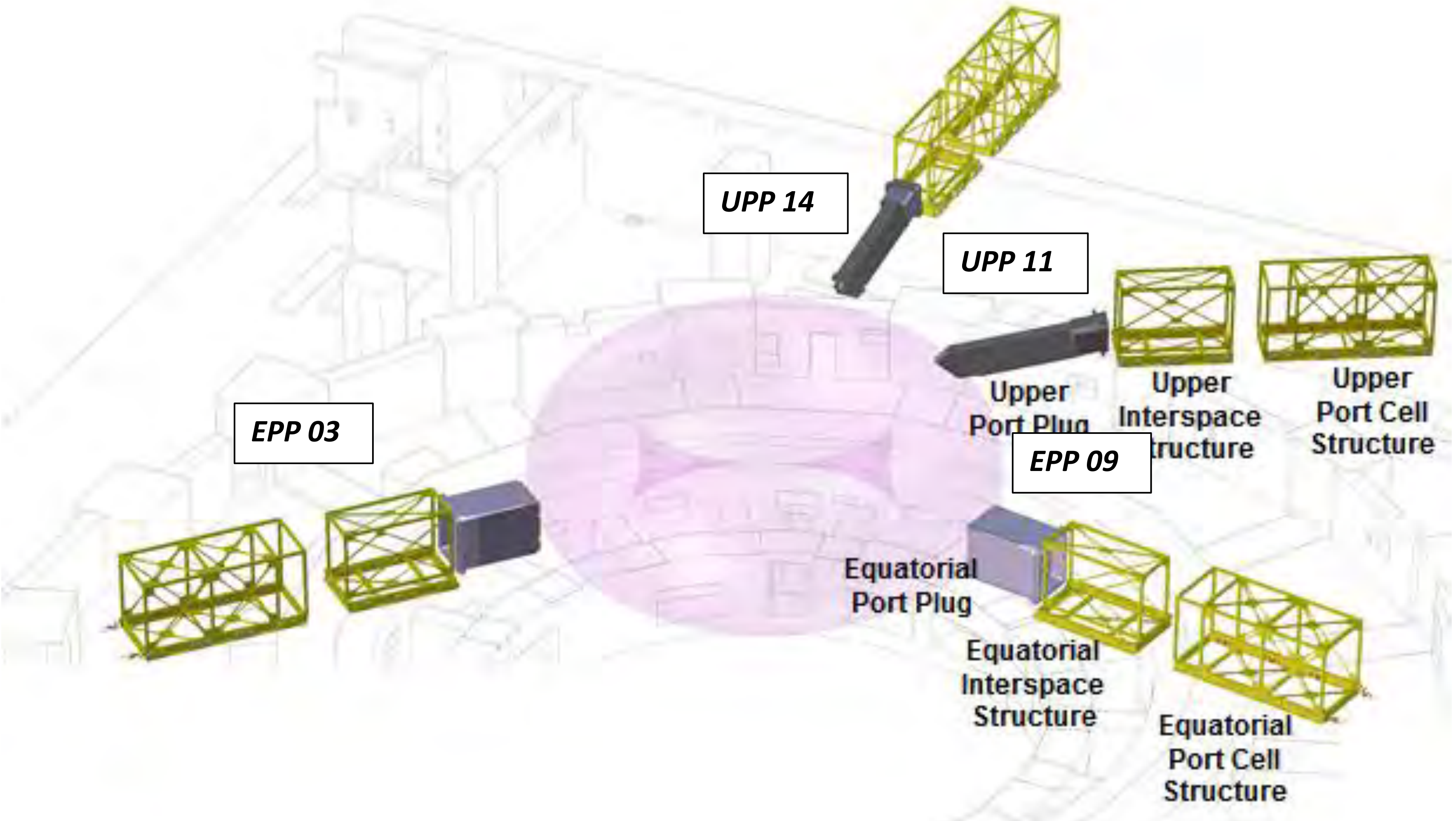

Cryostat
Central Solenoid
Poloidal Field Coils
Toroidal Field Coils
Upper Port
Equatorial Port
Port Cell
Interspace
Lower Port
Vacuum Vessel
Divertor
• CODAC
• Water Cooling
• Cryogenics
• Diagnostics
• Vacuum Systems
china eu india japan korea russia usa
iter
2016 EDITION
TOKAMAK
&PLANT SYSTEMS

US ITER – Seven World Class Diagnostics



- There are 7 US ITER diagnostic systems integrated into ITER.
- The diagnostics are distributed in 13 different installations.
- US ITER has diangostics in 11 different port plugs
    - Requires significant collaboration between ITER member nations

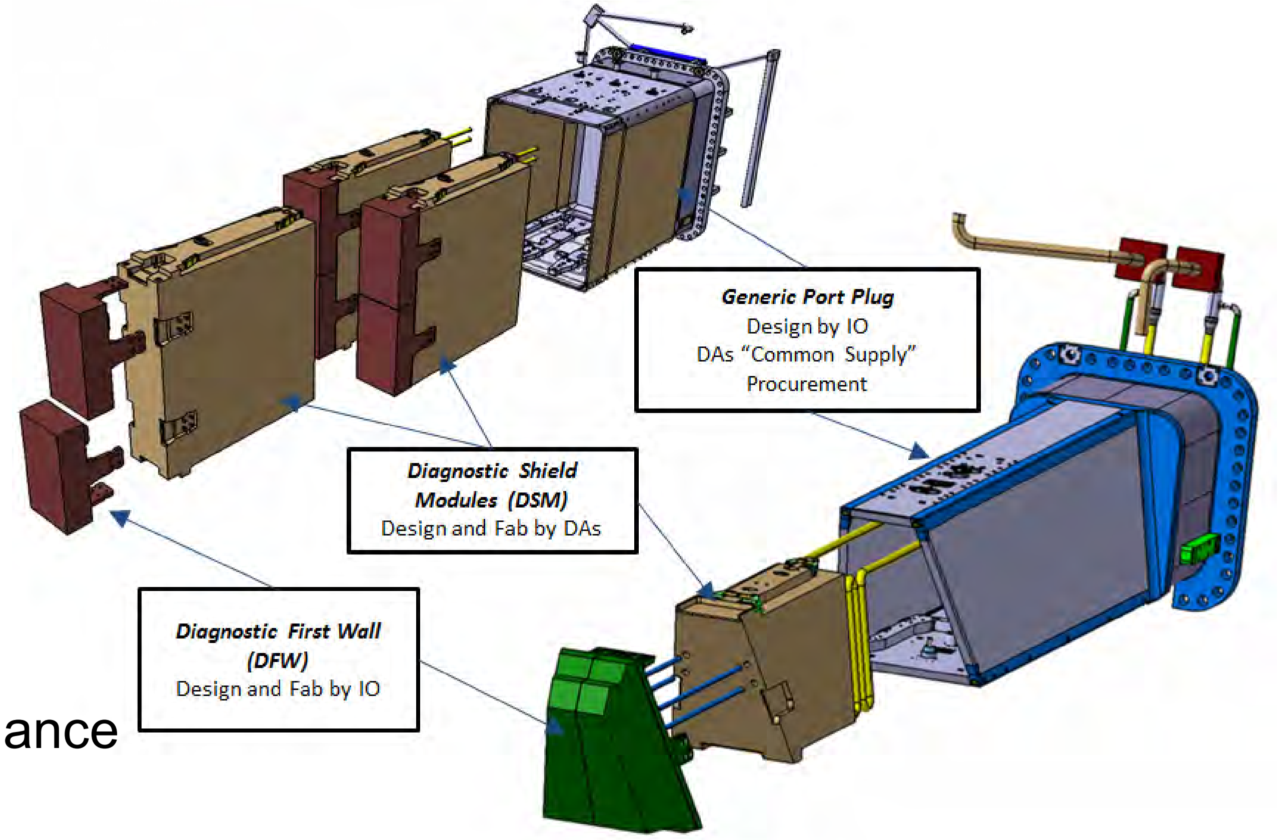
US ITER – Four integrated Port Plug Packages



- There are 4 US ITER port plug packages integrated into ITER.
- Each package consists of port plug, interspace structure, bio-shield, and port cell structure
- Each port plug package requires integrated global ITER analysis
  - This is even more difficult with the integration of 11 diagnostics from 5 different ITER Members

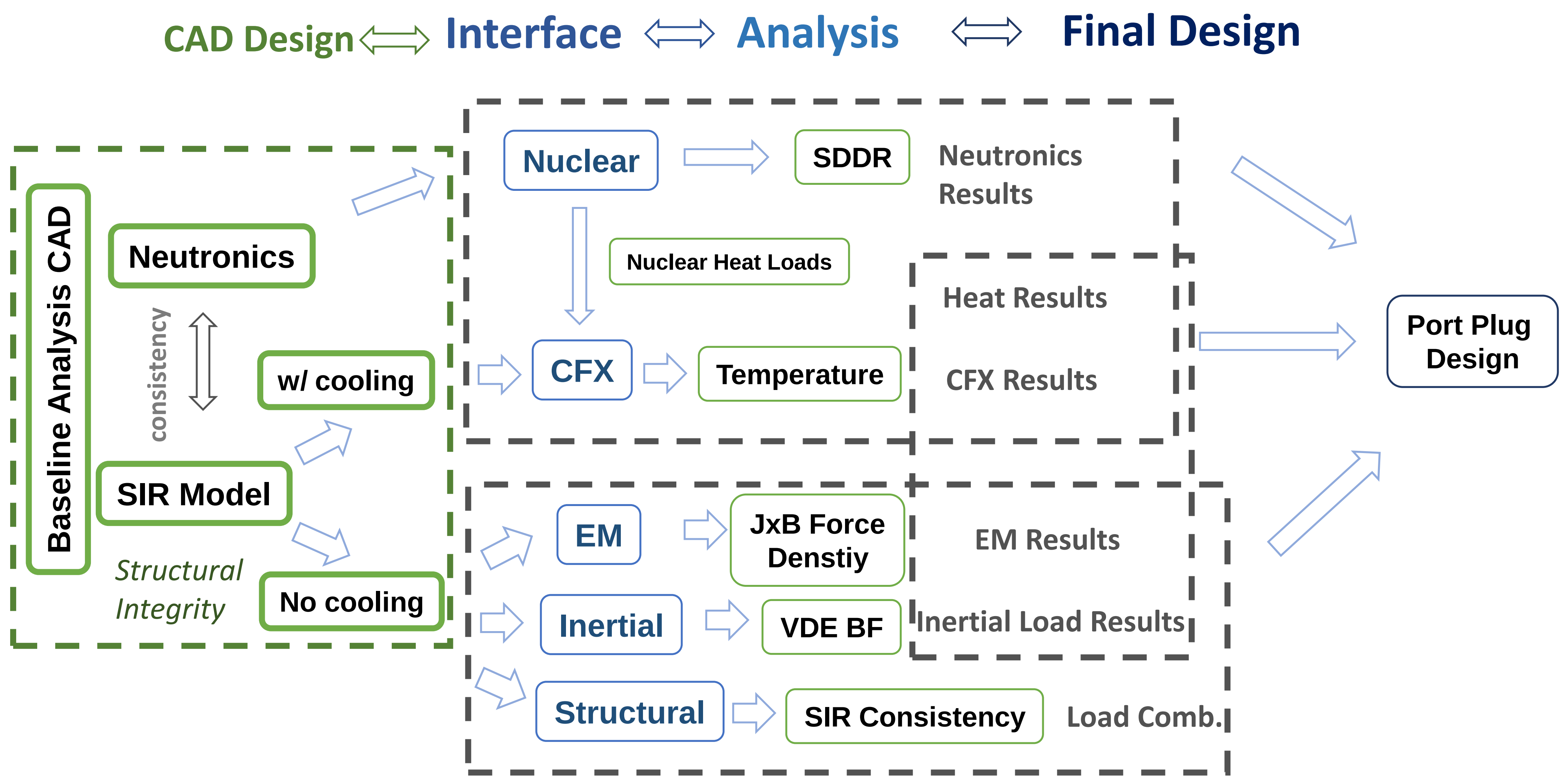
US ITER – Equatorial and Upper Port Plugs

- The many roles of a Port Plug
  - Plasma facing component
  - 14 MeV neutron shield
  - Primary vacuum boundary
  - Tritium confinement
  - Heat Exchanger
  - Withstand EM disruptions
  - Housing and protecting the diagnostics
  - Diagnostic remote handling and maintenance

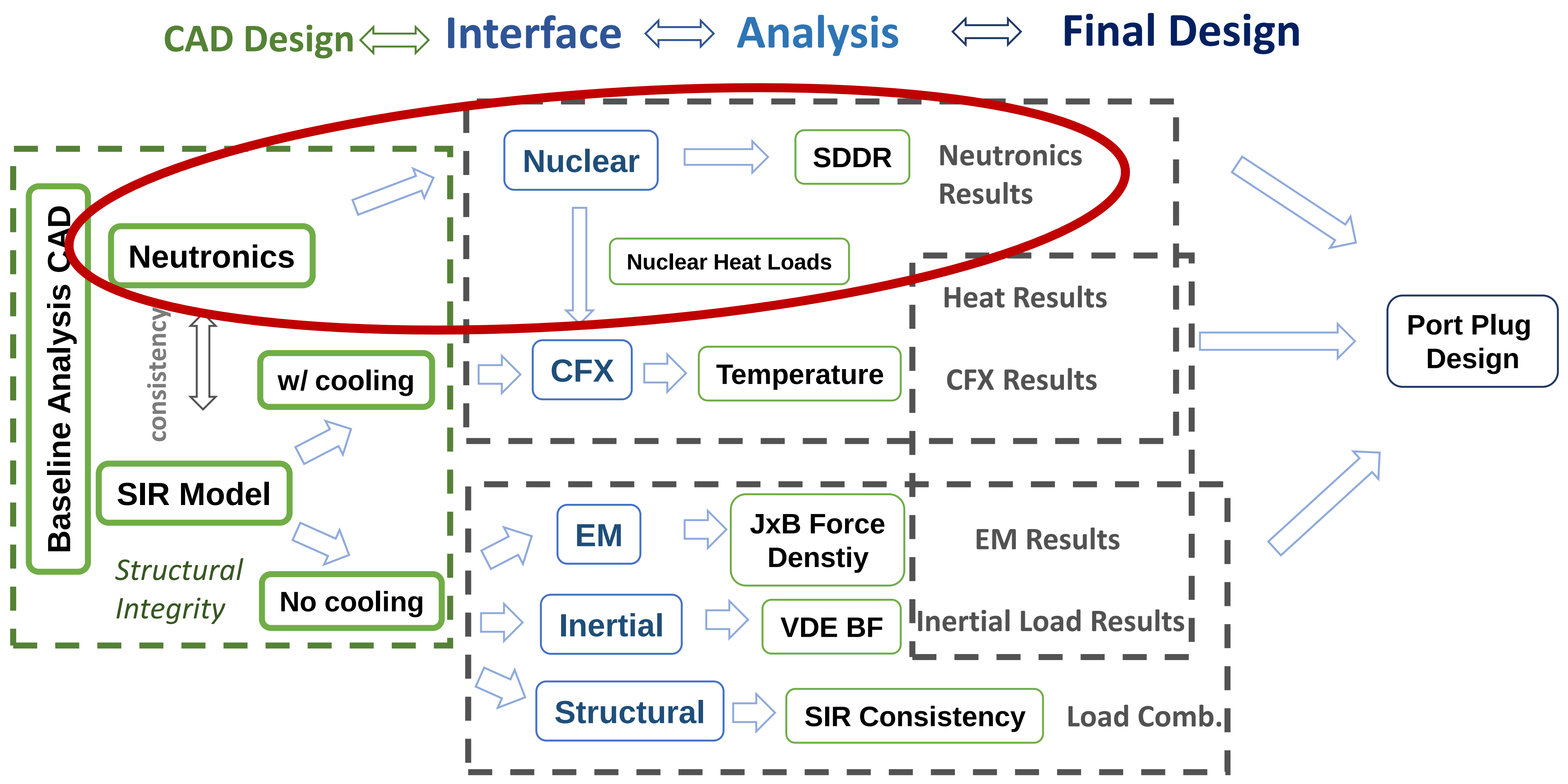


Port Plug	Dry Weight (mt)	Length (m)
Equatorial	45	3.4
Upper	25	5.5

Port Plug Analysis Requirements



Port Plug Analysis Requirements



Nuclear Computational Procedure

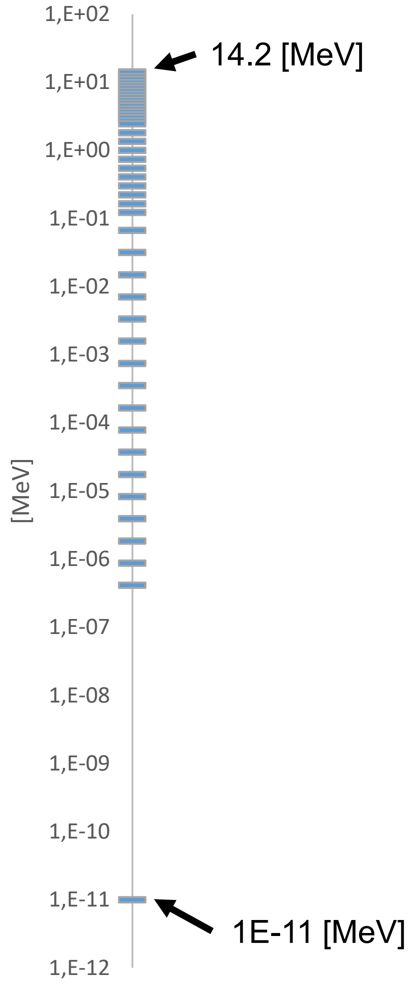
- **Attila neutronics code**
  - Distributed by Varex Imaging (https://www.vareximaging.com)
  - Attila deterministically solves the linear Boltzmann Transport Equation

$$\frac{d}{ds}\psi(\vec{r},E,\hat{\Omega}) + \sigma_t(\vec{r},E)\psi(\vec{r},E,\hat{\Omega}) = Q_s(\vec{r},E,\hat{\Omega}) + Q_f(\vec{r},E,\hat{\Omega}) + q(\vec{r},E,\hat{\Omega})$$

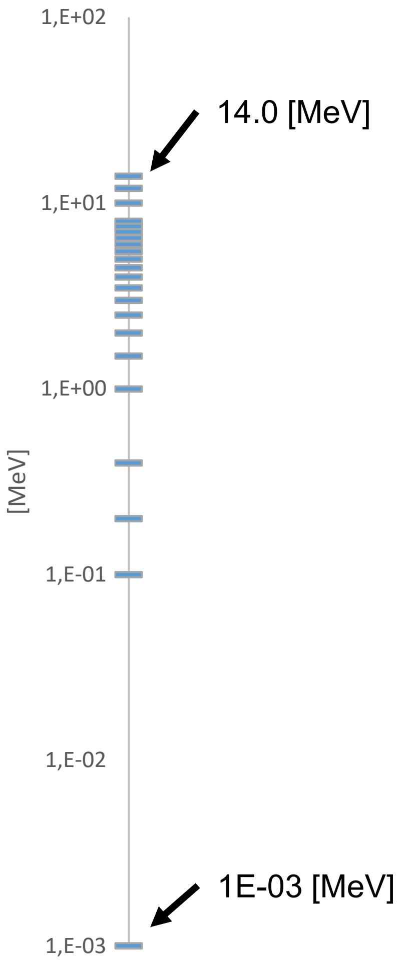
  - Attila solves the linear Boltzmann Transport Equation by discretizing the equation in space, energy, and angle, then iterating to convergence
    - Space – Linear Discontinuous Finite Element Method on Unstructured Tetrahedral Elements
    - Energy – Multi-Group Method with particle energies discretized into finite width bins
    - Angle – Discrete Ordinates Method, which solves the transport equation by sweeping mesh along discrete angles
- Benchmarked along with MCNP for ITER analysis
  - Fusion Engineering and Design 88 (2013) 2022-2040
- JASSBY PPPL cluster specific for ITER neutronics calculations
  - 6 systems
  - 16 processors per system
  - 283 GB memory per system

US ITER Nuclear Analysis Energy and Angle Discretization

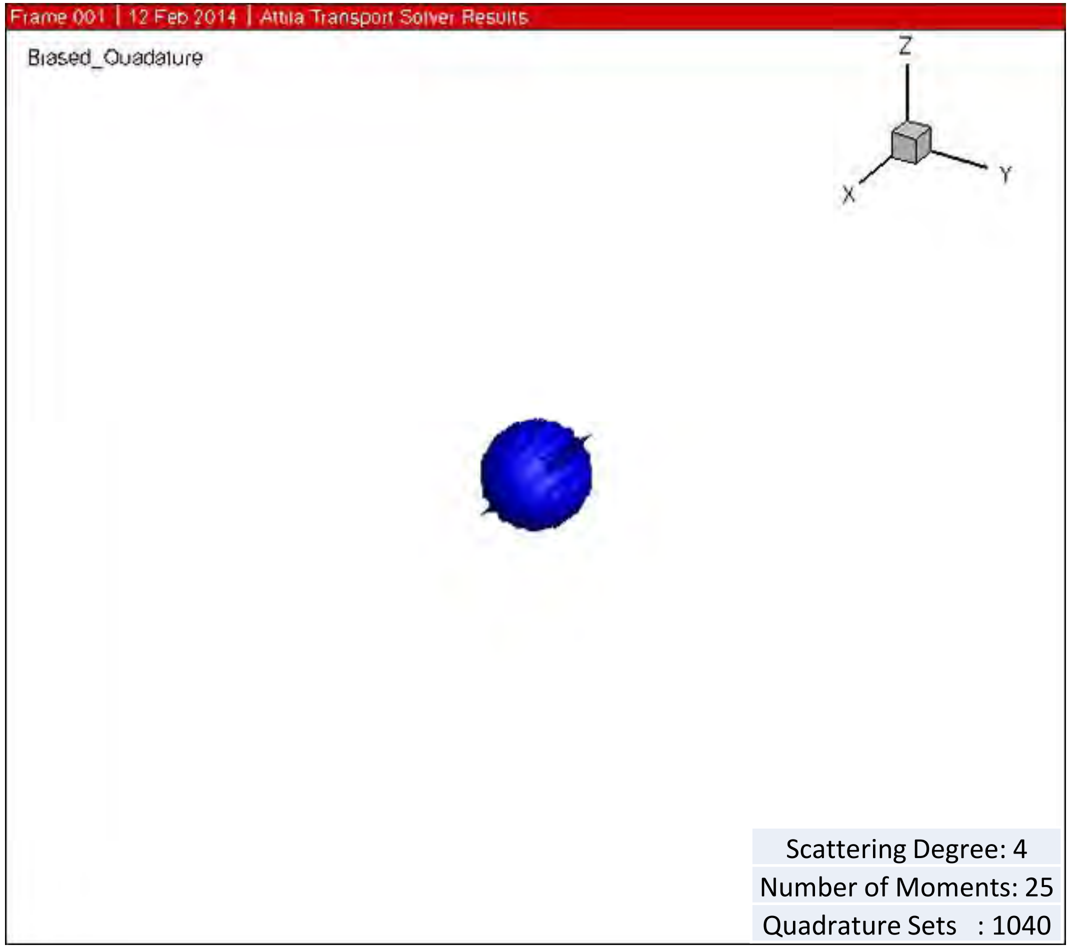
46 Neutron Groups



21 Gamma Groups

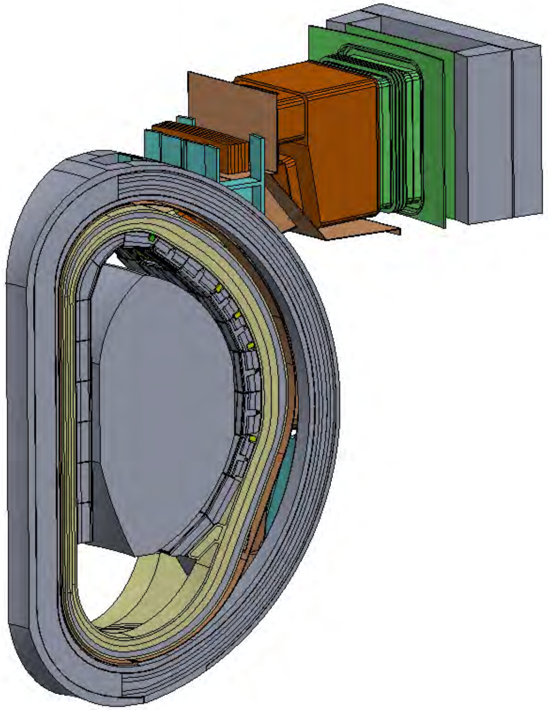


Neutron and Gamma Energy Groups
FENDL 2.1 Cross Section Library

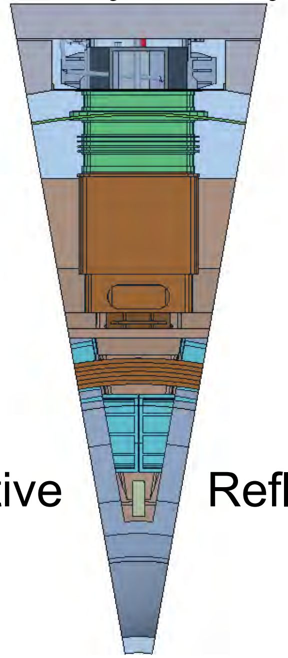


Biased Quadrature based angle discretization

US ITER Nuclear Analysis UP14 Model

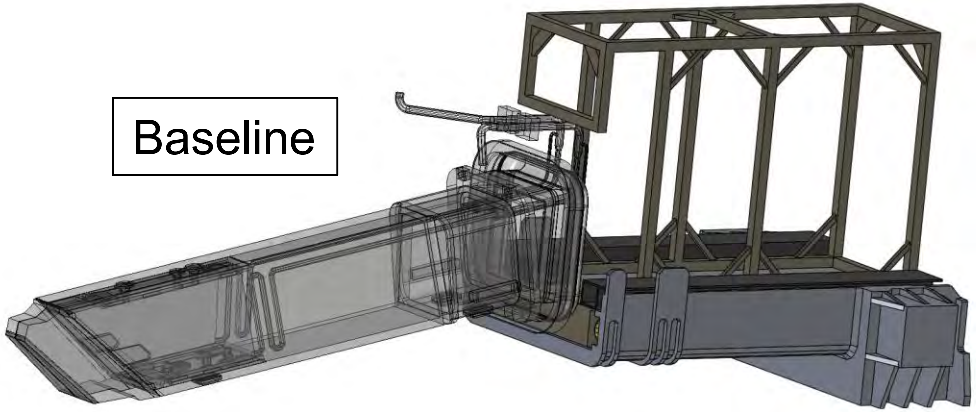


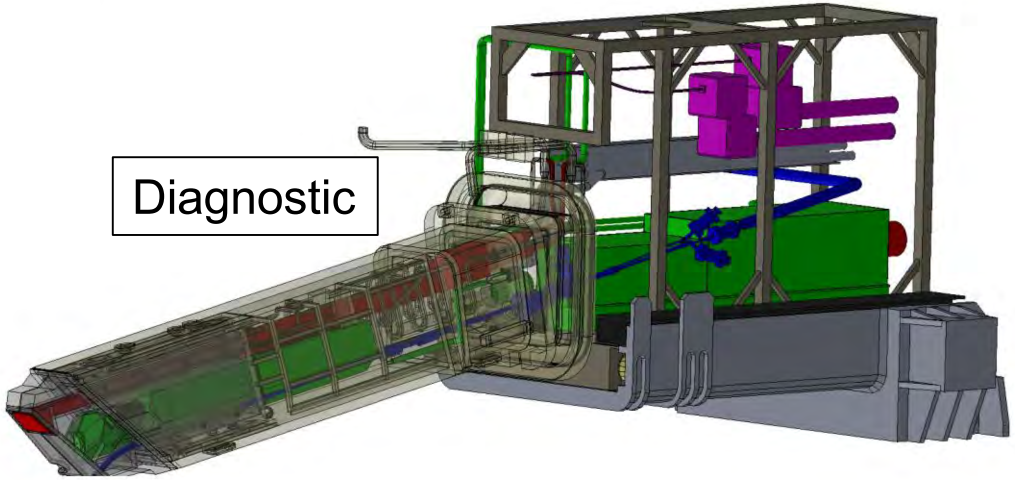
20° symmetry

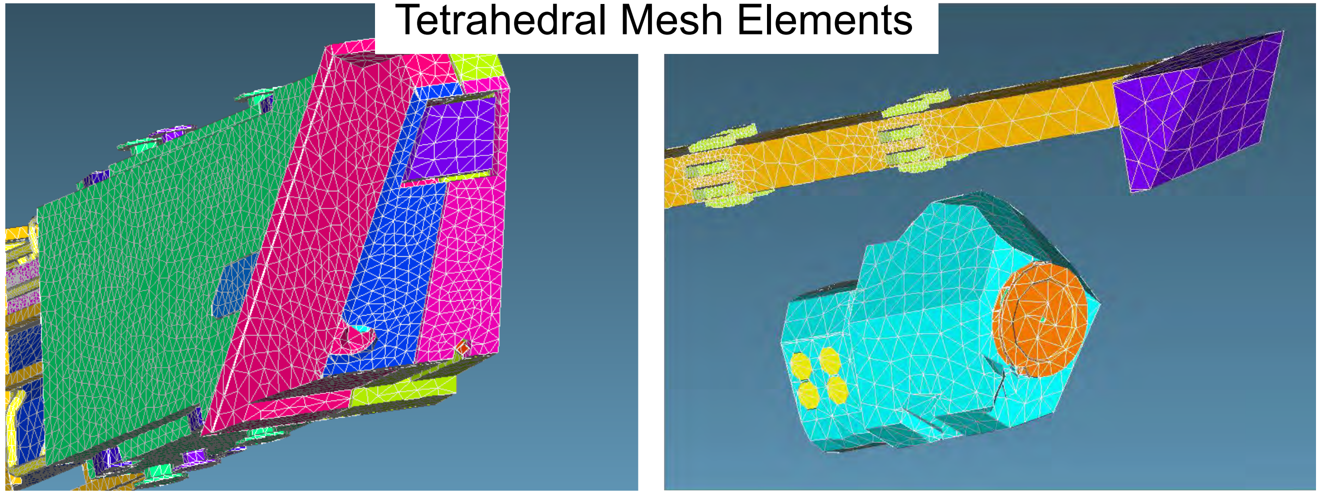


Reflective

Reflective

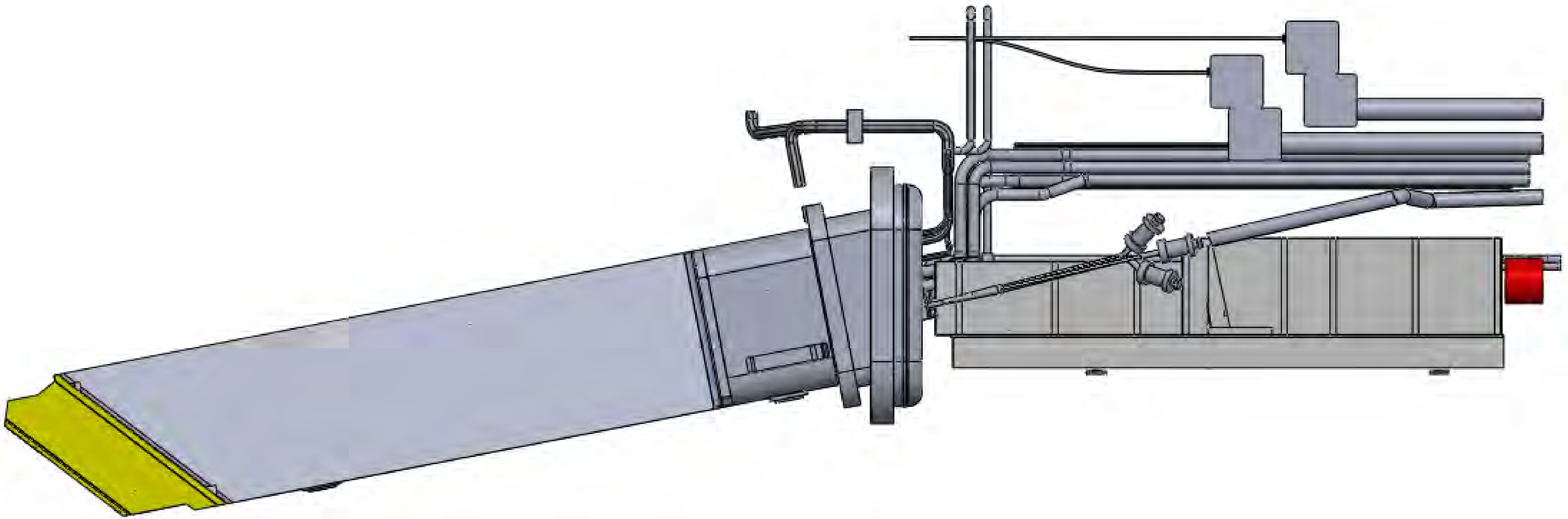






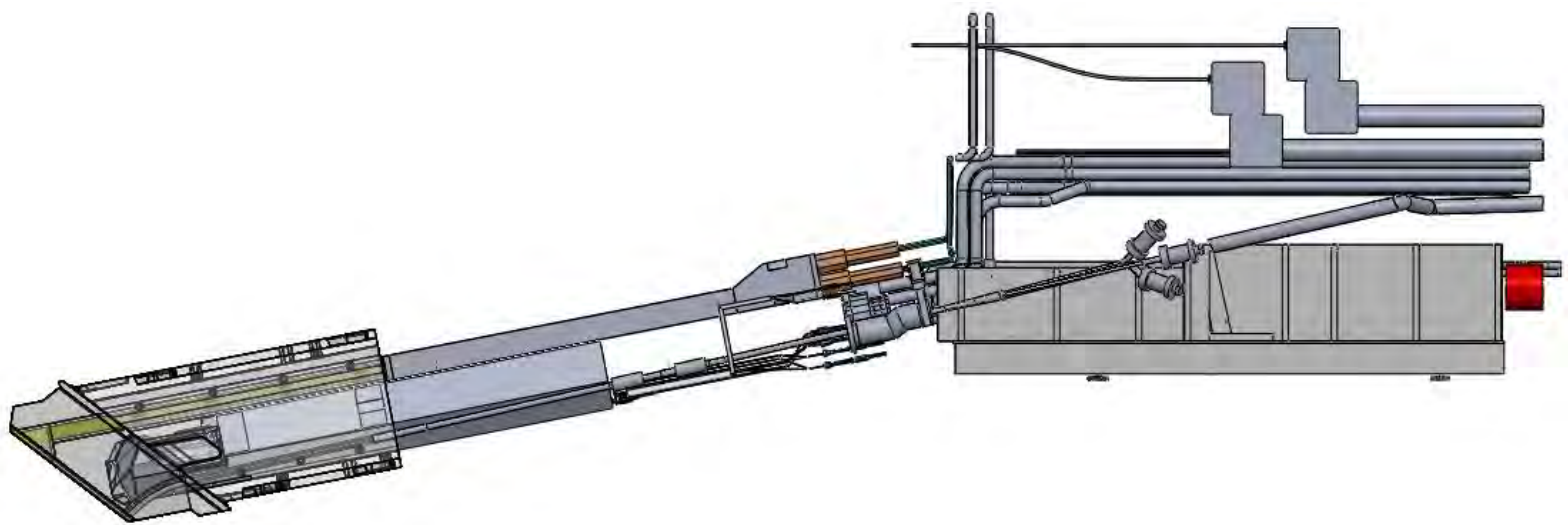
Material definitions use worst case impurity count

US ITER Nuclear Analysis UP14 Model



- Upper port plug diagnostic model showing the port plug region along with the interspace region
- Three diagnostics are hosted within UP14
    - Global Discharge Cleaning (GDC)
    - Upper Wide Angle Viewing (UWAV)
    - Distruption Mitigation System (DMS)

US ITER Nuclear Analysis UP14 Model



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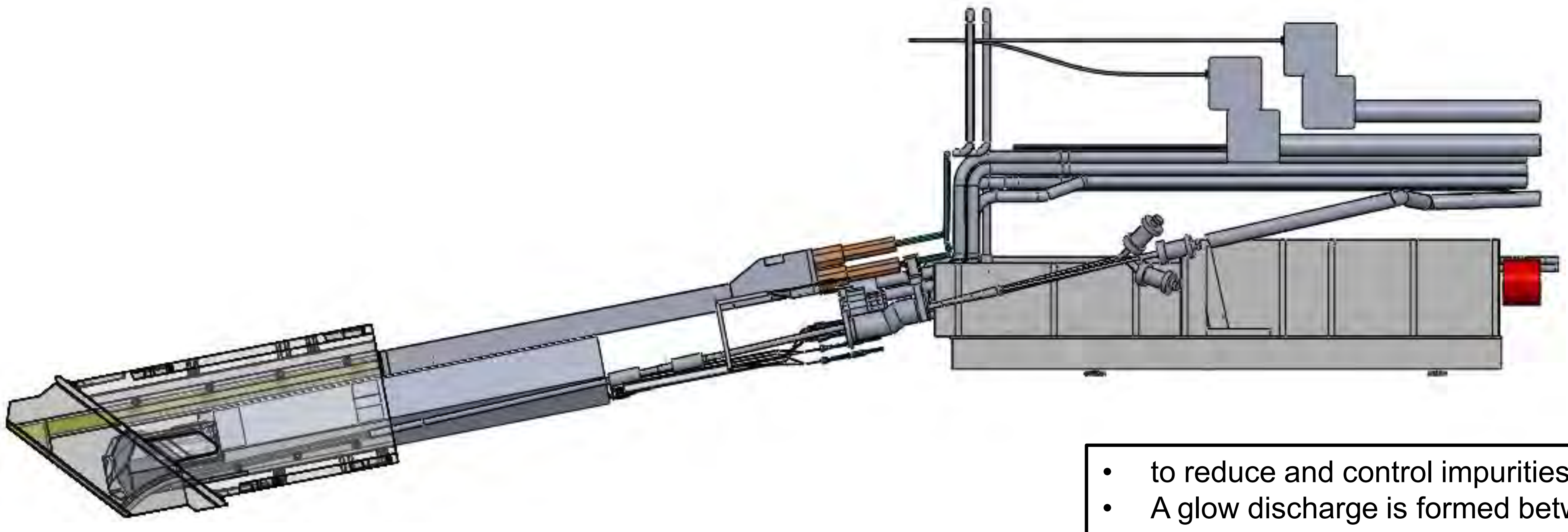
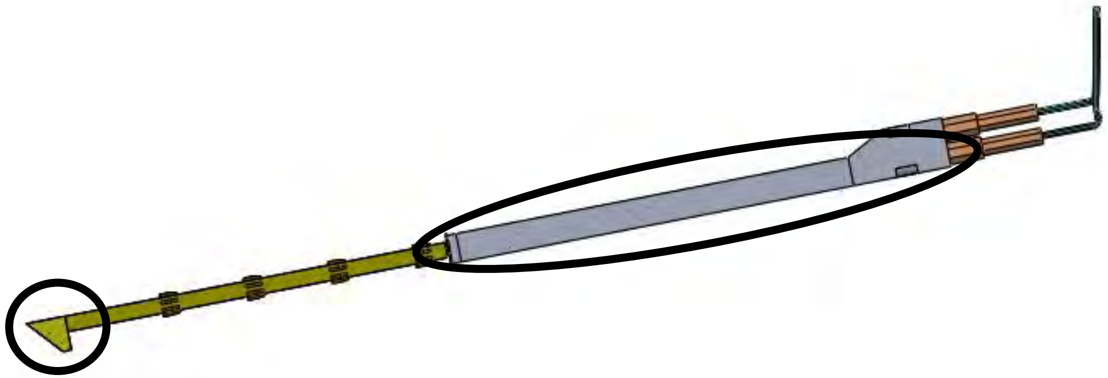
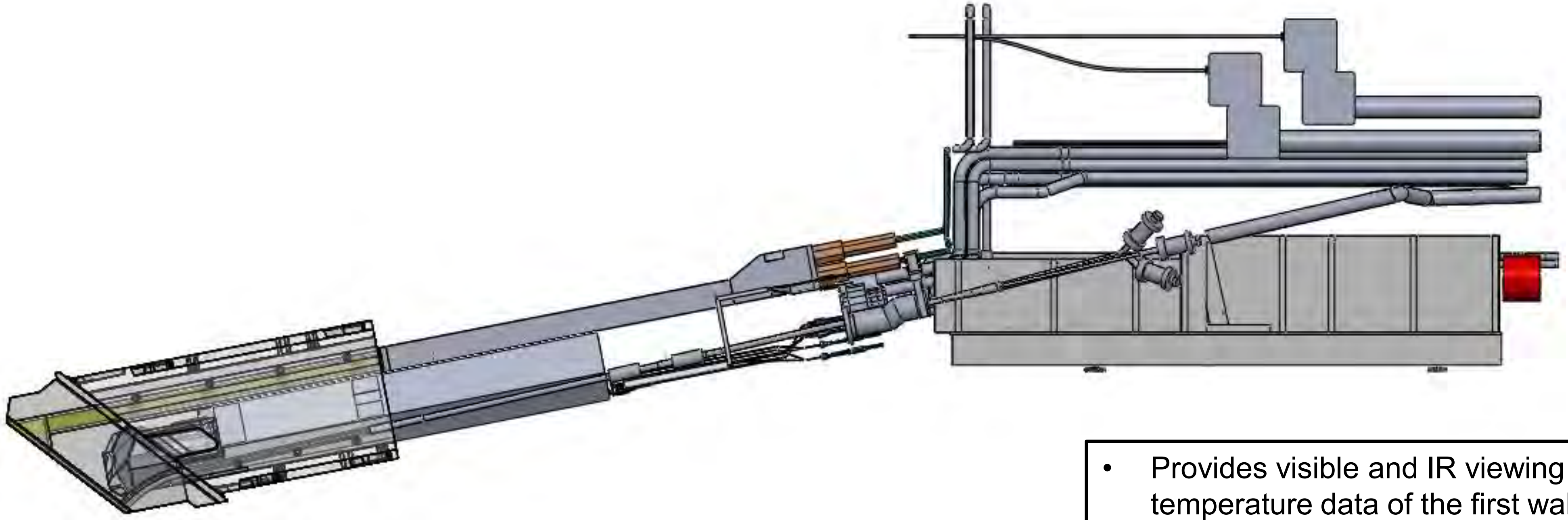
US ITER Nuclear Analysis UP14 Model - GDC

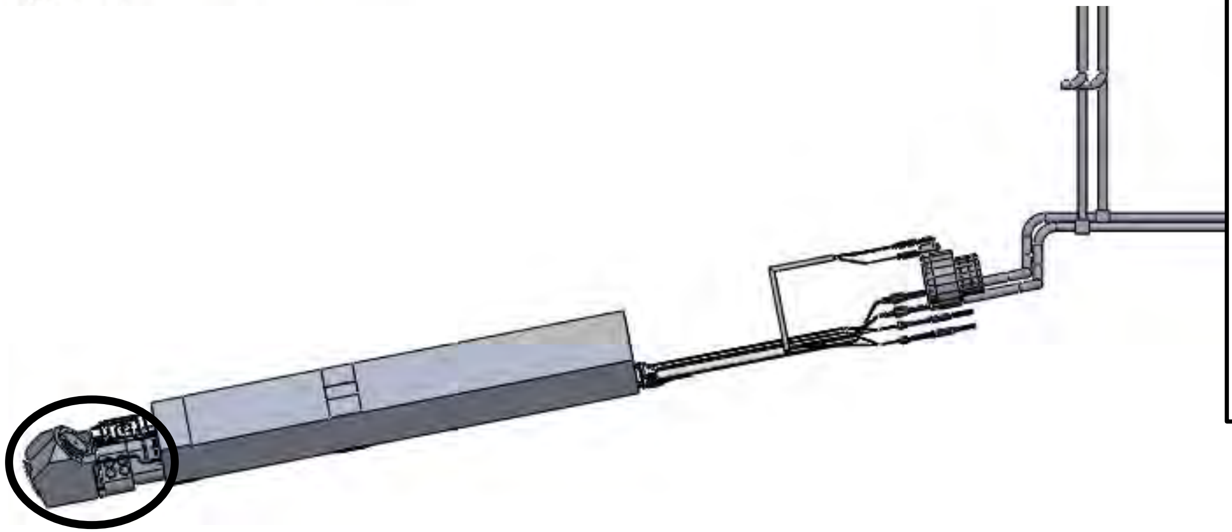




- to reduce and control impurities
- A glow discharge is formed between the electrodes and the plasma facing surfaces
- Impurities will be liberated by the ion bombardment
  - swept out by pumping
- Particular challenges are:
  - Volumetric heating on plasma facing surface
  - Direct streaming due to straight diagnostic

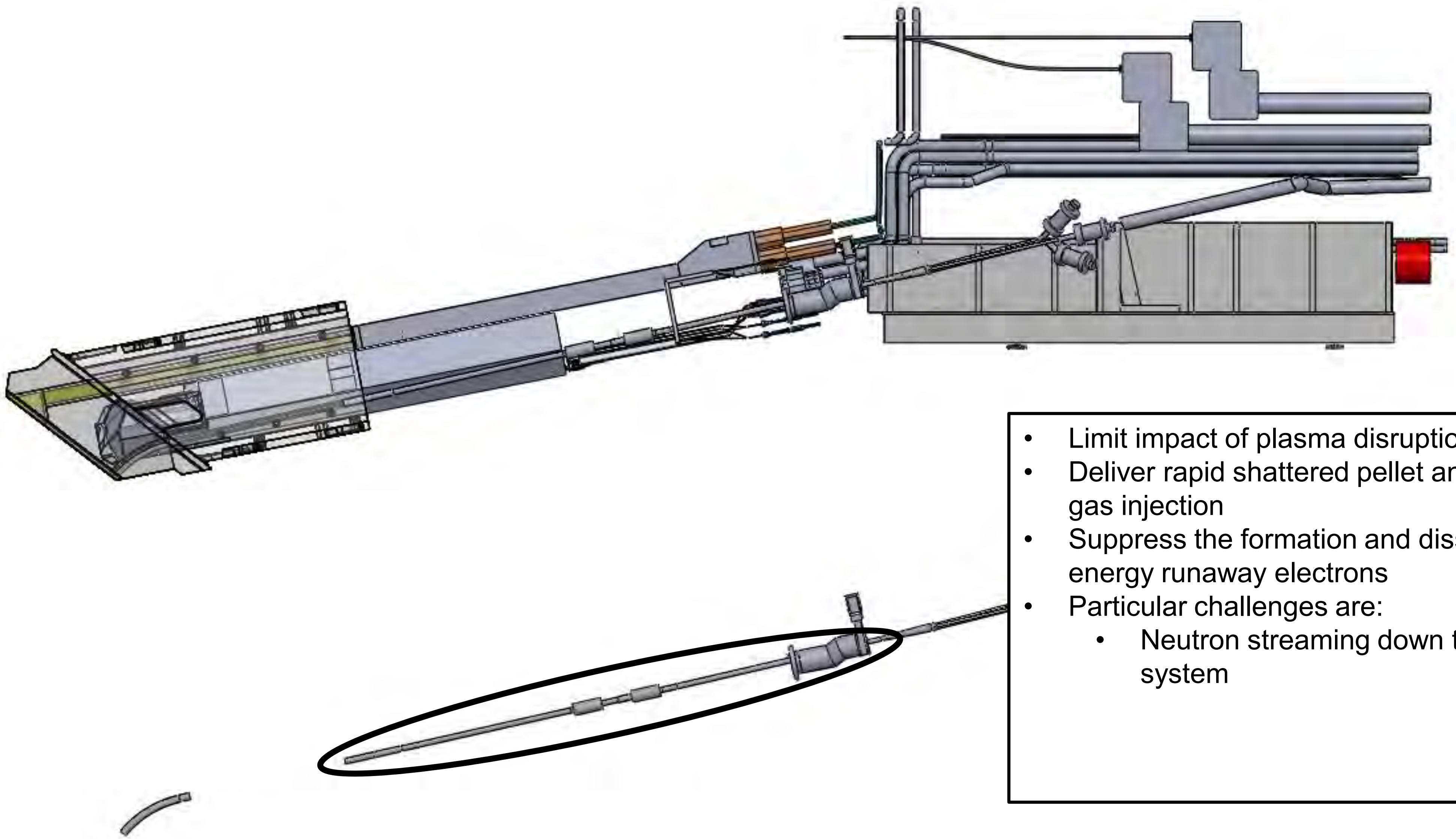
US ITER Nuclear Analysis UP14 Model - UWAV





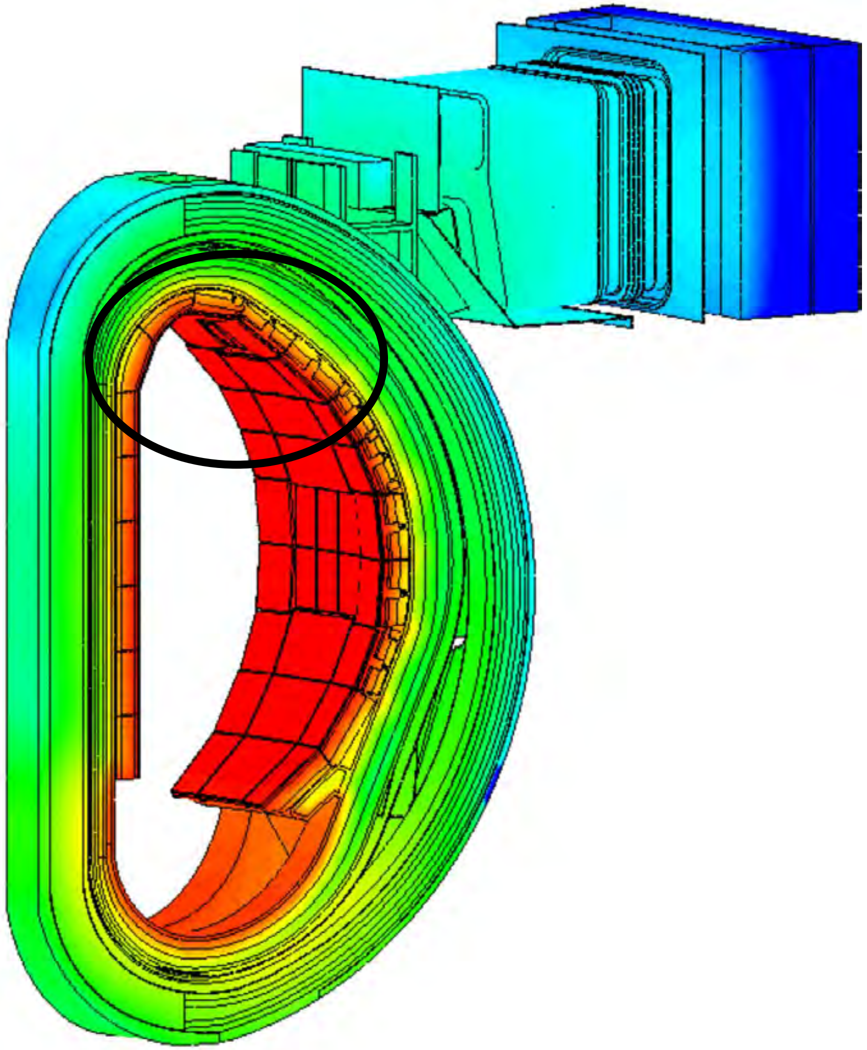
- Provides visible and IR viewing and temperature data of the first wall.
- The emphasis is on coverage rather than spatial resolution.
- The spectral coverage of the cameras
  - visible range (400-700 nm)
  - IR range (3-5 μm)
- Particular challenges are:
  - the first mirror degradation risk
  - low emissivity and high reflectivity of the first wall

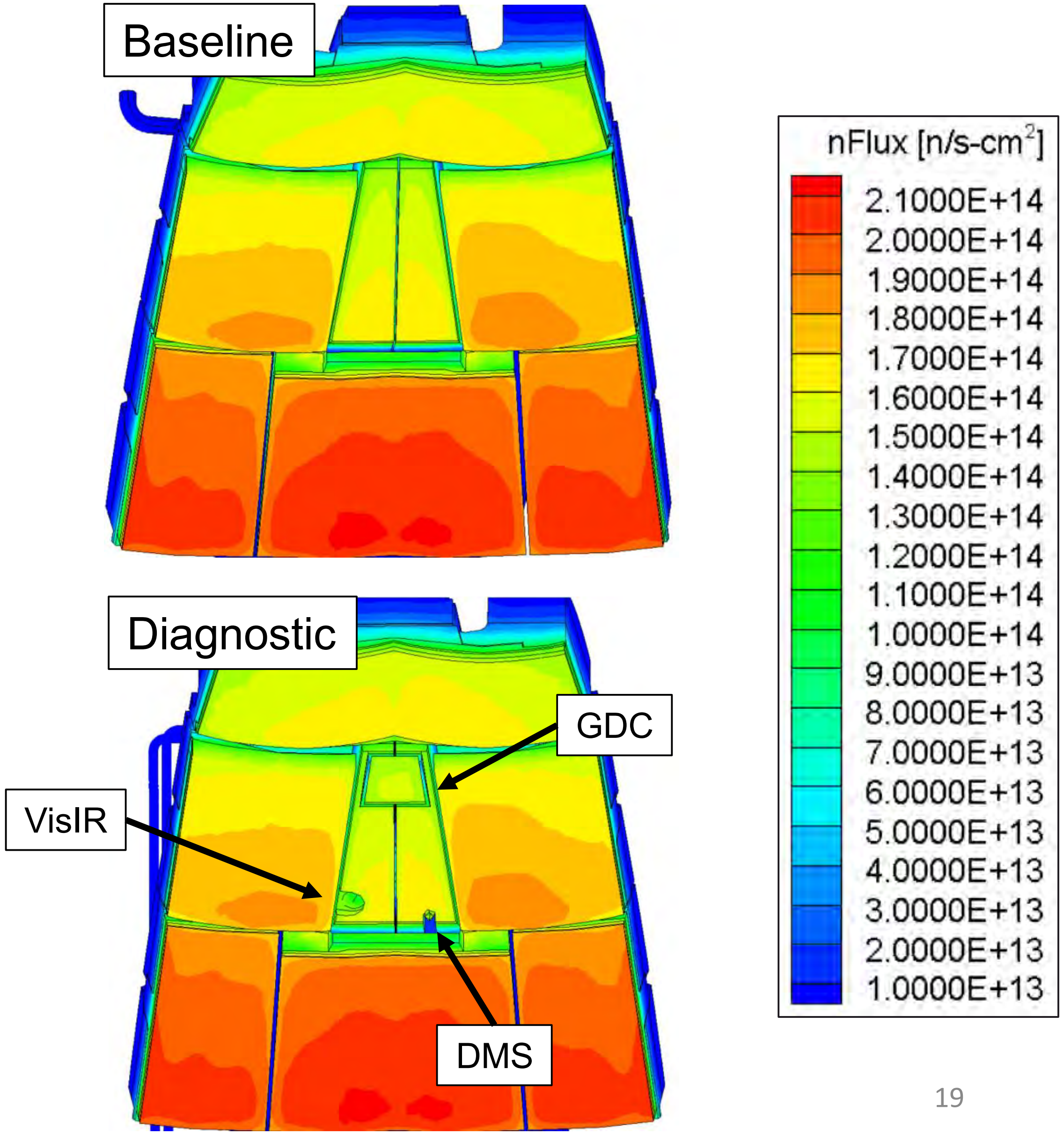
US ITER Nuclear Analysis UP14 Model - DMS



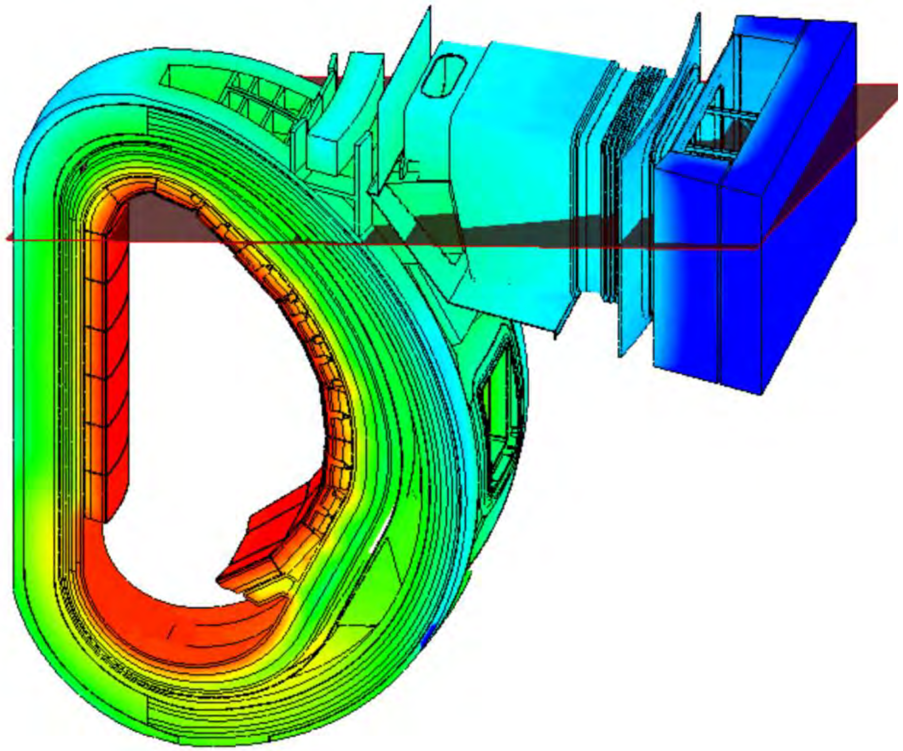
- Limit impact of plasma disruptions
- Deliver rapid shattered pellet and massive gas injection
- Suppress the formation and dissipate high energy runaway electrons
- Particular challenges are:
  - Neutron streaming down the delivery system

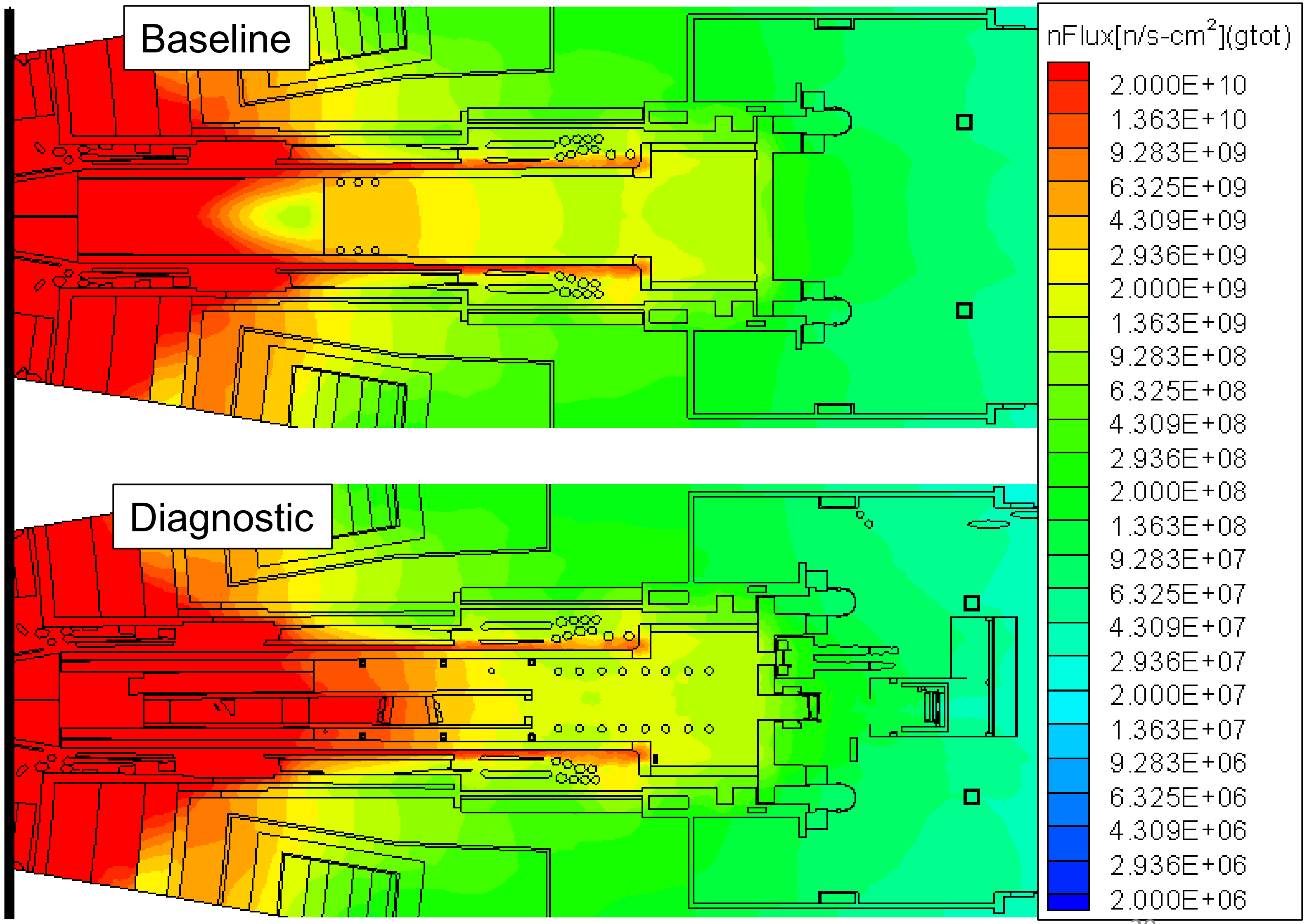
Plasma Facing Components Neutron Flux



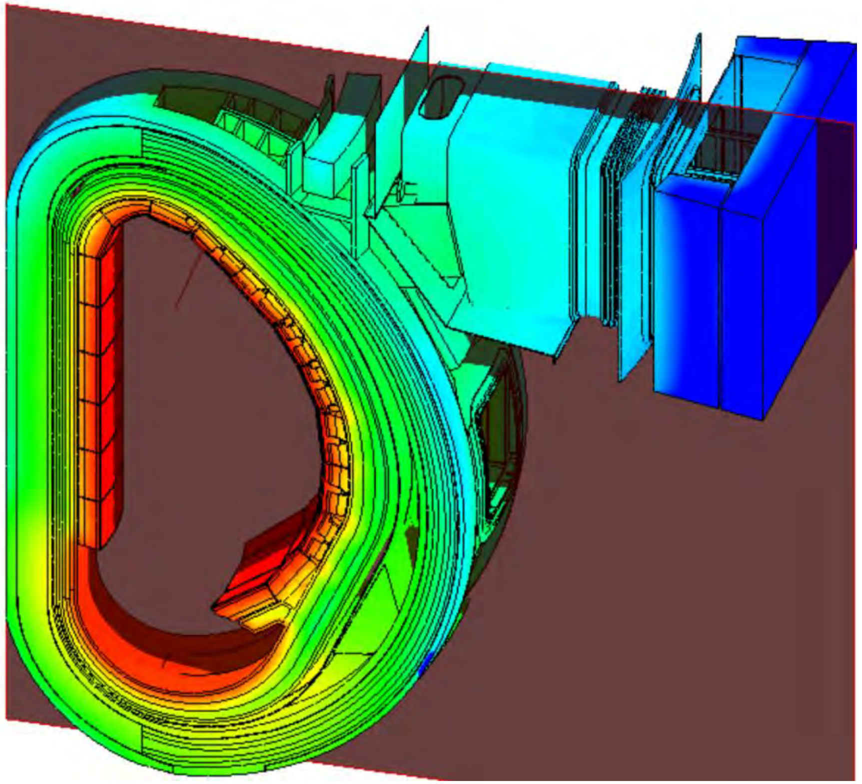


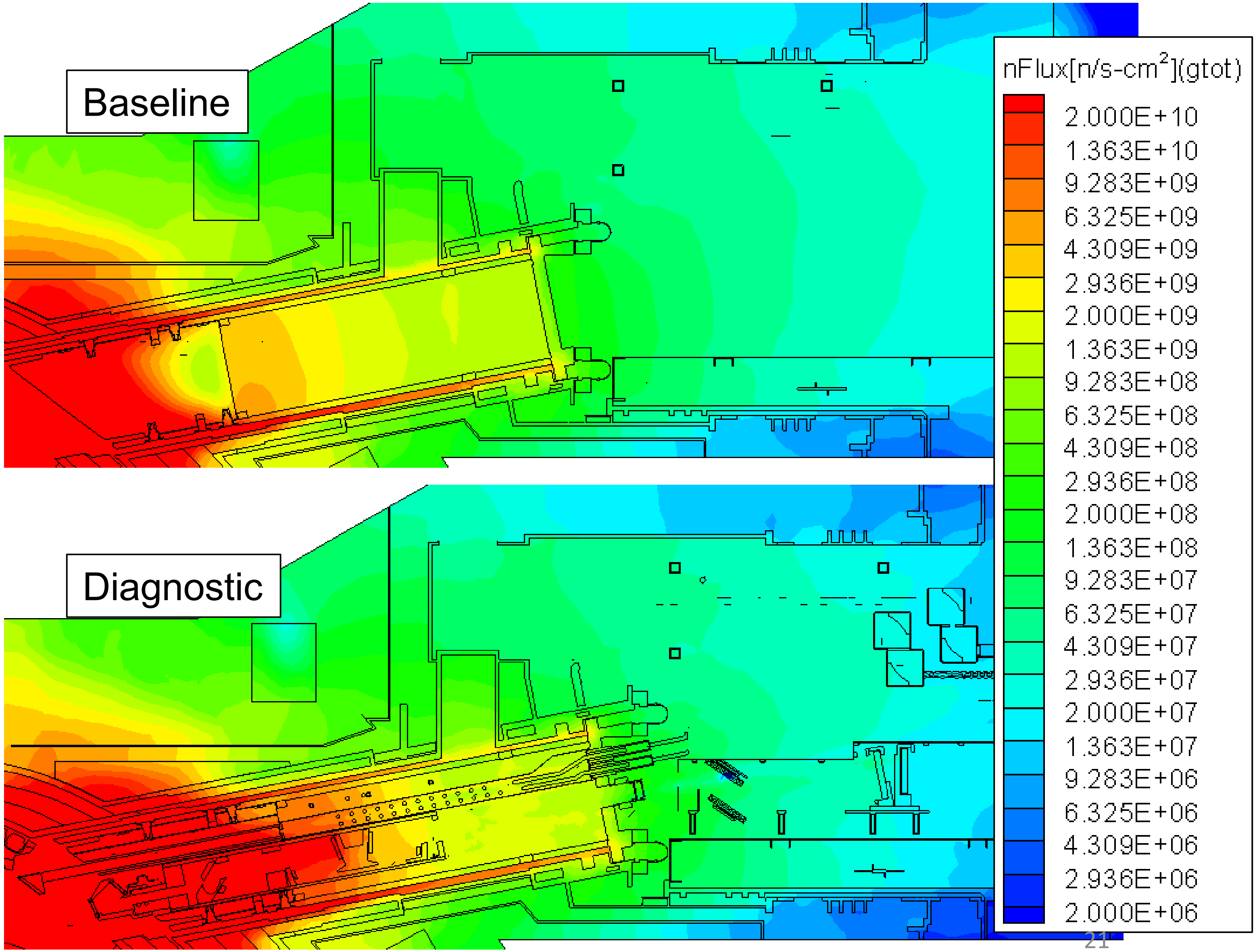
Horizontal View of the Neutron Flux



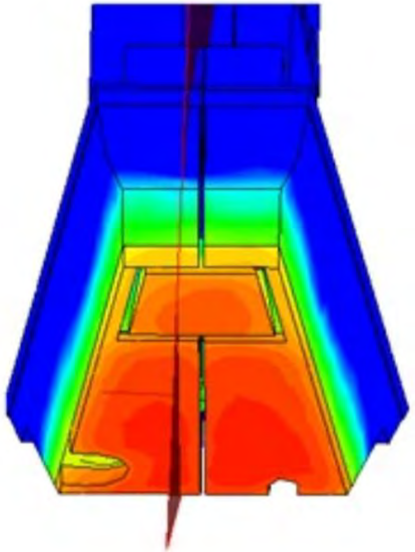


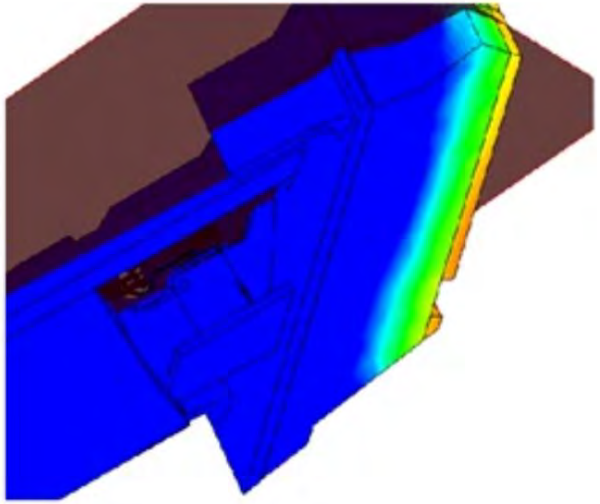
Vertical View of the Neutron Flux

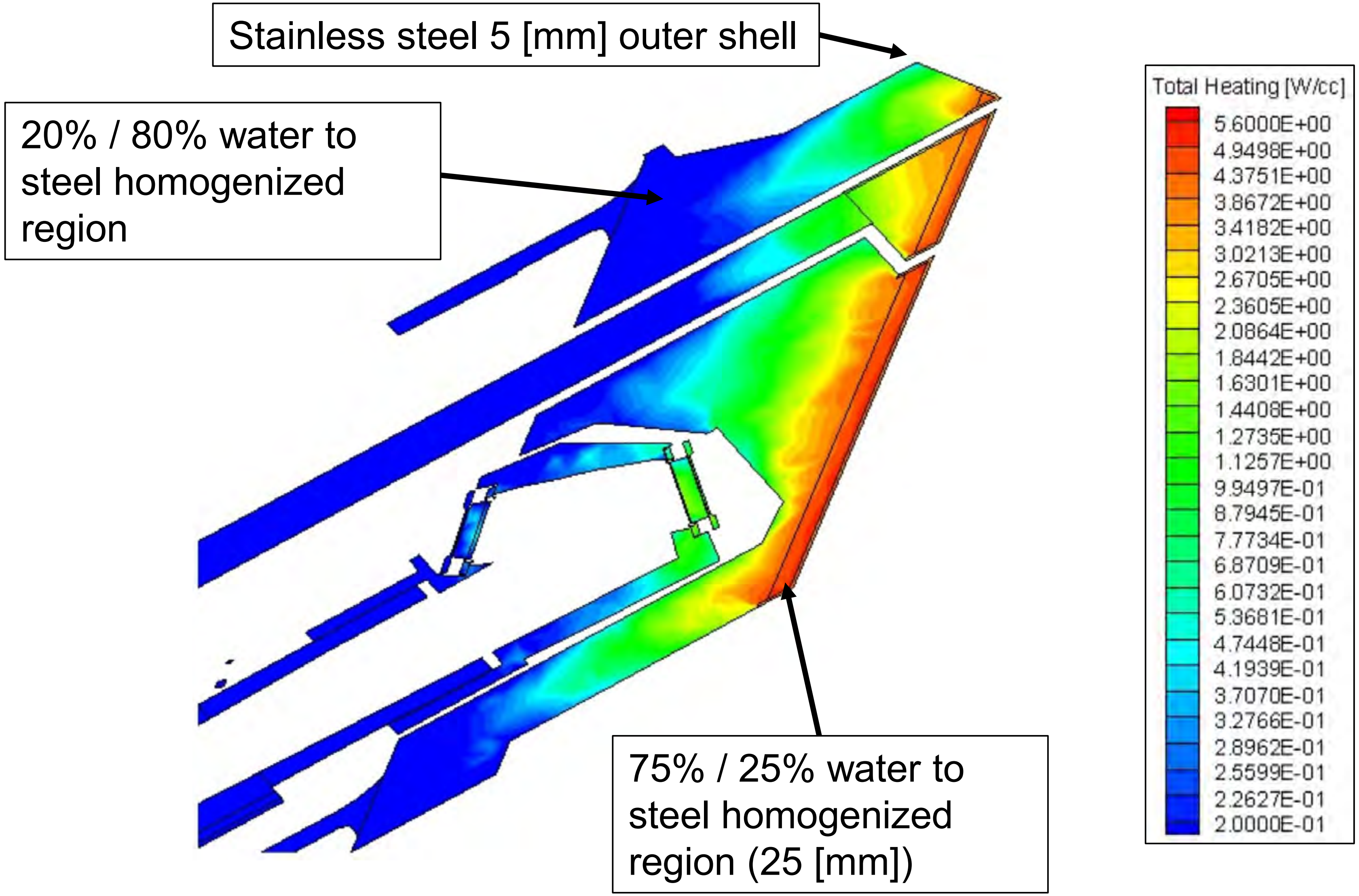




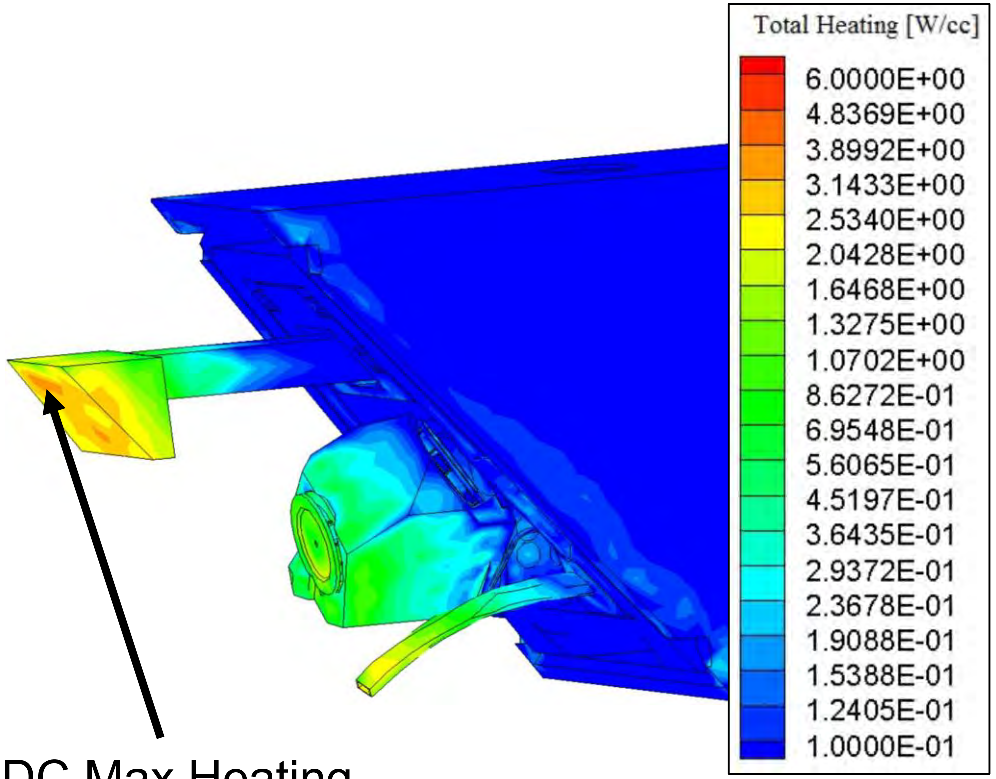
Nuclear Heating Results



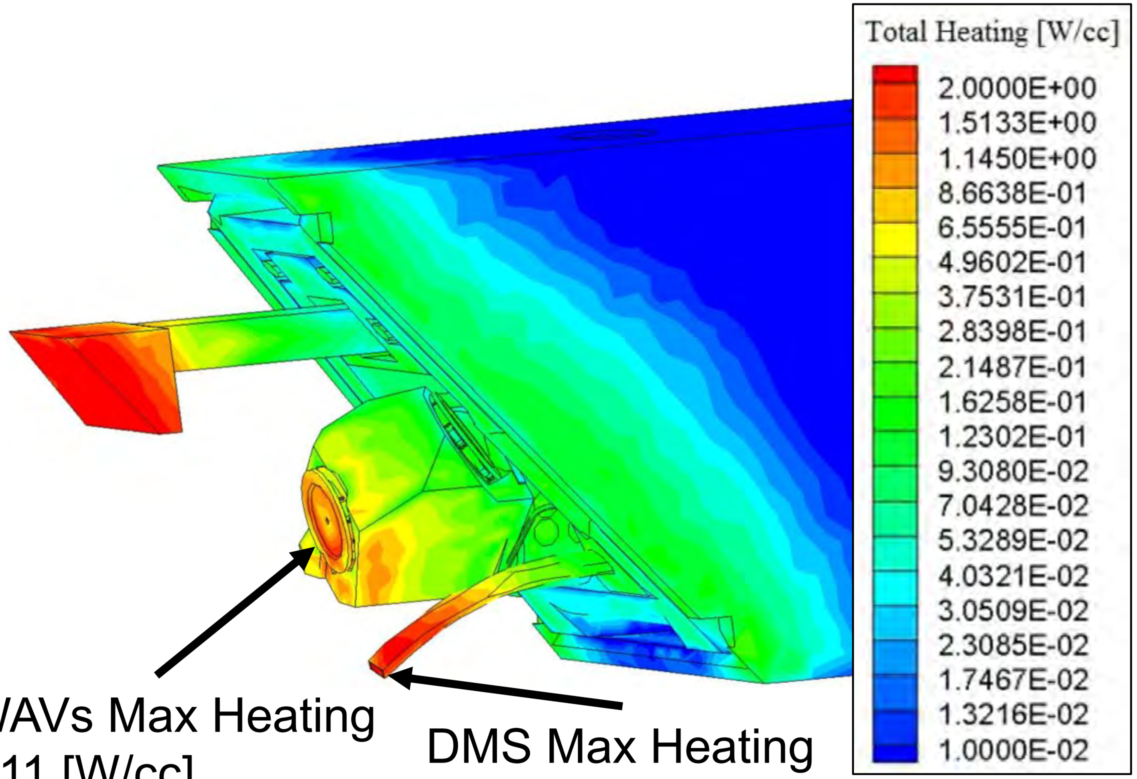




Nuclear Heating – Diagnostic Maximums



GDC Max Heating
5.003 [W/cc]

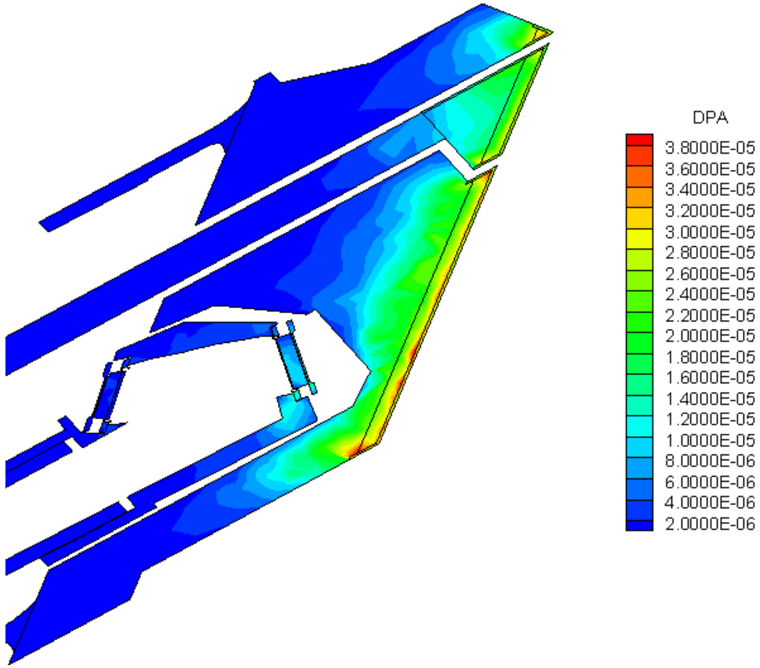


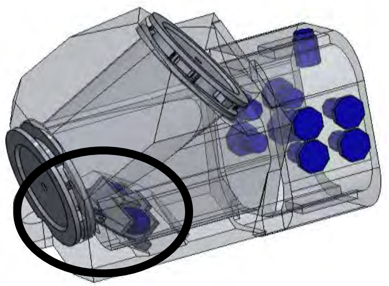
UWAVs Max Heating
2.511 [W/cc]

DMS Max Heating
4.012 [W/cc]

UP14 Component	Nuclear Heating [W/cm³]		
	Neutron	Gamma	Total
Left DFW	58.921	238.495	143.741
Right DFW	30.402	123.274	153.676
VisIR System	1.628	12.003	13.631
GDC System	6.569	20.992	27.561
DMS System	0.989	9.044	10.034

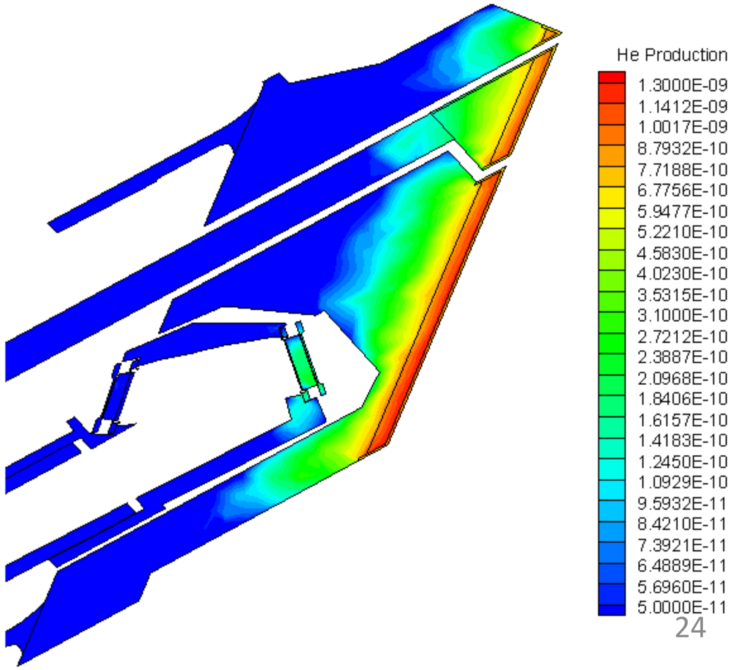
DPA and He production Results



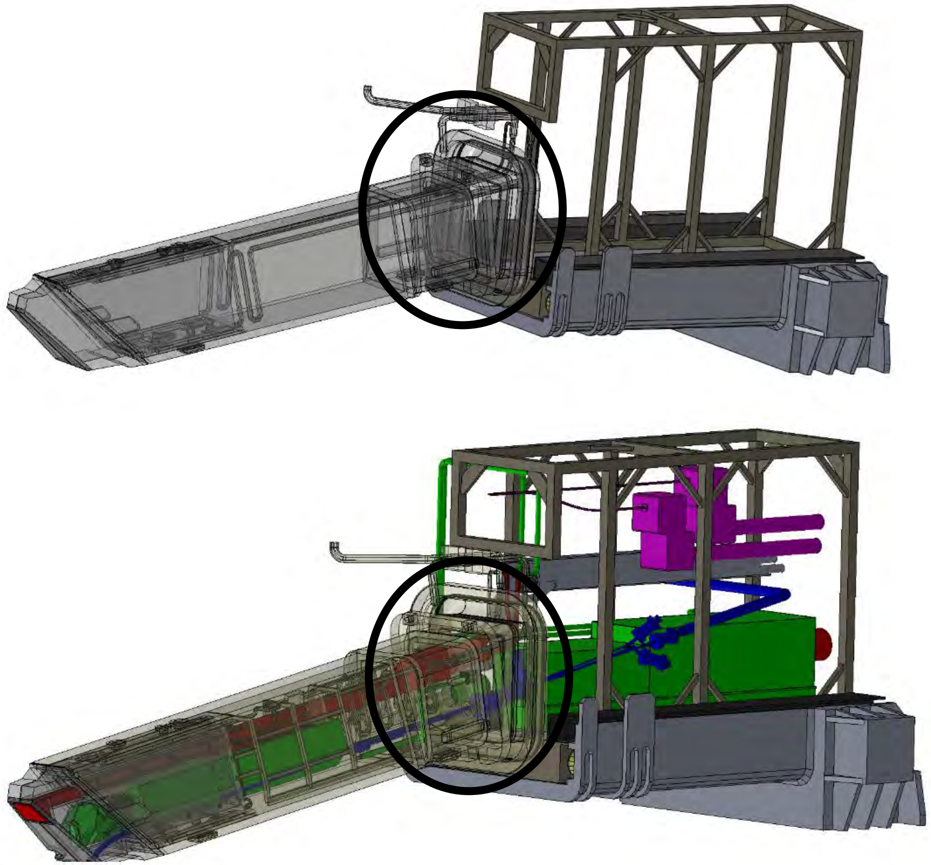


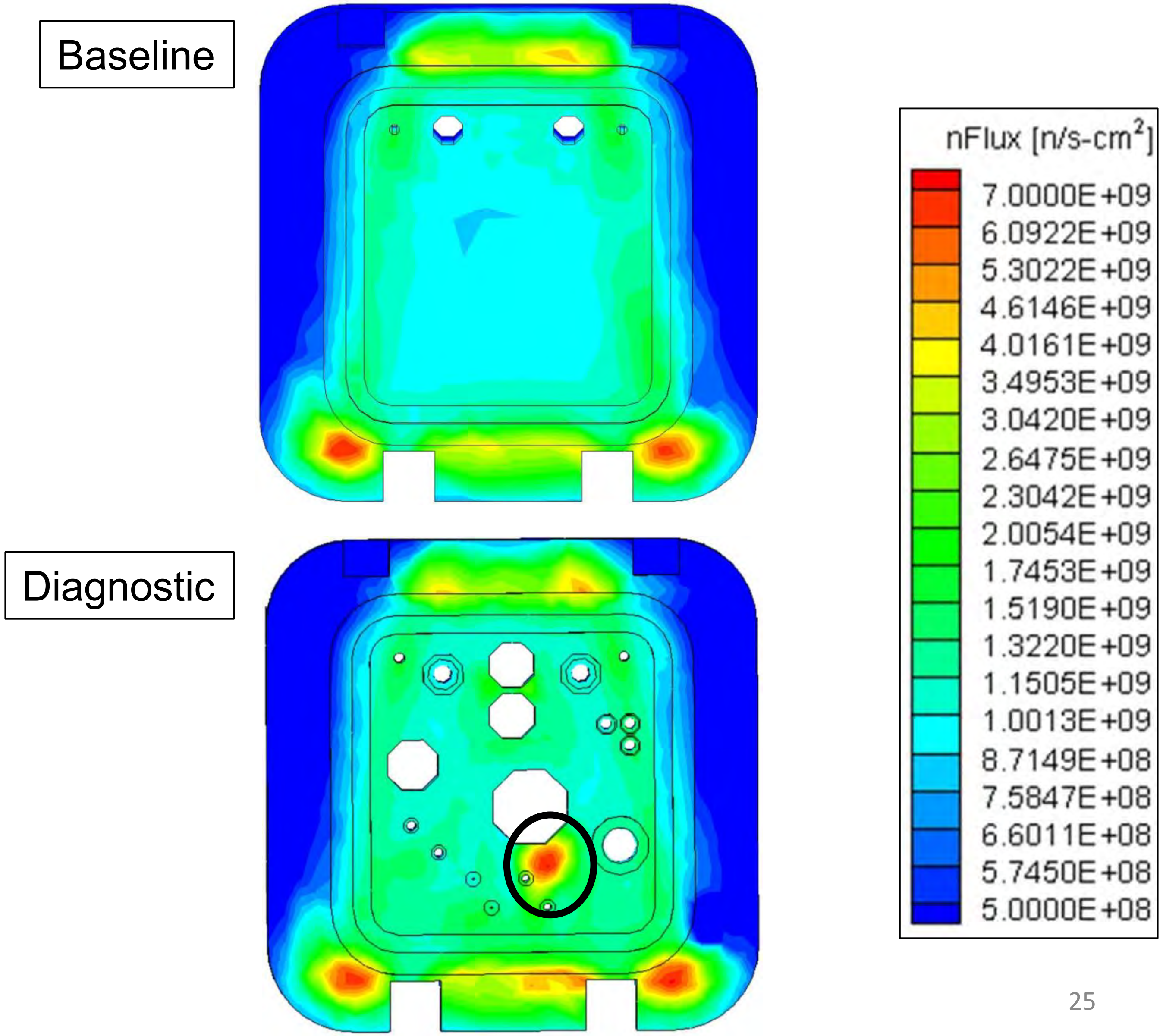
- The damage limit of 0.5 [dpa] has been established for any single bolt location in the port plug.
- The damage in the shutter bolts was determined to be 0.189 [dpa].
- The damage to the SS-625 Mirror 2 holder was 0.538 [dpa] and a bolted connection in that location may require consideration of irradiation-induced property changes

- He production limited to 1 [appm] to permit re-welding of 316L(N)-IG stainless steel components.
  - higher He concentrations could cause crack formation during the re-welding process.
- Only plasma facing components exceed this limit.

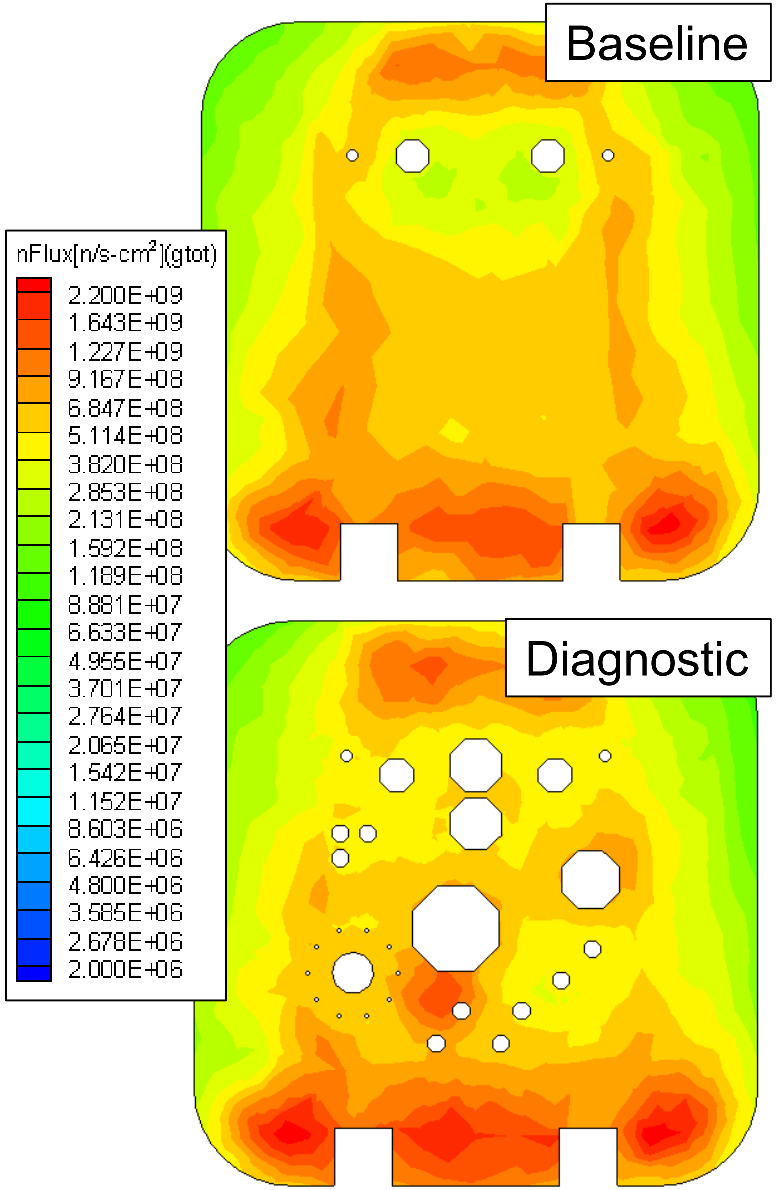


Neutron flux comparison on the Closure Plate

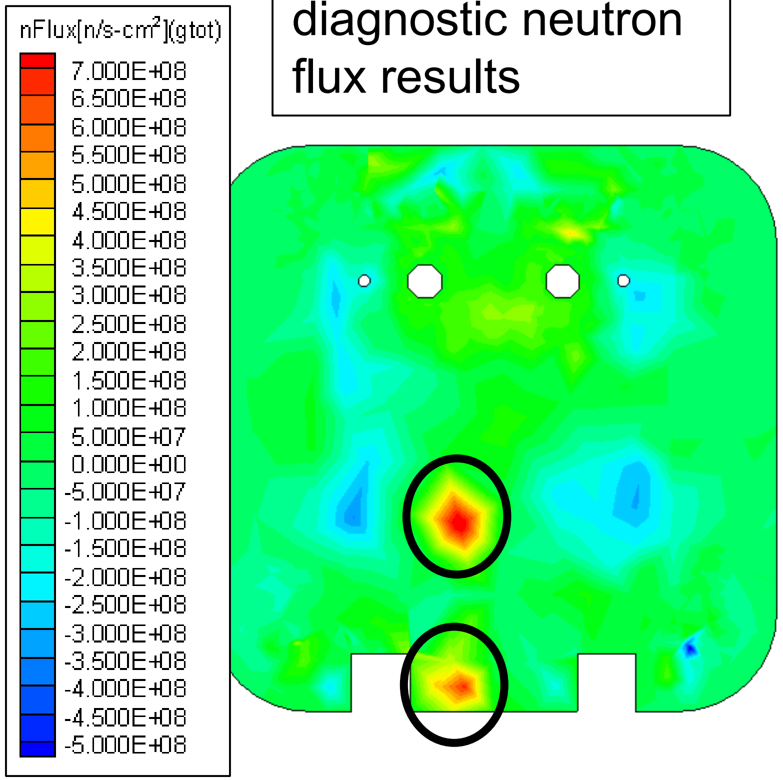




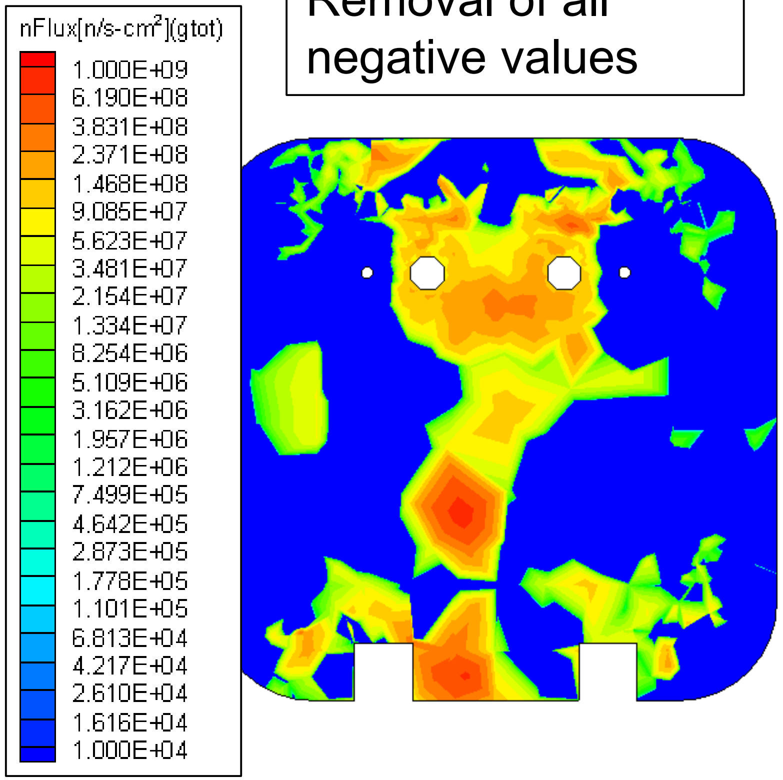
Neutron flux comparison on the Closure Plate



Subtraction of the baseline from the diagnostic neutron flux results

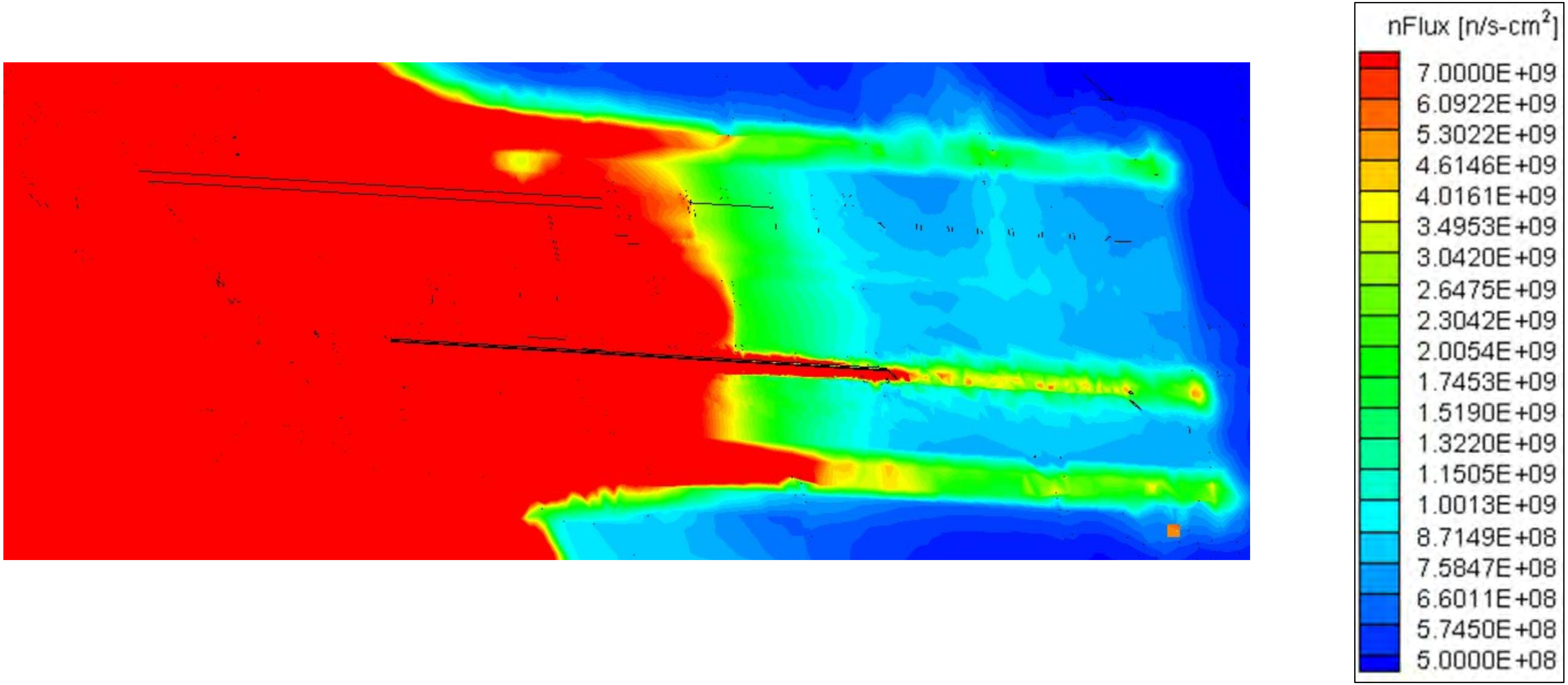


Removal of all negative values

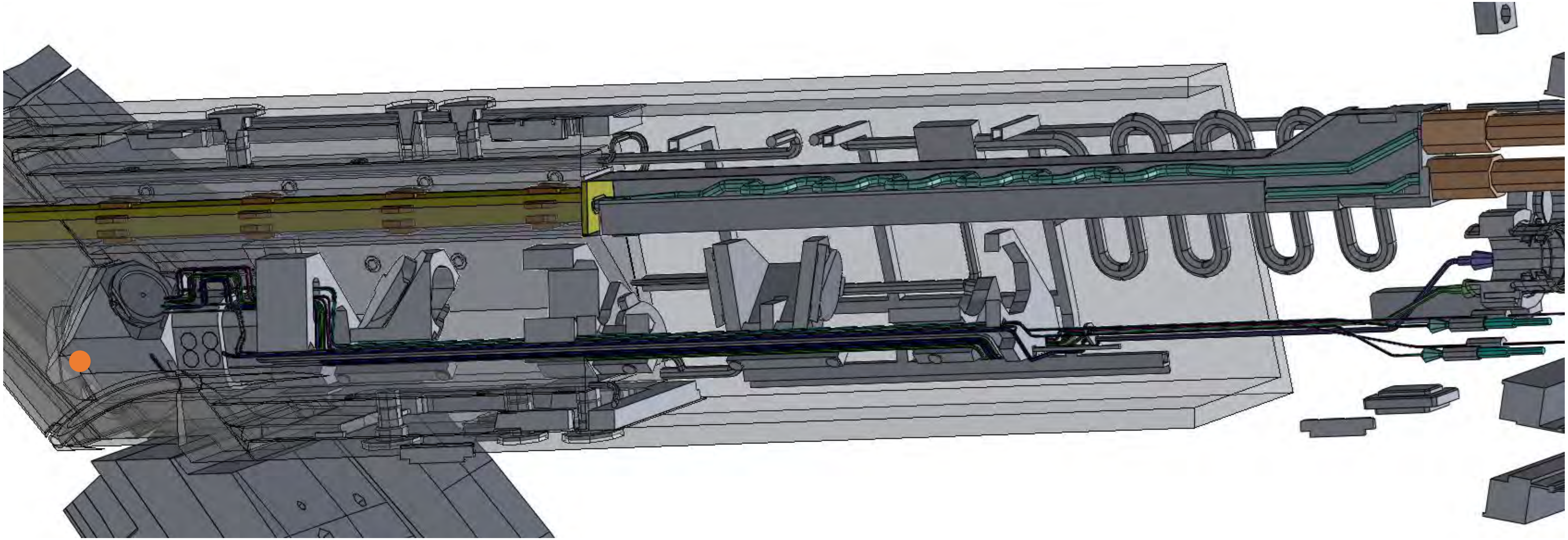


Shows only increase contribution of neutron flux due to the diagnostics

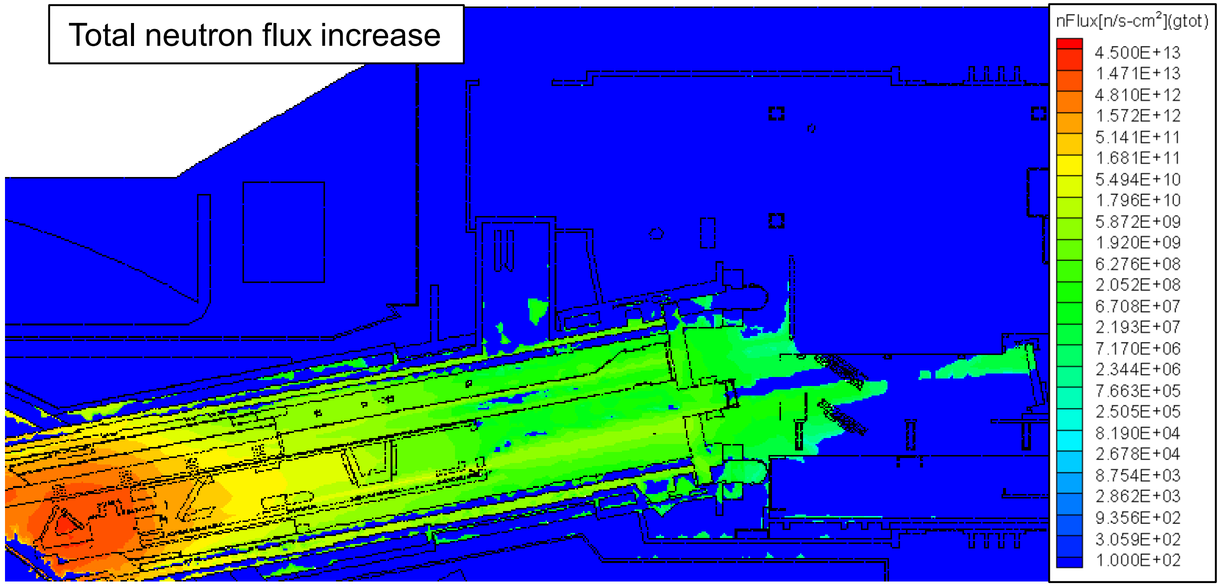
Upper Port 14 Problematic Location

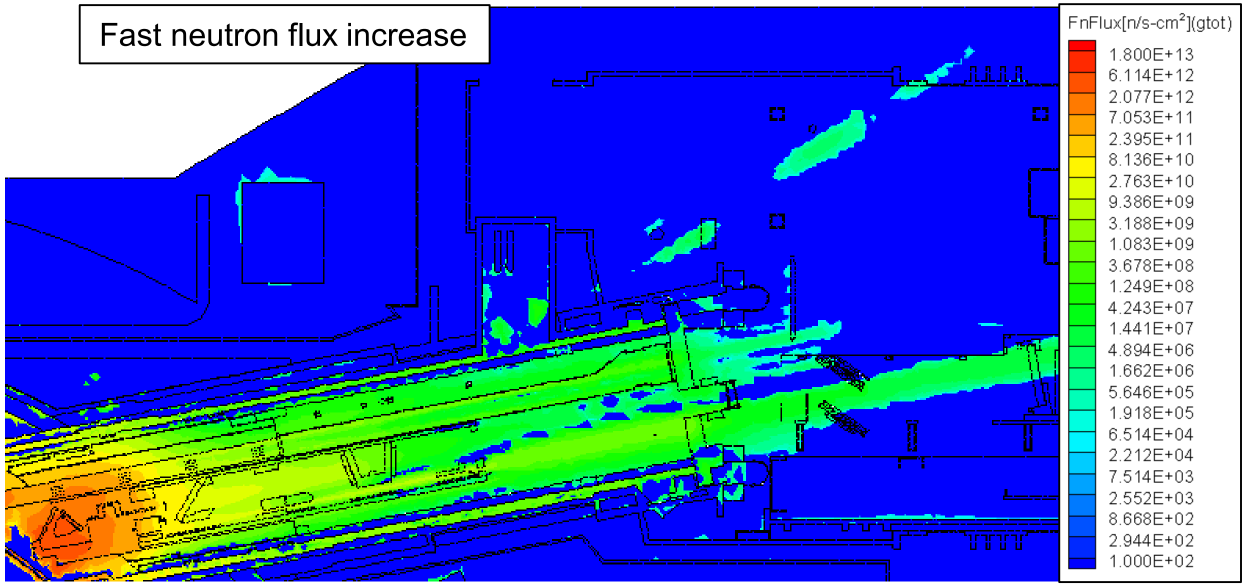


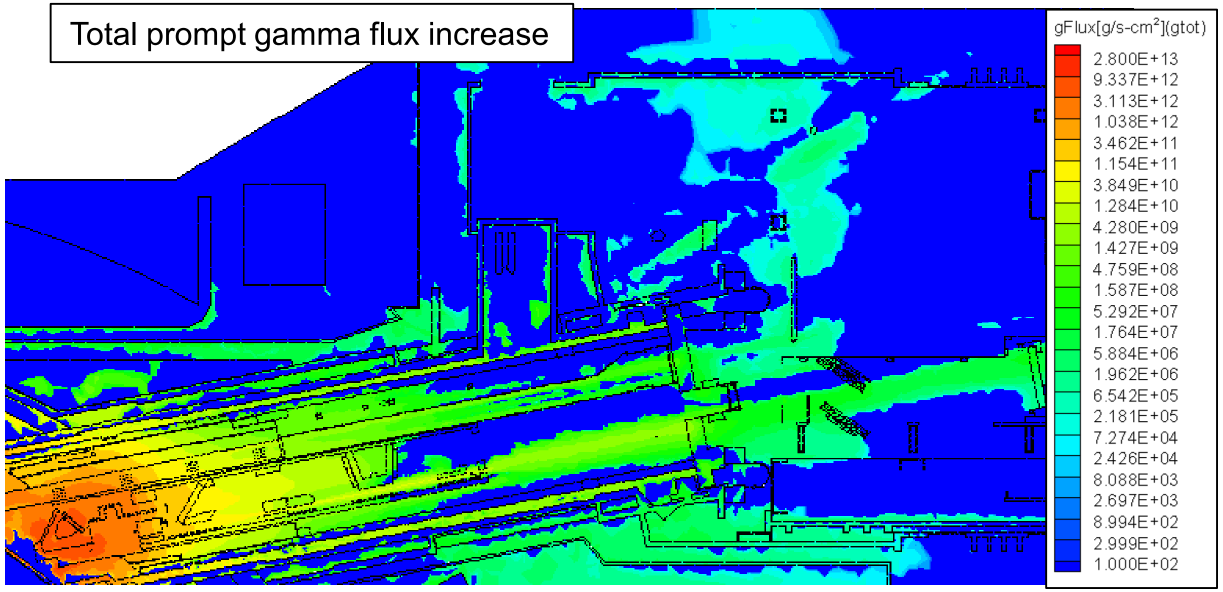
Detailed View of Upper Port 14 Problematic Area

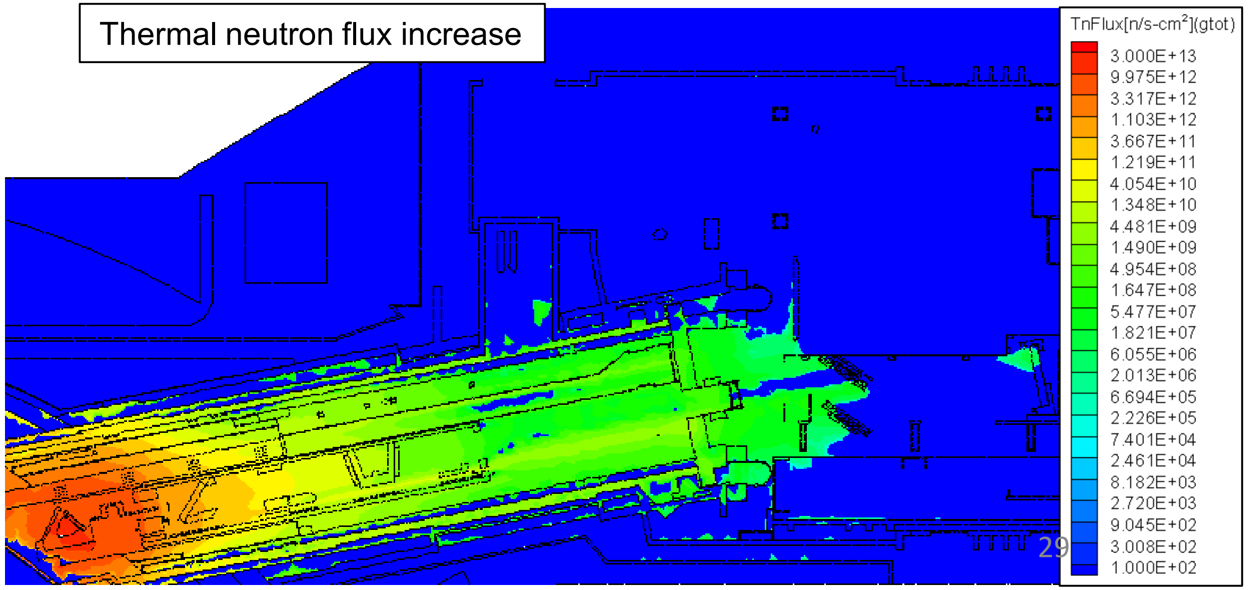


Increase in neutronics due to diagnostics

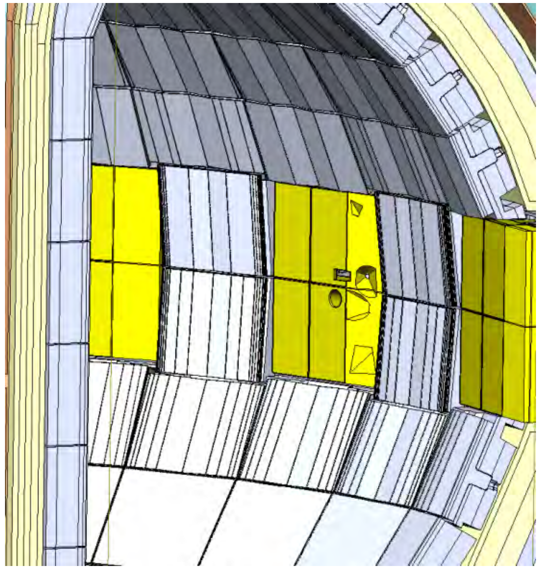


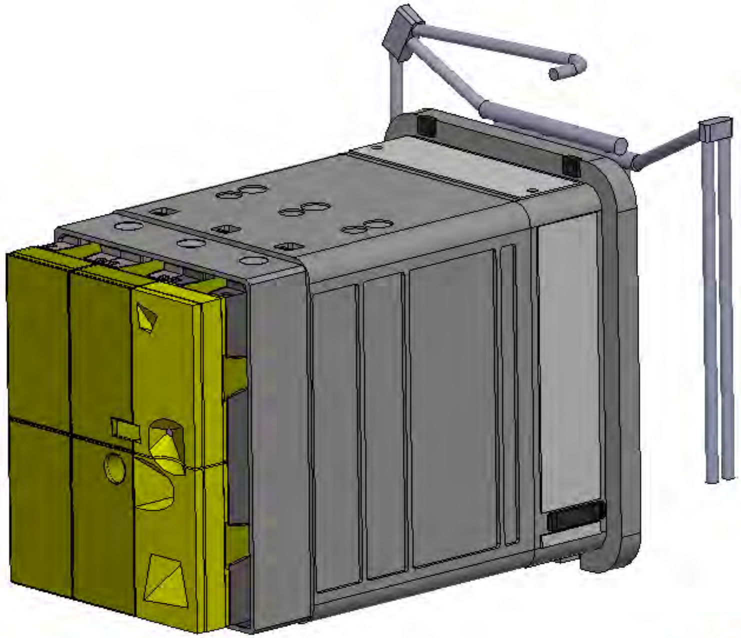


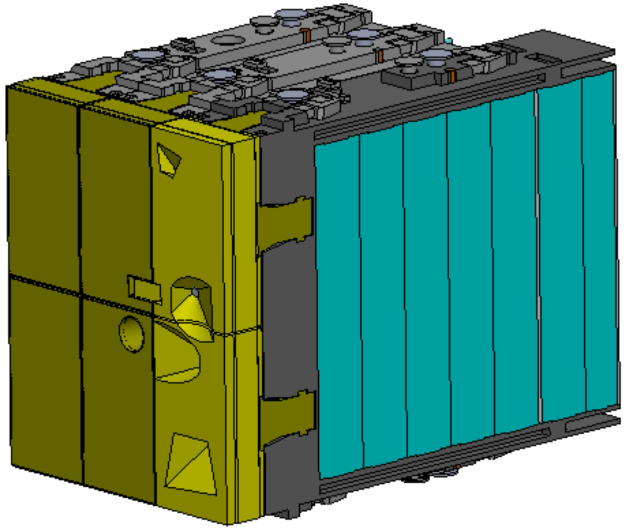


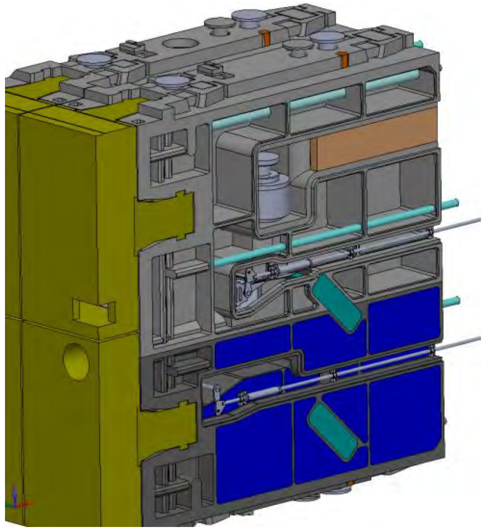


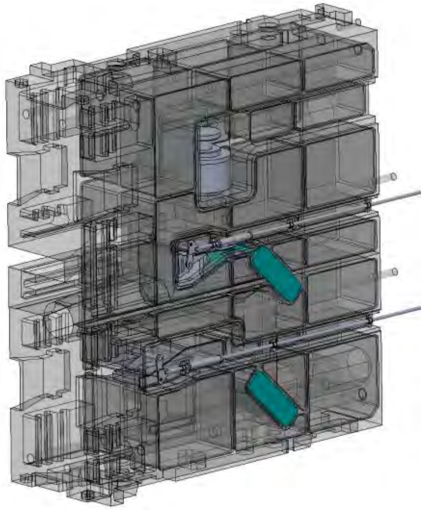
Upcoming EP09 nuclear analysis

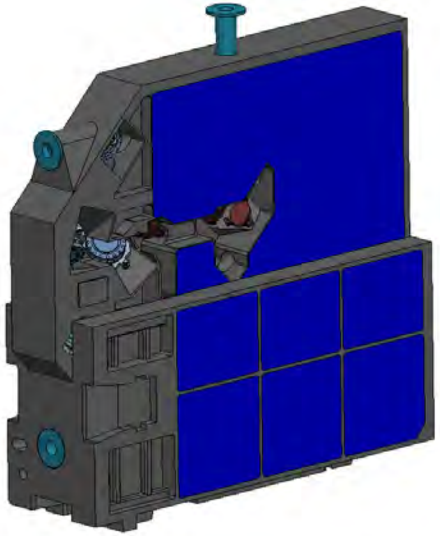


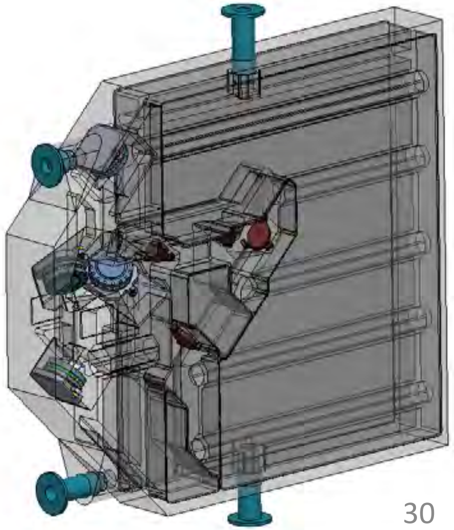












Conclusion

- The Upper Port 14 nuclear analysis has shown problematic areas that have to be addressed before development can continue.
  - Nuclear Heating
    - Overall the nuclear heating does not show significant problems.
    - Information will be used to help design cooling strategies.
  - DPA and He Production
    - Material damage and helium production rates throughout the port plug were shown to be well below their respective limits
    - component analysis can largely ignore radiation-induced changes in material properties.
    - Any bolts introduced into the VisIR mirror M2 assembly will require radiation-induced changes
      - Material damage rates in the M2 assembly were shown to be very close to the limit
  - Neutron Flux
    - Current neutron levels show that the shutdown dose rate requirement will not be met.
    - UWAVs port plug piping design presents a significant streaming path for neutrons
    - It was recommended that a labyrinth and/or additional material be incorporated into the design to effectively minimize activation and shut down dose levels.

Thank you