**- Synergy Innovation between Nuclear Energy and Renewable Energy -**

# Fusion neutronics computations for ITER Diagnostic Generic Upper Port Plug

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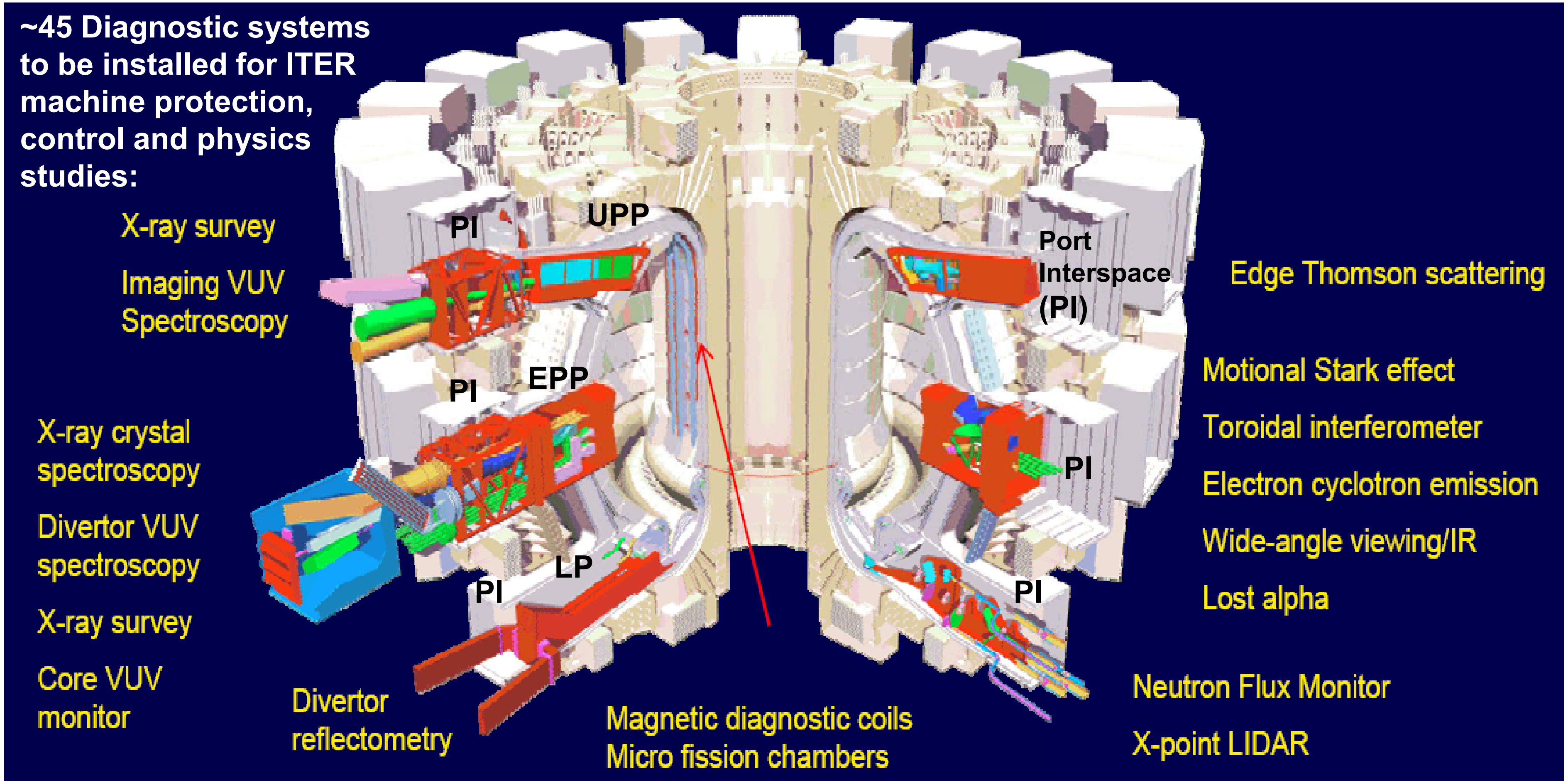
# Introduction

**<u>Objectives</u>** – CAD-based neutronics computational support for design development of the ITER Diagnostic Generic Upper Port Plug (DGUPP) which will host many Diagnostic systems.

**<u>The objectives have been reached</u>** by Monte Carlo (MCNP) radiation transport and activation analyses resulting in developing new 3D MCNP model and studying potential design improvements for radiation shielding of the Port Interspace (PI) where personnel access is planned for Upper Port maintenance.



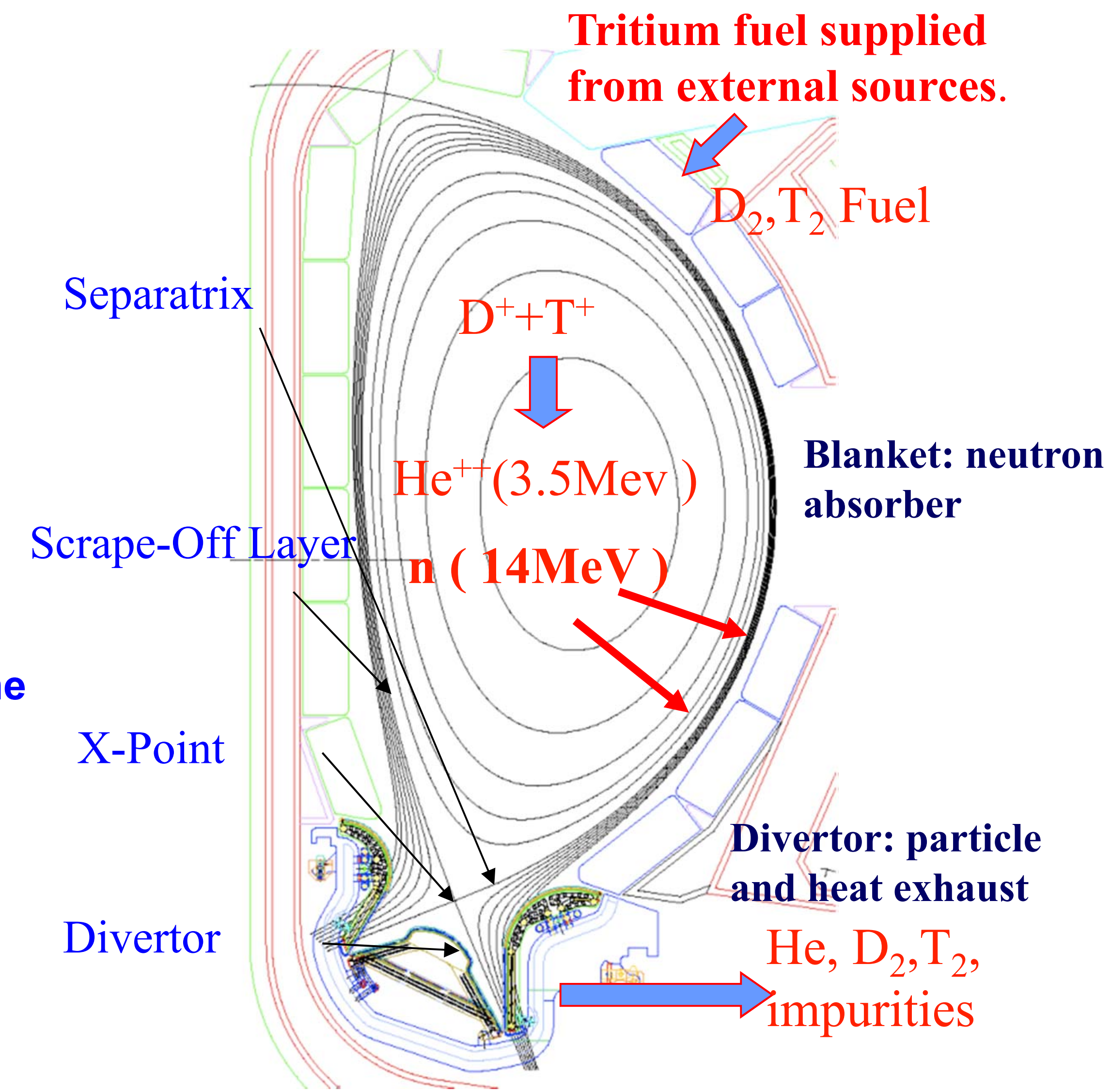
# Plasma Engineering Features

## Plasma Shaping

- D-shaped elongated plasma to increase plasma performance
- Better confinement of plasma pressure by magnetic field, but needs vertical plasma stability

## Single-null poloidal divertor configuration

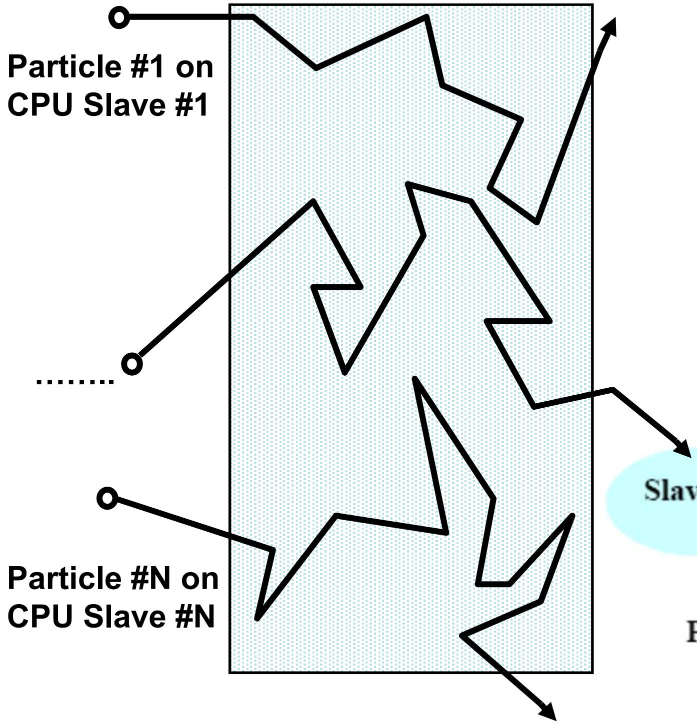
- Charged particles approaching the wall are then swept out of the plasma chamber into a divertor chamber

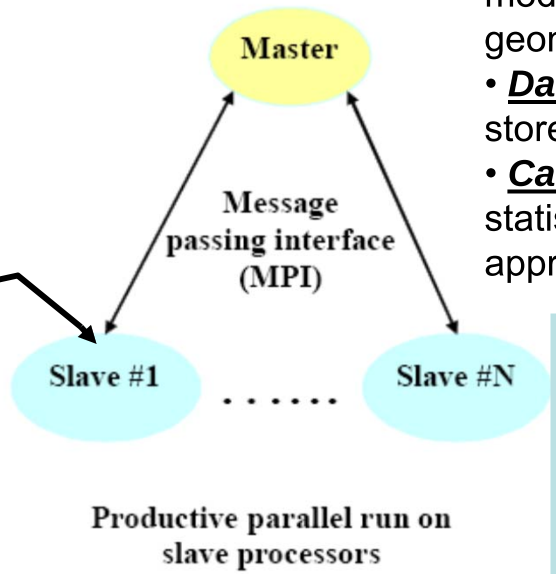


# Monte Carlo (MC) radiation transport runs on supercomputers

⇒ *Simulation of independent random pathways on microscopic level, i. e. tracking of individual particle histories from "birth" to "death"*

⇒ *Simulation can be computed on parallel multiprocessor systems*




***Monte Carlo method*** is most suitable computational technique for nuclear fusion applications. It's because of the following:

- ***Geometry***: complex fusion devices can be modelled in 3D geometry without major geometry approximations
- ***Data:*** continuous energy representation as stored on evaluated data files in ENDF format
- ***Calculation accuracy:*** only limited by statistics and data uncertainties (no numerical approximations)

**Used supercomputers:**

- Europe HPC-FF system at JSC (Germany);
- CampusGrid OpusIB, SCC-KIT (Germany);
- Europe HC3 at SCC-KIT (Germany);
- Europe BWGrid (Germany)
- **IFERC-CSC Helios (Japan)**
- **EUROfusion HPC Marconi-Fusion (Italy)**

The maximum speed-up was found on **IFERC-CSC Helios** supercomputer with **OpenMP / MPI parallelization** for non-biased MCNP5 run equalled **2500 on 4096 cores** (or ~850 on 1024 cores, and ~450 on 512 cores) – because dependence of speed-up to number of cores is not linear due to ovethead time spent for communications betweeen computing nodes.

# **Fusion Neutronics Methodology**: Codes, Tools, Nuclear Data

➧ To reach the objectives, **we used the state-of-the-art codes and interfaces** approved for ITER neutronics applications:

- ❑ **SpaceClaim** software reads CAD models, solves geometry problems, allows to work in 3D without having to be a CAD expert
- ❑ **CAD-to-MCNP conversion tools:**
  - ❑ **MCAM & SuperMC (FDS Team, China)**
  - ❑ **McCad (KIT, Germany)**
- ❑ **Radiation transport calculations (n/gamma fluxes, nuclear heat, gas production):**
  - ❑ Monte Carlo code **MCNP5 v1.60, MCNP6 (LANL)**
  - ❑ **FENDL-2.1 (IAEA)** neutron cross-section library
  - ❑ **B-lite MCNP model (IO)** 40 tor-degree with all the components of ITER with modifications for the Upper Port area. C-lite model is not ready for Upper Port.
- ❑ **Activation and Shut-Down Dose Rate (SDDR) calculations:**
  - ❑ **FISPACT-2007 (CCFE)** inventory code and **EAF-2007 (EU)**
  - ❑ **D1S code (ENEA)**
  - ❑ **R2Smesh (KIT)**
- ❑ **Vizualisation: Paraview** (Kitware) in vtk-format

# CAD-Based Monte Carlo Rad. Transport

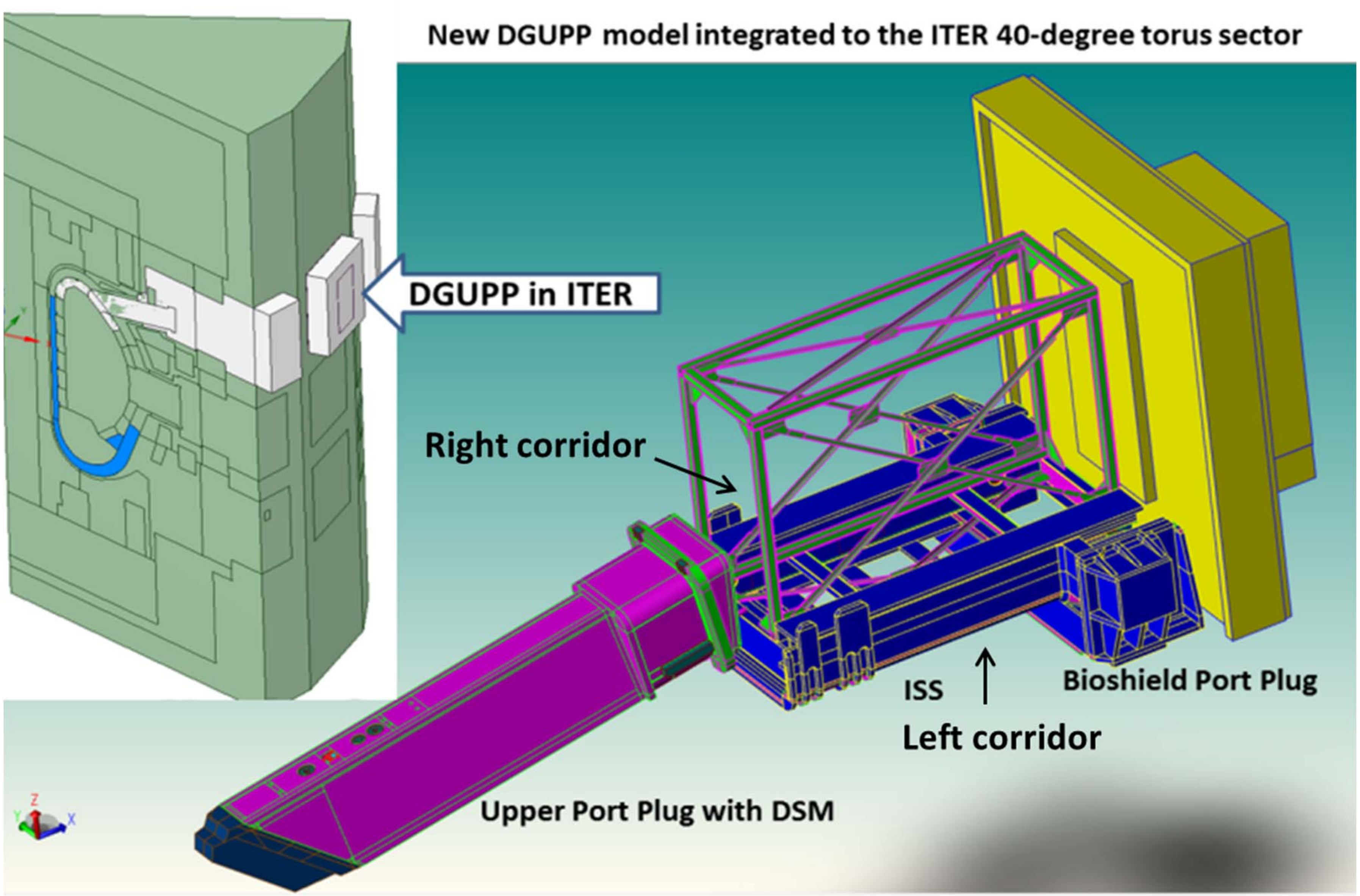
**Three modelling approaches** of CAD-based Monte Carlo transport simulations:

1. **Constructive Solid Geometry (CSG)** – traditional approach with **CAD to Monte Carlo models conversion codes**:
   - SuperMC (FDS team, China);
   - McCad (KIT fusion neutronics group, Germany).
2. Unstructured Mesh (UM) geometry in MCNP6 (LANL, USA);
3. Direct particle tracking technique with Direct Accelerated Geometry Monte Carlo (DAGMC) library – MCNP patch developed by University of Wisconsin–Madison, USA.

**Three stages of CAD (CSG) – to – MC models geometry conversion:**

1) Geometry simplification – remove the unnecessary details;
2) Approximation of free-form and spline surfaces to 1$^{st}$ and 2$^{nd}$ order surfaces accepted of MCNP;
3) Material definition with homogenization setting up the material mixtures for the simplified cells, such as steel-water shielding composition of 60 vol.% steel – 40 vol.% water.

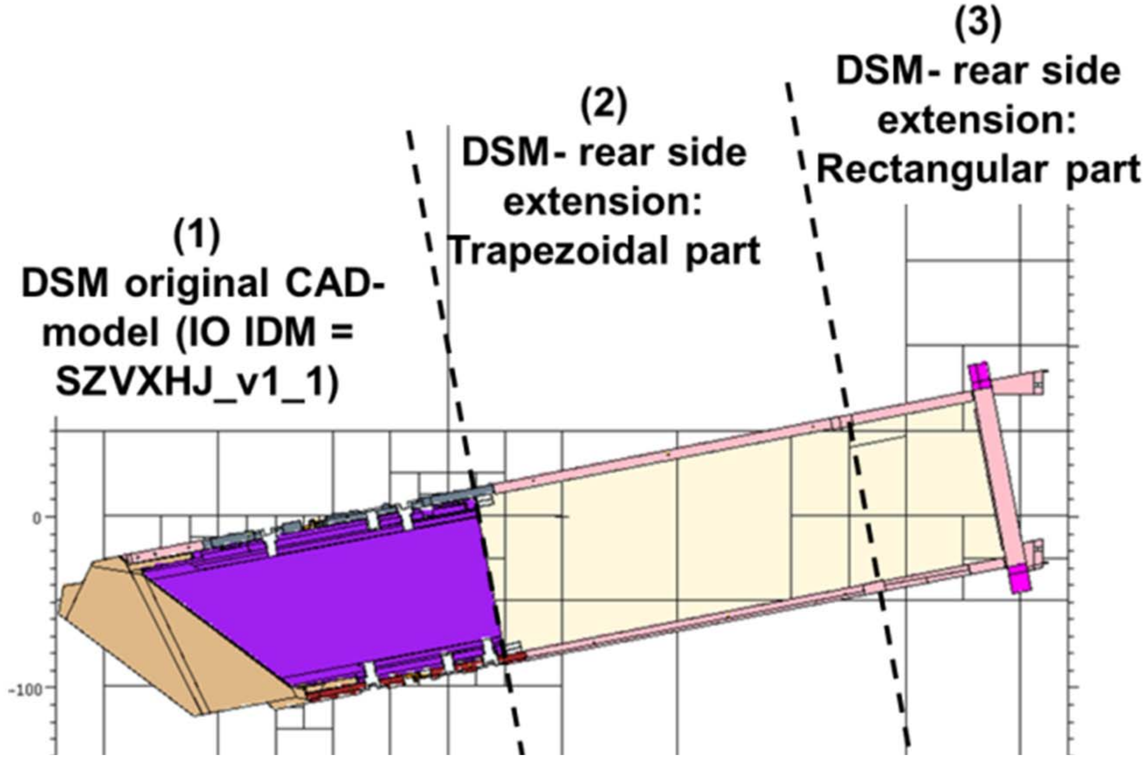
# ITER Diagnostic Generic Upper Port Plug (DGUPP) model



# DGUPP with 3 constituent parts of the Diagnostic Shielding Module (DSM) used in following DGUP two MCNP models a) and b)

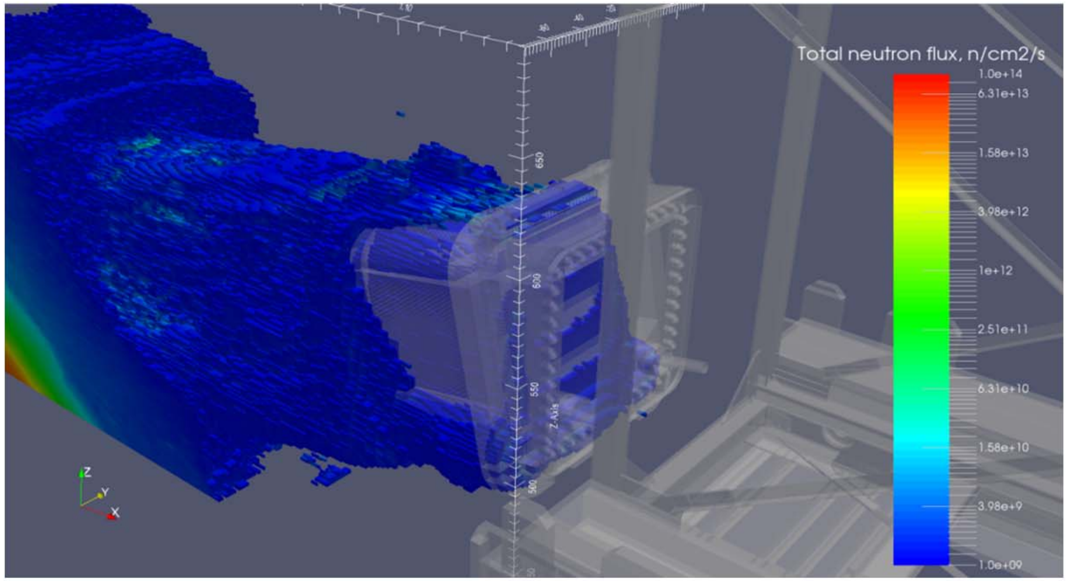
**Parametric study has been carried out on the shielding features of two DSM models:**

**a) Short-DSM DGUPP with only one DSM part (1);**
**b) Long-DSM DGUPP with three DSM parts (1)+(2)+(3).**

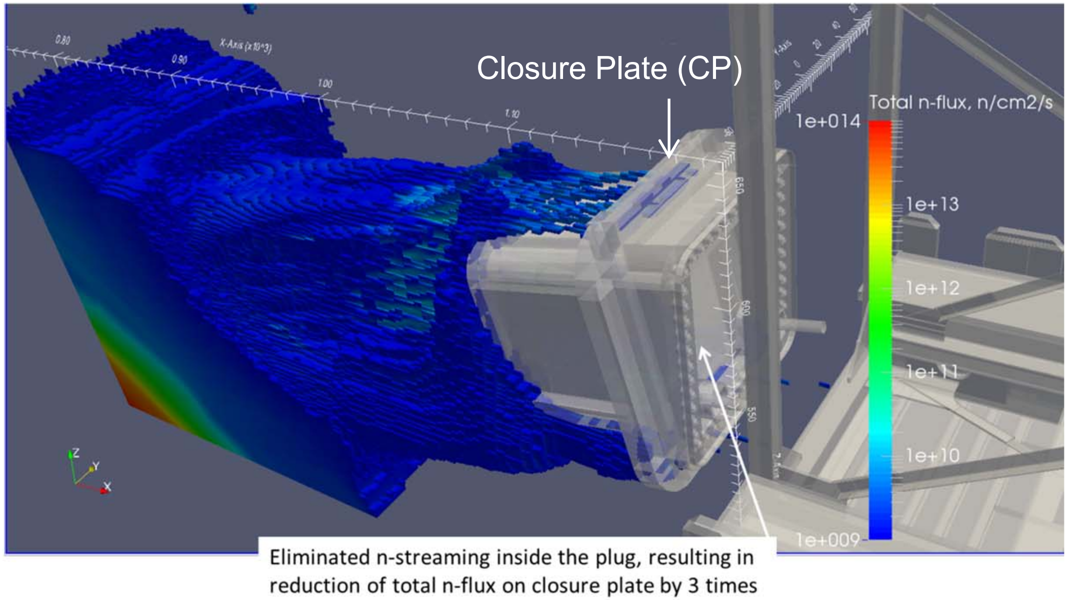


# Neutron Flux maps of DGUPP in ITER C-lite MCNP model

**Short DSM**

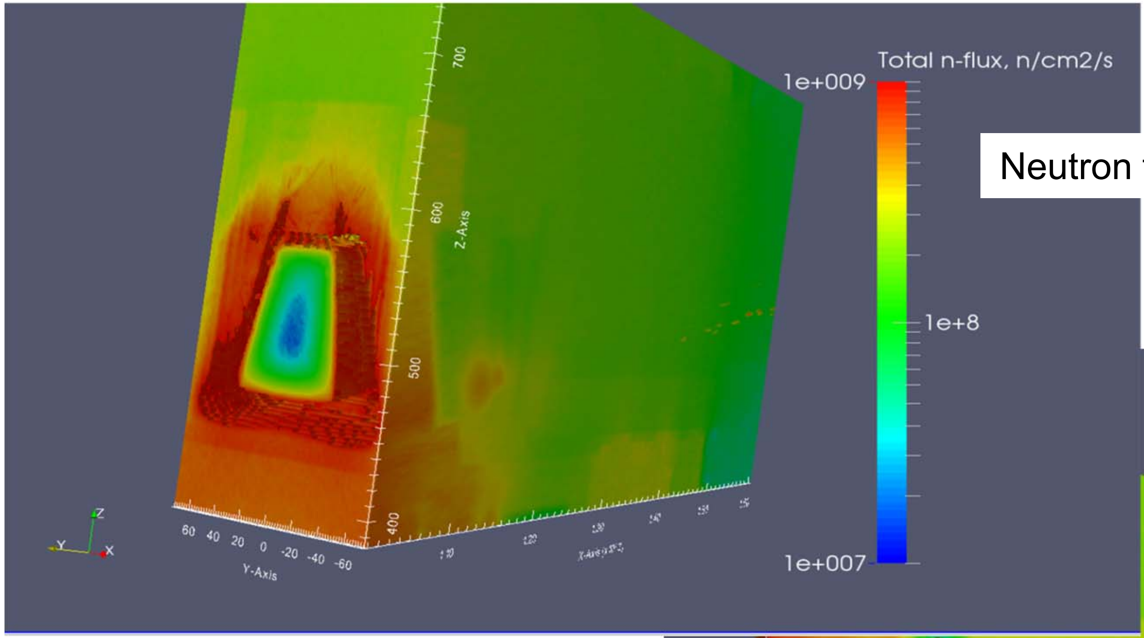



**Long DSM up to CP – no streaming inside the port plug space**

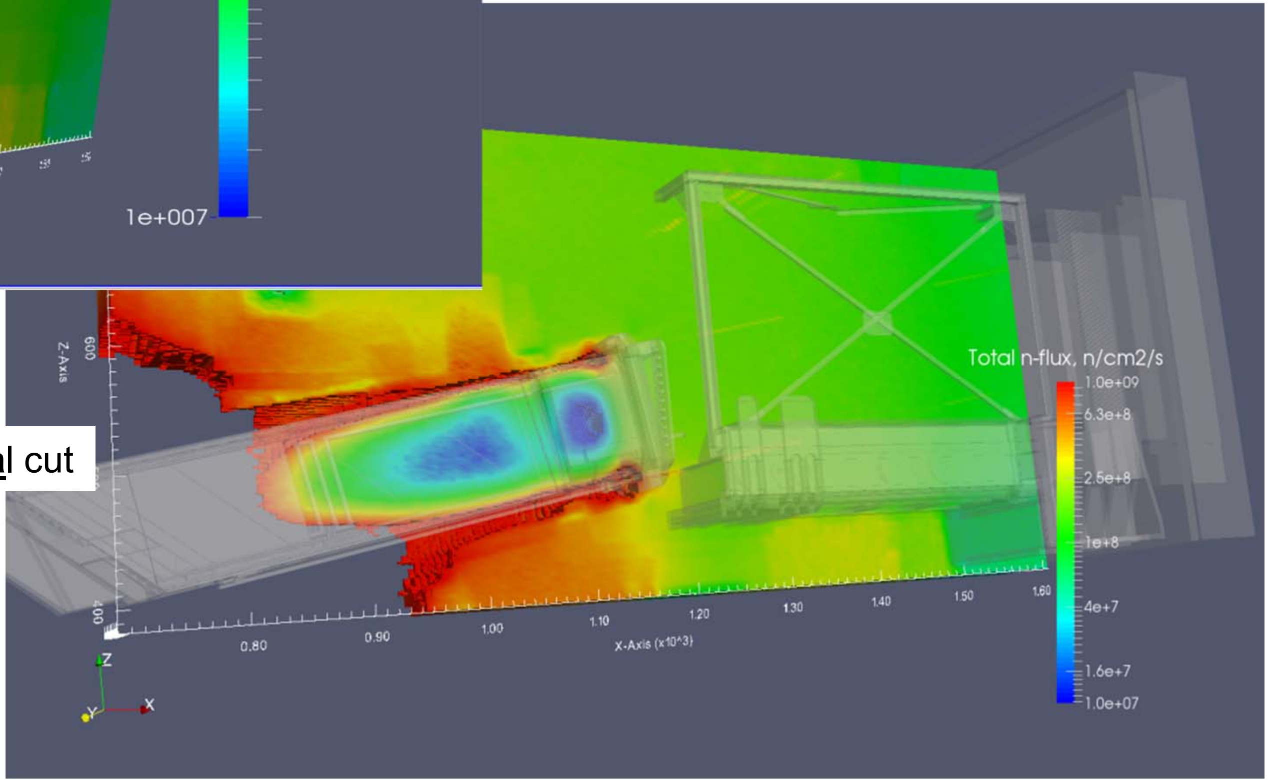


# Total neutron flux in DGUPPv2 with long DSM, threshold between (1e7-1e9) n/cm$^2$/s

From this thresholded map follows that total n-flux inside the DSM is below 1e9 n/sm2/s.
Neutrons are substantially moderated inside the DSM .



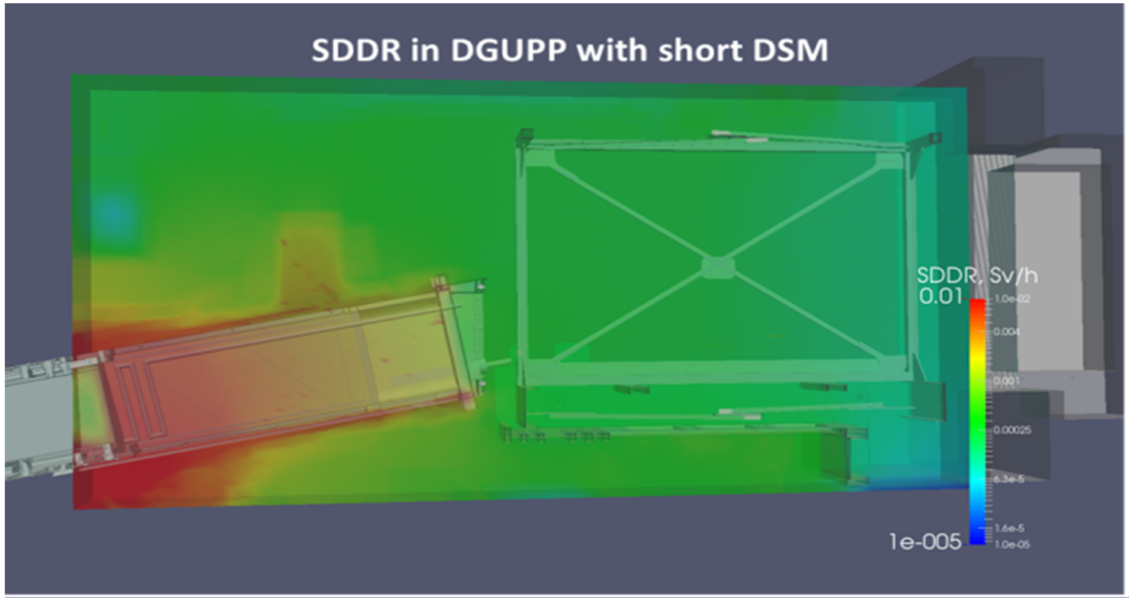

Neutron flux map with **Toroidal-Vertical** cut



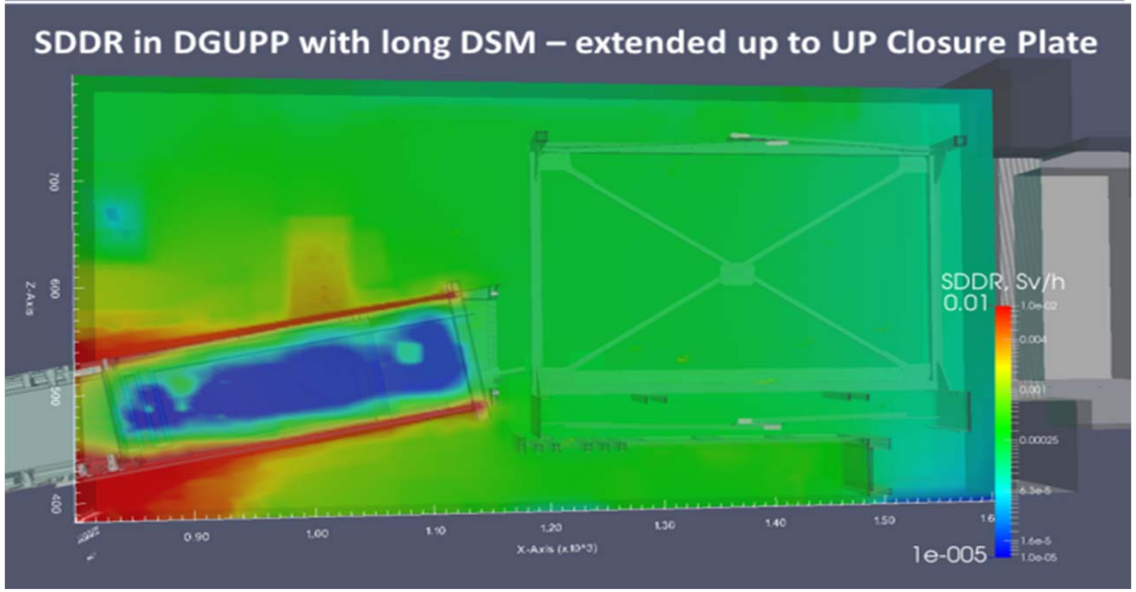

Neutron flux map with **Radial-Vertical** cut

# Shut-Down Dose Rate (SDDR) maps of DGUPP in ITER C-lite MCNP model

**Short DSM**

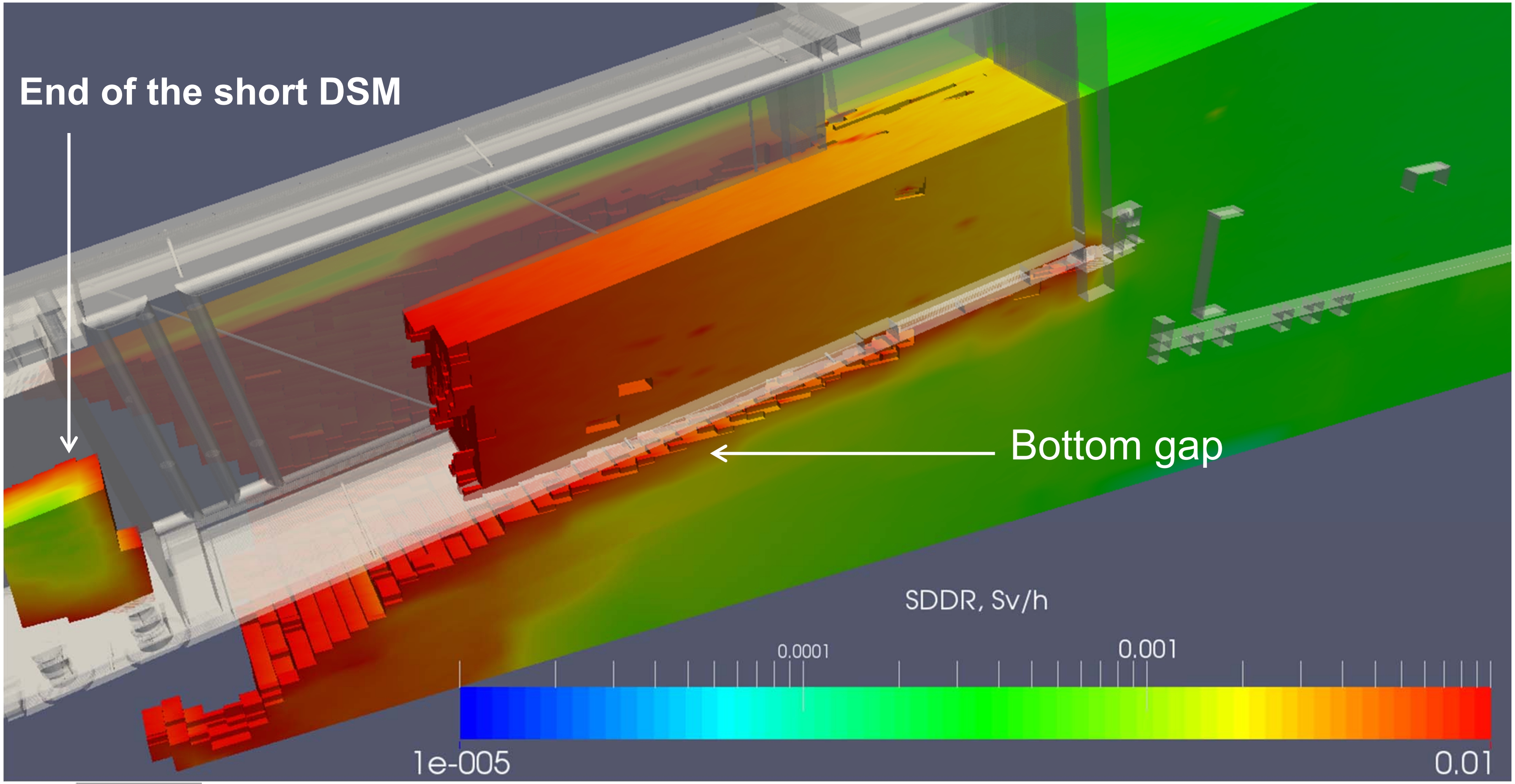



**Long DSM**

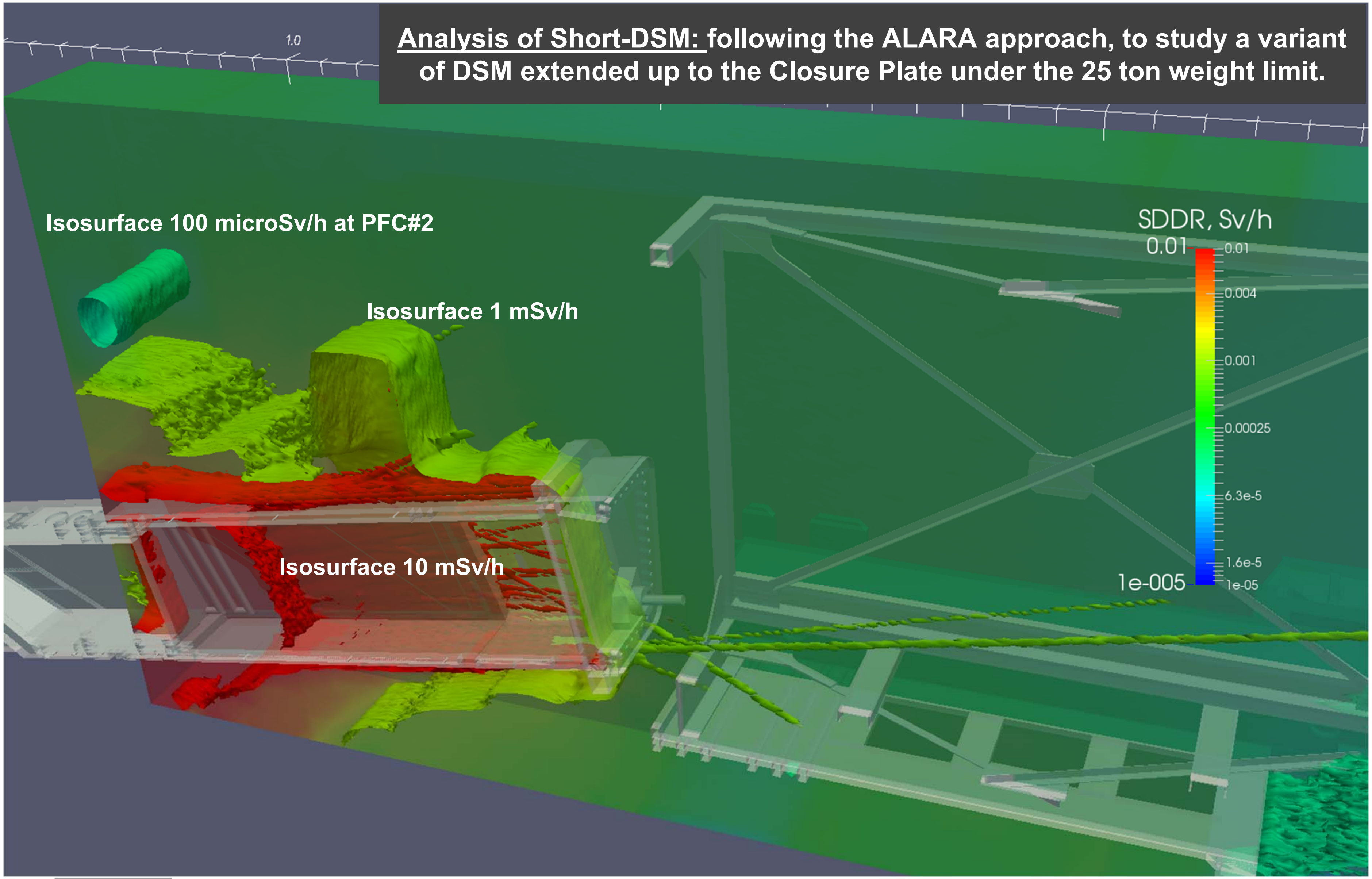


# SDDR (Sv/h) map in a quarter of the DGUPP with short DSM

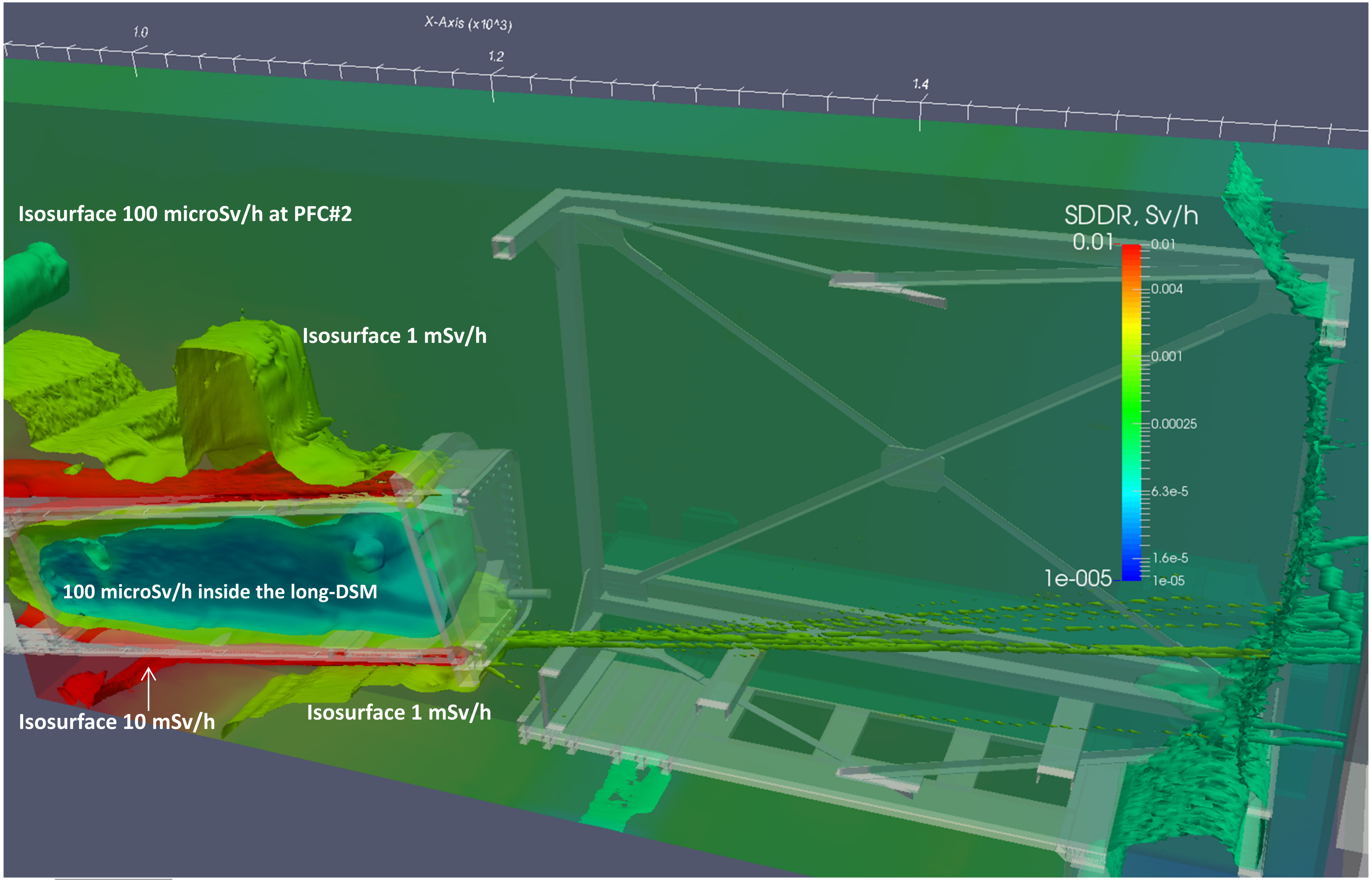
**Demonstrated:** Radiation streaming along the bottom and side gaps and inside the port structure behind the short DSM → need to improve DSM shielding design



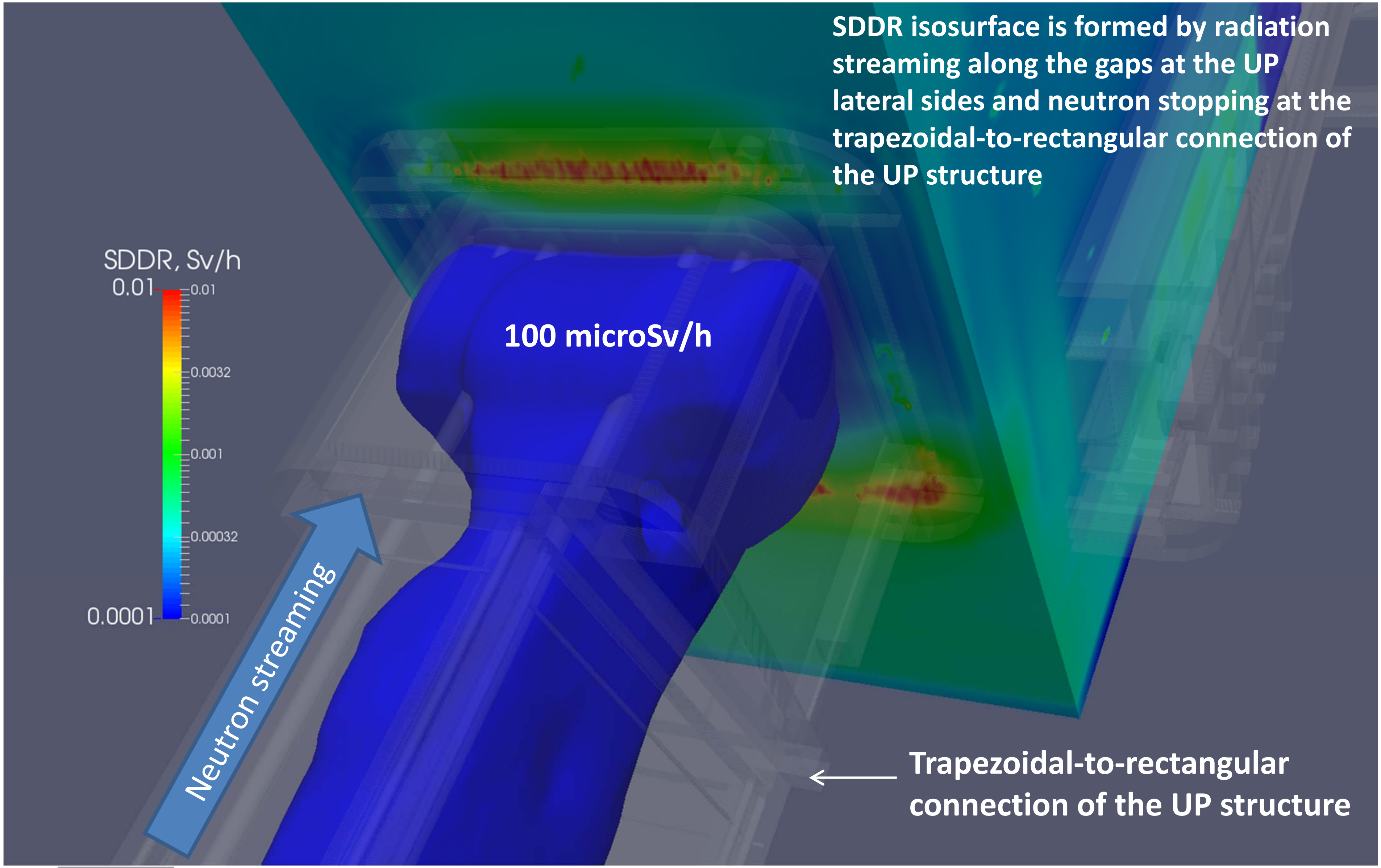
# Short-DSM of DGUPP with SDDR isosurfaces



# <u>Long-DSM</u> of DGUPP with SDDR isosurfaces



# Map isosurface in DGUPP with long DSM - to mitigate radiation streaming



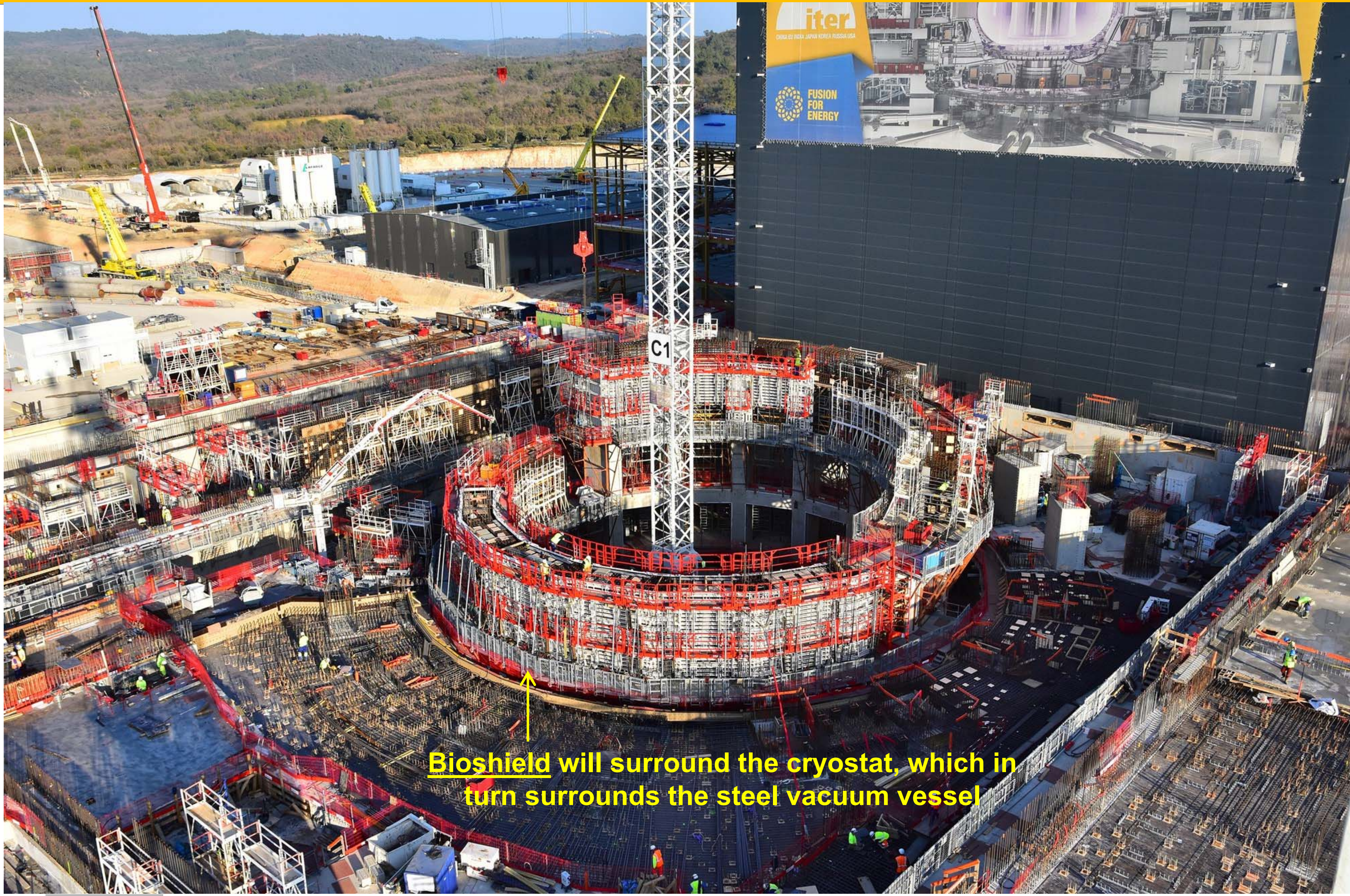
# Conclusions 1

- Design development of the ITER Diagnostic Generic Upper Port Plug (DGUPP) is in progress.
- 3D maps of neutron fluxes and Shut-Down Dose Rate (SDDR) with isosurfaces plotted the DGUPP allowed to find the radiation pathways, hot spots - most critical areas from neutronics perspectives.
- Revealed radiation streaming along the bottom and side gaps and inside the empty space of port structure behind the short Diagnostic Shielding Module (DSM) motivated the need to further improve the design of DSM.

# Conclusions 2

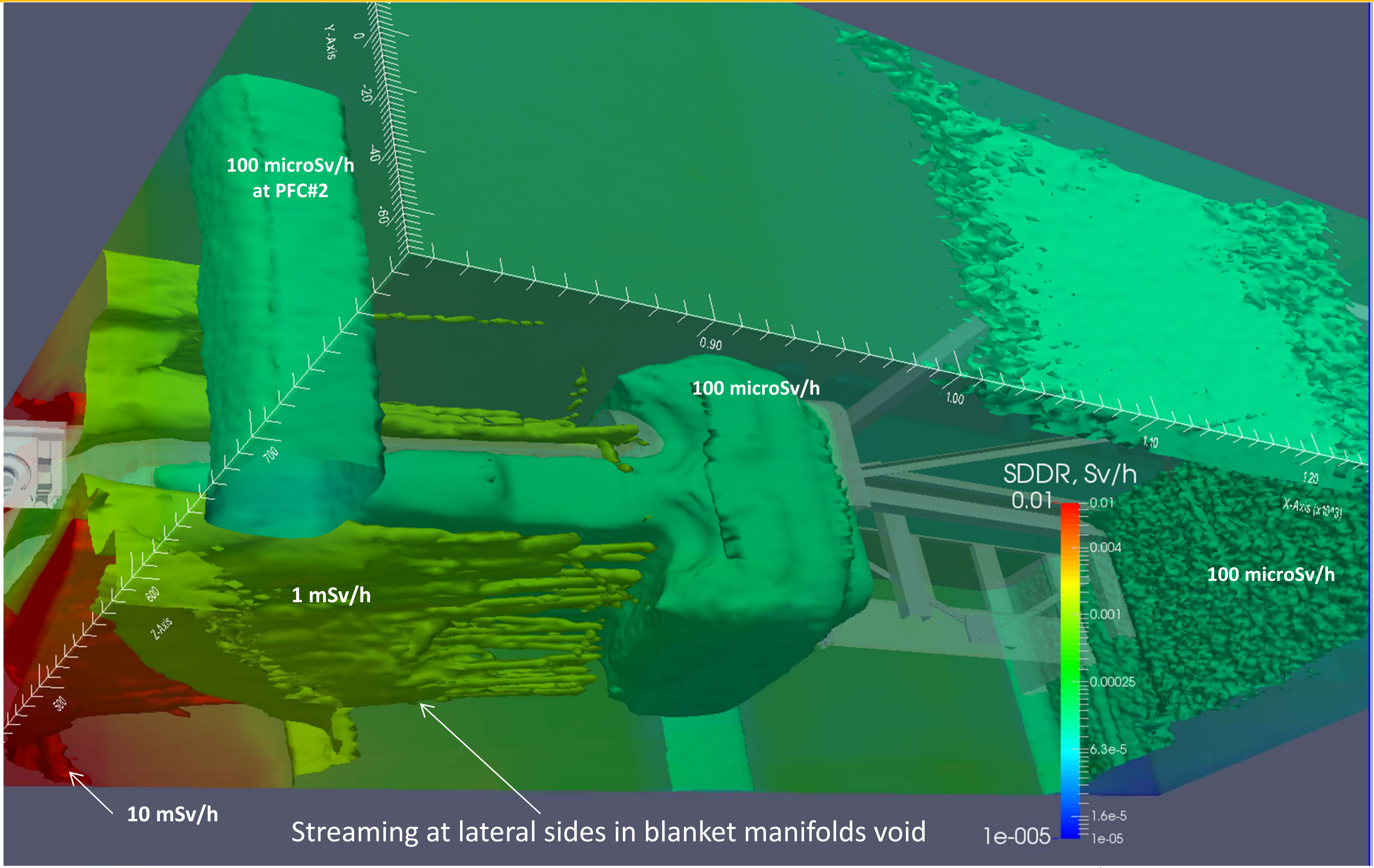
- A study has been carried out on a possible shielding improvement consisting in elongation of the DSM in a variant of Long DSM. The engineering implementation of the Long DSM option is still under consideration. Along that, particular attention should be devoted to shielding insertion at the trapezoidal-to-rectangular connection of the UP rear structure. At this place neutron streaming could be stopped most effectively
- Presented neutronics results were obtained in parametric study of the DGUPP shielding performance. These results are not absolute, they depend on other systems of ITER model C-lite v2 of 2015, which was updated afterwards.
- Neutronic investigation is going on DGUPP improvement and SDDR reduction by taking into account the updated ITER C-Model and by aiming to find engineering solutions.

# Progress on ITER construction: April 2017



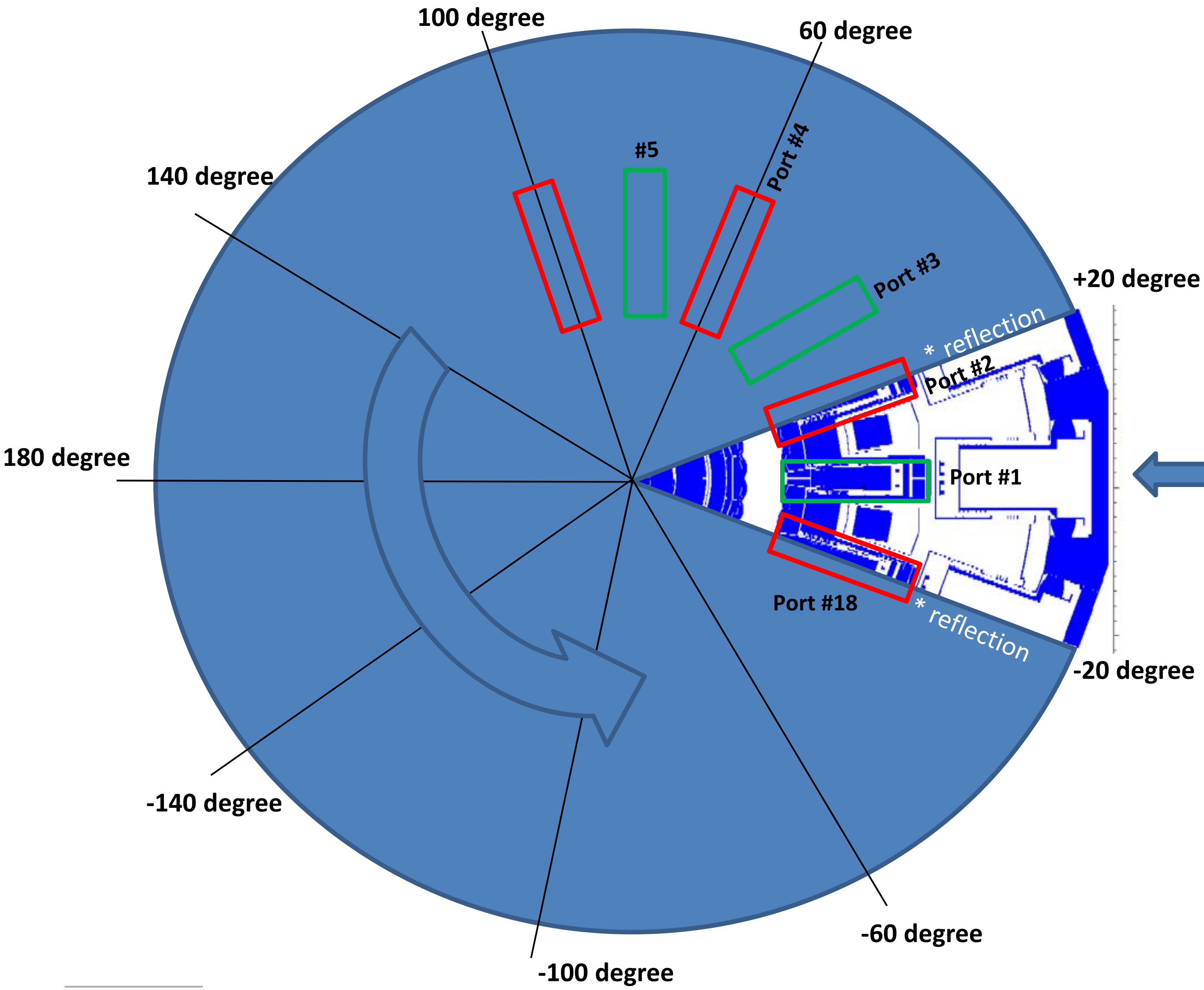
# BACK slides

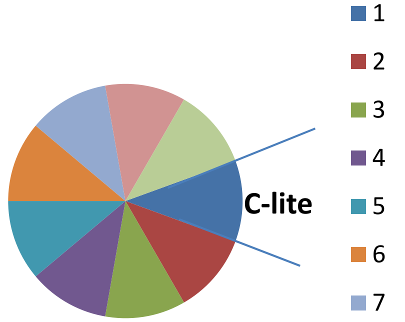
# SDDR in long-DSM DGUPP with **filled DGUPP-VV gaps** – streaming at lateral sides in blanket manifolds void space



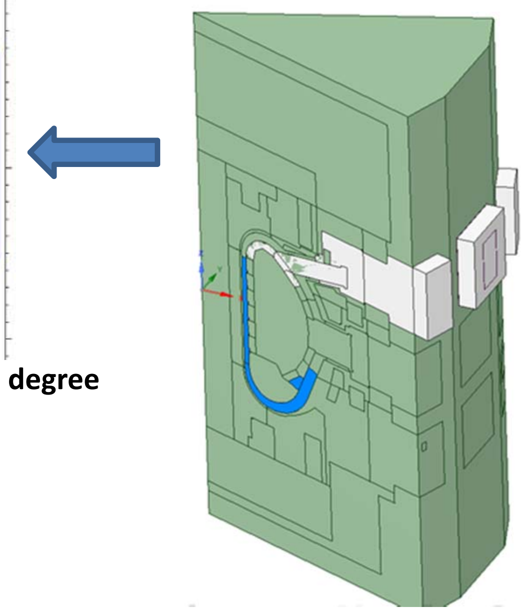

Streaming at lateral sides in blanket manifolds void

- MCNP models called “C-lite” or “C-Model” in 40 degree toroidal sector symmetrically represents the whole 360 degree of ITER machine;
- 40 degree is copying symmetrical 9 times by using the reflective boundary conditions.




9x40 degree identical toroidal sectors



40 degree sector of C-Model