- Neutronics Challenges of Fusion Facilities -

Neutronics analysis for ITER Diagnostic Generic Upper Port Plug

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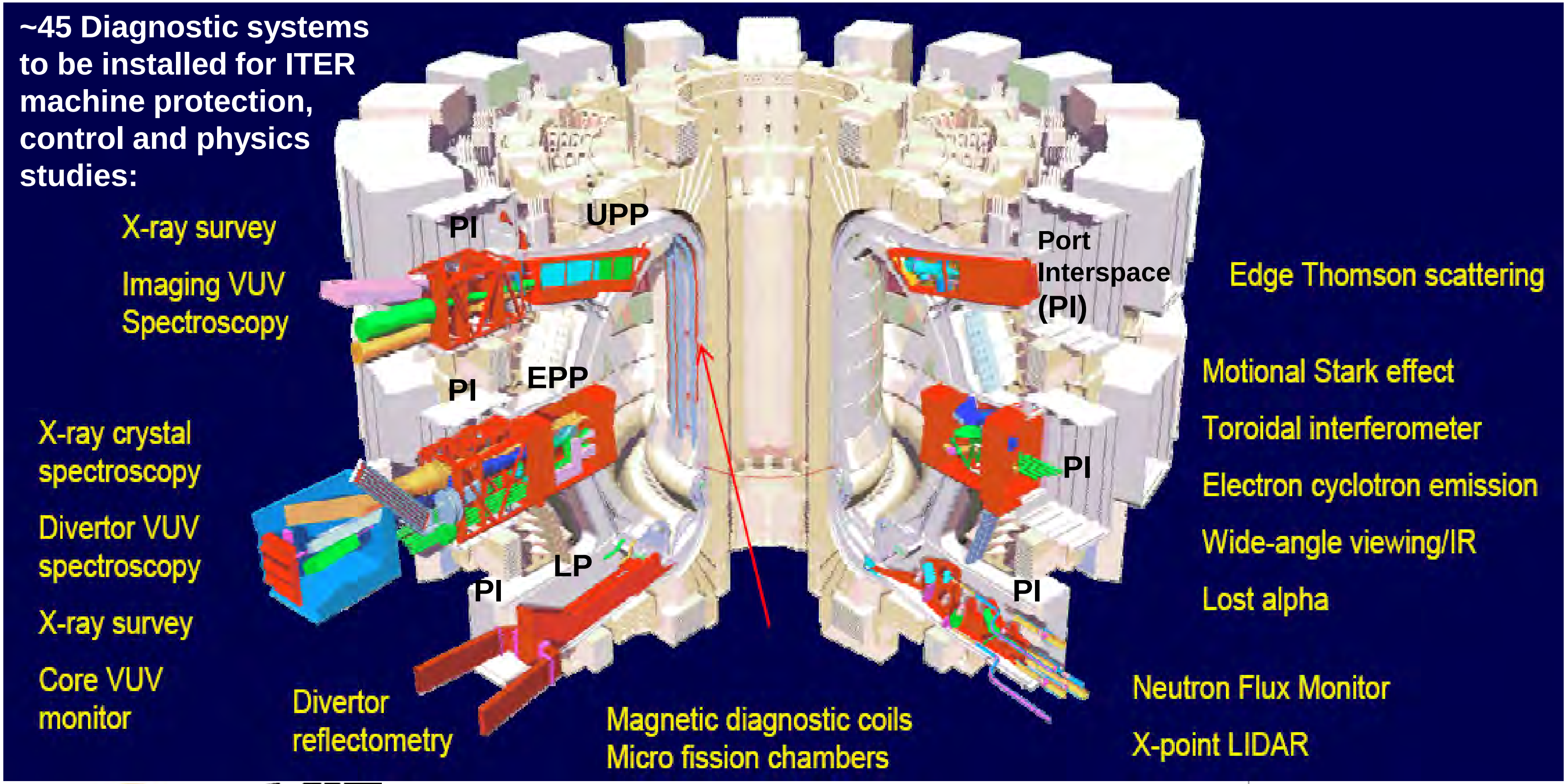
Introduction

<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.

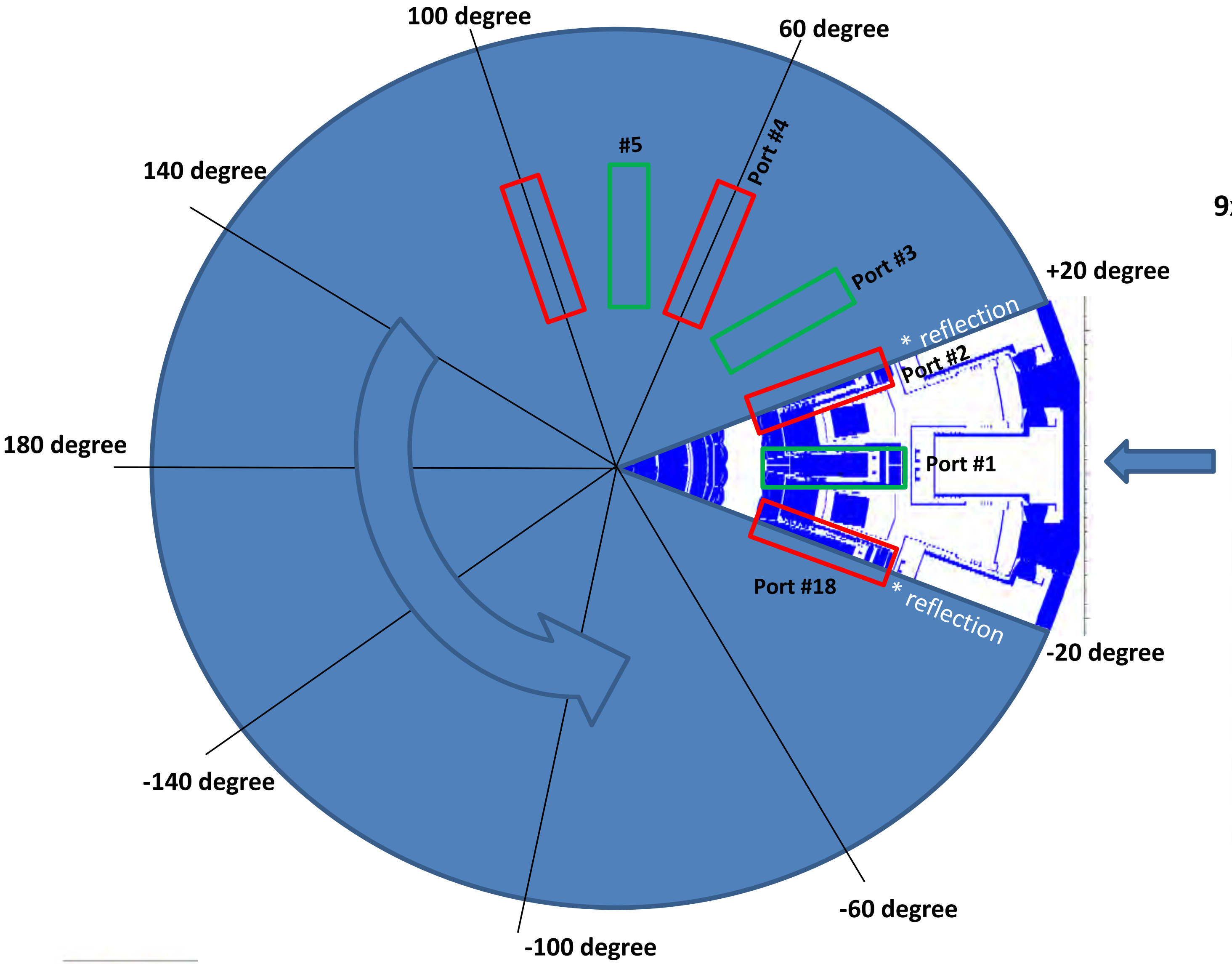


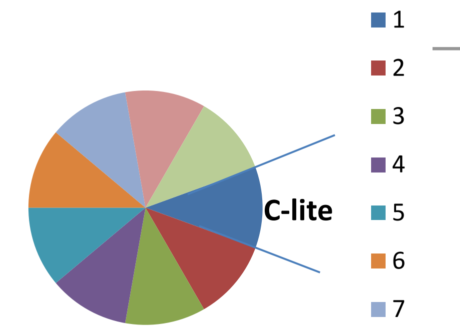
Fusion Neutronics Methodology: Codes, Tools, Nuclear Data

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

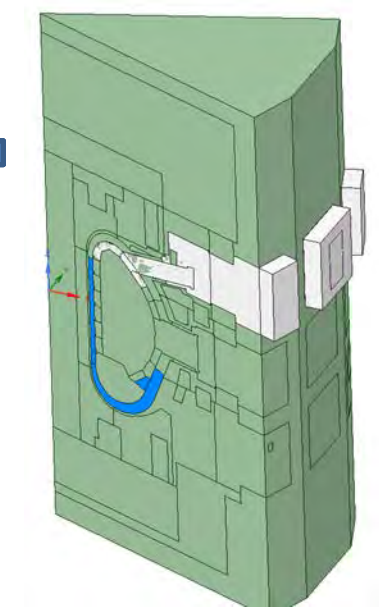
- **SpaceClaim** software reads CAD models, solves geometry problems, allows to work in 3D without having to be a CAD expert
- **CAD-to-MCNP conversion tools:**
  - **SuperMC (FDS Team, China)**
  - **McCad (KIT, Germany)**
- **Radiation transport calculations (n/gamma fluxes, nuclear heat, gas production):**
  - 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

- 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.



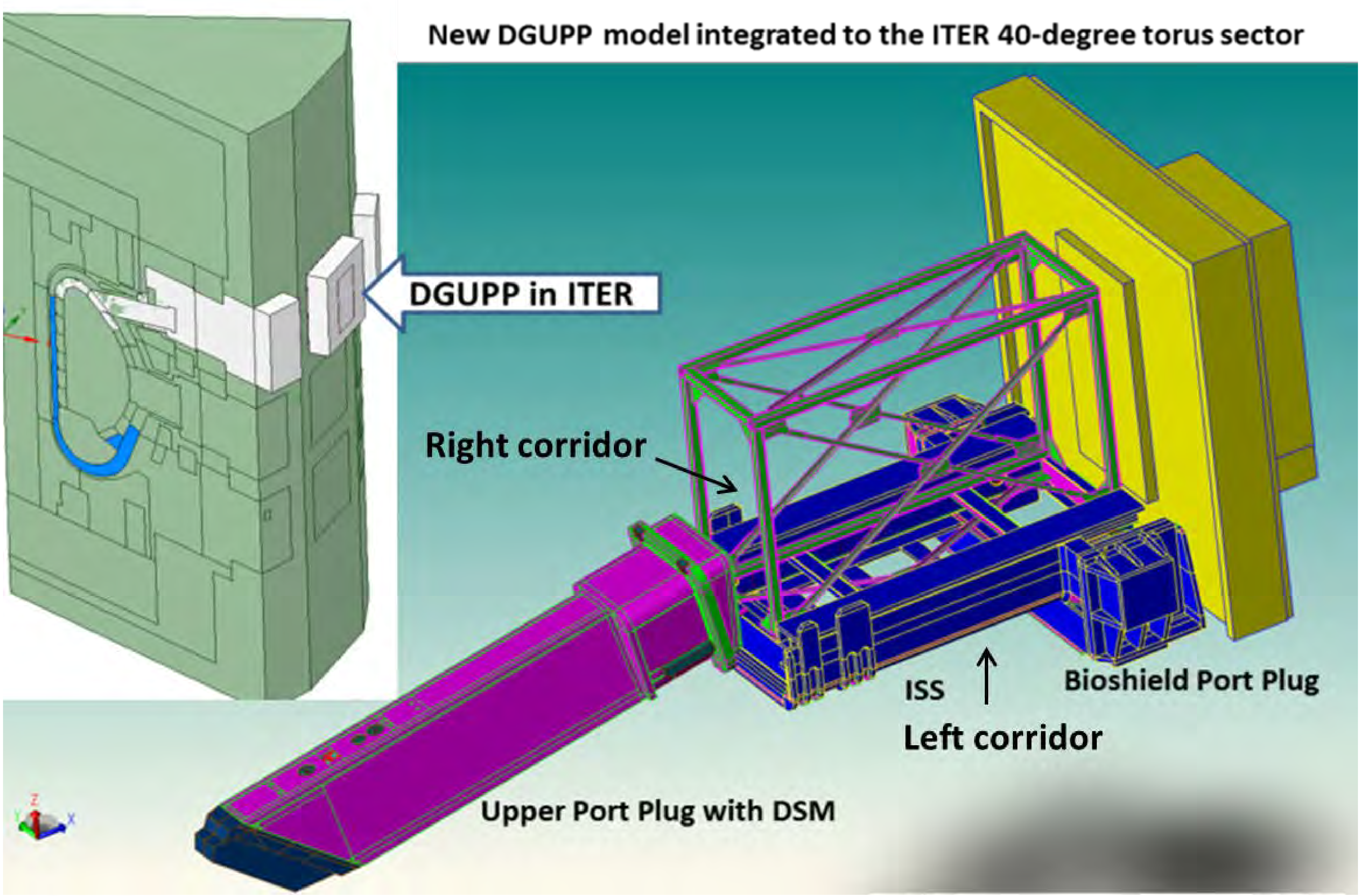


9x40 degree identical toroidal sectors

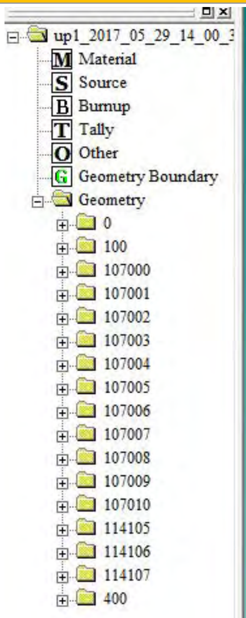


40 degree sector of C-Model

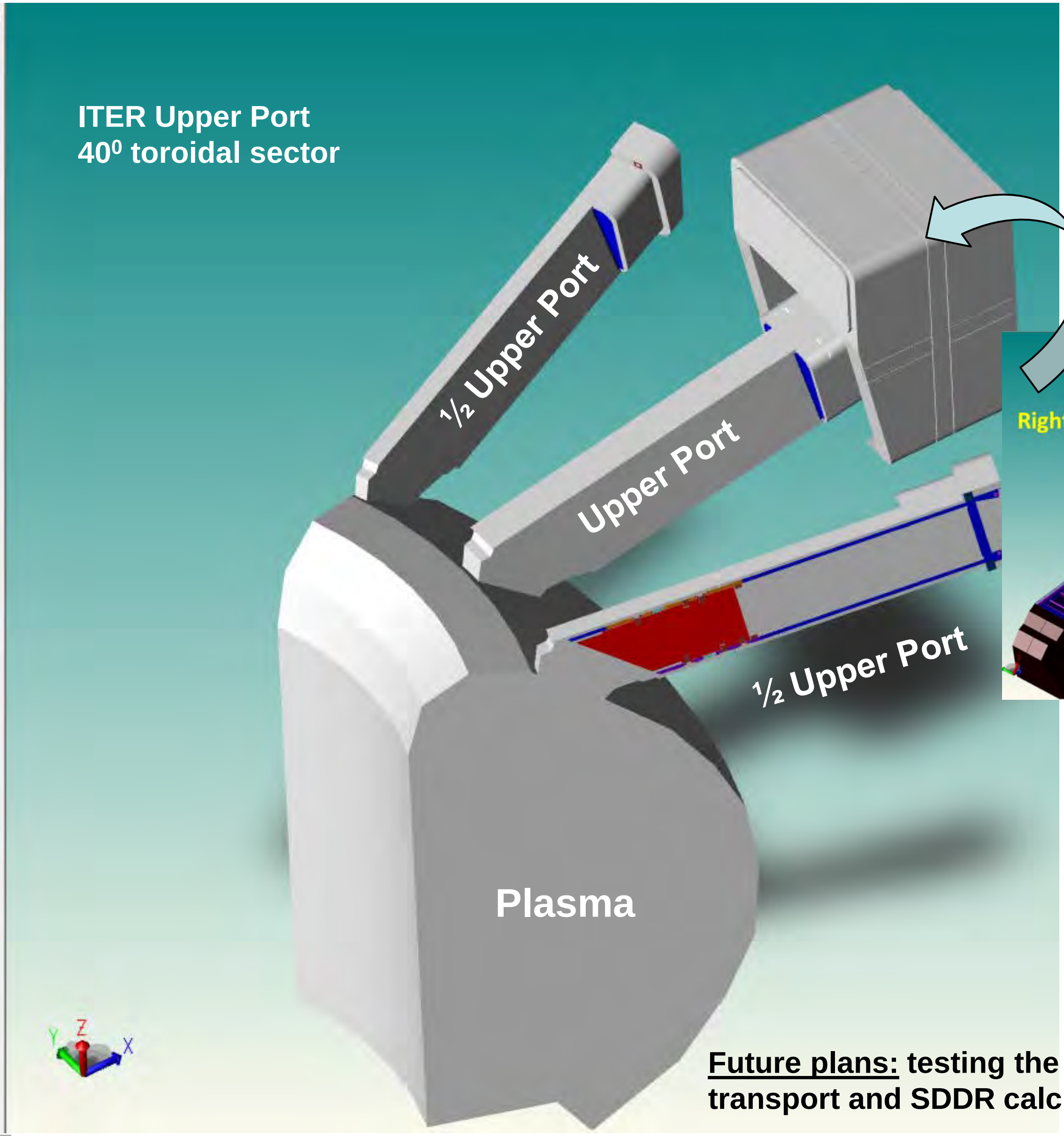
Diagnostic Generic Upper Port Plug (DGUPP) converted with SuperMC to MCNP

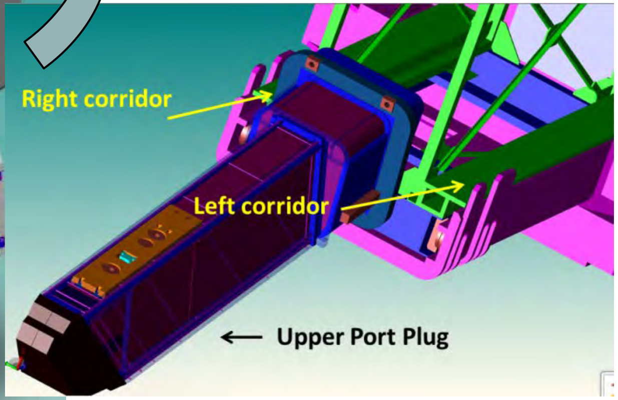


Use of the SuperMC code for CAD geometry conversion



SuperMC menu





<u>This work</u> was performed with MCNP6 and FISPACT coupled through R2Smesh code developed at KIT:

- **Neutron spectra, mesh-distributed decay gamma sources, decay gamma transport → SDDR analysis.**

SuperMC code allows:

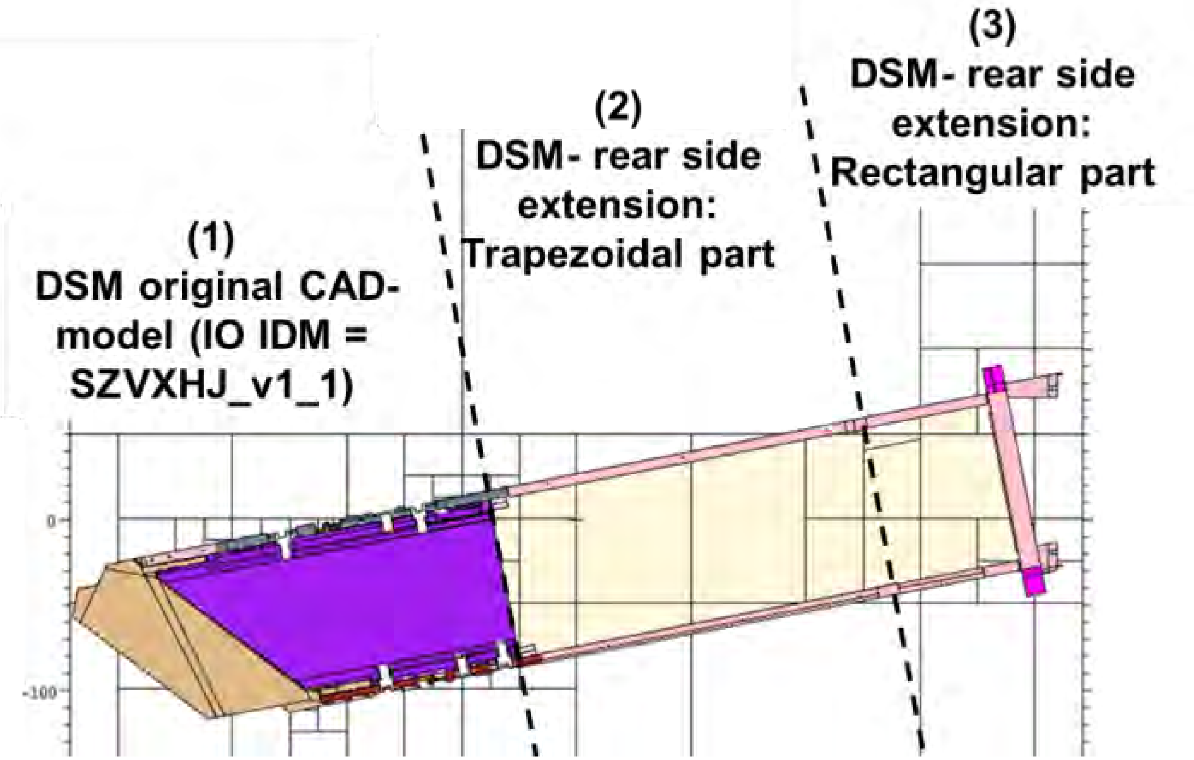
- **Bi-directional conversion CAD ←→ MCNP (and other Monte Carlo codes);**
- **Neutron, gamma radiation transport;**
- **Activation and burnup calculations**

<u>Future plans:</u> testing the SuperMC capabilities of radiation transport and SDDR calculations in ITER DGUPP

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

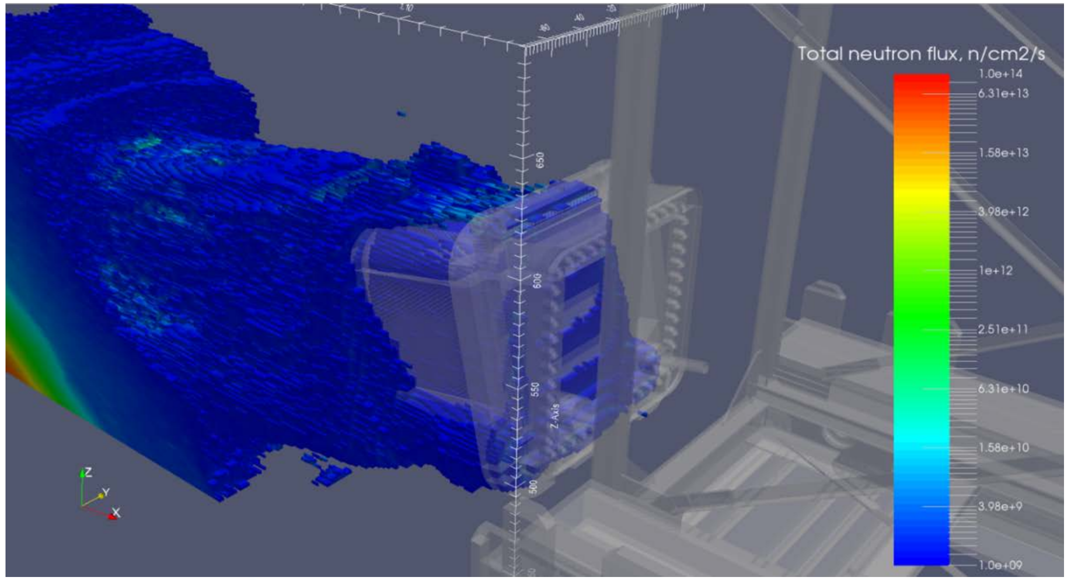
Parametric study has been carried out on the shielding features of two DSM models:

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

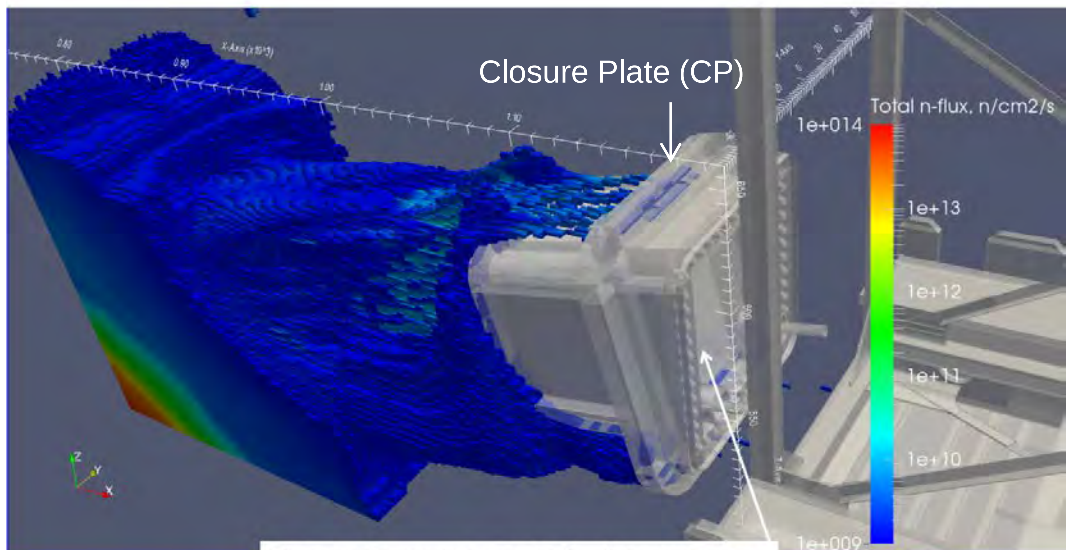


Neutron Flux maps of DGUPP in ITER C-lite MCNP model

Short DSM



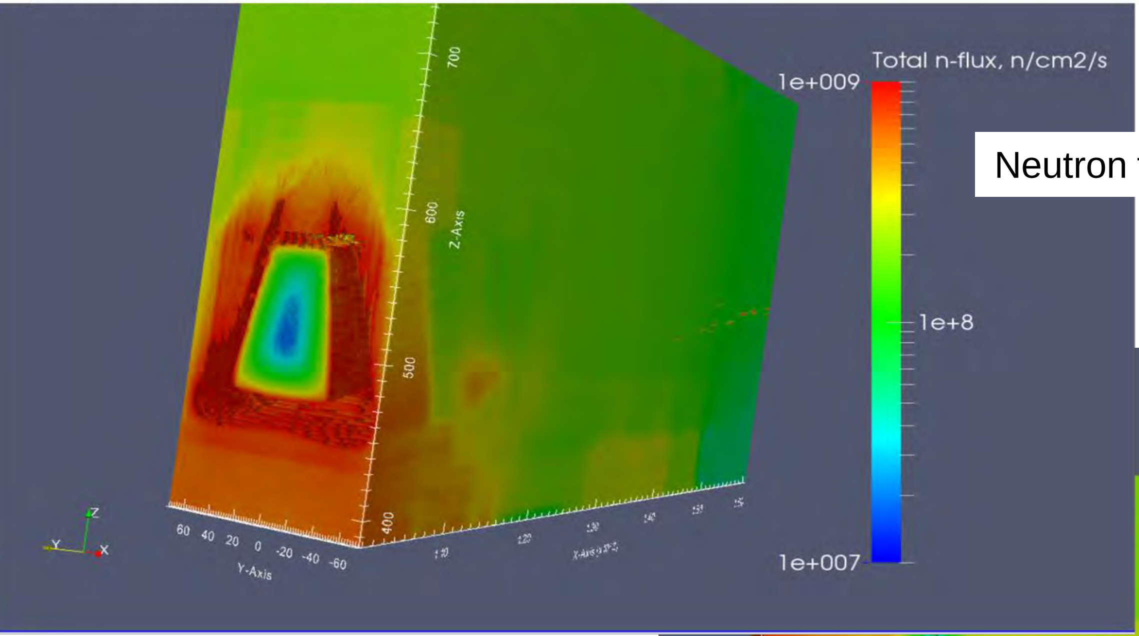
Long DSM up to CP – no streaming inside the port plug space



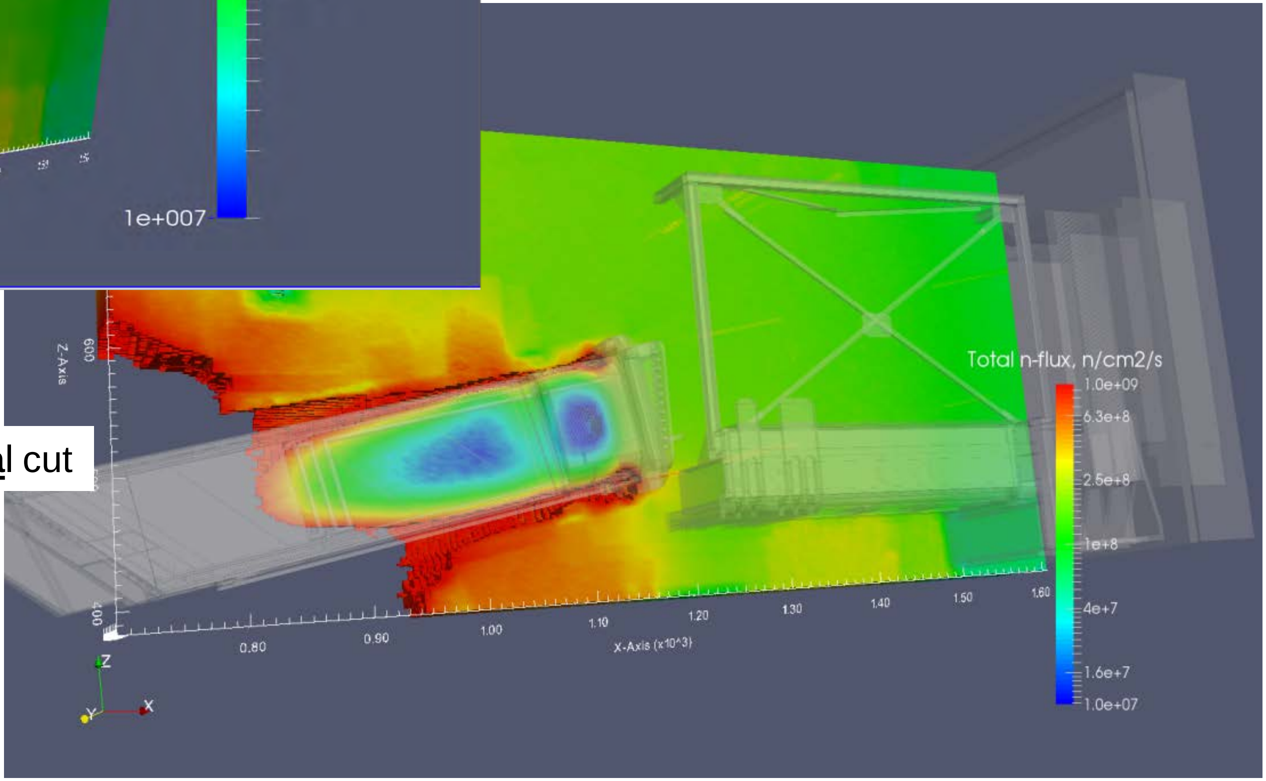
Eliminated n-streaming inside the plug, resulting in reduction of total n-flux on closure plate by 3 times

Total neutron flux in DGUPPv2 with long DSM, threshold between (1e7-1e9) n/cm²/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 .



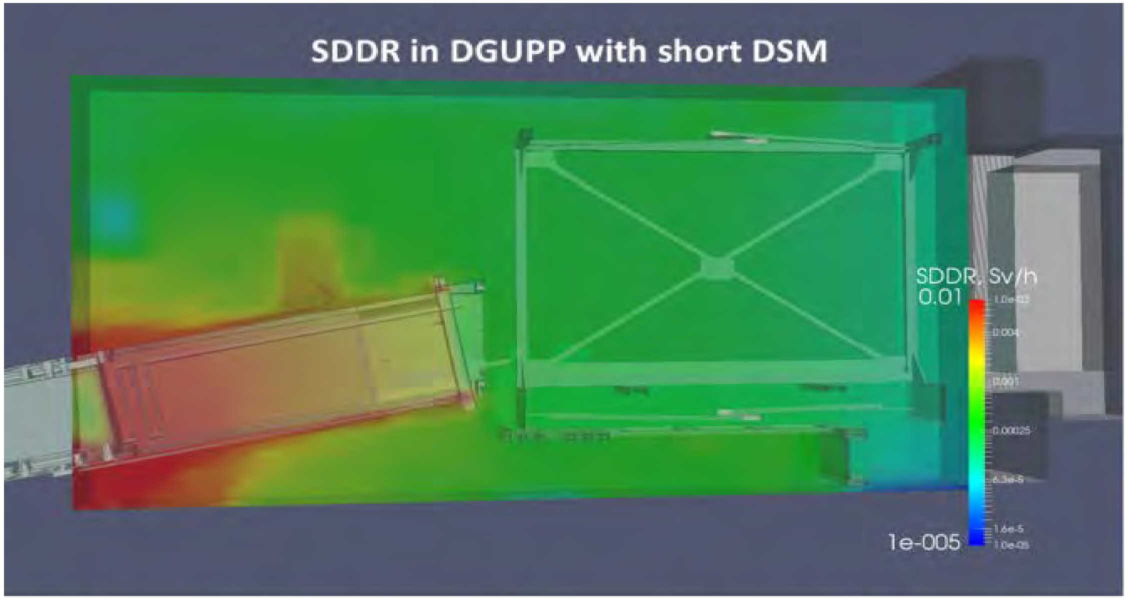
Neutron flux map with **Toroidal-Vertical** cut



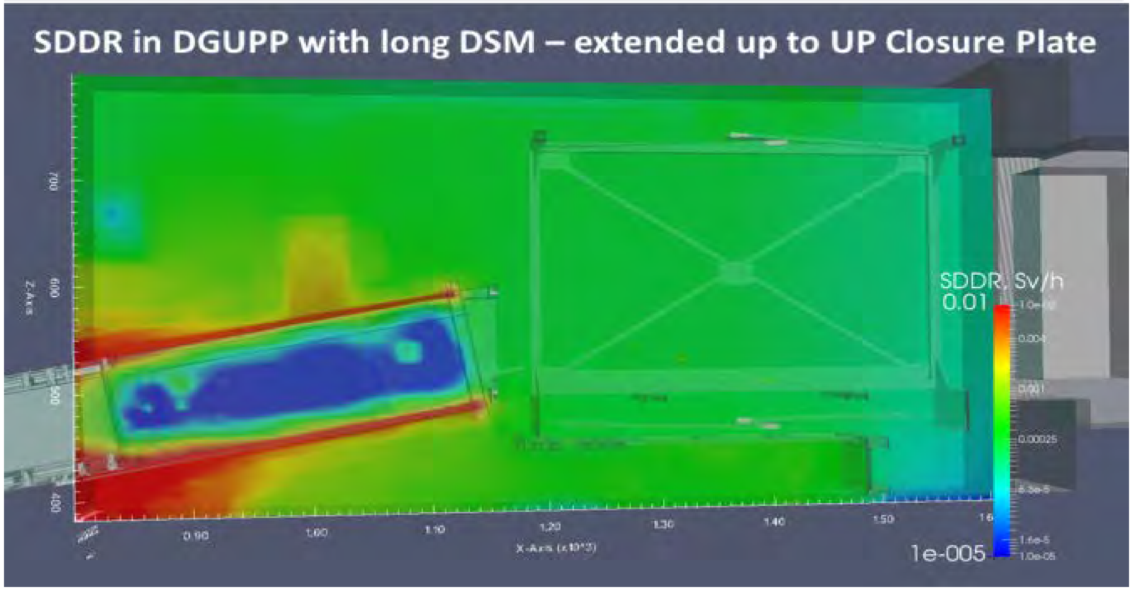
Neutron flux map with **Radial-Vertical** cut

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

Short DSM

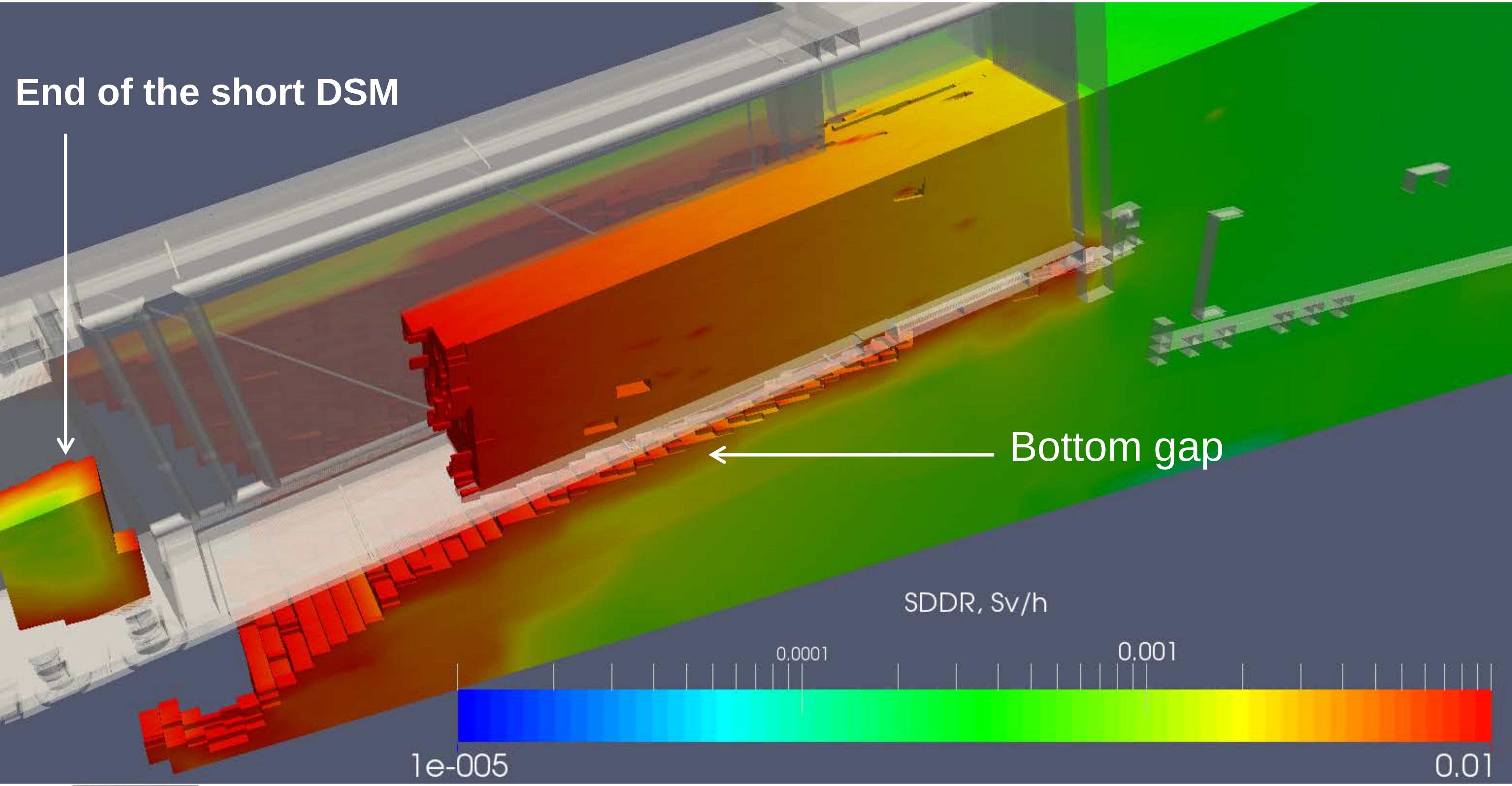


Long DSM



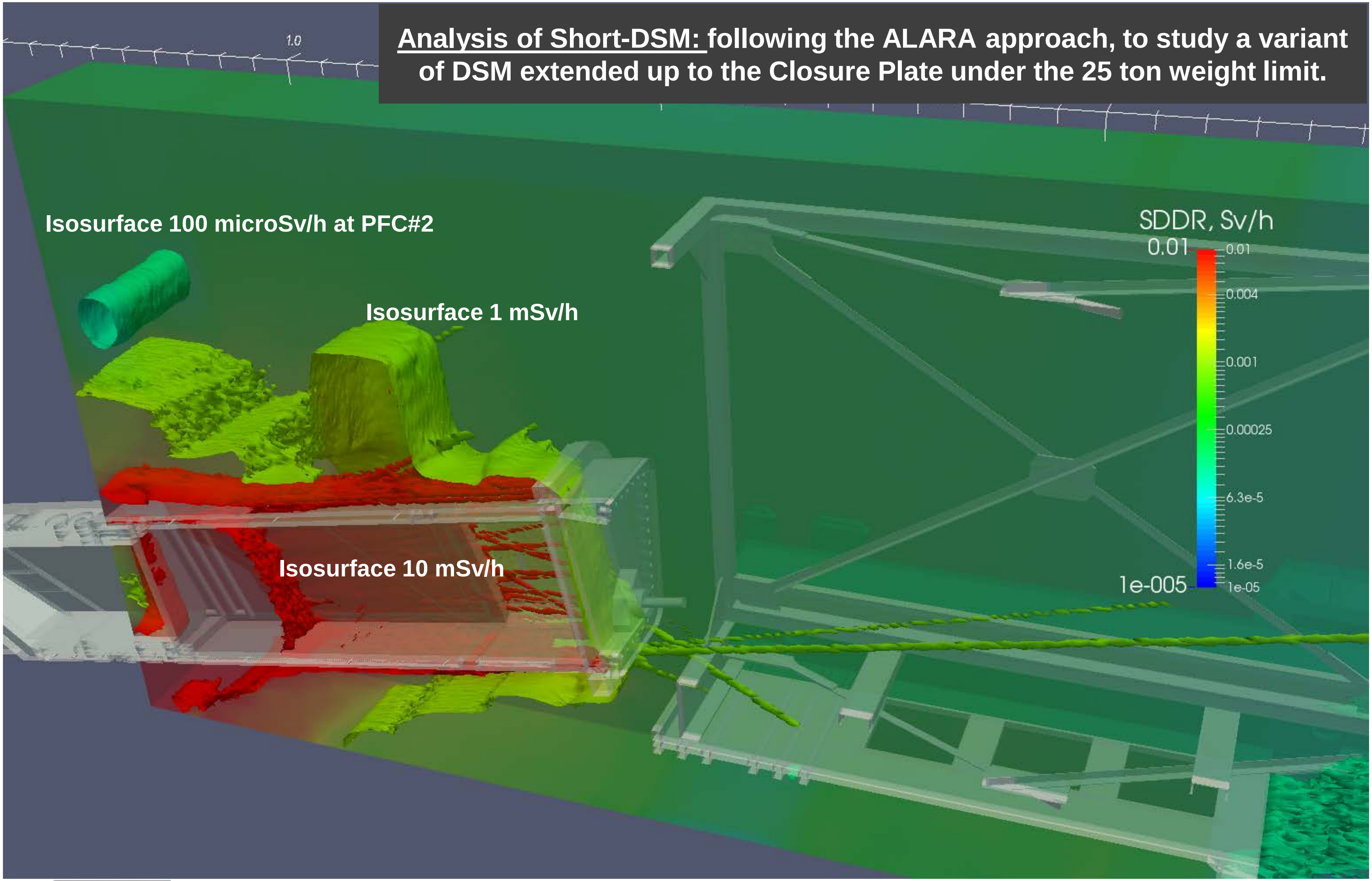
SDDR (Sv/h) map in a quarter of the DGUPP with short DSM

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

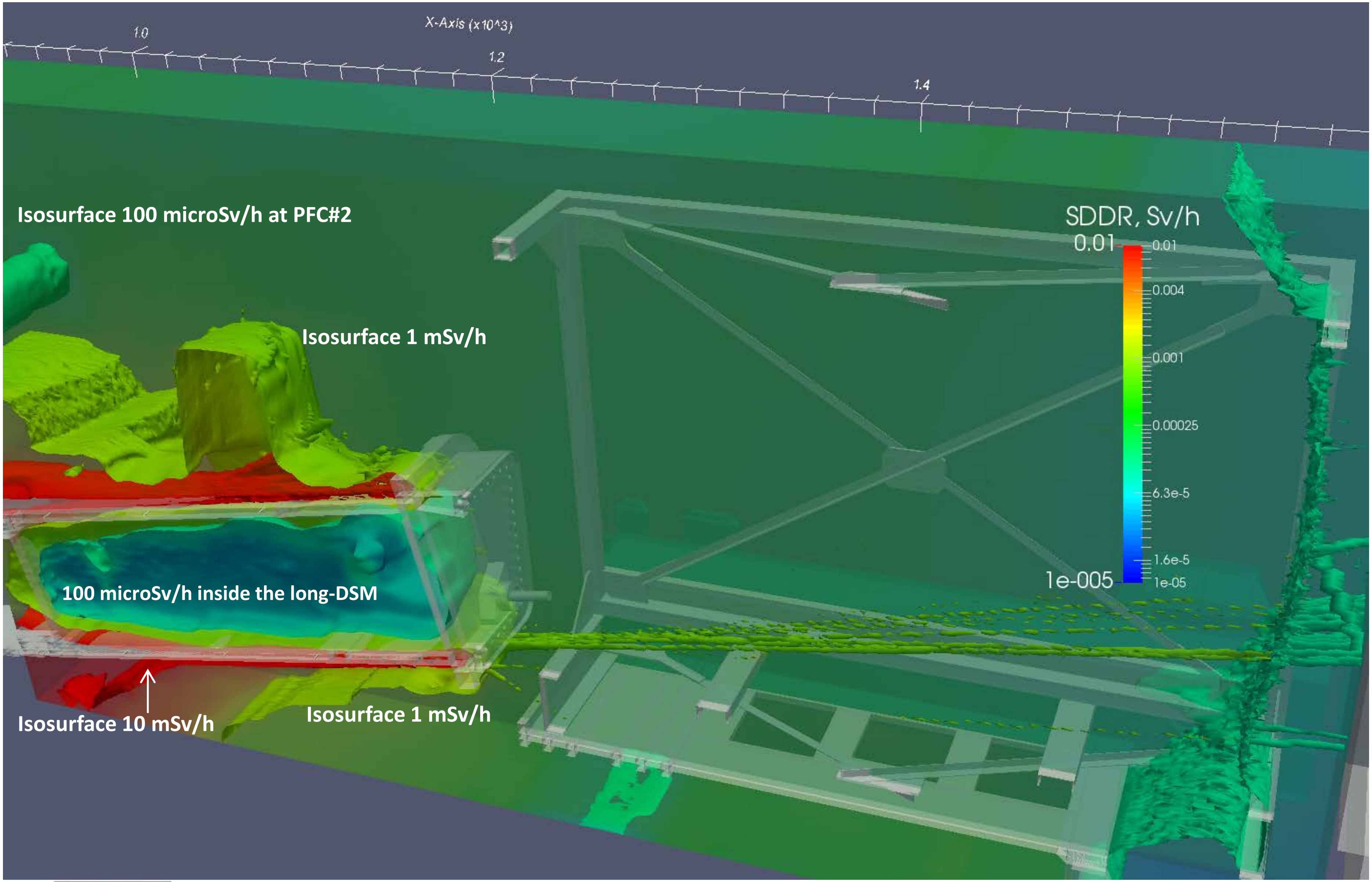


Short-DSM of DGUPP with SDDR isosurfaces

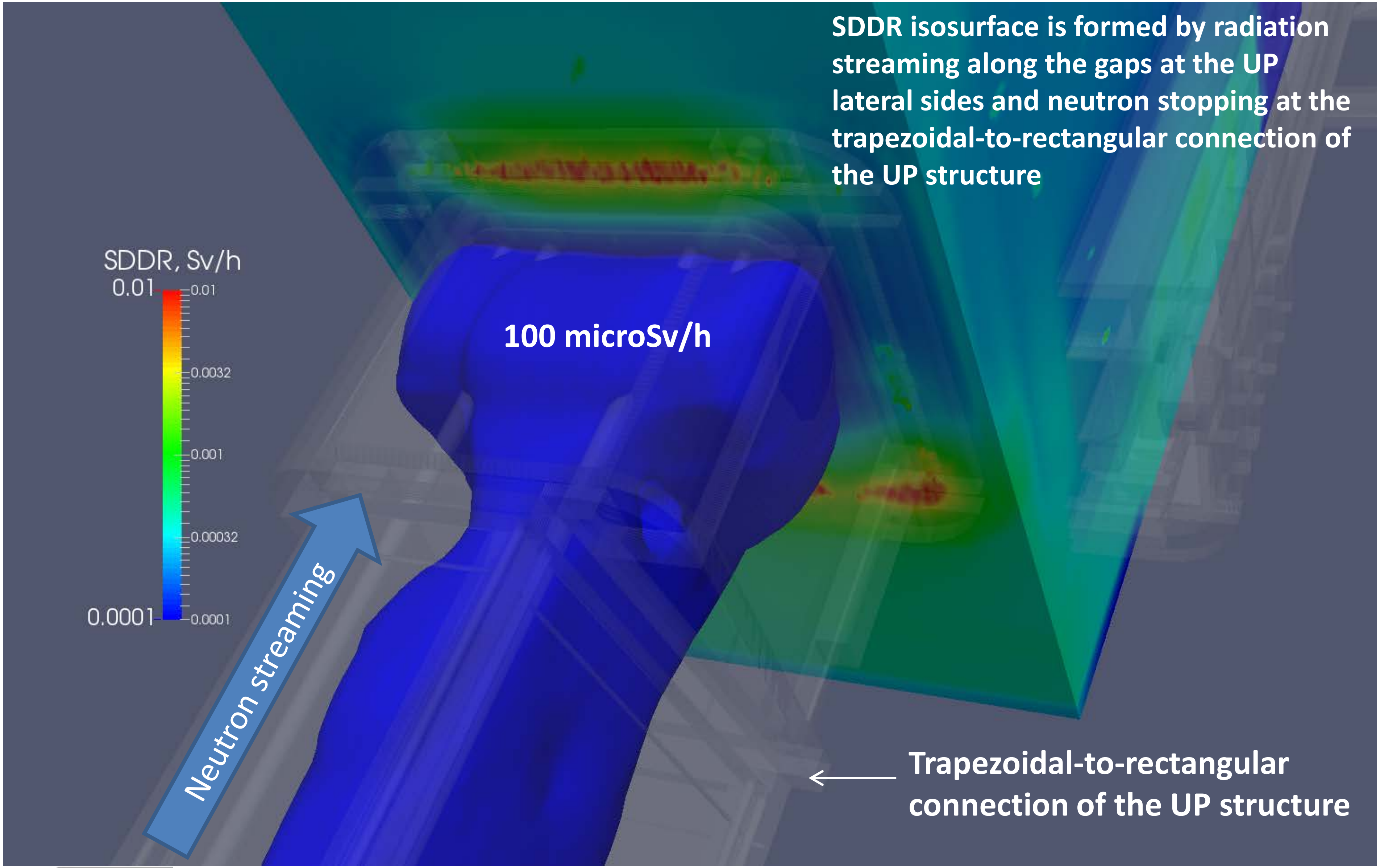
<u>Analysis of Short-DSM:</u> following the ALARA approach, to study a variant of DSM extended up to the Closure Plate under the 25 ton weight limit.



Long-DSM of DGUPP with SDDR isosurfaces



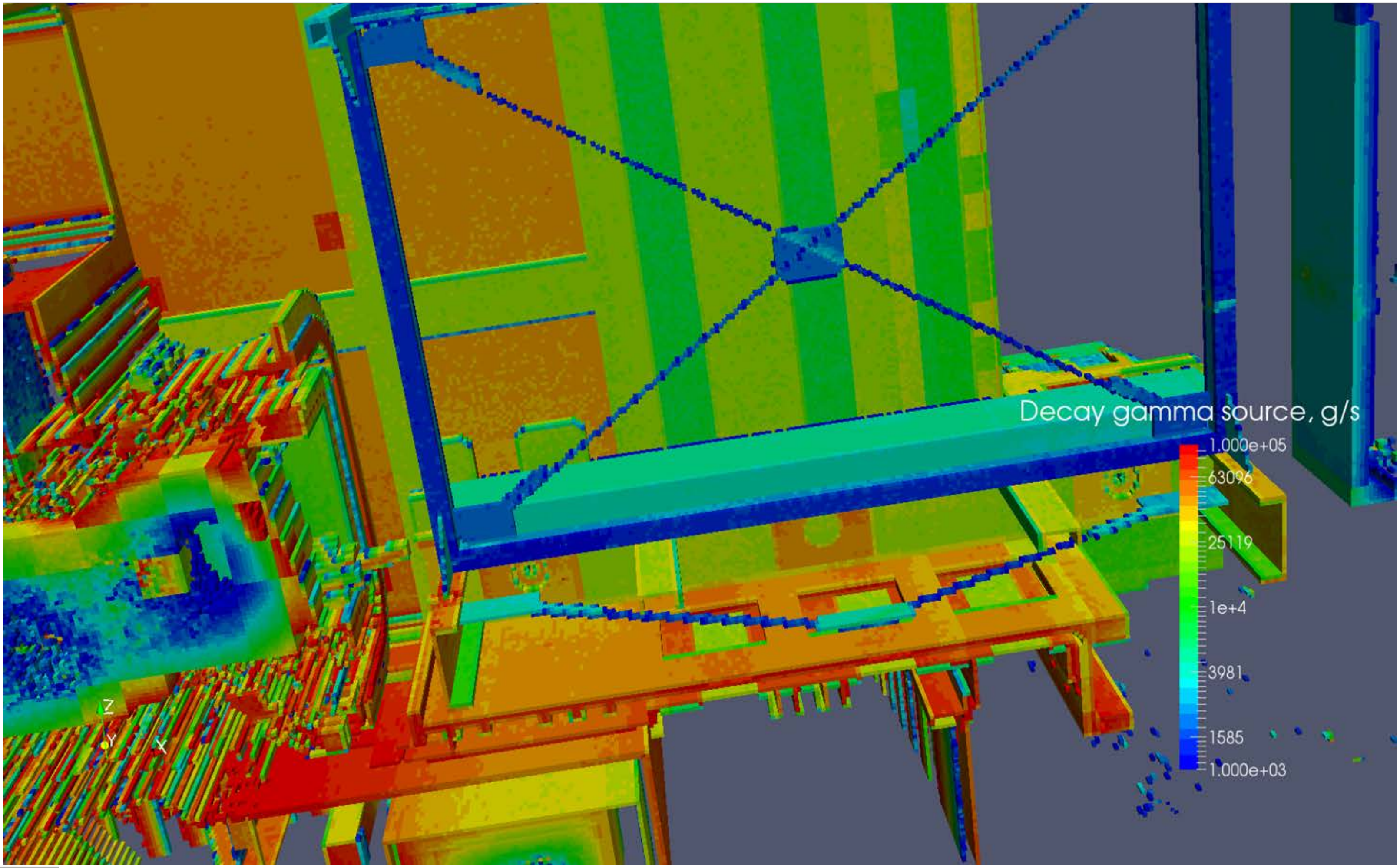
Map isosurface in DGUPP with long DSM - to mitigate radiation streaming



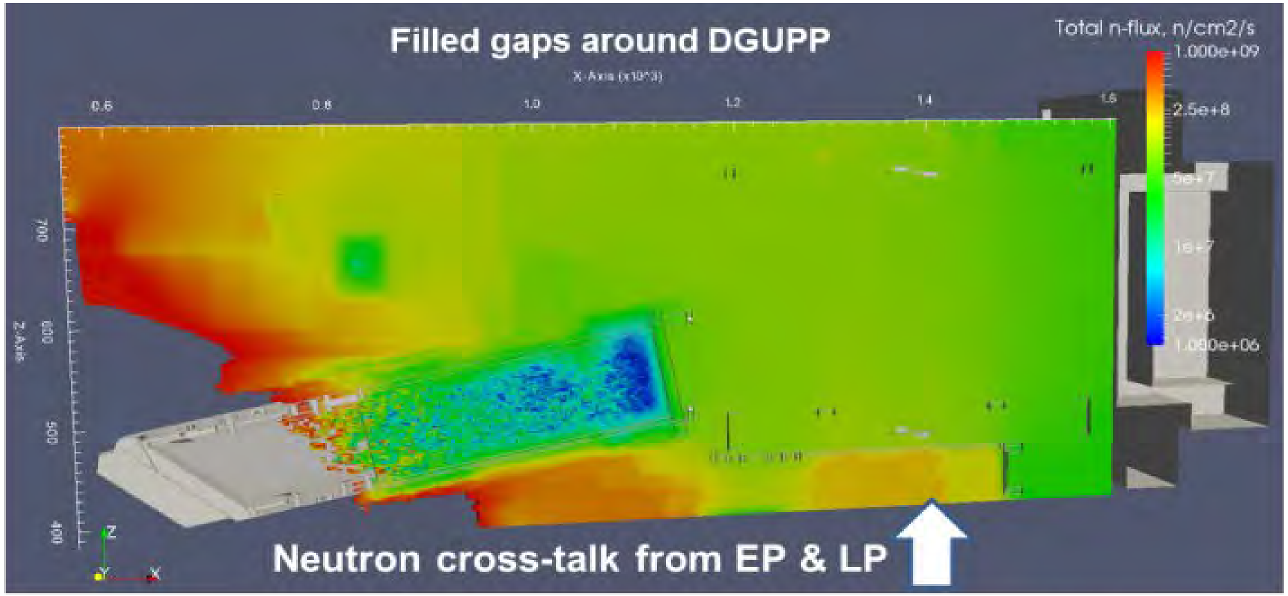
Decay gamma sources distribution in DGUPP Inter Space Structure

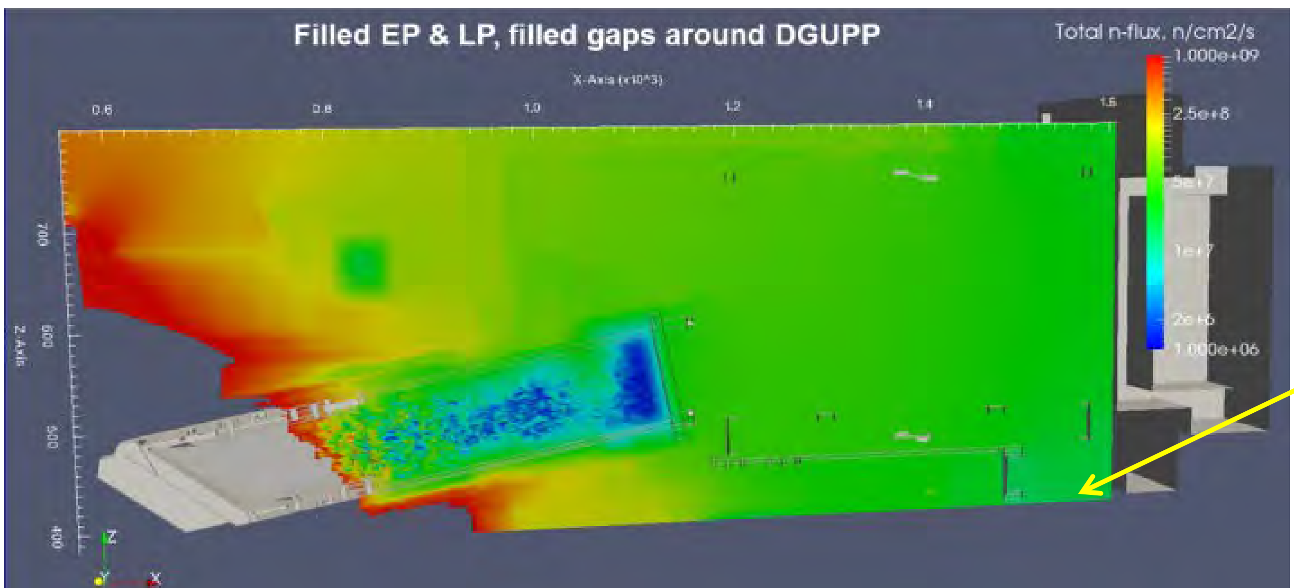
The lowest sources →

Material	Range of decay gamma sources, g/s	Maximum decay gamma source, g/s
Aluminum type 6061	2e2 - 5e3	5e3
Steel SS316L(N)-IG, Co 0.03 wt.%	1e4 – 5e4	5e4
Steel SS316L(N)-IG, Co 0.05 wt.%	5e4 – 1e5	1e5

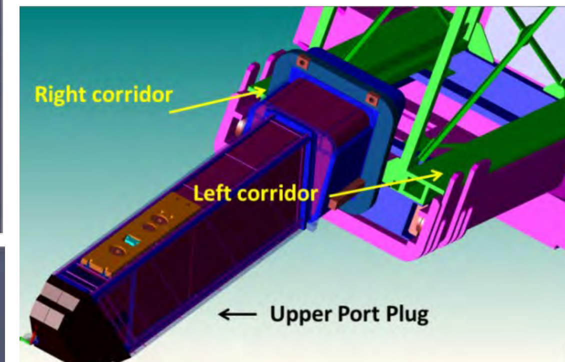


Neutron cross-talk from the ITER Equatorial & Lower Ports (EP & LP) to DGUPP





Neutrons from EP & LP caused additional activation of the DGUPP materials
→ resulted SDDR increment of 75 μSv/h in front of maintenance Right and Left corridors of the DGUPP Inter-Space Structure

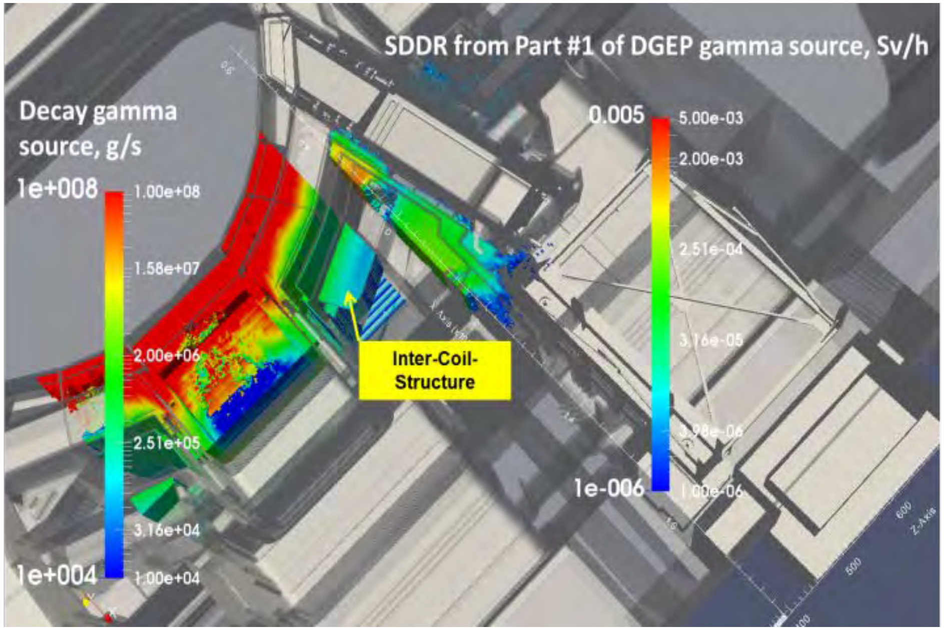


SDDR calculated in the C-lite models with baseline EP & LP and totally prevented (killed) radiation inside the EP & LP.

As the baseline models, the DGEP design of 2015 and Cryopump LP were used.

Gamma cross-talk from Diagnostic Generic Equatorial Port (DGEP) to DGUPP

SDDR at DGUPP from decay gamma sources at <u>Part#1 of DGEP</u>

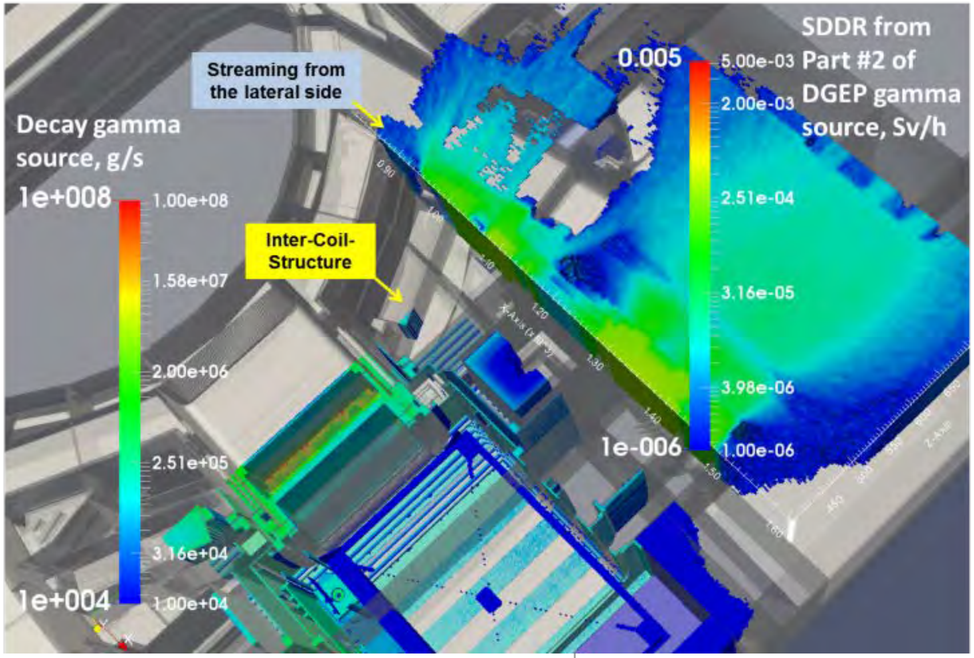


Location in UPP and Upper Port Interspace	SDDR at DGUP from gamma source at *Part#1 of DGEP*, µSv/h	SDDR at DGUP from gamma source at *Part#2 of DGEP*, µSv/h	SDDR at DGUP from gamma source at *whole DGEP*, µSv/h
In UP Closure Plate	3e-3 (low statistics)	0.11	0.11
At front of UP ISS Left Corridor	0.44	4.97	5.41
At front of UP ISS Right Corridor	0.43	4.92	5.35

<u>Inter-Coil-Structure</u> stops gamma streaming from high intensity decay gamma sources at Part #1 of DGEP (first wall panel, blanket and VV)
→ **localized character of gamma cross-talk** effect to SDDR at Upper Port interspace of DGUPP

<u>Impact of gamma cross-talk</u> proved to be as small as **5 µSv/h** in comparison with 15 times larger neutron cross-talk of **75 µSv/h**

Dominant contribution of decay gamma sources <u>Part#2 of DGEP</u> to SDDR map at DGUPP



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.
- Should follow the ALARA principle, with low activated materials, reduced contents of impurities - parent isotopes contributed to short and long term SDDR (Co, Ta, Ni, Nb).

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.

BACK slides

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