Neutronics for Diagnostic Systems of ITER Port Plugs

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Content

General info

- **Fusion neutronics in ITER tokamak**
- **Parallel Monte Carlo runs on supercomputers**

Applications

- **Shielding for Diagnostics Ports:**

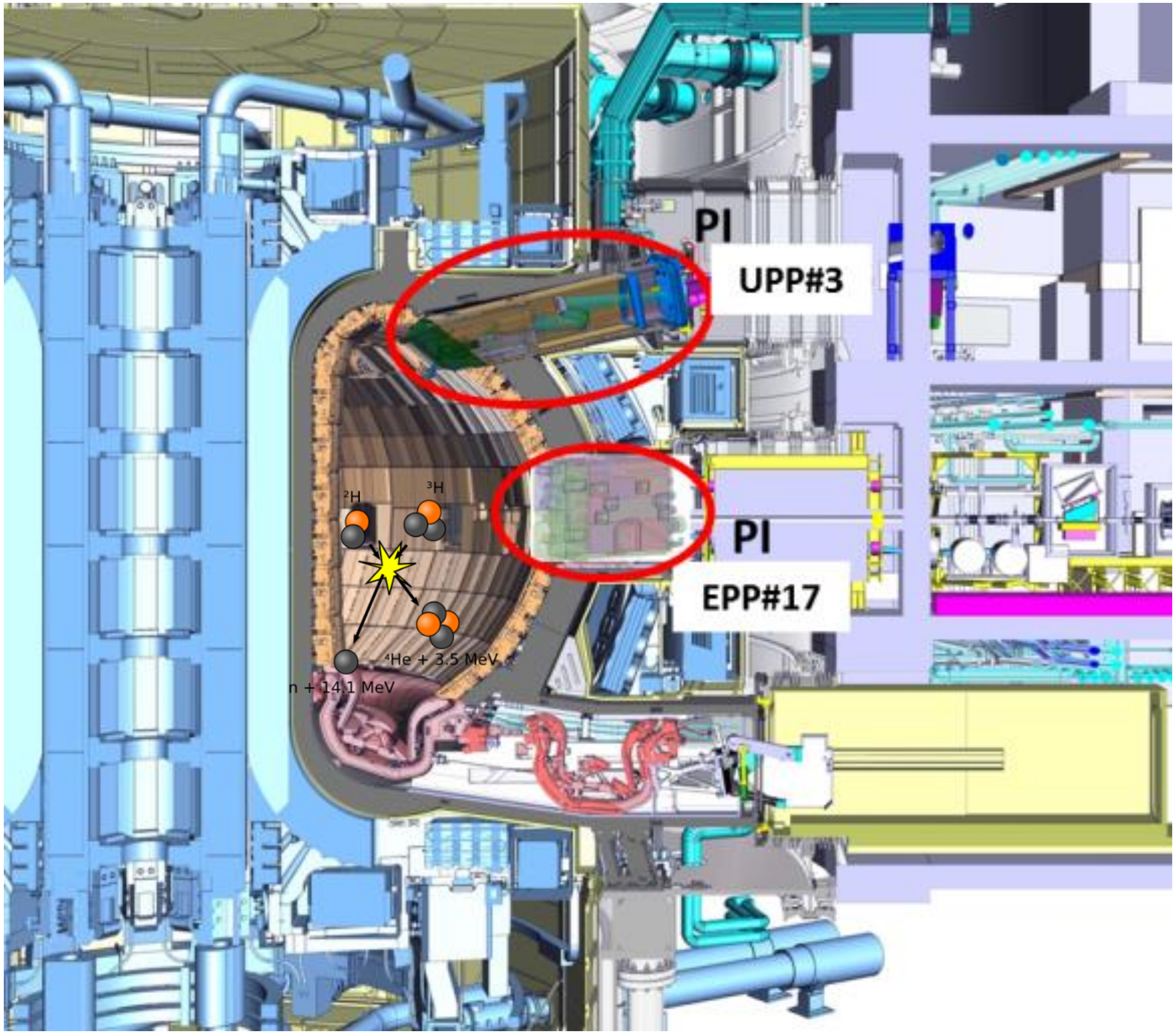
  Upper Port #3

  Equatorial Port #17

ITER tokamak: CAD model

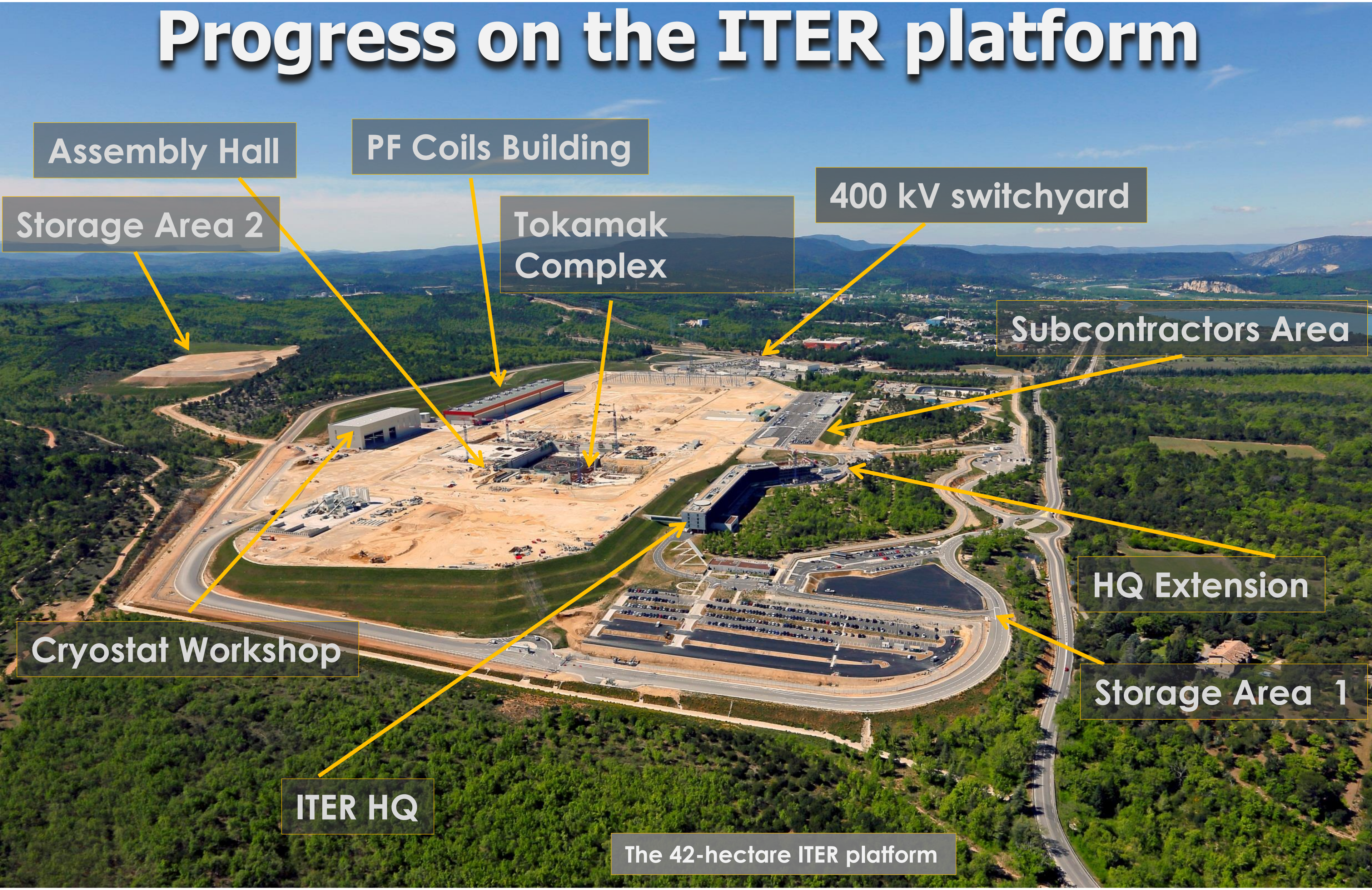
Diagnostics Port Plugs

- House 80% of ITER Diagnostics
- Port plugs are large structures which play the dual and conflicting roles of providing diagnostic access while ensuring that the vacuum vessel ports are adequately “plugged” against the leakage of nuclear radiation and are vacuum leak tight.
- ITER has 18 ports at the Equatorial and Upper levels
- ITER's operational phase is expected to last for 20 years: "shakedown" period H-H, D-D, D-T with 500 MW fusion power



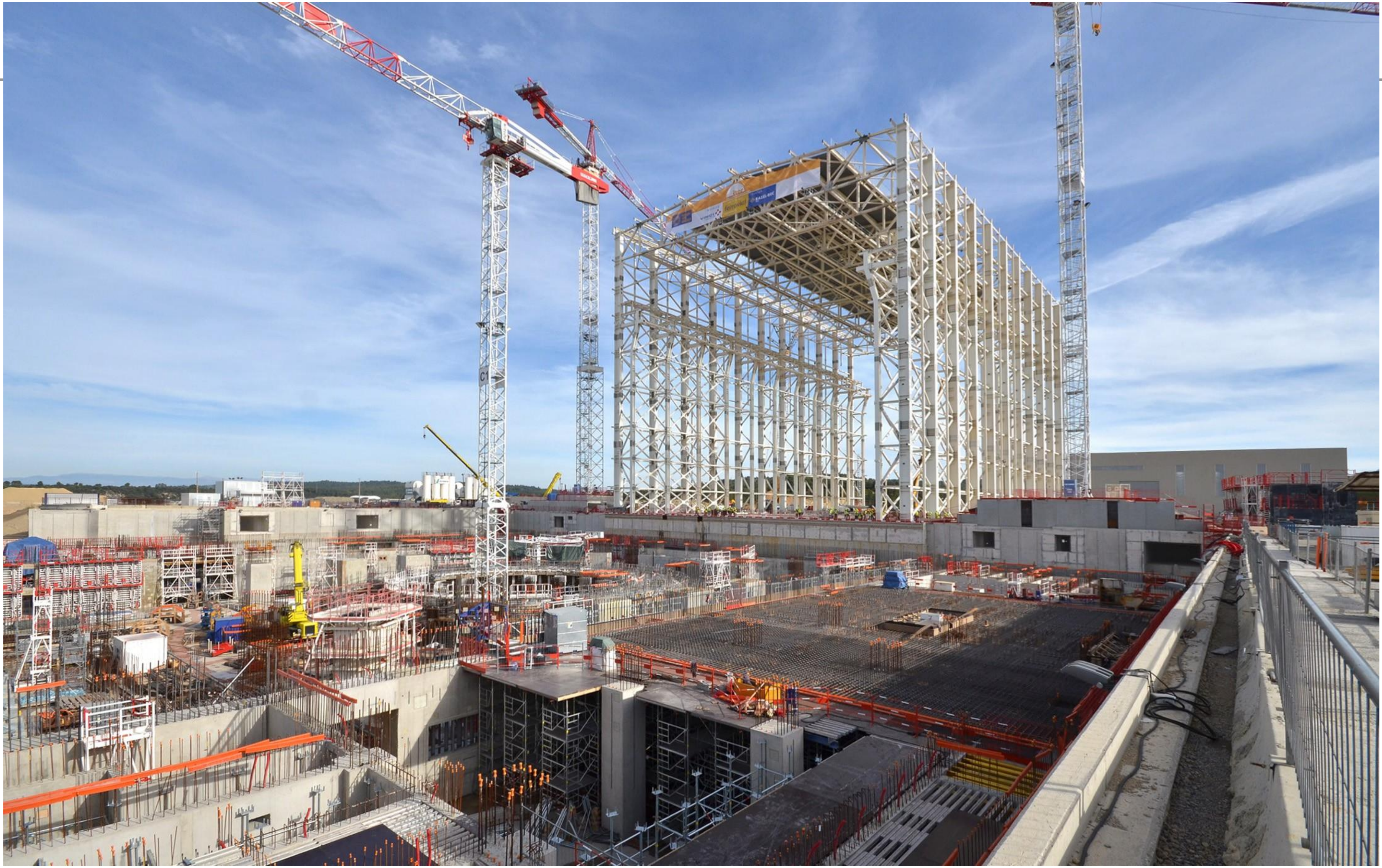
First Plasma and subsequent D-T full power operation: **originally scheduled for 2020 and 2027**, Updates will be reported to the ITER Council in November 2015, check: **www.iter.org**

Progress on the ITER platform



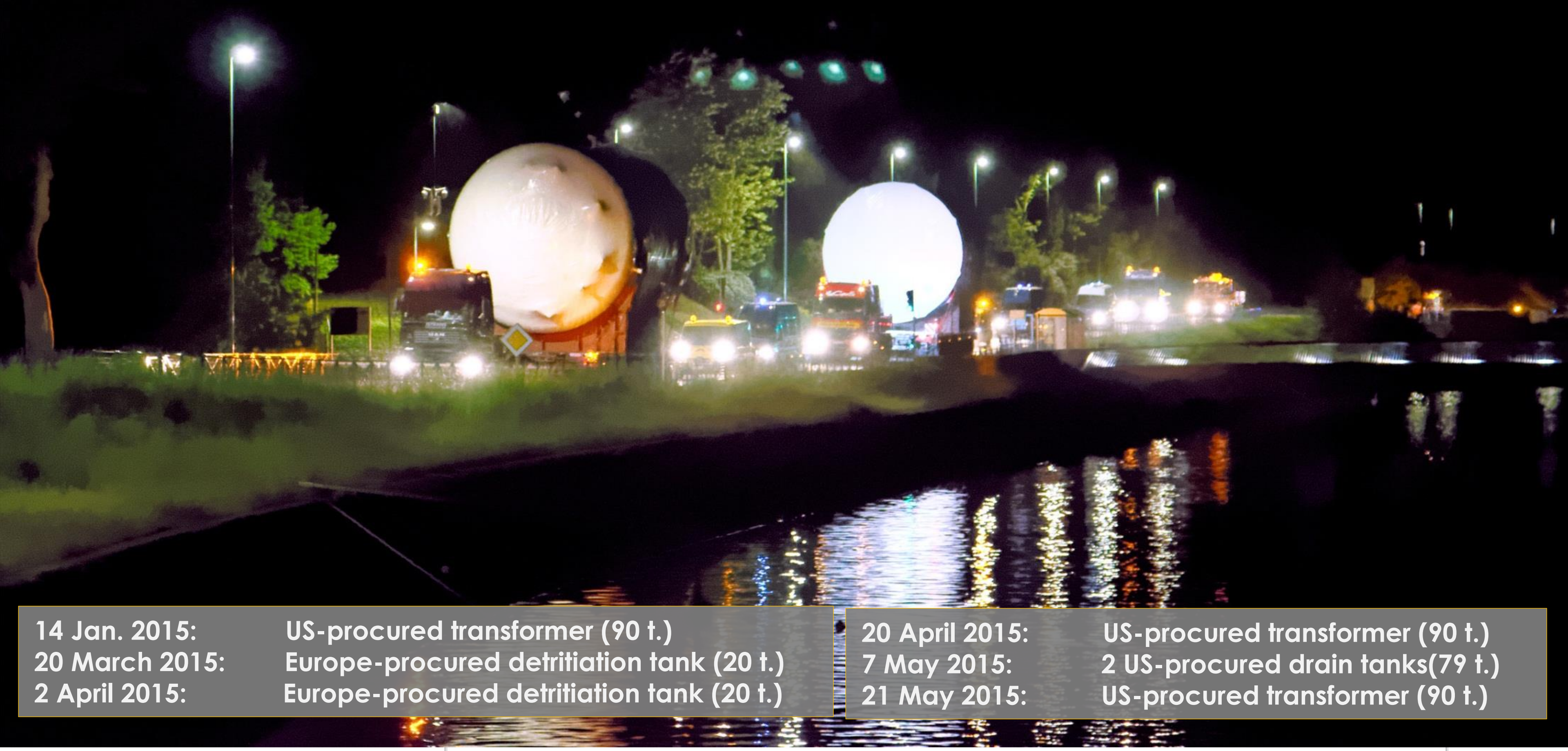
ITER progressing: tokamak pit and assembly building

Summer 2015: circle marks the location of the future ITER Tokamak. Components will enter on the far side of the Assembly Building (structural pillars already in place) for verification, pre-assembly, transfer to the Tokamak Pit for integration into the machine.



Autumn 2015: The roof segment of the ITER Assembly Building is successfully raised to its final position in September. Work is underway on the second basement level of the Tokamak Complex (B1).

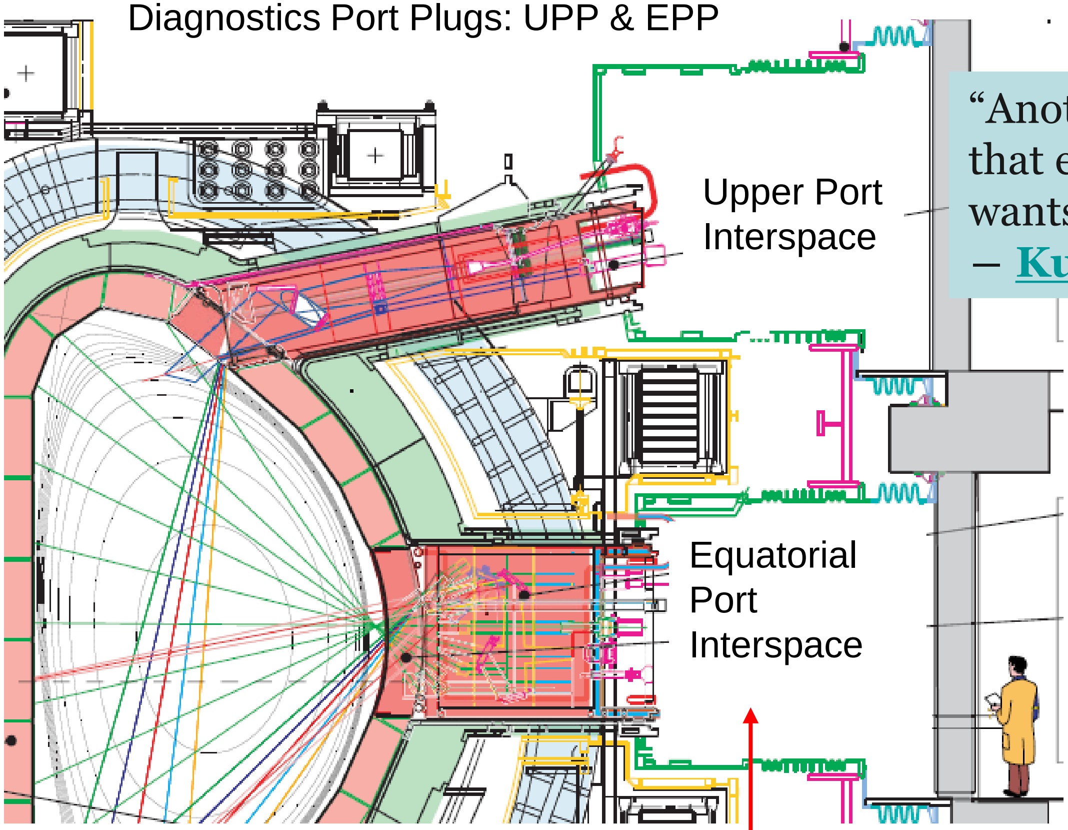
Deliveries have started



14 Jan. 2015: US-procured transformer (90 t.)
20 March 2015: Europe-procured detritiation tank (20 t.)
2 April 2015: Europe-procured detritiation tank (20 t.)

20 April 2015: US-procured transformer (90 t.)
7 May 2015: 2 US-procured drain tanks(79 t.)
21 May 2015: US-procured transformer (90 t.)

Safe maintenance at ITER Ports – from behind the Port Plugs: Poject Requrements for Shut-Down Dose Rate (SDDR)



"Another flaw in the human character is that everybody wants to build and nobody wants to do **maintenance**..."
– **Kurt Vonnegut**, ***Hocus Pocus***

.... Except of personnel at ITER (Diagnostic physicists, engineers, experimentalists...)

Neutronics computational support must be provided for the Port Plugs design development

10^6 sec after shut-down, SDDR < 100 microSv/h

24 hrs after shut-down, SDDR < 10 microSv/h

Neutronics computational methodology: Codes, Tools, Nuclear Data

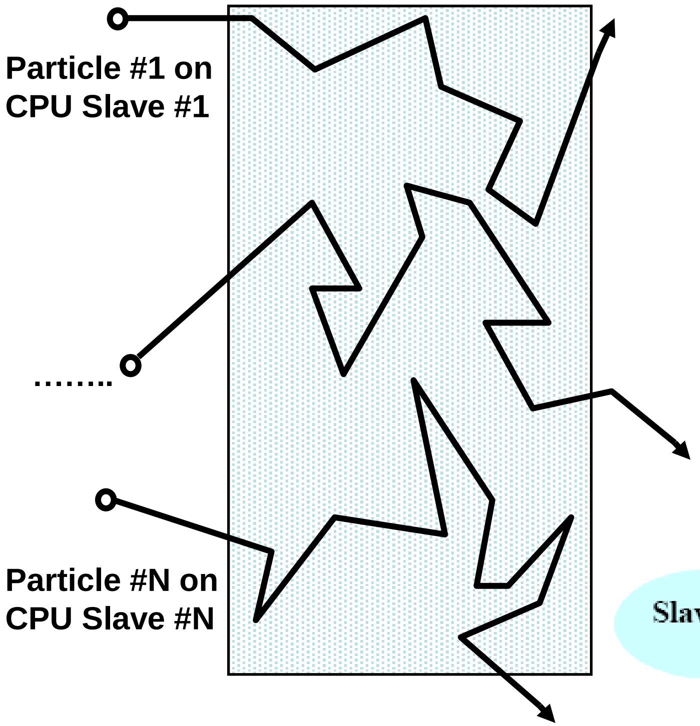
We have used the state-of-the-art codes and interfaces approved for ITER neutronics applications

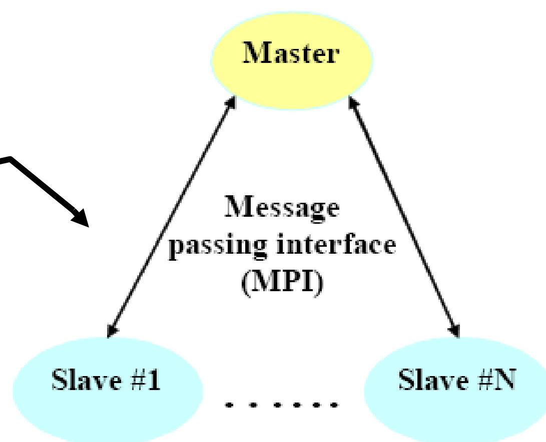
- **SpaceClaim** software reads CAD models, solves geometry problems, allows to work in 3D without having to be a CAD expert
- **CAD-to-MCNP conversion tools:**
  - **MCAM 5.2 (FDS Team, China)**
  - **McCad (KIT, Germany)**
- **Radiation transport calculations (n/gamma fluxes, nuclear heat, gas production):**
  - 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

Monte Carlo (MC) radiation transport runs on supercomputers

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

⇒ *Simulation can be computed on <u>parallel</u> multiprocessor systems*





Productive parallel run on slave processors

<u>Monte Carlo method</u> is most suitable computational technique for nuclear fusion applications. Because of:

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

MCNP speed-up on HELIOS supercomputer

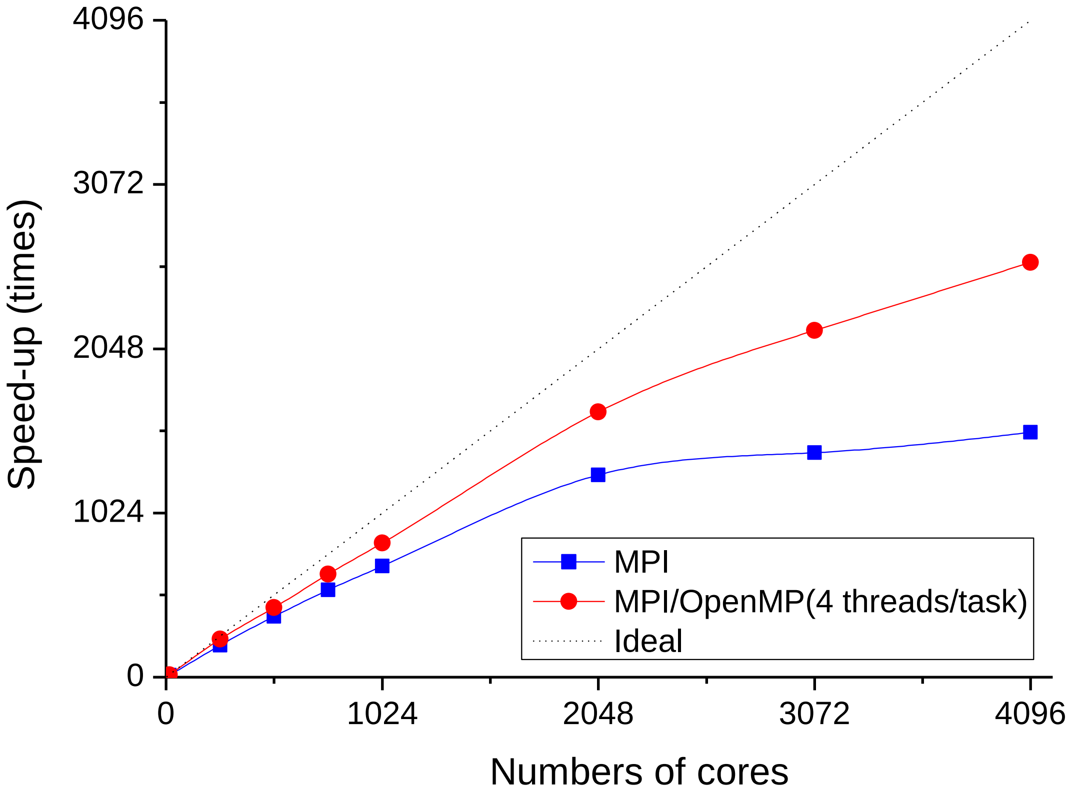
Methodological 3 steps to get the reliable MCNP results:

1. Plot the map of statistical relative errors

2. To reduce the statistical relative errors - use Monte Carlo Variance Reduction Techniques (VRTs), like the most advanced MCNP6 weight window generator in an iterative manner.

Arrange the target tally of VRTs close to the area of interest.

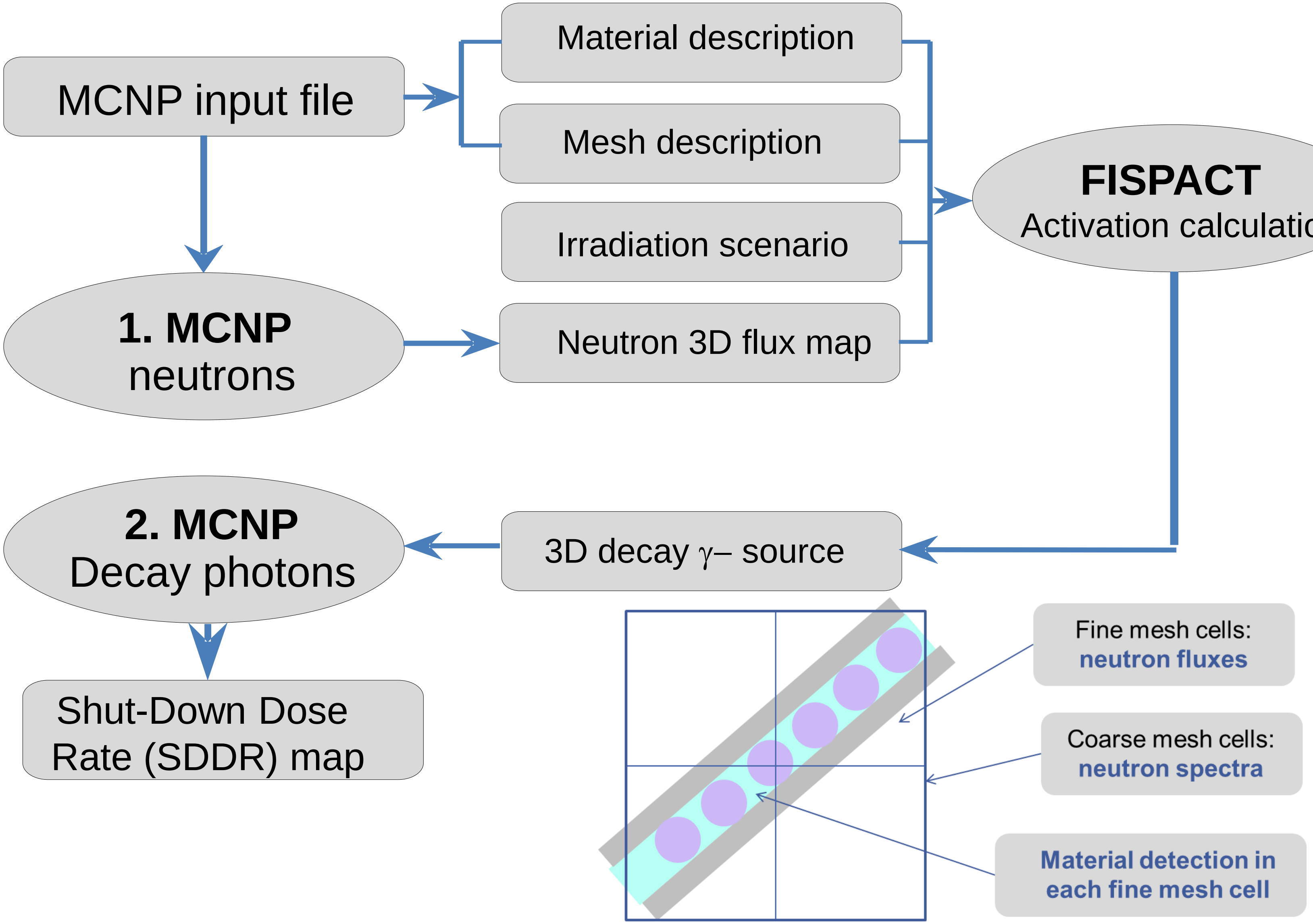
3. Confirm that area of interest cross the area of statistically reliable results.



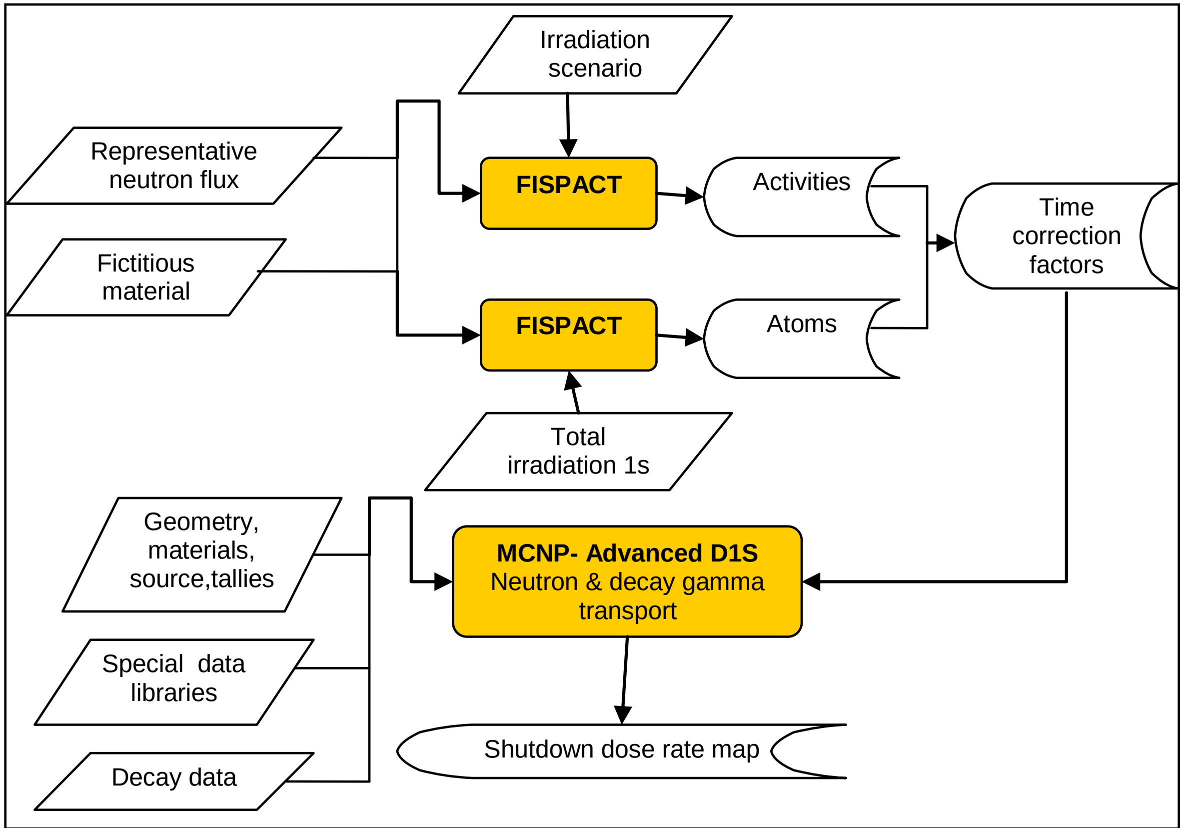
HELIOS

HELIOS: OpenMP/MPI parallelization for non-biased MCNP5 run **speed-up is about 2500 on 4096 cores !**

Rigorous 2-Step mesh (R2Smesh-2.2) code (KIT) for SDDR calculations



Direct 1-Step (D1S) method of SDDR calculations



Advanced-D1S approach developed by ENEA: block-scheme workflow

Replacement of prompt photons by decay gammas in MCNP transport calculation

⇒ ***One single MCNP run*** *for neutron and decay photon transport calculation*

Special purpose MCNP activation data files: **Replacement of prompt photon production data (yields & spectra) by decay gamma data**

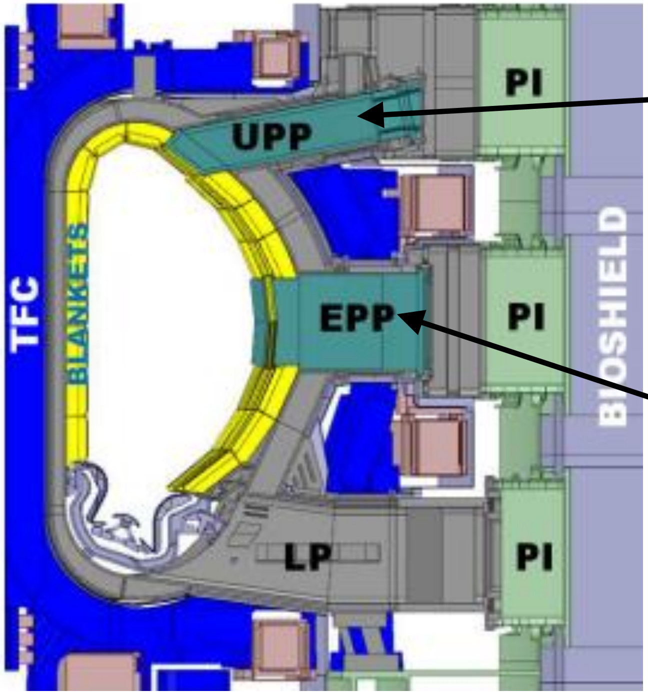
No activation calculation for decay gamma sources – **use of time correction factors**

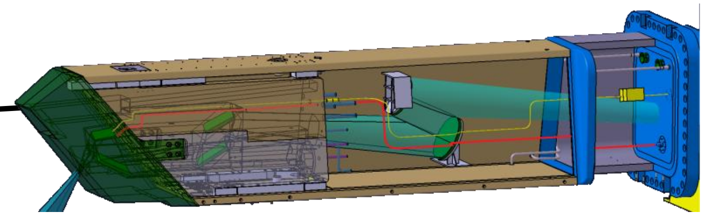
Adjustment of time correction factors required for decay gamma source to assess correct decay gamma dose rate

⇒ *Depending on radio-nuclide, irradiation history and cooling times.*

⇒ *Method developed by ITER JCT and ENEA teams specifically for application to ITER shutdown dose rate estimations*

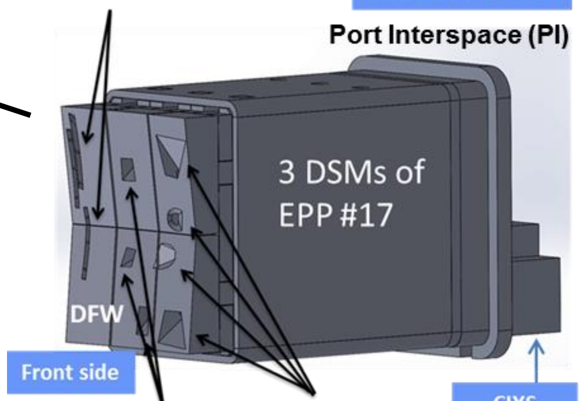
Fusion Neutronics Applications





UPP#3

Charge eXchange Recombination Spectroscopy (**CXRS**) and Glow Discharge Cleaning (**GDC**) installed in UPP#3



EPP#17

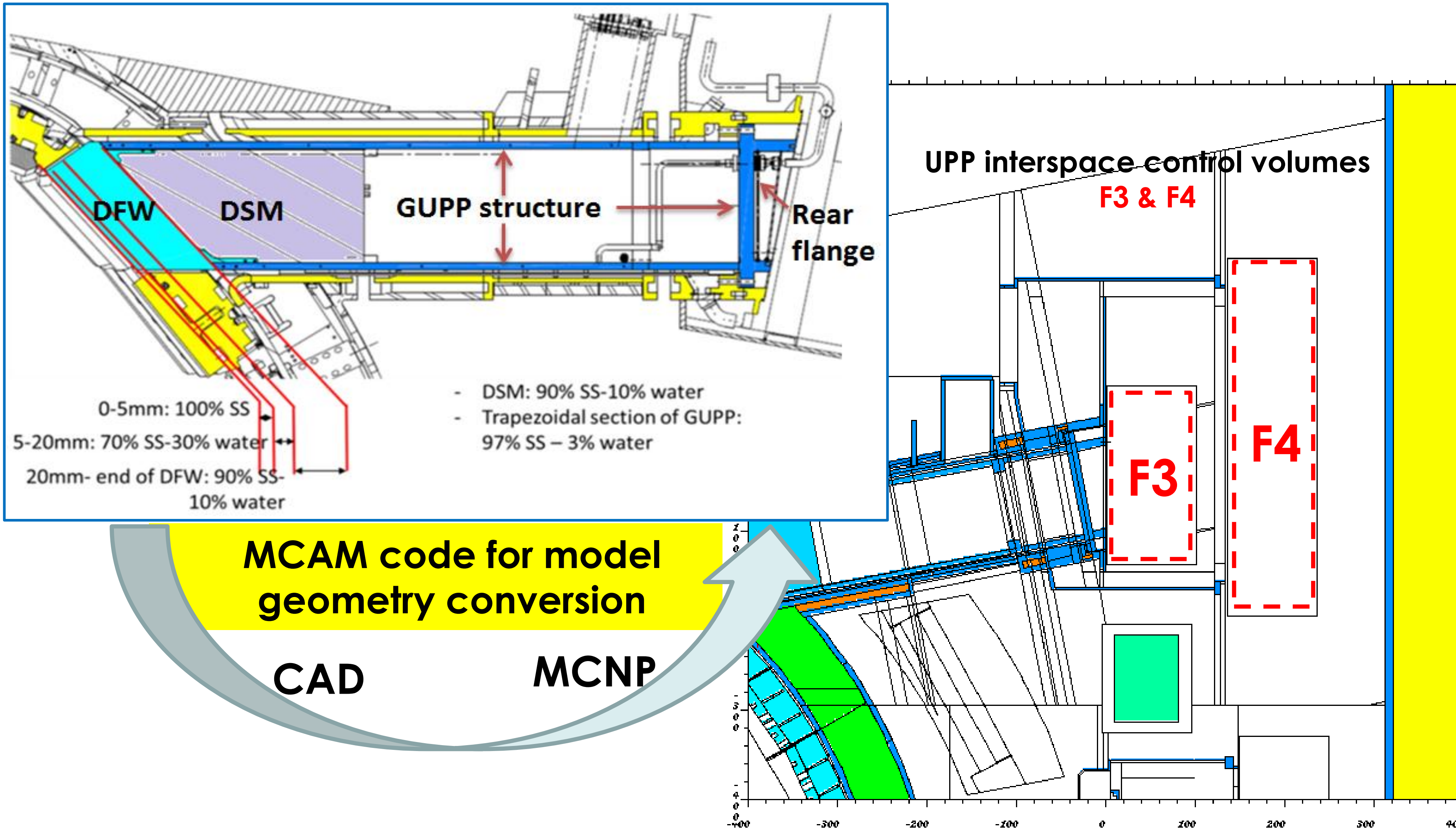
Aims:

- **Provide neutronics support** for design development of Charge eXchange Recombination Spectroscopy (CXRS) in UPP #3 and all the diagnostic systems inside the EPP#17
- **Check the current design** to satisfy the ITER radiation requirements;
- **Recommend** possible shielding improvements in accordance with ALARA principle – for the Shut-Down Dose Rate (SDDR) in Port Interspace (PI)

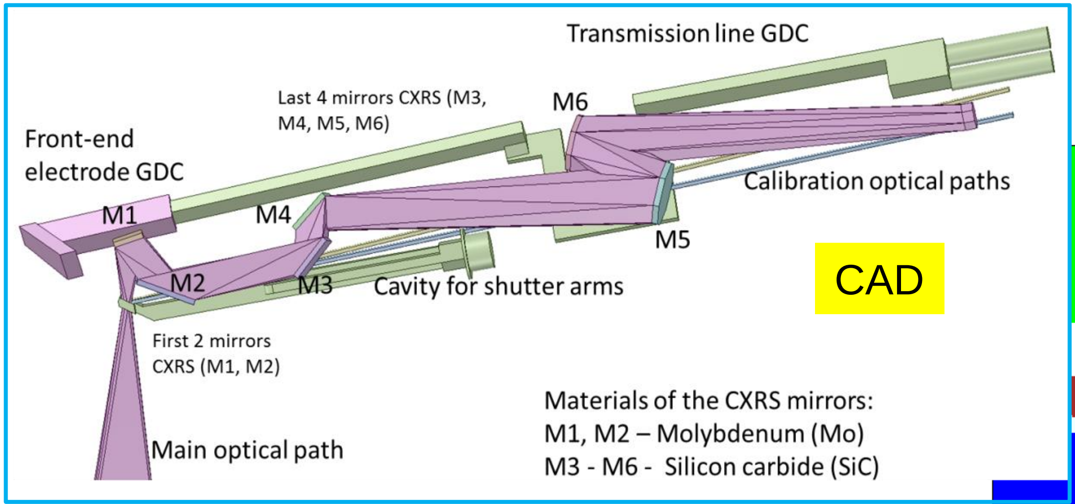
EPP#17 Diagnostic tenants:

- Visible/Infrared wide angle viewing diagnostics (WAV-VIR)
- Core Imaging X-Ray Spectrometer (CIXS)
- Tritium Monitor
- Divertor thermography

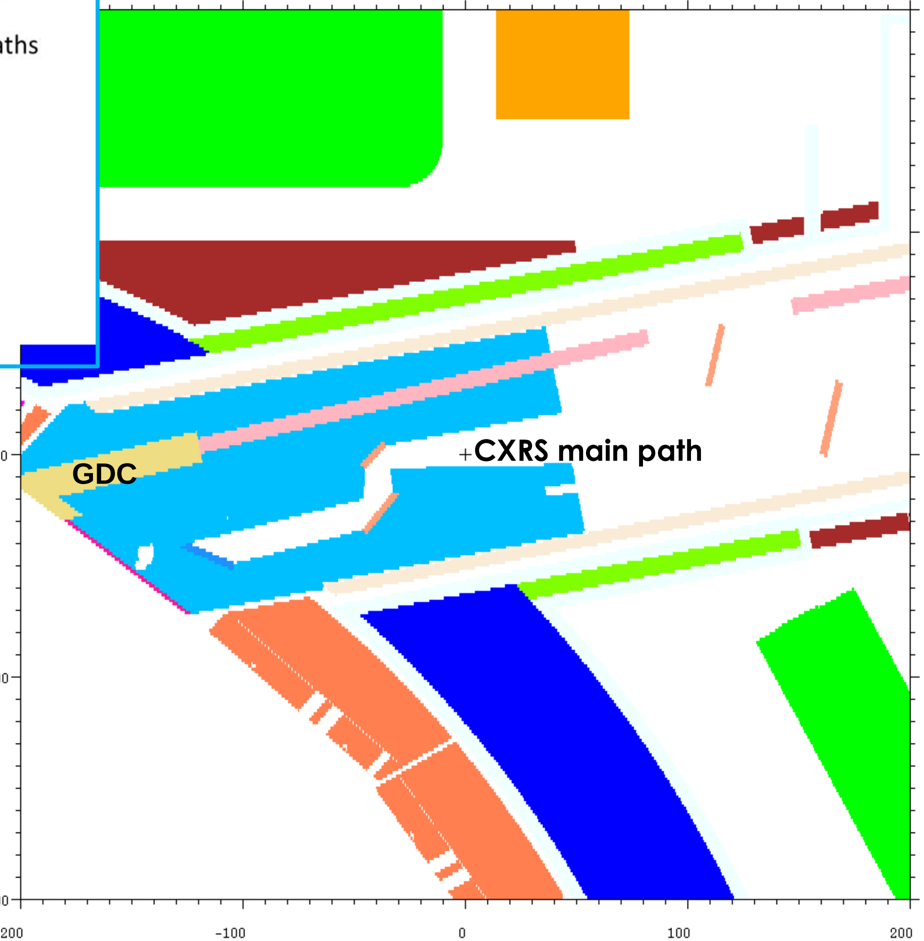
MCNP modeling of the Generic Upper Port Plug (GUPP)



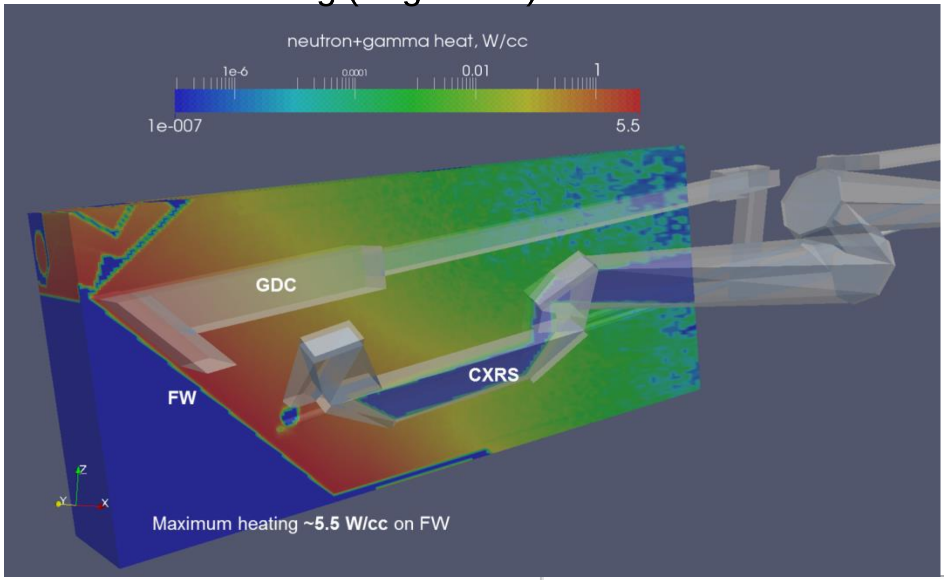
CAD-to-MCNP model geometry conversion (using MCAM and McCad codes)



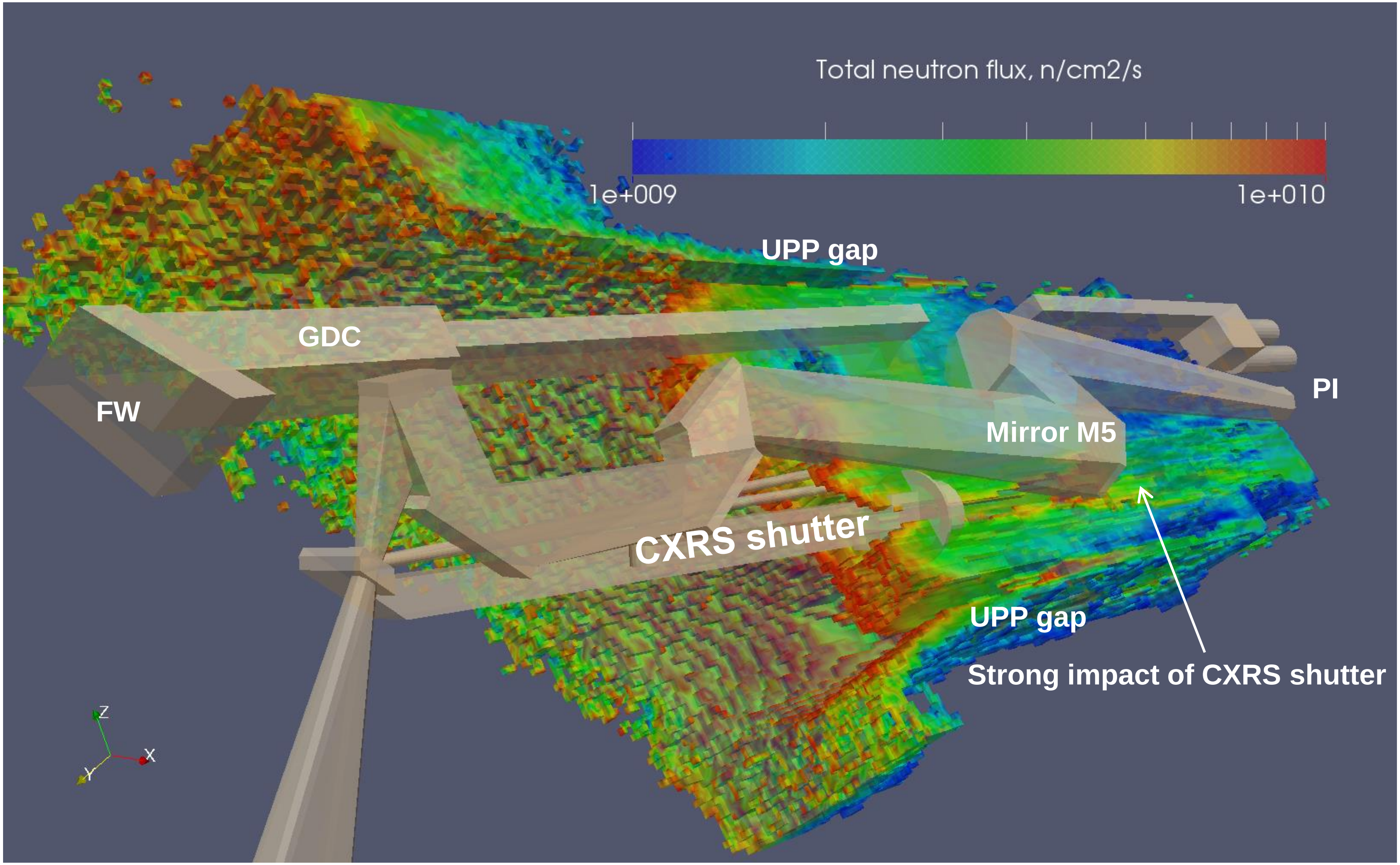
MCNP neutronic model



Nuclear heating (n+gamma) distribution



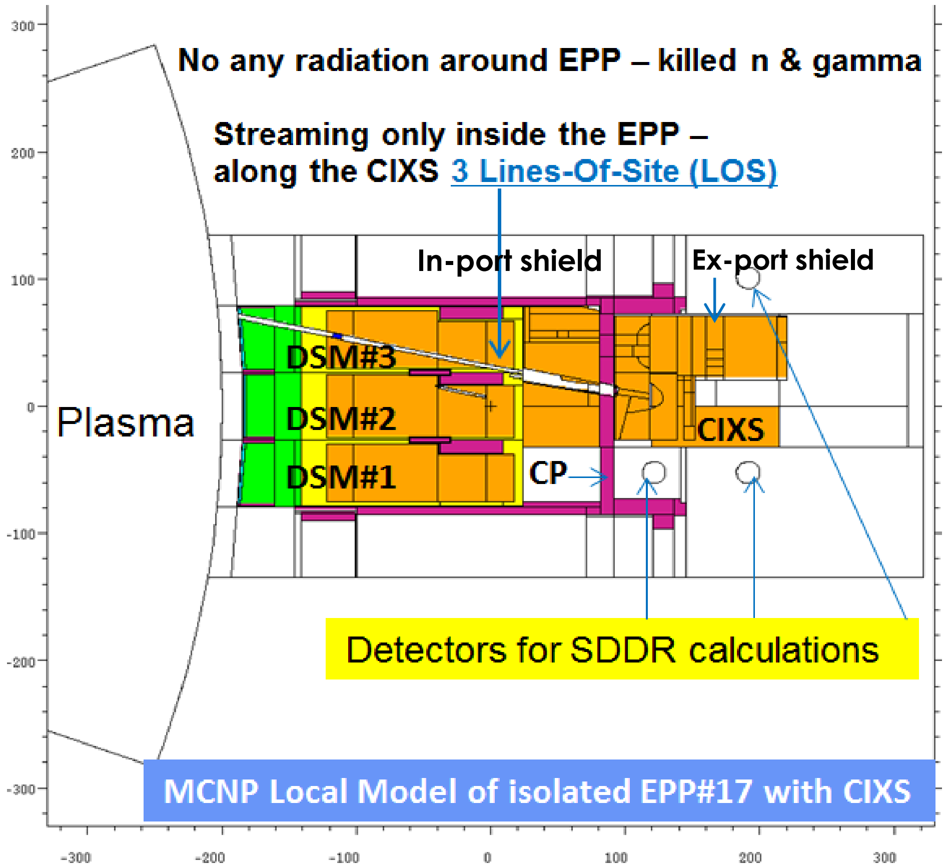
Impact of CXRS shutter – on neutron flux streaming



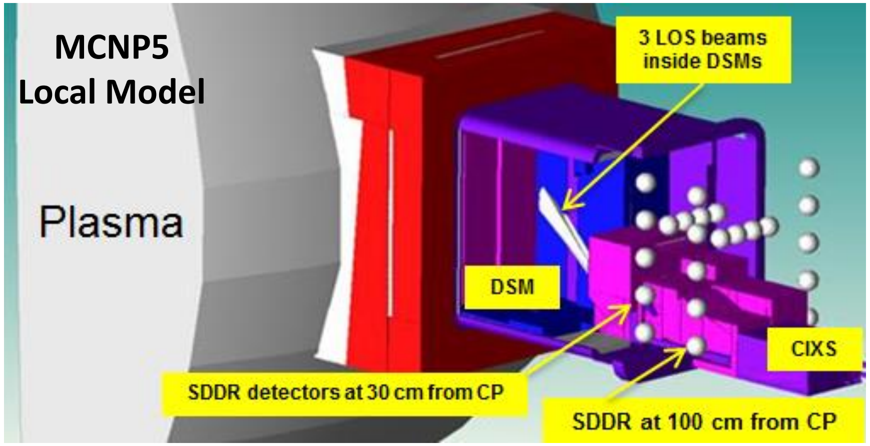
EPP#17: MCNP Local Modeling Approach

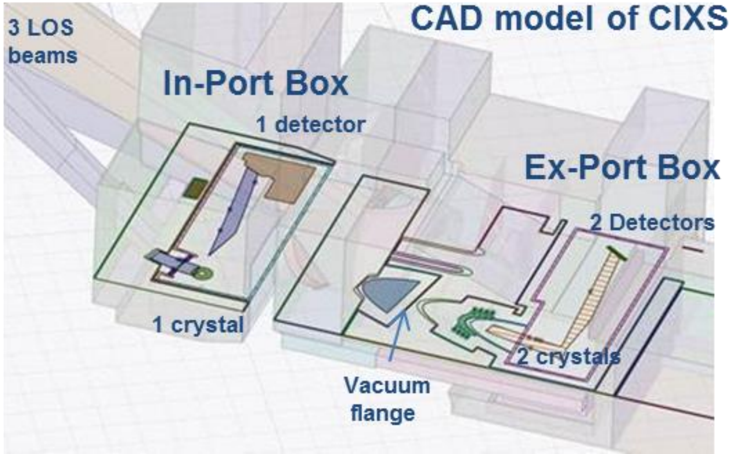
Core Imaging X-Ray Spectrometer (CIXS) with straight 3 Line-of-Site (LOS) apertures

1) Radiation shielding optimization - Shut-Down Dose Rate (SDDR) as the target parameter
2) Reducing the fluence levels on the detectors to minimize the number of their changes



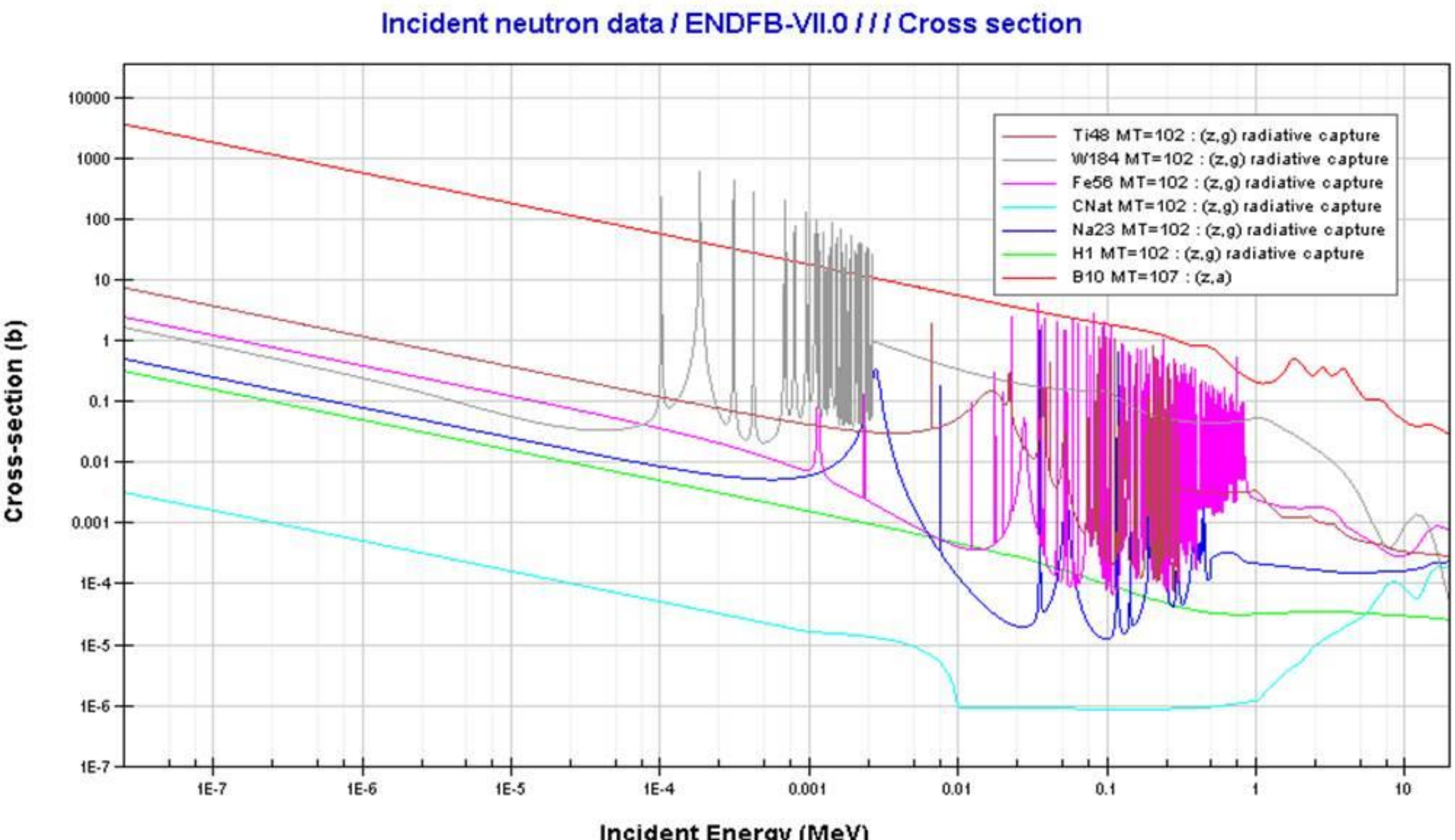
MCNP Local Model of isolated EPP#17 with CIXS





Neutron shielding: moderate and absorb !

The neutron absorption is high on B-10 and on the resonances of W-184.
For moderation the best are hydrates (TiH2) materials with hydrogen.



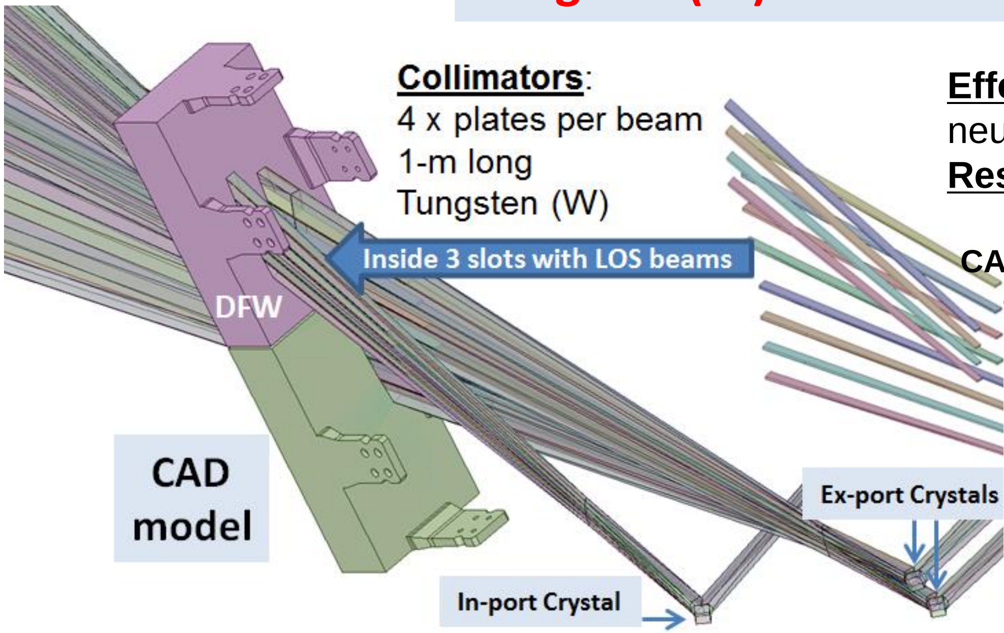
n - Moderation

Element	Atomic Weight	Number of Collisions
Hydrogen	1	27
Deuterium	2	31
Helium	4	48
Beryllium	9	92
Carbon	12	119
Uranium	238	2175

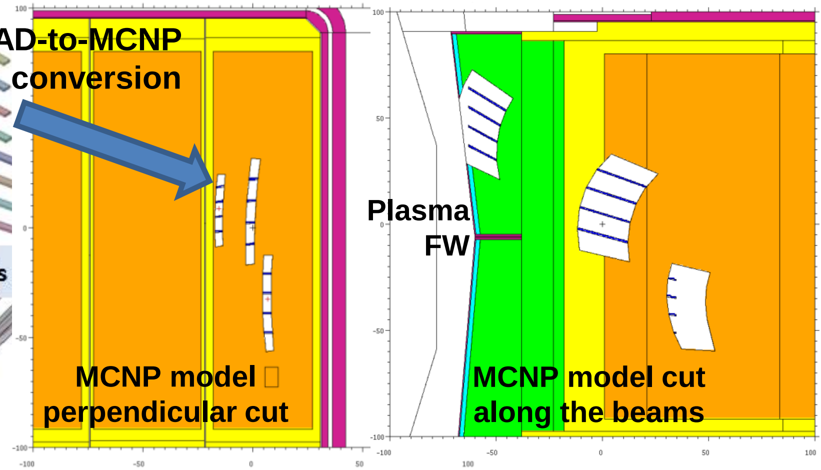
n – Absorption on reactions (n,g), (n,alpha),…

Average number of collisions required to reduce a neutron's energy from 2 MeV to 0.025 eV by elastic scattering

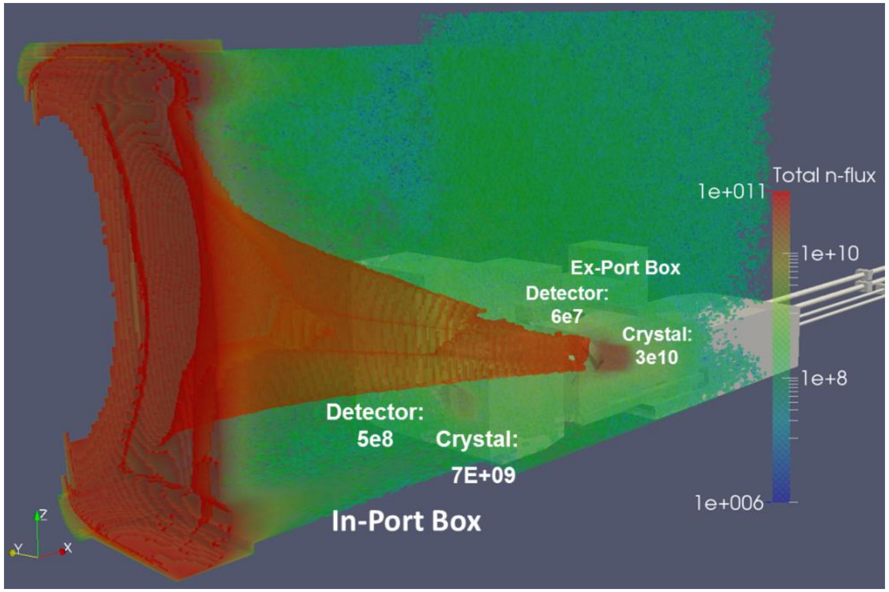
Tungsten (W) collimators inside the CIXS beams



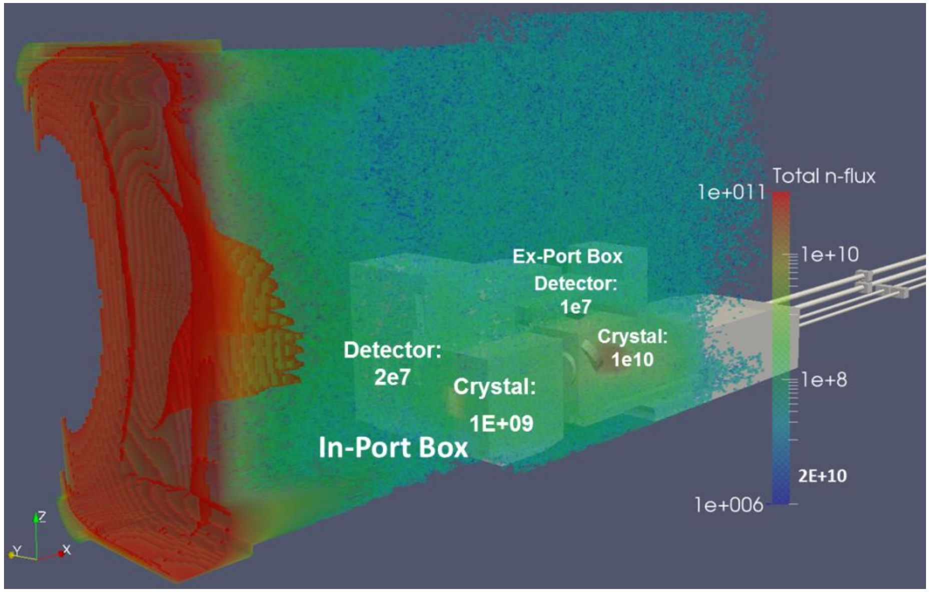
Effect: split of sweeping poloidal angle – neutrons are collided with W-collimators.
Result: less length of direct-streaming neutrons.



Map of total n-flux for the CIXS model having no-collimated LOS beams



Map of total n-flux for the CIXS model with collimated LOS beams

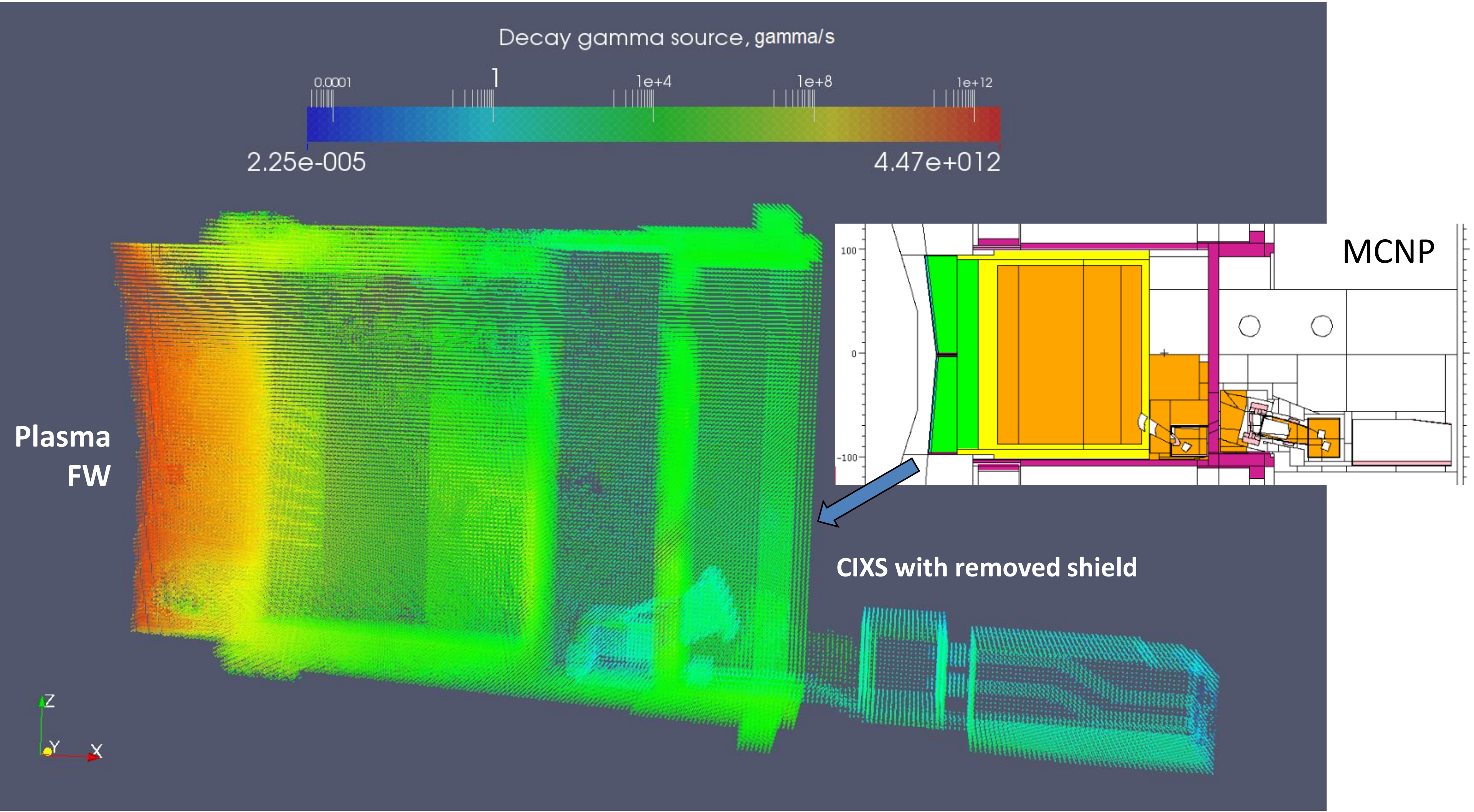


EPP#17 maintenance: distribution of decay gamma sources in the MCNP model

Investigating various shielding combinations during maintenance with significant cost impact:

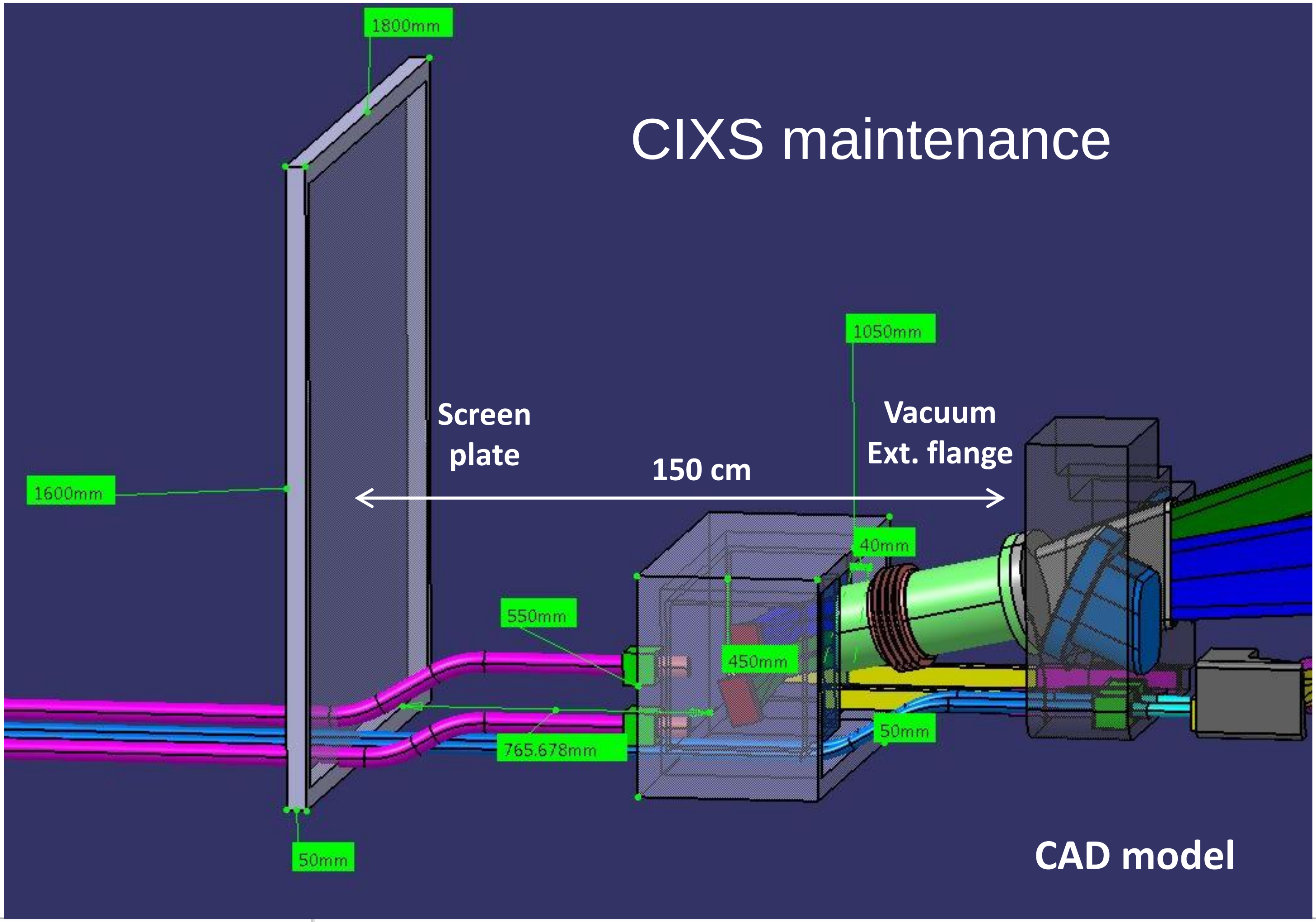
→ Outcomes are used to determine whether the maintenance access:

- manual
- ✓ **pseudo remote with long reach tools**
- completely remote handling



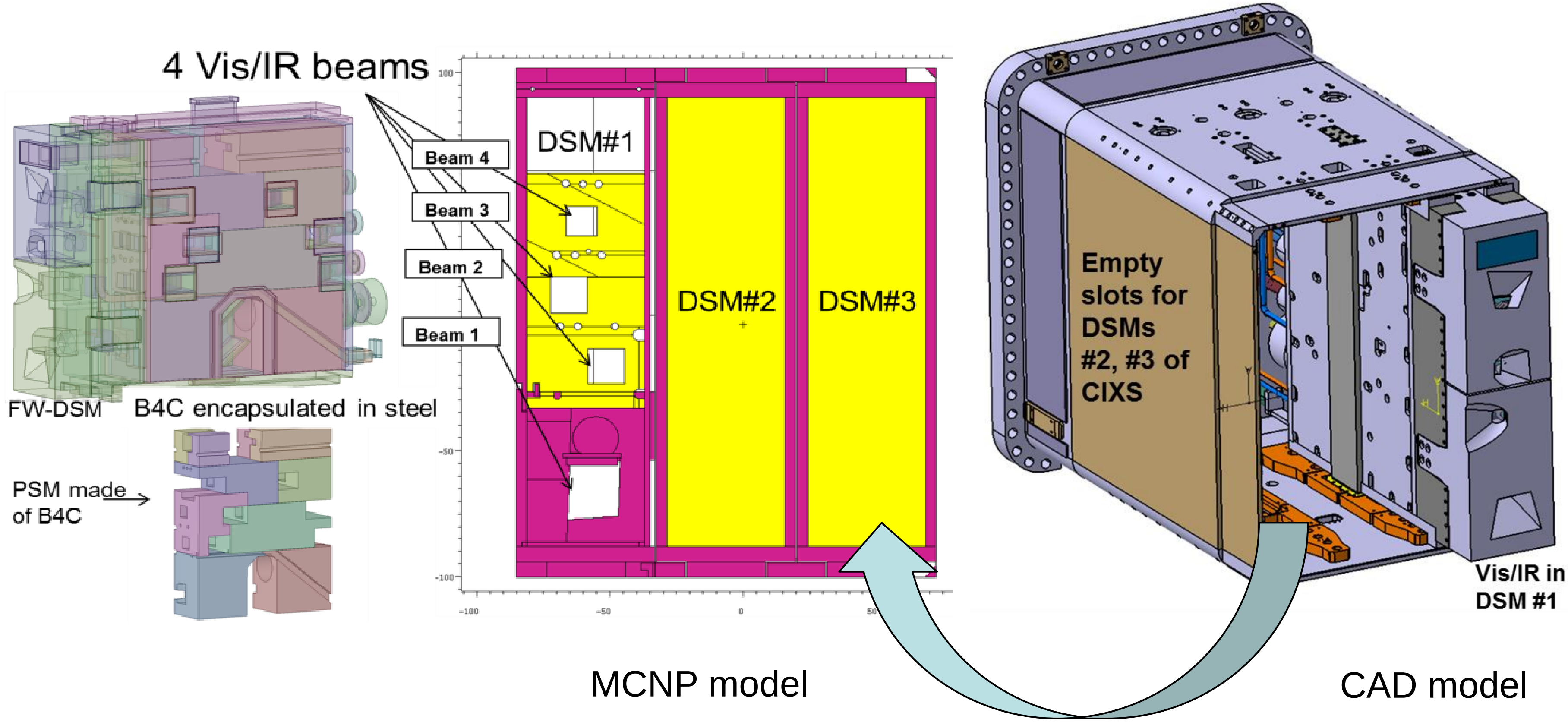
Screen plate as a temporal shield of personnel

Screen plate placed in Port Interspace (PI) for a worker protection during the Vacuum Extension Flange maintenance. Screen plate is not irradiated by neutrons, it is made of steel, 5 cm thick. **Its purpose is** to absorb decay gammas from the radioactive materials of CIXS and EPP#17



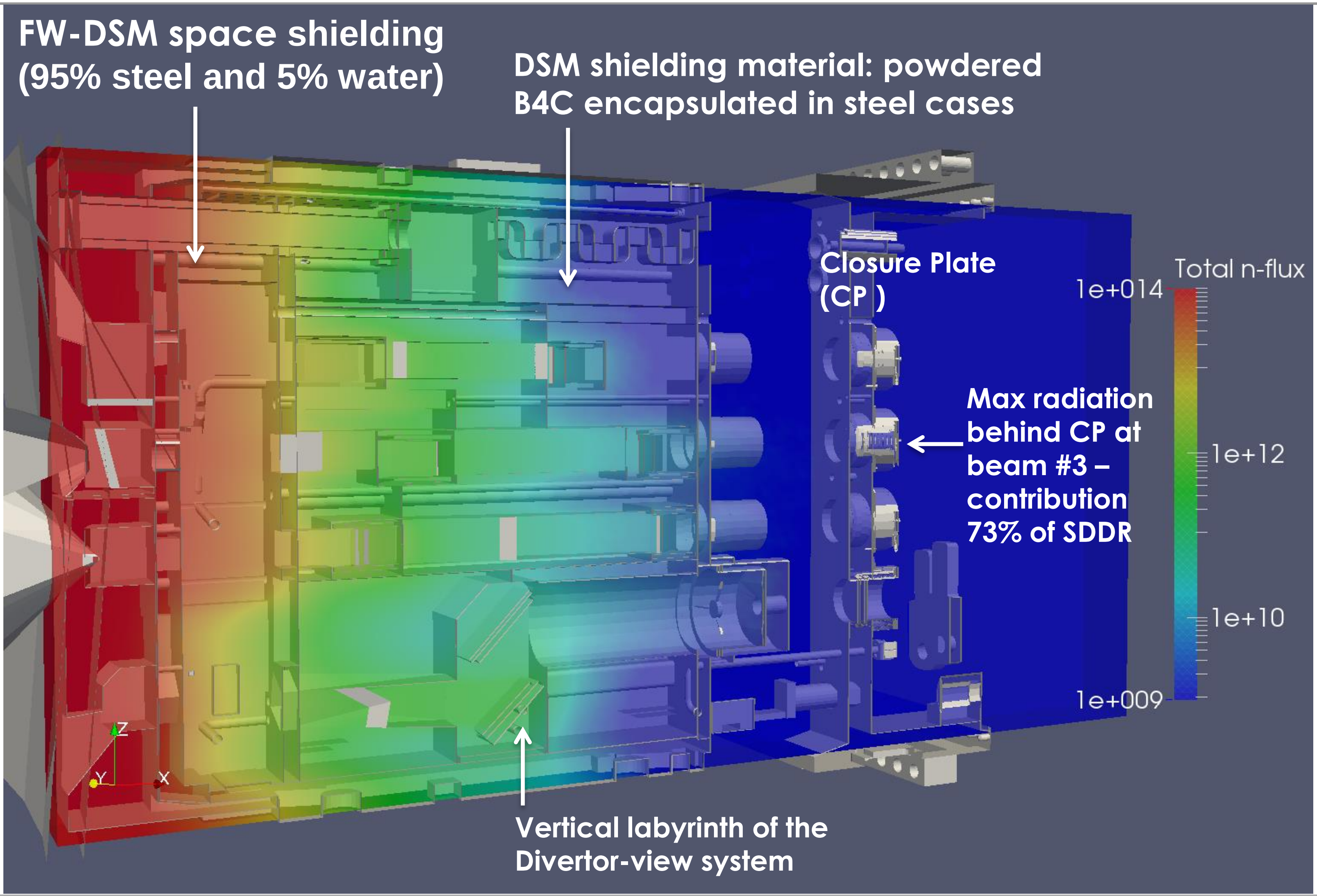
Local Modeling Approach: Vis/IR system in DSM#1 of EPP #17

Vertical cross-cut of MCNP local model with Vis/IR in DSM#1 and bulk shield in DSMs #2, #3 filled with B_4C (yellow color) and steel (magenta).

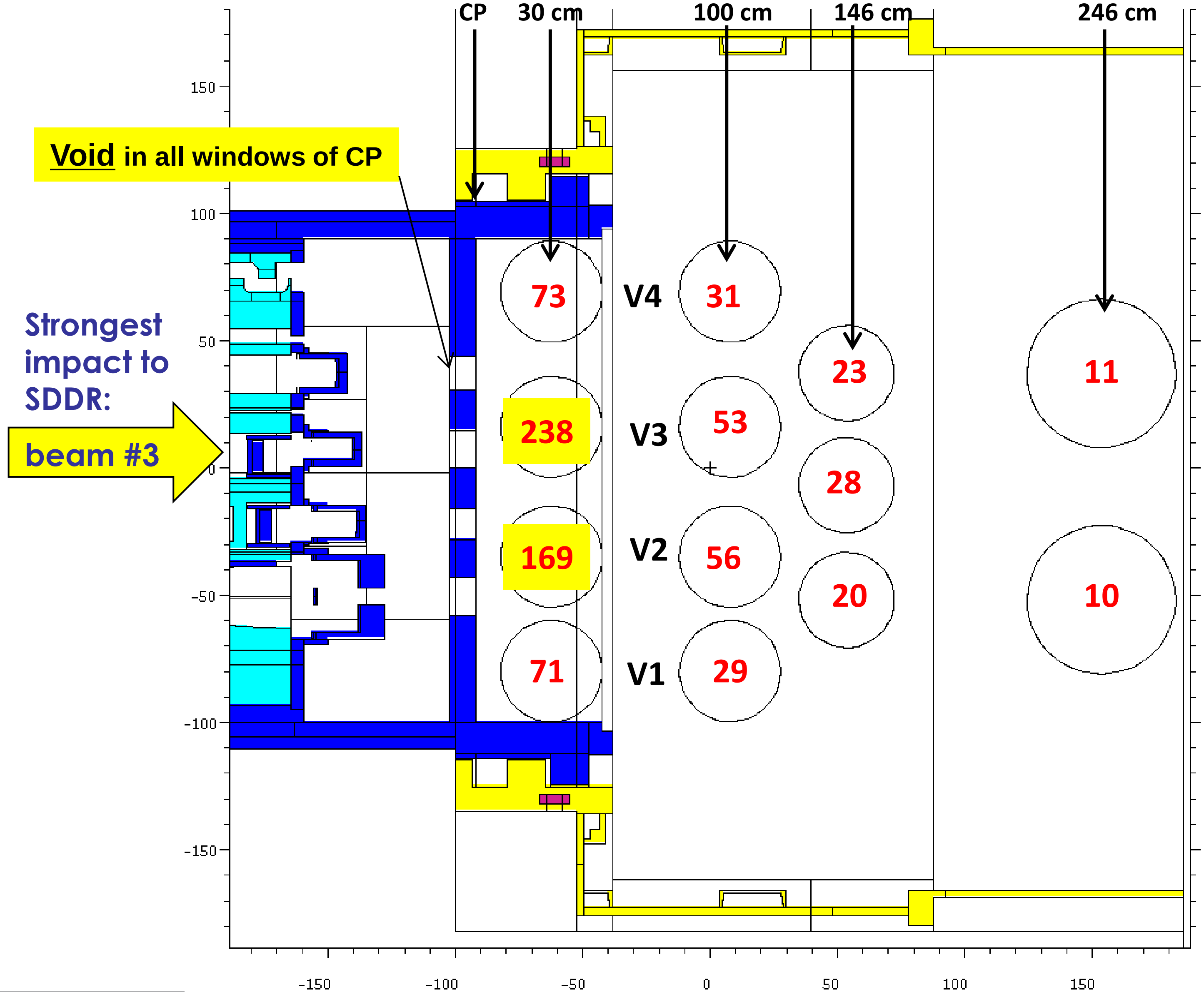


Empty slots are filled with B_4C

Map of total neutron flux ($n/cm^2/s$) for the **Reference** DSM#1 EPP-local model



Vertical distributions of SDDR (microSv/h) behind CP in Reference DSM#1 EPP-local model



Effect on SDDR behind CP by varying shielding material compositions

(Sintered and two types of vitrified B4C were considered instead of powdered B4C used as Reference shielding materials)

SDDR detector	SDDR (microSv/h) in Ref. EPP-local model with powdered B4C, density 1.89 g/cc, at 30cm/100cm from CP	SDDR (microSv/h) at 30 cm from CP, DSM with BGlass + B4C 70, dens. 2.541 g/cc	SDDR (microSv/h) at 30 cm from CP, DSM with BGlass + B4C 80, dens. 2.534 g/cc	SDDR (microSv/h) at 30 cm from CP, DSM with sintered B4C, dens. 2.52 g/cc
V4	73/31	-7%	-15%	-41%
V3	238/53	-22%	-21%	-35%
V2	169/56	-24%	-37%	-48%
V1	71/29	-12%	-36%	-22%

Conclusions for Vis/IR system neutronics

- Shield improvement of the Divertor-view vertical labyrinth has been provided.
- Father design work could be focused on horizontal labyrinth inside the beam #3, which contributes up to 73% in middle detector behind the Closure Plate (CP).
- Reduction of SDDR behind the Closure Plate windows are expected by closing the holes with window materials. These SDDR calculated with void CP windows.
- The best shielding performance is proven for the sintered B4C, resulting to SDDR reduction by 40%, while increasing the weight only by 424 kg (5% of the total weight of DSM).
- The SDDR results are presented with 5% -11% MCNP statistics of the D1S method.