Neutronics analysis for ITER Diagnostic Generic Upper Port Plug

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Objectives – CAD-based neutronics computational support for design development of the ITER Diagnostic Generic Upper Port Plug (DGUPP) which will host many Diagnostic systems. The objectives have been reached 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.

~45 Diagnostic systems to be installed for ITER machine protection, control and physics studies:
- X-ray survey
- Imaging VUV Spectroscopy
- X-ray crystal spectroscopy
- Divertor VUV spectroscopy
- X-ray survey
- Core VUV monitor
- Divertor reflectometry
- Magnetic diagnostic coils
- Micro fission chambers
- Edge Thomson scattering
- Motional Stark effect
- Toroidal interferometer
- Electron cyclotron emission
- Wide-angle viewing/IR
- Lost alpha
- Neutron Flux Monitor
- X-point LIDAR
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.
Diagnostic Generic Upper Port Plug (DGUPP) converted with SuperMC to MCNP

New DGUPP model integrated to the ITER 40-degree torus sector

DGUPP in ITER

Right corridor

ISS

Bioshield Port Plug

Upper Port Plug with DSM

Left corridor
Use of the SuperMC code for CAD geometry conversion

SuperMC code allows:
• Bi-directional conversion CAD ↔ MCNP (and other Monte Carlo codes);
• Neutron, gamma radiation transport;
• Activation and burnup calculations

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

This work 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.
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

Closure Plate (CP)

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 \((1e7-1e9) \text{ n/cm}^2/\text{s}\)

From this thresholded map follows that total n-flux inside the DSM is below \(1e9 \text{ n/sm}^2/\text{s}\). 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
**Demonstrated:** Radiation streaming along the bottom and side gaps and inside the port structure behind the short DSM \(\rightarrow\) need to improve DSM shielding design
Analysis of Short-DSM: 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

Isosurface 100 microSv/h at PFC#2

Isosurface 1 mSv/h

100 microSv/h inside the long-DSM

Isosurface 10 mSv/h

Isosurface 1 mSv/h
Map isosurface in DGUPP with long DSM - to mitigate radiation streaming

SDDR isosurface is formed by radiation streaming along the gaps at the UP lateral sides and neutron stopping at the trapezoidal-to-rectangular connection of the UP structure.

100 microSv/h

Trapezoidal-to-rectangular connection of the UP structure
Decay gamma sources distribution in DGUPP Inter Space Structure

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

Decay gamma sources, g/s

[Image of decay gamma sources distribution in DGUPP Inter Space Structure]

The lowest sources

Iter
Karlsruhe Institute of Technology

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2017 ANS Annual Meeting - San Francisco, CA, USA, June 11-15, 2017
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 Part#1 of DGEP

Inter-Coil-Structure 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

Impact of gamma cross-talk 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 Part#2 of DGEP to SDDR map at DGUPP

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

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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