Neutronics Analysis of the IVVS/GDC Plug in ITER

U. Fischer, D. Leichtle, A. Serikov

Association KIT-Euratom, Institute for Neutron Physics and Reactor Technology
Outline

- Introduction
- Computational approach
- Nuclear responses during operation
- Activation, shutdown nuclear heating and occupational dose rates
- Summary
Introduction

- **IVVS/GDC plug unit**
  - **In-Vessel Viewing System (IVVS)**
    - Laser based optical system for inspections between plasma pulses or during ITER shut-down
  - **Glow Discharge Cleaning Unit (GDC)**
    - Cleaning and wall conditioning during intermediate ITER maintenance periods
  - Common port for IVVS/GDC plug assumed in this work

- **Neutronics analysis**
  - to provide input required for design strategy
    - Operational nuclear loads on GDC electrode head
    - Activation, afterheat and radioactive waste
    - Occupational radiation dose distributions around GDC/IVVS after shutdown
**IVVS/GDC plug unit**

- **IVVS probe**
  - Laser-based in-vessel viewing and metrology
- **GDC electrode**
  - Producing glow discharge in the vacuum vessel
- **IVVS deployment system**
  - To move the IVVS along the tube from parking position to various working positions
- **GDC deployment system**
  - To move the GDC in parked position, shielding and working position
- **Housing structure**
  - Providing the support/guidance to the deployment systems (rails, racks, stops, ...)
- **VV port tube**
  - Equipped with end flange and feed-troughs for the various services
Computational Approach

- Neutron transport, activation and decay photon transport calculations
  - Transport calculations: Monte Carlo code MCNP5 using FENDL-2.1 nuclear cross-section data
  - Activation calculations: Inventory code FISPACT using EAF-2007 activation cross-section data

- Shut-down dose rate calculations
  - Rigorous-2-step (R2S) approach of KIT coupling transport and activation calculations through automated interfaces

- Nuclear responses
  - Provided in IVVS/GDC geometry cells, and, on superimposed fine mesh grids
Modelling Approach

- Geometry model based on Alite 4.1 MCNP model, provided by ITER IO

- Preliminary MCNP model of isolated IVVS/GDC plug unit provided by F4E, Barcelona

- IVVS/GDC model corrected, updated, and integrated into full Alite torus sector model (lower port).
Geometry model
Alite model with integrated IVVS/GDC plug

U. Fischer et al., Nuclear analysis of IVVS/GDC plug in ITER
# Calculational Details

- **MCNP** calculations on HPC-FF/JUROPA at FZ Jülich using parallel MPI communication technique
- Mesh-based weight window generator for variance reduction
- Typically $2 \times 10^9$ source neutron histories tracked consuming around 6200 CPUh on 560 CPUs of HPC-FF
- Normalisation to 500 MW fusion power
- SA2 irradiation scenario for activation calculations (20 y ITER operation), cooling times: 0s, 1h, 1d, 12d, 100d

<table>
<thead>
<tr>
<th>Duration</th>
<th>Neutron wall load MW/m²</th>
<th>Fusion power</th>
<th>Norm. to 500 MW</th>
<th>Norm. to neutron source rate at 500 MW</th>
<th>Repetition</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 yr</td>
<td>0.003</td>
<td>2.68</td>
<td>0.00536</td>
<td>1.057E+17</td>
<td></td>
</tr>
<tr>
<td>10 yr</td>
<td>0.0231</td>
<td>20.6</td>
<td>0.0412</td>
<td>8.124E+17</td>
<td></td>
</tr>
<tr>
<td>0.667 yr</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.000E+00</td>
<td>once</td>
</tr>
<tr>
<td>1.325 yr</td>
<td>0.0465</td>
<td>41.5</td>
<td>0.083</td>
<td>1.637E+18</td>
<td></td>
</tr>
<tr>
<td>3920 s</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.000E+00</td>
<td>17 times</td>
</tr>
<tr>
<td>400 s</td>
<td>0.56</td>
<td>500</td>
<td>1</td>
<td>1.972E+19</td>
<td>3 times</td>
</tr>
<tr>
<td>3920 s</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.000E+00</td>
<td></td>
</tr>
<tr>
<td>3920 s</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.000E+00</td>
<td></td>
</tr>
<tr>
<td>400 s</td>
<td>0.784</td>
<td>700</td>
<td>1.4</td>
<td>2.761E+19</td>
<td>3 times</td>
</tr>
</tbody>
</table>

U. Fischer et al., Nuclear analysis of IVVS/GDC plug in ITER
Operational Nuclear Responses

- Neutron flux distribution
  - Total neutron flux density from $10^{14}$ (at first wall) to $10^5$ cm$^2$s$^{-1}$ (at bioshield level) over length of about 11 m
  - $10^{13}$ cm$^2$s$^{-1}$ at GDC tip

- Nuclear heating
  - Photon contribution dominant for structural materials (steel, copper)
  - Maximum $\approx 0.6$ Wcm$^{-3}$ in copper cap of GDC tip
  - 3.2 kW total nuclear heating power in GDC electrode (Be, CuCrZr, steel)
Activation and waste classification

- Activity inventory
  - Calculated for all IVVS/GDC components 12 days after shutdown assuming full SA2 irradiation scenario.

- Radioactive waste classification
  - According to French radwaste regulations, classification depends on specific nuclide activity, half-life and radio-toxicity
  - LMA (maximal level of activity) discriminates low level active A-type from medium level B-type waste
  - All IVVS/GDC components, except Be protective layer of GDC probe, were shown to be classifiable as low level A-type waste
  - Only Be cover will be medium level B-type waste with specific activity of $3.85 \times 10^8$ Bq/g (LMA limit: $2 \times 10^5$ Bq/g) due to tritium accumulation
Shutdown heating and absorbed decay photon radiation dose

- Nuclear heating after shutdown calculated for IVV/GDC material cells and on superimposed mesh assuming SA2 operation of ITER
- Afterheat dominated by decay photon heating
- Maximum is 4mW/cm\(^3\) in Cu heat sink of GDC probe, i.e. less than 1% of respective maximum operational heating.
- Decreases to values in the order of 10\(^{-8}\) W/cm\(^3\) at the entrance to the bioshield

Decay photon heating distribution [W/cm\(^3\)] at shutdown

U. Fischer et al., Nuclear analysis of IVVS/GDC plug in ITER

ISFNT-10, Portland, USA, September, 12-16, 2011
Shutdown heating and absorbed decay photon radiation dose

Decay photon and operational nuclear heating rates (in Gy/s) at the GDC tip (SA2 20y irradiation scenario)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 s</td>
<td>12d after shutdown</td>
</tr>
<tr>
<td>CuCrZr heat sink</td>
<td>67.3</td>
<td>0.47</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.9 $10^{-3}$</td>
</tr>
<tr>
<td>Be layer</td>
<td>286</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.1 $10^{-3}$</td>
</tr>
<tr>
<td>SS316 core rod</td>
<td>24.1</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.2 $10^{-3}$</td>
</tr>
<tr>
<td>SS316 shaft</td>
<td>4.5</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6.4 $10^{-4}$</td>
</tr>
</tbody>
</table>

- Total absorbed dose during 20 y ITER operation: 1100 MGy in CuCrZr heat sink and 400 MGy in steel core rod.
- At 12 d after shutdown, absorbed decay photon radiation sums up to 0.01 MGy (Cu heat sink) and 0.004 MGy (steel core rod).
Occupational shutdown dose rates

- Assessment of shutdown dose rate distribution in and around IVVS/GDC plug using R2S approach
- Required to ensure safe handling of activated plug during maintenance periods including extraction and transport to Hot Cell
- Dose rate dominated by heavily activated GDC head with peaking values around 5 Sv/h
- 1.5 m behind GDC head doserate falls below 50 mSv/h
- Further downstream, doserate is less than 5 mSv/h
- Recommendation to facilitate maintenance: separation of GDC head from other parts of the system
Summary

- Detailed neutronics analysis performed to provide input to design process of IVVS/GDC system.
- Focus on operational loads, activation, and decay photon radiation doses.
- GDC head gets heavily activated and dominates decay gamma activity of the entire plug and the resulting shutdown dose rate around the plug.
- It is recommended to separate GDC head from the system prior to further operations in Hot Cell.
- All IVVS/GDC components, except Be protective layer, were shown to be classifiable as low level radwaste of A-type according to French regulations.
Acknowledgement

The work leading to this publication has been partially funded by the European Joint Undertaking for ITER and the Development of Fusion Energy (Fusion for Energy) under contract No. F4E-OPE-144. The views and opinions expressed herein reflect only the author’s views. Fusion for Energy is not liable for any use that may be made of the information contained therein.

The analyses made use of an adaptation of the Alite MCNP model which was developed as a collaborative effort between the FDS team of ASIPP China, ENEA Frascati, JAEE Naka, and the ITER Organization.