Neutronics Analysis of the IVVS/GDC Plug in ITER

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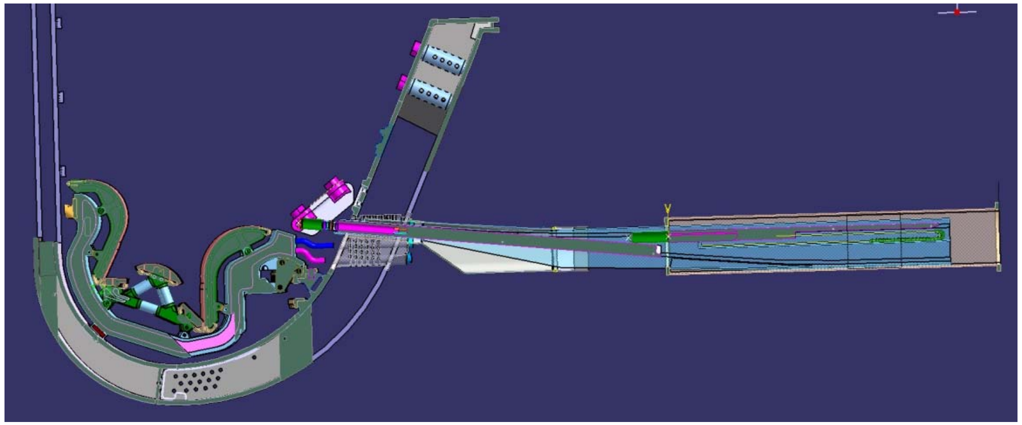
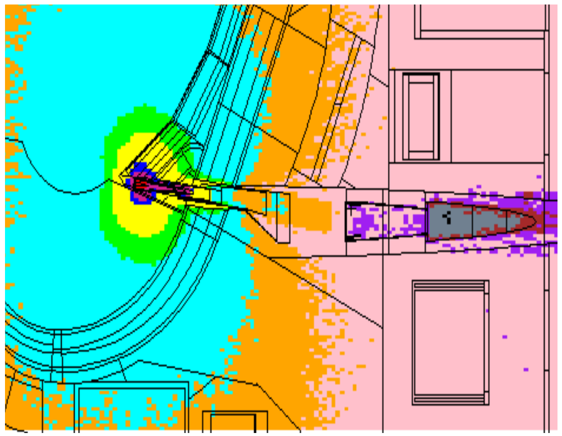
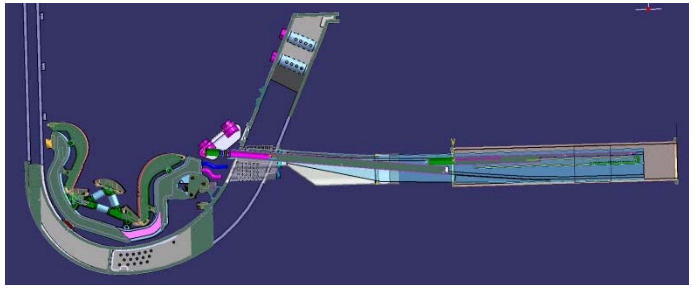




Outline

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

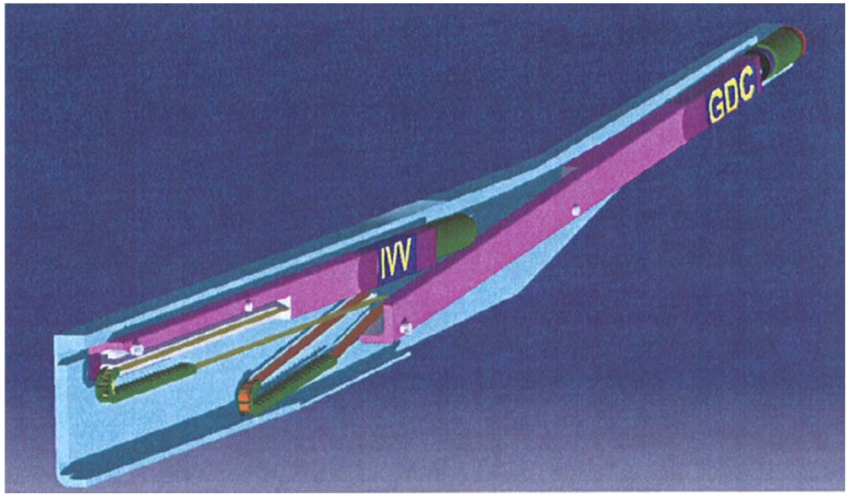
Introduction



- 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
  - Occuptational radation 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

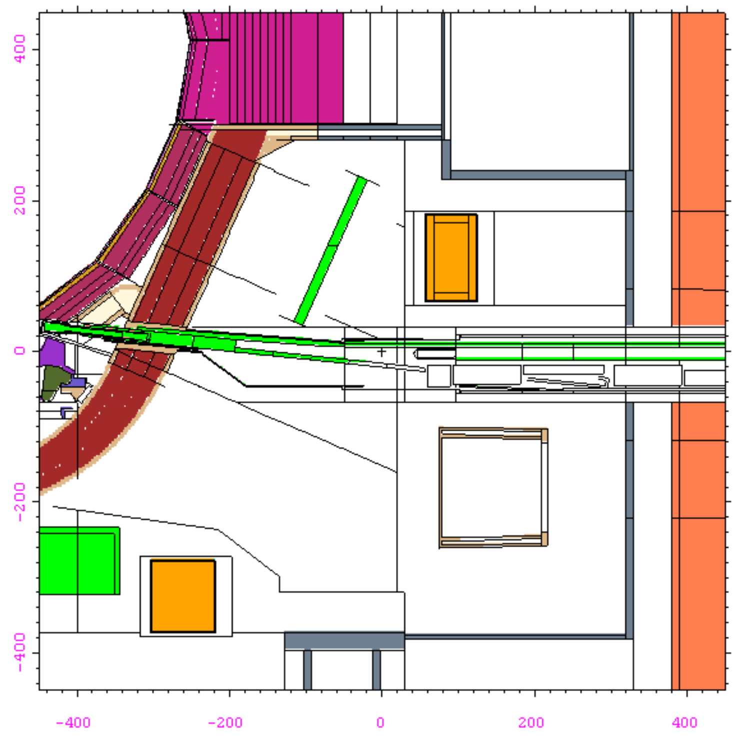
Computational Approach

- 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
  - Povided in IVVS/GDC geometry cells, and, on superimposed fine mesh grids

Modelling Approach

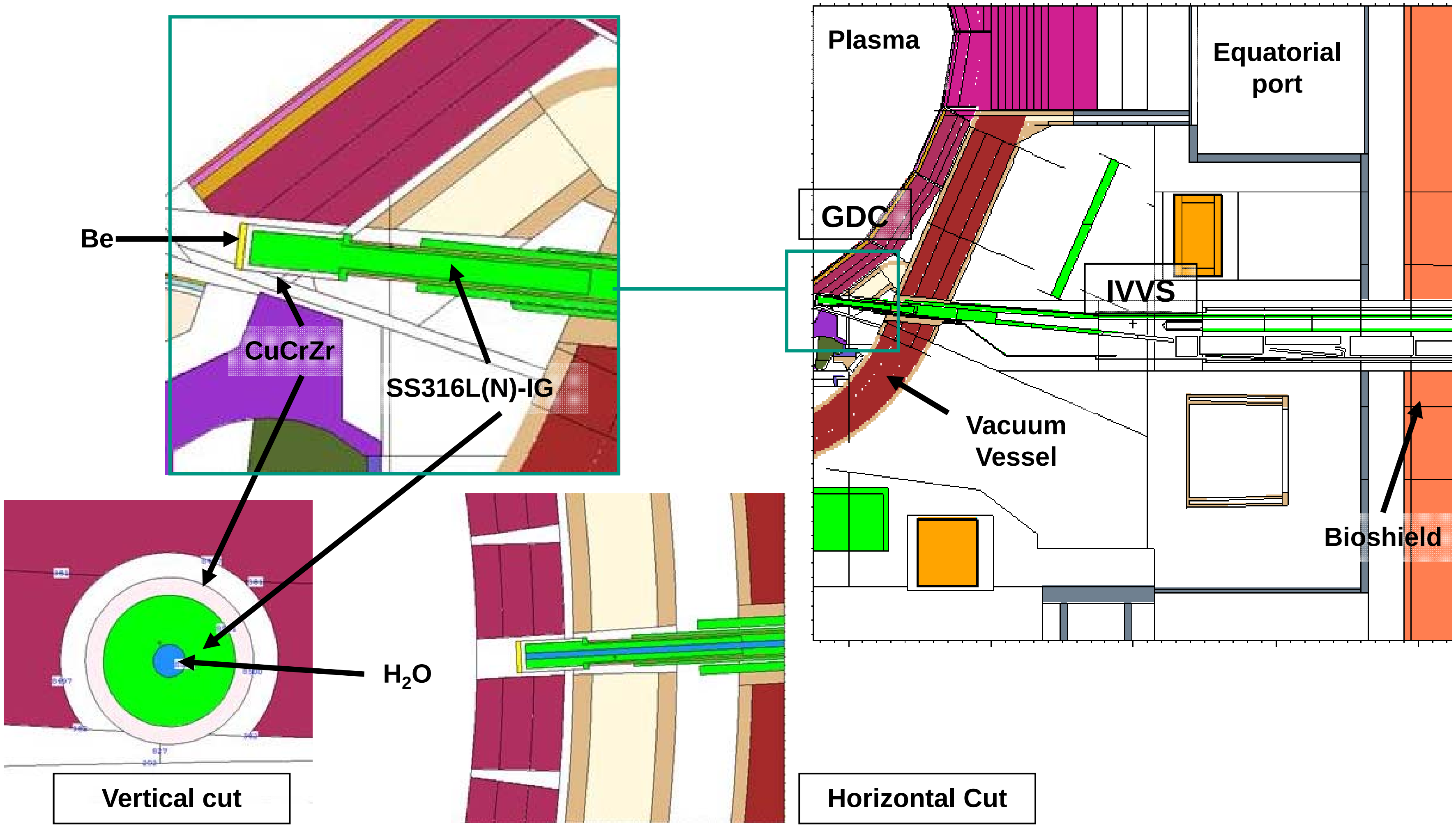
- Geometry model based on Alite 4.1 MCNP model, provided by ITER IO

- 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



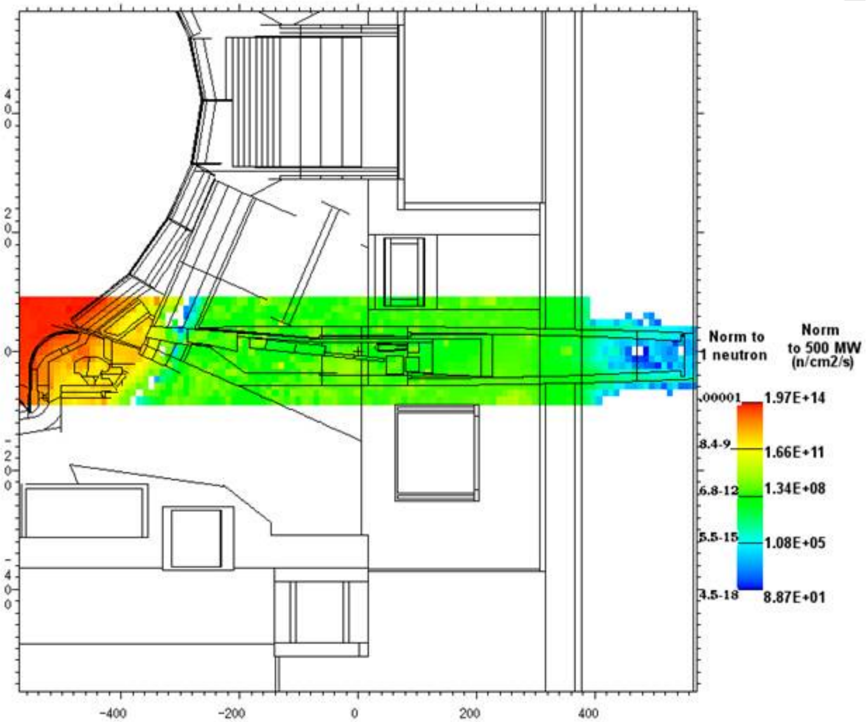
Calculational Details

- MCNP calculations on HPC-FF/JUROPA at FZ Jülich using parallel MPI communication tchnique
- Mesh-based weight window generator for variance reduction
- Typically 2 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

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

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 ≈ 0.6 Wcm^{-3} in copper cap of GDC tip
  - 3.2 kW total nuclear heating power in GDC electrode (Be, CuCrZr, steel)

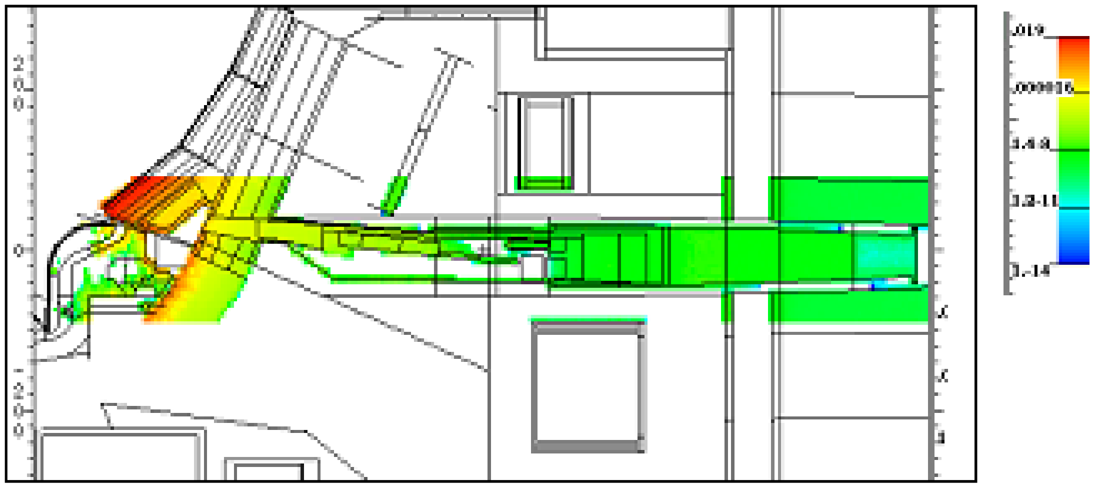
Activation and waste classification

- 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 10^8 Bq/g (LMA limit: 2 10^5Bq/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

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)

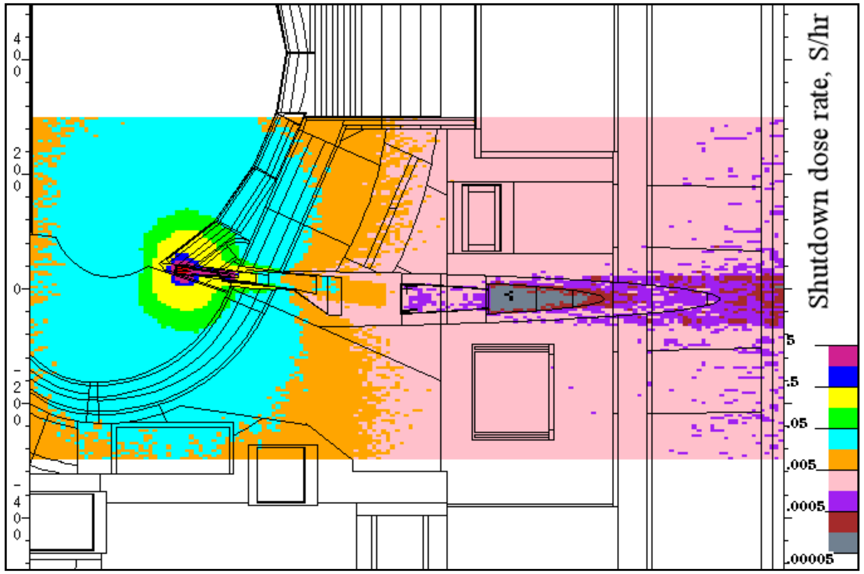
Material	Operational dose [Gy/s]	Absorbed decay photon radiation dose [Gy/s]	
		0 s	12d after shutdown
CuCrZr heat sink	67.3	0.47	$3.9\ 10^{-3}$
Be layer	286	1.4	$4.1\ 10^{-3}$
SS316 core rod	24.1	0.08	$1.2\ 10^{-3}$
SS316 shaft	4.5	0.03	$6.4\ 10^{-4}$

- 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

Karlsruhe Institute of Technology

- 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



Shutdown dose rate distribution [Sv/h] 12d after shutdown following 20y SA2 ITER operation

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

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- 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, JAEA Naka, and the ITER Organization.