Neutronics calculations for the ITER Collective Thomson Scattering Diagnostics

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Neutronics calculations for the ITER Collective Thomson Scattering Diagnostics

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Outline

• Introduction
• ITER project
• Experience from MCNP calculations on fission reactors utilized on fusion
• A simplified MCNP 40° model for CTS
• Examples of calculations on CTS
• Shutdown dose rate calculation
• Prospective
ITER Schedule

- Costs: 15 billion euro
- Start of construction 2010
- First plasma: 2020 using H as test fuel
- 2027: Q=10, 50MW in 500MW out
- Deuterium+Tritium ~ 14.1 MeV (neutrons) 3.5 MeV (alpha)
- Decommissioning 2040
- DEMO ~ 2035-2040
### Overall Tokamak parameters

<table>
<thead>
<tr>
<th>Fusion Power &amp; Plasma</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total fusion power</td>
<td>500 MW</td>
</tr>
<tr>
<td>Plasma major radius (R)</td>
<td>6.2 m</td>
</tr>
<tr>
<td>Plasma minor radius (a)</td>
<td>2.0 m</td>
</tr>
<tr>
<td>Plasma current ($I_p$)</td>
<td>15 MA</td>
</tr>
<tr>
<td>(eventual 17MA Capability)</td>
<td></td>
</tr>
<tr>
<td>Toroidal field at 6.2 m radius ($B_T$)</td>
<td>5.3 T</td>
</tr>
<tr>
<td>Approximate Plasma Volume</td>
<td>816m$^3$</td>
</tr>
<tr>
<td>Approximate Plasma Surface</td>
<td>680m$^2$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Components</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of TF coils</td>
<td>18</td>
</tr>
<tr>
<td>Number of CS modules</td>
<td>6</td>
</tr>
<tr>
<td>Number of PF coils</td>
<td>6</td>
</tr>
<tr>
<td>In Vessel Coils – ELM suppression</td>
<td>ELM: 27 picture frame-type coils</td>
</tr>
<tr>
<td>Vertical Stabilization</td>
<td>VS: 2 pairs of toroidal ring coils</td>
</tr>
<tr>
<td>Vacuum vessel segmentation (fabrication)</td>
<td>9</td>
</tr>
<tr>
<td>Divertor segmentation (Cassettes)</td>
<td>54</td>
</tr>
<tr>
<td>Shielding Blanket Modules</td>
<td>440</td>
</tr>
<tr>
<td>Ports (Lower, Equatorial, Upper)</td>
<td>44 (9 + 17 + 18)</td>
</tr>
<tr>
<td>Cryostat</td>
<td>1 assembly (4 sections)</td>
</tr>
<tr>
<td>Thermal shields</td>
<td>4 sub-assemblies</td>
</tr>
<tr>
<td>VVPSS</td>
<td>1 assembly</td>
</tr>
</tbody>
</table>
The phases of ITER

Start Deuterium-Tritium Operations 2027
First Plasma 2020
Complete Tokamak Assembly, Begin Commissioning 2019
Start Tokamak Assembly 2015
Arrival of the first manufactured component 2014
Start Tokamak Complex construction 2013
Start Tokamak Complex excavation 2010
Site Levelling 2008

www.iter.org

China, India, Japan, Korea, Russia, USA
Progress on the ITER platform
Tokamak Pit seismic system with 493 columns

The Tokamak Pit

Resting on the 493 columns of the Tokamak Pit seismic system, a second basemat (1.5-m. thick) will support the 360,000-ton Tokamak Complex buildings.
Background

- Recently F4E awarded DTU and IST to partner in the design of a Collective Thomson scattering (CTS) diagnostic for ITER, F4E-FPA-393
- The CTS diagnostic utilizes probing radiation of ~60 GHz emitted into the plasma and, using a mirror, collects the scattered radiation by an array of receivers
- Having a direct and unshielded view to the plasma, the first mirror will be subject to significant radiation and among the first tasks in the CTS design, is to determine whether the mirror will need active cooling
- In order to address this question, a simplified MCNP model of the relevant equatorial port plug #12 was developed based on the full C-lite ITER MCNP model
- The first steps toward benchmarking the simplified model to the full C-lite model have almost been completed
- Based on this, we have done the first calculations of heat-loads across the mirror
Reasons for joining ITER project

- Experience in calculation of neutron and gamma fluxes and neutron activation in fission reactors by means of the Monte Carlo code MCNP

- Local Association Euratom/Risø DTU Plasma group, need for in-house neutronics calculation capabilities for designing the Collective Thomson Scattering (CTS) diagnostics system to be installed in one of the drawers in equatorial port plug #12
Layout of ITER machine

- TF-magnet
- cryostat
- vacuum vessel
- blanket modules
- test blanket port
- plasma chamber
- divertor

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Status as of December 2013

• A simplified ITER 40 degree geometry input model for MCNP-5 has been developed
• Detailed geometric description of the CTS diagnostics system
• Well suited for parametric studies
• The input model has been benchmarked against the ITER A-lite model
Examples of geometry covered and results obtained

XZ and XY cross sections of the Torus 40 degrees model.

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Benchmark

Total heat deposition in the Blanket

Heat deposition (W/(g*MeV))

Energy (MeV)

TORUS FEAT

A-lite

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Benchmark

Neutron flux in the Vacuum Vessel

Energy (MeV)

Flux (neutron/(MeV*sec*cm^2))

TORUS FEAT

A-lite

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Mirror in slit

First Mirror
Blanket module key
Beams (extreme cases)
Blanket #3 Blanket cut-out

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Nuclear heating of TF winding pack

Design limit = $1.4 \times 10^{-4}$ W/g

Heat deposition [W/g]

Slit height [mm]

Cavity and slit
No cavity

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Fast neutron flux in TF coil insulator (epoxy)

Fast neutron flux ($E > 0.1$ MeV) in TF coil insulator

Slit height [mm]
1.00
2.00
3.00
4.00
0.50
1.50
2.50
3.50
Fast neutron flux [$10^{10}$ nHe/m²s⁻¹]
0 10 20 30 40 50 60
Slit height [mm]

Design limit

Cavity and slit
No cavity

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Examples of geometry covered and results obtained

Position of the mirrors M1 and M2 of the LF CTS system (XZ views)

**TABLE 1. Heat deposition in the mirrors of the LF CTS system.**

<table>
<thead>
<tr>
<th></th>
<th>Photon Heat Deposition (W/g)</th>
<th>Neutron Heat Deposition (W/g)</th>
<th>Total Heat Deposition (W/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mirror 1</td>
<td>4.95E-2 (±0.45%)</td>
<td>2.11E-3 (±0.98%)</td>
<td>5.16E-2 (±0.44%)</td>
</tr>
<tr>
<td>Mirror 2</td>
<td>6.00E-2 (±0.18%)</td>
<td>8.15E-3 (±0.48%)</td>
<td>6.81E-2 (±0.20%)</td>
</tr>
</tbody>
</table>

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Mirror design of the CTS system

Figure 26: Modelling of the mirror shapes and the centre beam of the LFS CTS receiver
CTS launcher and receiver beams

Figure 27: Equatorial port #12 on ITER with LFS CTS launcher and receiver beams, rear view
CTS equatorial port plug

LFS-BS probe beam
LFS-BS receiver beams (two extreme cases)
Blanket
HFS-FS
Probe beam
Plug Front Plate
Probe waveguides
Receiver wave guides
Scattering Volumes
LFS-BS probe beam

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Total heat load on mirror for different material composition

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MCNP feature allowing to stop a simulation at a given surface, and restart it later.

Potential to speed up series of simulations:
- If the overall model is complicated (like C-lite).
- If the difference between configurations are small.

CTS mirror not in C-lite yet → test SSW/SSR on simple 40 degree model (with C-lite source discussed up till now).

Capability to couple to ROOT analysis framework - proven useful in the design of the target-moderator-reflector system at the European Spallation Source.

Neutron flux in CTS mirror

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Dose Rate Criteria (inside bio-shield)

- Where planned maintenance is required the dose-rate must be less than 100µSv/hr.
- For unplanned maintenance it must be ALARA and never more than 2mSv/hr.
- Average occupational radiation exposure must be less than 500 man.mSv/yr
- Systems must be designed with ALARA in mind
Shutdown dose-rate

Activation of especially Cobalt (50%) and Tantalum (20%) in stainless steel structure cause significant nuclear heating which is problematic in terms of maintenance.

ITER limits: 100 $\mu$Sv/h 10 days after shutdown in areas were maintenance is expected.

For the CTS this means the interspace area.
Neutron attenuation through the equatorial port plug

Figure 1: Orders of magnitude of neutron attenuation from the plasma to the Port Cell

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Methods for Shutdown Dose Rate Calculation

There are several methods to calculate dose rate at ITER:

- MCNP+FISPACT, MCNP6 (ACT card), "Advanced D1S method"

- In addition to these more precise methods, experience (NAR) show that for ITER a simple scaling of fast neutron (>1MeV) flux is able to predict dose-rate with a precision satisfactory for our purposes.
Shutdown dose-rate calculation

- Neutron flux at entrance wall to the port interspace: 5.94807E-13 n/cm^2/(source_neutron) >1MeV
- Conversion factor (normalization in CLITE): 1.9718E19 =>
- Flux: 5.94807E-13 x 1.9718E19 n/cm^2/s = 6.35E8 n/cm^2/s
- Flux to shutdown-dose-rate conversions:
  1.33E-5 (micro Sv/h) / (n/cm^2/s)
- Shutdown dose-rate:
  6.35E8 n/cm^2/s * 1.33E-5 (micro Sv/h) / (n/cm^2/s)
  = 156 micro Sv/h
Horizontal view of Equitorial Port Plug from mcnp/C-lite

Stainless steel port plug

Surface for neutron flux calculation

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Conclusion

- Even without cut outs in FDW to install any version of the CTS, the limit is exceeded (consistent with observations at other diagnostics)

- => a global solution is needed, shielding must be added. For the CTS, we can study relative changes in shut-down dose-rates using the above scaling approach
Prospective

- Further benchmarking our 40 degree model against C-lite MCNP reference model
- Further neutronics analyses of the CTS system to determine whether active cooling of the CTS mirror is needed
- Calculation of the CTS system contribution to the shutdown dose rate of EPP #12
Thanks for your attention
C-lite horizontal plot
Scale of equatorial port plug diagnostics first wall

Scale of EPP EDFW

(6) EDFW’s per EPP Port
Figure 3.15 - Equatorial port plug 1 and the new drawers concept.