Innovations in 3-Dimensional Neutronics Analysis for Fusion Systems

Paul Wilson

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17th TOFE (2006)

11/14/06
Overview

• Motivation & Background

• Tools
  – Monte Carlo
  – Deterministic

• Applications

• Current issues
  – Model development
  – QA & ITER Benchmark
Motivations

• Reduce impacts of manual conversion of 3-D model data
  – Time
  – Simplifications
  – Errors

• Extend richness of geometric representation
• Translator approach

• Production experiences
  – IFMIF
  – ITER ECH Port

U. Fischer, et al
Monte Carlo Tools
MCAM
ASIPP (China)

- Bi-directional translator
  - Large geometry manipulation feature set
- Production experience
  - TBM
  - Port limiter
  - etc...

Y. Wu, et al
Monte Carlo Tools
TopAct

• Translator approach

• Production experience
  – NIF “Clamshell”
  – US ITER TBM

J. Latkowski, et al
• Direct use of solid model geometry in MCNPX
  – Use Common Geometry Module (CGM) to interface MCNPX *directly* to CAD & other geometry data

• Production experience
  – ITER FWS
  – ARIES-CS
  – HAPL
Model generated by designers using common tools facilitates analysis
Compare results to 3-D analysis in full ITER 40 degree sector.
Examine effect of non-uniform blanket and divertor on TBR in real 3-D geometry
Neutron Source Methodology

- Generate hex mesh in real space from uniform mesh in flux coordinate space
- Generate cumulative distribution function for source density in hex mesh
- Sample hex mesh and mesh cells for source position

Increasing Poloidal Angle (0° at O/B midplane)
NWL Maps (colormaps in MW/m²)

5 cm SOL

30 cm SOL

uniform src

Radiative heating

Poloidal Angle (degrees)

Toroidal Angle (degrees)
HAPL Final Optics
Deterministic ATTIKA Transpire

- Finite element discrete ordinates
  - Automated tetrahedral mesh generation
- Production experience
  - ATR
  - Medical physics facility shielding

G. Failla, et al
ATTILA Mesh for ARIES-CS Mockup
Duct Shielding Response

Frame 001 | 10 Nov 2006 | Allia Transport Solver Results

Data File Attributes:
- Problem Title: first_run
- File Name: first_run_jigplot_out_1.p6
- Created: 16:15:25, 06 Nov 2006
- Host Name: hif, ep.wisc.edu
- Variables: 13
- Zones: 29

logPho0(p01)
CAD Issues Requiring “Repair”

Human effort shifts from traditional MCNP model creation to CAD/Solid Model repair

- Overlapping Volumes (i.e.: clashes)
- Mating surfaces not contacting
- Slight “Misalignment”
  - Imprint generates ultra thin surfaces
  - Doesn’t always require repair

- Complex Surface Definition
Examples of Typical CAD Issues and Typical Repairs

Issue – Overlapping Volumes
Action – Edit geometry to establish proper contact

Issue – No Contact
Action – MAY require recreating volume

Edges cross at this point
ITER QA & Neutronics

• Shift to licensing phase of large nuclear system
  – Need for 3-D analysis
  – Facilitate analysis with design modifications
  – Quality assurance of model development
ITER Benchmark

- 802 cells
  - 23 in complement
- 9834 surfaces
  - 397 on reflecting boundary
ITER Benchmark

• Comparing 4 results
  – Neutron wall loading
  – Divertor fluxes and heating
  – Magnet heating
  – Midplane port shielding/streaming

• Participants
  – UW, FZK, ASIPP, JAEA + ATTIOLA
Neutron Wall Loading: results

- Poloidal Distance [cm]
- Neutron Wall Loading [MW/m²]

Graph showing neutron wall loading as a function of poloidal distance. The graph is labeled:
- Black line: Segmented
- Red line: by FW/S module
TF Coils: results

<table>
<thead>
<tr>
<th>Distance from top of I/B TF coil [cm]</th>
<th>Heating [kW]</th>
<th>Nuclear Heating (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>Neutron 1.39 ± 0.05</td>
</tr>
<tr>
<td>8.1 kW in all TF I/B legs</td>
<td>18.4 ± 0.6</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>2.47 ± 0.06</td>
<td>Photon 17.0 ± 0.6</td>
</tr>
<tr>
<td>200</td>
<td>31.8 ± 0.7</td>
<td></td>
</tr>
<tr>
<td>300</td>
<td>3.82 ± 0.04</td>
<td>Total 31.8 ± 0.7</td>
</tr>
<tr>
<td>400</td>
<td>44.6 ± 0.4</td>
<td></td>
</tr>
<tr>
<td>500</td>
<td>60.4 ± 0.6</td>
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</tr>
<tr>
<td>600</td>
<td>65.6 ± 0.9</td>
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</tr>
<tr>
<td>700</td>
<td>71.6 ± 1.0</td>
<td></td>
</tr>
<tr>
<td>800</td>
<td>35.5 ± 0.2</td>
<td></td>
</tr>
<tr>
<td>900</td>
<td>415 ± 2.3</td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td>450 ± 2.5</td>
<td></td>
</tr>
</tbody>
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Nuclear Heating (W)

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<tr>
<td>3.82 ± 0.04</td>
<td>44.6 ± 0.4</td>
<td>48.4 ± 0.5</td>
</tr>
<tr>
<td>5.41 ± 0.05</td>
<td>60.4 ± 0.6</td>
<td>65.8 ± 0.6</td>
</tr>
<tr>
<td>6.03 ± 0.12</td>
<td>65.6 ± 0.9</td>
<td>71.6 ± 1.0</td>
</tr>
<tr>
<td>5.16 ± 0.08</td>
<td>57.0 ± 0.7</td>
<td>62.2 ± 0.8</td>
</tr>
<tr>
<td>3.38 ± 0.04</td>
<td>40.9 ± 0.5</td>
<td>44.3 ± 0.6</td>
</tr>
<tr>
<td>2.27 ± 0.04</td>
<td>29.9 ± 0.5</td>
<td>32.2 ± 0.6</td>
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<tr>
<td>3.66 ± 0.08</td>
<td>45.7 ± 1.3</td>
<td>49.4 ± 1.4</td>
</tr>
<tr>
<td>1.88 ± 0.05</td>
<td>24.0 ± 0.7</td>
<td>25.9 ± 0.7</td>
</tr>
<tr>
<td>8.1 kW in all TF I/B legs</td>
<td>450 ± 2.5</td>
<td></td>
</tr>
</tbody>
</table>
Mid-plane Port: results

Distance from First Wall [cm]

Neutron Flux [n/cm².s]

- Total
- 1 MeV - 20 MeV
- 0.1 - 1 MeV
- 1 eV - 0.1 MeV
- < 1 eV
Future Developments

• Advanced tetrahedral mesh tallies

• Coupled deterministic/Monte Carlo

• Coupled activation/photon transport
Questions?

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