Application of Multiprocessor Calculations in IRT BNCT Channel Design

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The Research Reactor IRT

- is arranged on the eastern part of Sofia
- is water-moderated water-cooled pool type reactor
- was built and put into operation in 1961
- is in a process of nuclear fuel conversion and refurbishment
Applications

- Boron Neutron Capture Therapy
- Neutron activation analysis
- Radioisotope production
- Radio-pharmacy
- Materials irradiation
- Neutron radiography
- Material structure studies
- Metrology
Boron Neutron Capture Therapy
General Requirements

- Facility with well filtered and collimated epithermal neutron beam
- An irradiation room, an observation and monitoring room, patient preparation room, other facilities: Doctor’s needs, boron measurements, etc.
- Excellent infrastructure for communication with the base hospital
- Well trained interdisciplinary team
Current activities

- Research on NCT facility - Modeling of IRT NCT Beam Tube
- NCT Scientific Information System
- NCT Scientific Infrastructure Building
- Strengthening the interdisciplinary team

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Modeling of BNCT Beam Tube on IRT reactor

The neutron beam tube configuration of the Massachusetts Institute of Technology Reactor (MITR), USA is being considered in the calculational modeling of geometry and material composition of filter/collimator of the beam tube. A distinguish only is that the tube entrance will be adjusted directly to the IRT reactor core.
IRT BNCT facility schematic
The preliminary results of neutron and gamma transport calculations performed for the model have shown that the NCT facility will be able to supply an epithermal neutron flux of about $5 \times 10^9$ n/cm$^2$s, with quality, which is close to the best value reached in the world until now.

The model meets the existing requirements (IAEA-TECDOC-1223).
Design Tool

- **MCNP (Monte Carlo Neutron Photon)** is a multi-purpose particle transport code
- Possible primary particles are neutron, photon and electron. The modified version, MCNPX, contains many primary particles (even neutrinos)
- The presence of low energy neutrons in BNCT creates problems in the usage of deterministic codes. Therefore, MCNP has been adopted as background calculation engine in several BNCT-dedicated treatment planning systems (**NCTPlan, BDTPS**). SERA uses another Monte Carlo code, **rtt_MC**, which is reduced version of Morse.
- MCNP can be used in the transport of the particles since their origin (nuclear reactor) in order to get the dose distribution in the patient organ (head, liver, hand, etc.).
- To this purpose, it is possible to simulate the geometry of the reactor core, the shielding, filters, beam channels and finally also the patient’s organ.
Evaluated Parameters

- $\Phi_{\text{epi in}}$ - epithermal neutron flux at the collimator entrance
- $J_{\text{epi}}$ - epithermal neutron current at the collimator exit
- $\Phi_{\text{epi}}$ - epithermal neutron flux at the collimator exit
- $J_{\text{epi}}/\Phi_{\text{epi}}$ – neutron beam collimation
- $D_{\text{fast}}$ – fast neutron dose rate at the collimator exit
- $D_{\text{fast}}/\Phi_{\text{epi}}$ - fast neutron dose rate per epithermal neutron at the collimator exit
- $D_{\text{fn}}$ - neutron dose rate from neutrons with $E > 0.5$ eV at the collimator exit
- $D_{\text{fn}}/\Phi_{\text{epi}}$ - neutron dose rate per epithermal neutron from neutrons with $E > 0.5$ eV at the collimator exit
- $D_{\gamma}$ – photon dose rate at the collimator exit
- $D_{\gamma}/\Phi_{\text{epi}}$ – photon dose rate per epithermal neutron at the collimator exit
- $D_{\text{Boron}}$ – Boron-10 dose rate at the phantom
Recent research

- Evaluation of the conic collimator length impact to the BNCT beam properties
- Evaluation the irradiation performance of the Teflon® in the F/M
- Evaluation of C-12 and Al₂O₃ as an alternatives to the Teflon® in the F/M 81 cm and 124 cm collimator - F/M length search
- Determination of biological doses in phantom for 81 cm and 124 cm collimator for the materials used as F/M
Multiprocessor calculations

Pros:
- Decreased calculation time
- Learning attitude
- “Modern” approach

Cons:
- Change of the MCNP version
- Change of computer platform
- Necessity of “proof for inheritance of the results”
MCNP5 Parallel capabilities

- MCNP5 is developed to execute on many different varieties of parallel computer systems
- MPI standard for message-passing for distributed-memory parallelism
- OpenMP standard for threading (shared-memory parallelism)
- PVM messagepassing is supported
Subject

To prove the consistency of the results between:

- Continuous calculation by 32-bit MCNP4C on Windows OS
- Multiprocessor 64-bit MCNP5 on Linux OS

To evaluate the speedup gained by Multiprocessor calculation
BNCT calculation flow

1. Criticality calculation
2. Epithermal flux determination
3. Bio dose determination

Criticality calculation
## Criticality calculations

<table>
<thead>
<tr>
<th>№</th>
<th>Platform</th>
<th>$k_{eff}$</th>
<th>$\sigma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>MCNP4C - Windows</td>
<td>1.00246</td>
<td>0.00016</td>
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<tr>
<td>2</td>
<td>MCNP5 - Windows</td>
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<tr>
<td>4</td>
<td>(2/1)-1</td>
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<tr>
<td>5</td>
<td>(3/1)-1</td>
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# Transport calculations

<table>
<thead>
<tr>
<th>Calculation</th>
<th>( J_{epi} ) cm(^{-2}) s(^{-1})</th>
<th>( \Phi_{epi} ) cm(^{-2}) s(^{-1})</th>
<th>( J_{epi}/\Phi_{epi} )</th>
<th>( D_{fast} ) Gy s(^{-1})</th>
<th>( D_{fast}/\Phi_{epi} ) cGy cm(^2)</th>
<th>( D_{fn} ) Gy s(^{-1})</th>
<th>( D_{fn}/\Phi_{epi} ) cGy cm(^2)</th>
<th>( D_{\gamma} ) Gy s(^{-1})</th>
<th>( D_{\gamma}/\Phi_{epi} ) cGy cm(^2)</th>
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<tbody>
<tr>
<td>1. 32-bit Windows</td>
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<td>6.58E+09</td>
<td>0.682</td>
<td>1.19E-03</td>
<td>1.81E-11</td>
<td>1.91E-03</td>
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<td>3.57E-04</td>
<td>5.43E-12</td>
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<tr>
<td></td>
<td>0.50%</td>
<td>0.48%</td>
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<tr>
<td>2. 64-bit Linux</td>
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<td>6.59E+09</td>
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<td>1.18E-03</td>
<td>1.78E-11</td>
<td>1.89E-03</td>
<td>2.64%</td>
<td>3.50E-04</td>
<td>5.31E-12</td>
</tr>
<tr>
<td></td>
<td>0.50%</td>
<td>0.48%</td>
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<td>Difference, (2/1)-1,%</td>
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# Speedup

<table>
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<tr>
<th>№</th>
<th>Platform</th>
<th>Time, h</th>
<th>σ</th>
<th>Time, h</th>
<th>R, %</th>
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<tr>
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<td>0.00015</td>
<td>0.4</td>
<td>0.48</td>
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</tbody>
</table>
Outcome

- Agreement between the results obtained by previous and current version of MCNP
- 10 time gain in speed only by using parallel computations
- Possibility to perform only one calculation to obtain biological dose for a reasonable time
THANK YOU