Burnup Calculations of TR-2 Research Reactor with MONTEBURNS Monte Carlo Code

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Introduction

- Burnup calculations of first and second core cycles of TR-2 Research Reactor have been performed using MONTEBURNS Monte Carlo code.
- The results were compared with the values of experiments and other codes (CNUREAS and reference calculations).
MONTEBURNS is a Monte Carlo burnup code that links the Monte Carlo transport code MCNP with the radioactive decay and burnup code ORIGEN2. MCNP calculates one-group cross-sections and fluxes that are used by ORIGEN2 in burnup calculations and provides criticality and neutron economy information if requested. After performing burnup calculations using ORIGEN2, MONTEBURNS passes isotopic compositions of materials back to MCNP to begin another burnup cycle.
A computer software system called Cekmece Nuclear Reactor System (CNUREAS) was developed in Cekmece Nuclear Research and Training Center based on WIMS and CITATION nuclear codes that are widely used in the analysis and calculations of the nuclear reactor systems.

WIMS produces material cross sections using cell model and CITATION uses these cross sections and computes neutron flux and fuel burnup.
TR-2 Research Reactor

- Located in Cekmece Nuclear Research and Training Center (CNAEM)
- First criticality in 1981
- 5 MW thermal power
- Open pool type
- Light Water Coolant/Modareted
- MTR type fuel element
  - 93% enriched U-Al fuel (HEU)
  - 20% enriched U3Si2-Al (LEU)
- Berilyum and Graphite Reflector
- Isotope production, education, training and research
Thirteen core cycles have been operated in TR-2. HEU and LEU fuels had been used in these core cycles.

Both HEU and LEU fuels are MTR-type with 23 plates for standard element and 17 plates for control element.

Only HEU fuels were used in TR-2 during the first twelve core cycles.

Two standard and one irradiation LEU fuel elements were inserted in the thirteenth cycle.
TR-2 Research Reactor

- First and second core cycles contained 10 standard and 4 control fuel elements.
- On one side, there were 4 Beryllium blocks as reflector and there were 2 Aluminum blocks at the corners of opposite site.
TR-2 Research Reactor

- Three dry irradiation facilities had been added to the core during the first and second core cycles.
- At the beginning of second core cycle, one standard fresh fuel element (S112) had been added to the core instead of fuel element S109.

### Time periods of first and second core cycles

<table>
<thead>
<tr>
<th>Cycle 1</th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>a</td>
<td>5.96 days</td>
<td>Startup</td>
</tr>
<tr>
<td></td>
<td>b</td>
<td>14.92 days</td>
<td>First Irradiation Tube Insertion</td>
</tr>
<tr>
<td></td>
<td>c</td>
<td>30.79 days</td>
<td>Second Irradiation Tube Insertion</td>
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</table>

<table>
<thead>
<tr>
<th>Cycle 2</th>
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<tr>
<td></td>
<td>a</td>
<td>5.75 days</td>
<td>Fresh Fuel Loading</td>
</tr>
<tr>
<td></td>
<td>b</td>
<td>33.33 days</td>
<td>Third Irradiation Tube Insertion</td>
</tr>
</tbody>
</table>
Modeling of TR-2 Research Reactor

- 3D model of TR-2 core was formed using MCNP5 monte carlo code.

MCNP5 model of TR-2 Research Reactor
Modeling of TR-2 Research Reactor

23-plate Standard Fuel Element

17-plate Control Fuel Element
Parallel Computing

- **Long computation time** is a disadvantage of Monte Carlo codes such as MCNP.
- To reduce run time, **parallelization** of MONTEBURNS was performed.
- MCNP5 used in MONTEBURNS code has been parallelized in eight HP ProLiant BL680C G5 systems utilizing the **MPI** parallel protocol.
- Simulations were performed on the **128 cores** Linux parallel computing machine system established in TAEK.
Parallel Computing

- **Master**: 4xIntel 2.4 GHz Quad-core
- **Blade 1**: 4xIntel 2.4 GHz Quad-core
- **Blade 2**: 4xIntel 2.4 GHz Quad-core
- **Blade 3**: 4xIntel 2.4 GHz Quad-core
- **Blade 4**: 4xIntel 2.4 GHz Quad-core
- **Blade 5**: 4xIntel 2.4 GHz Quad-core
- **Blade 6**: 4xIntel 2.4 GHz Quad-core
- **Blade 7**: 4xIntel 2.4 GHz Quad-core

MCNP5.MPI
## Technical Specifications of Parallel Computing System

<table>
<thead>
<tr>
<th>Server</th>
<th>Specification</th>
</tr>
</thead>
</table>
| 8 Blades | - Four 2.4 GHz Quad-core Intel Xeon 7330 processor  
          | - Total 32 GB DDR2 memory  
          | - Four 10/100/1000 Mbit/s Gigabit Ethernet  
          | - 4xDDR (20Gb) InfiniBand  
          | - Red Hat Enterprise Linux Advanced Platform 5 |
| 1 Main   | - 2.5 GHz Quad-core Intel Xeon 5420 processor  
          | - 4 GB DDR2 memory offload engine (TOE)  
          | - Two 10/100/1000 Mbit/s Gigabit Ethernet with TCP/IP |
## Parallel Computing

<table>
<thead>
<tr>
<th>Number of Core</th>
<th>Run Time (min)</th>
<th>Speed Up Factor</th>
</tr>
</thead>
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<td>1</td>
<td>1604</td>
<td>1.0</td>
</tr>
<tr>
<td>10</td>
<td>187</td>
<td>8.6</td>
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<tr>
<td>20</td>
<td>94</td>
<td>17.1</td>
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<tr>
<td>30</td>
<td>72</td>
<td>22.3</td>
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<tr>
<td>35</td>
<td>63</td>
<td>25.5</td>
</tr>
<tr>
<td>40</td>
<td>61</td>
<td>26.3</td>
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<tr>
<td>50</td>
<td>58</td>
<td>27.7</td>
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<td>70</td>
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<td>28.1</td>
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<tr>
<td>90</td>
<td>60</td>
<td>26.7</td>
</tr>
<tr>
<td>110</td>
<td>64</td>
<td>25.1</td>
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</table>

### Speed Factor of Parallel Computing

![Graph showing the speed-up factor with respect to the number of cores](image-url)
Results

- The reactor was assumed to be operating uninterruptedly during the cycles.
- Reference calculations had been made using GEREBUS diffusion code

![k-eff distribution for first and second core cycles](image-url)
Results

Burnup percentages are defined as:

\[
\text{Burnup} \, (\%) = 100 \times \left( 1 - \frac{M_i^{235}}{M_0^{235}} \right)
\]

where

- \( M_0^{235} \) = U-235 weight of fresh fuel element
- \( M_i^{235} \) = U-235 weight at the end of cycle \( i \)
## Results

<table>
<thead>
<tr>
<th></th>
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<tr>
<td>11.20</td>
<td>9.87</td>
<td>9.38</td>
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<tr>
<td>10.80</td>
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<tr>
<td>12.28</td>
<td>13.74</td>
<td>12.33</td>
<td>10.52</td>
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</table>

**Burnup percentages of end of the first core cycle**
## Results

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<th>7.84</th>
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<tr>
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<td>6.81</td>
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<td>6.74</td>
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<td>6.72</td>
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<td>5.57</td>
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<tr>
<td>CNUREAS</td>
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<td>Monteburns</td>
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<tr>
<td>Ref. Calc.</td>
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<tr>
<td>Ref. Exp.</td>
<td>5.40</td>
<td>4.69</td>
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</table>

Burnup percentages of end of the second core cycle
Conclusion

- Time dependent **k-eff distribution** and **burnup** values results at the end of first and second cycles are **compatible** with each other.

- Some minor differences are observed between MONTEBURNS and reference results due to **lack of cross-section** set in **ORIGEN2 library** for TR-2 type research reactors that have MTR-type HEU fuels.
Conclusion

- Although the reactor had been operated **6 hours a day** and **5 days in a week**, it is assumed that the reactor was continuously operated 24 hours a day for all core cycles in all of the calculations (MONTEBURNS, CNUREAS and reference).

- **All control rods** were assumed to be **out** in all of the calculations, while Control Rod 2 (C018) was in to sustain the criticality in the operational case.
Conclusion

- The control rod fluxes could not be measured and the surrounding fluxes were averaged in the experiment leading to larger deviations with the calculations.

- With parallel computing system, MONTEBURNS results have been obtained in a shorter time (speed up factor 25.5)
THANK YOU
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Istanbul (the Bosphorus) strait at the junction of civilizations. The narrow passage of the Black Sea to the world oceans