IAEA 10 MW$_{th}$ MTR benchmark static calculation with SERPENT code

Presented: Marat Margulis
Yaniv Shaposhnik
Supervised by: Dr. Erez Gilad
Motivations and objectives

- Research Reactor core modeling lack of knowledge
  - Predict the core performance in normal and accident states
    - e.g. fuel temperature (melting), criticality
  - Full core MC simulations are time and resource consuming
  - MC transient calculations – out of reach

- The goal of this project is to
  - Develop a general tool which will be accurate and also relatively fast for RR modeling
  - Therefore, the SERPENT-DYN3D sequence is developed
    - Validated against data taken from the IAEA benchmark
IAEA Benchmark

- 10 MW light water pool type MTR
  - Research Reactor core for conversion of HEU to LUE
- Provides a detailed MTR specifications
  - Steady-state neutronic kinetics and thermohydraulic
  - Several accident scenarios
IAEA MTR core

- Core grid – 6x5
  - 21 fuel assembly
    - 23 fuel plates
  - 4 control assembly
    - 17 fuel plates
- Core active length – 60 cm
- Axial reflector – 15 cm
  - 20% - Al
  - 80% - $H_2O$
- Radial reflector - Graphite
The results obtained from SERPENT were compared to those obtained by WIMS-D4 and ANL Benchmark

- Calculations performed on an unit cell configuration (IAEA-TECDOC, 1980)

- The simulation was performed both for HEU and LEU
BU fuel element calculations - Results

HEU k-inf

- Benchmark (ANL)
- WIMS-4D
- Serpent
- Serpent-ANL

Burnup, %

k-inf
HEU Difference in k-inf

- **Serpent**
- **WIMS-4D**
- **Benchmark (ANL)**

Difference in $k_{\text{inf}}$, pcm

Burnup, %

0, 5, 10, 25, 30, 45, 50
LEU $k_{\text{inf}}$

![Bar chart showing LEU $k_{\text{inf}}$ values for different burnup percentages. The chart compares results from Benchmark (ANL), WIMS-4D, Serpent, and Serpent-ANL.]
LEU Difference in k-inf

![Bar chart showing LEU Difference in k-inf for different burnup values. The chart compares results from Serpent, WIMS-4D, and Benchmark (ANL).]
The next table present the atom densities in HUE fuel as a function of BU

<table>
<thead>
<tr>
<th>Burnup (%)</th>
<th>$U^{235}$</th>
<th>$U^{238}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Benchmark (ANL)</td>
<td>WIMS-4D</td>
</tr>
<tr>
<td>0</td>
<td>1.61790E-03</td>
<td>1.61790E-03</td>
</tr>
<tr>
<td>5</td>
<td>1.53701E-03</td>
<td>1.53702E-03</td>
</tr>
<tr>
<td>10</td>
<td>1.45612E-03</td>
<td>1.45612E-03</td>
</tr>
<tr>
<td>25</td>
<td>1.21342E-03</td>
<td>1.21342E-03</td>
</tr>
<tr>
<td>30</td>
<td>1.13254E-03</td>
<td>1.13253E-03</td>
</tr>
</tbody>
</table>

- The same behavior was spotted in all the benchmark cases
Core criticality result

A fuel MTR calculation was carried out in SERPENT

The results were checked vs. previous calculation

<table>
<thead>
<tr>
<th>Organization (code)</th>
<th>93% Fresh</th>
<th>93% BOL</th>
<th>93% EOL</th>
<th>20% Fresh</th>
<th>20% BOL</th>
<th>20% EOL</th>
</tr>
</thead>
<tbody>
<tr>
<td>SERPENT (ENDF-VII)</td>
<td>1.18410±0.00023</td>
<td>1.02381±0.00016</td>
<td>1.00037±0.00017</td>
<td>1.16636±0.00016</td>
<td>1.02003±0.00027</td>
<td>0.999156±0.00017</td>
</tr>
<tr>
<td>MCNP5</td>
<td>1.18962±0.00034</td>
<td>*</td>
<td>*</td>
<td>1.17238±0.00033</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>ANL (DIF2D)</td>
<td>1.18343</td>
<td>1.0232333</td>
<td>1.00038</td>
<td>1.1683</td>
<td>1.02127</td>
<td>1.00142</td>
</tr>
<tr>
<td>EIR (CODIFF)</td>
<td>1.1939413</td>
<td>1.032204</td>
<td>1.009607</td>
<td>1.15937</td>
<td>1.010724</td>
<td>0.992637</td>
</tr>
<tr>
<td>OESGAE (EXTERMINATOR)</td>
<td>1.1966</td>
<td>1.032</td>
<td>1.009</td>
<td>1.1813</td>
<td>1.032</td>
<td>1.012</td>
</tr>
<tr>
<td>CEA (NEPTUNE)</td>
<td>1.202</td>
<td>1.04041</td>
<td>1.01703</td>
<td>1.187</td>
<td>1.0394</td>
<td>1.01913</td>
</tr>
<tr>
<td>JAERI (ADC)</td>
<td>1.18104</td>
<td>1.04199</td>
<td>1.02195</td>
<td>1.18339</td>
<td>1.05782</td>
<td>1.04122</td>
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<tr>
<td>CNEA (EXTERMINATORII)</td>
<td>1.20018</td>
<td>1.03765</td>
<td>1.01425</td>
<td>1.1815</td>
<td>1.03316</td>
<td>1.013</td>
</tr>
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</table>

* Data not available

The results obtained from SERPENT are in a good agreement with the result presented in the IAEA benchmark (ANL)
Core criticality result

HEU Difference in k-eff

- MCNP5
- EIR (CODIFF)
- CEA (NEPTUNE)
- ANL (DIF2D)
- OESGAE (EXTERMINATOR)
- JAERI (ADC)
- CNEA (EXTERMINATORII)

Difference in k-eff, pcm

Burnup, %

93% Fresh
93% BOL
93% EOL

MCNP5
EIR (CODIFF)
CEA (NEPTUNE)
ANL (DIF2D)
OESGAE (EXTERMINATOR)
JAERI (ADC)
CNEA (EXTERMINATORII)
Core criticality result

LEU Difference in k-eff

- MCNP5
- EIR (CODIFF)
- CEA (NEPTUNE)
- OESGAE (EXTERMINATOR)
- ANL (DIF2D)
- JAERI (ADC)
- CNEA (EXTERMINATORII)

Difference in \( k_{eff} \), pcm

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-2000 -1000 0 1000 2000 3000 4000 5000

-2000 -1000 0 1000 2000 3000 4000 5000
In order to verify that the results are not influenced by a statistical error

- This was performed by the built-in SERPENT option of Shannon Entropy verification

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**HUE**

- [Graph showing data for HUE]

**LUE**

- [Graph showing data for LUE]
Summary

- Demonstrate the capabilities of SERPENT in MTR analysis
- IAEA 10 MW$_{th}$ MTR core was examined
  - Good agreement on XS, ND & eigenvalues on assembly as well as core level (ANL)
- Future – Develop a general tool to accurately model MTR
  - Steady-state
  - Transients
- DYN3D - SERPENT simulation sequence
Thank you for your attention
The flux distribution obtained from SERPENT correspond to the one obtained in MCNP 5 calculation.

- Thermal flux in presented at the images below

(left – SERPNET, right – MCNP5)