Stakeholder Outcomes: Task 1

“The Quest for TREAT Benchmarks”

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Outline

- The Benchmark
- Steady-State Results
  - Monte Carlo
  - Deterministic
- Transient Analyses
  - Ongoing
- Significant Challenge
  - Hodoscope
  - Other voided regions

Path Forward
# The Benchmark

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Fuel Assemblies</th>
<th>Control Rod Assemblies</th>
<th>Zirconium Assemblies</th>
<th>Types of Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Critical Mass (MCM)</td>
<td>133</td>
<td>8</td>
<td>16</td>
<td>Temperature Coefficient</td>
</tr>
<tr>
<td>MCM+</td>
<td>135</td>
<td>8</td>
<td>16</td>
<td>Flux Distribution</td>
</tr>
<tr>
<td>M8CAL</td>
<td>318</td>
<td>20</td>
<td>0</td>
<td>Rod Worth Data</td>
</tr>
</tbody>
</table>

**Evaluators**

- **Internal Reviewers**
  - Thomas Downar
  - Volkan Seker

- **University of Michigan**

- **Independent Reviewer**
  - John Bess, INL
  - Richard Lell, ANL
The Models
## Serpent TREAT Reactivity Calculations

<table>
<thead>
<tr>
<th>CORE</th>
<th>K-effective</th>
</tr>
</thead>
<tbody>
<tr>
<td>MCM</td>
<td>1.00413 ± 20 pcm</td>
</tr>
<tr>
<td>MCM+</td>
<td>1.00171 ± 20 pcm</td>
</tr>
<tr>
<td>M8CAL</td>
<td>1.00394 ± 20 pcm</td>
</tr>
</tbody>
</table>

![Graph showing reactivity vs rod position](image)

- **EXP**
- **SERPENT**

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*INL Idaho National Laboratory*
Serpent TREAT M8CAL Flux Calculations
Uncertainty Quantification

<table>
<thead>
<tr>
<th>Parameter(s) perturbed</th>
<th>Sample size</th>
<th>Average $k_{\text{eff}}$</th>
<th>Relative uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>All parameters listed in Table 1</td>
<td>300</td>
<td>$1.0073 \pm 1.1749E-5$</td>
<td>$1273.4 \pm 1.2pcm$</td>
</tr>
<tr>
<td>The five parameters below</td>
<td>1200</td>
<td>$1.0069 \pm 5.8865E-6$</td>
<td>$1171.6 \pm 0.6pcm$</td>
</tr>
<tr>
<td>Boron content</td>
<td>300</td>
<td>$1.0044 \pm 1.1806E-5$</td>
<td>$1093.9 \pm 1.2pcm$</td>
</tr>
<tr>
<td>Flat to flat distance of fuel block</td>
<td>300</td>
<td>$1.0064 \pm 1.1763E-5$</td>
<td>$222.7 \pm 1.2pcm$</td>
</tr>
<tr>
<td>Standard fuel assembly outer radius</td>
<td>300</td>
<td>$1.0041 \pm 1.1770E-5$</td>
<td>$30.6 \pm 1.2pcm$</td>
</tr>
<tr>
<td>Al-6063 can thickness</td>
<td>300</td>
<td>$1.0044 \pm 1.1788E-5$</td>
<td>$335.6 \pm 1.2pcm$</td>
</tr>
<tr>
<td>Zr-3 can thickness</td>
<td>300</td>
<td>$1.0040 \pm 1.1845E-5$</td>
<td>$894.2 \pm 1.2pcm$</td>
</tr>
</tbody>
</table>

Table 2. TREAT minimum critical core uncertainty analysis summary

- Reference $k_{\text{eff}} : 1.00413 \pm 0.0002$.
- Boron content and Zr-3 can thickness were recognised as the two most significant factors.
- Perturbations of flat to flat distance of fuel block caused shift in the mean $k_{\text{eff}}$ value.
PARCS TREAT Calculations

- Serpent Cross Section Generation
- If Extracted from 3D M8CAL Model

<table>
<thead>
<tr>
<th>Core</th>
<th>Serpent</th>
<th>PARCS</th>
<th>( k_{\text{eff}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>MCM</td>
<td>1.00413 ± 20 pcm</td>
<td>1.00177</td>
<td>1.00394 ± 20 pcm</td>
</tr>
<tr>
<td>MCM+</td>
<td>1.00171± 20 pcm</td>
<td>0.99769</td>
<td>1.01167</td>
</tr>
<tr>
<td>M8CAL</td>
<td>1.00394 ± 20 pcm</td>
<td>1.04821</td>
<td>Diff 773 pcm</td>
</tr>
</tbody>
</table>
PROTEUS Meshing
PROTEUS MCM Eigenvalue Solutions

<table>
<thead>
<tr>
<th>Case</th>
<th>Serpent</th>
<th>PROTEUS</th>
<th>Angle</th>
<th>(\Delta k(\text{pcm}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>2D Fuel Element (FE)</td>
<td>1.66673 (± 3)</td>
<td>L5T15</td>
<td>-32</td>
<td></td>
</tr>
<tr>
<td>2D Core w/o PGR</td>
<td>1.29939 (±15)</td>
<td>L5T15</td>
<td>-167</td>
<td></td>
</tr>
<tr>
<td>2D Core w/ PGR</td>
<td>1.23041 (±22)</td>
<td>L5T15</td>
<td>337</td>
<td></td>
</tr>
<tr>
<td>3D Single FE</td>
<td>1.45473 (±20)</td>
<td>L5T15</td>
<td>220</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>L9T15</td>
<td>196</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>L15T15</td>
<td>174</td>
<td></td>
</tr>
<tr>
<td>3D 2x2 (3FE,1CE)</td>
<td>1.27926 (±21)</td>
<td>L5T15</td>
<td>120</td>
<td></td>
</tr>
<tr>
<td>3D 2x2 (2FE,2CE)</td>
<td>1.16952 (±21)</td>
<td>L5T15</td>
<td>143</td>
<td></td>
</tr>
<tr>
<td>3D Core (15x15) w/o PGR</td>
<td>1.19798 (±27)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3D Full Core</td>
<td>1.00357 (±27)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.00424 (±38)</td>
<td>L5T15</td>
<td>407 **</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>L15T25</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

** Eigenvalue difference is expected to be reduced with higher angular order**
PROTEUS Partial M8CAL Eigenvalue Solutions

<table>
<thead>
<tr>
<th>Case</th>
<th>Serpent</th>
<th>PROTEUS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Angle</td>
</tr>
<tr>
<td>3D Partial Core</td>
<td>1.37609 (±16)</td>
<td>L5T15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>L15T15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>L5T25</td>
</tr>
<tr>
<td></td>
<td></td>
<td>L15T25</td>
</tr>
</tbody>
</table>
OpenMC – M8CAL

- Tally a 2 cm diameter cylindrical air volume with trace uranium nuclides
Status of OpenMC Transient Modeling

- Installed Transition Rate (TR) Matrix Method in OpenMC 0.7.0 (UM OTF Doppler version)
- Verified using sample problem supplied by TRMM author Ben Betzler
- Investigated infinite lattice (3x3 assemblies) benchmark problem (homogeneous fuel)
  - Validated fidelity vs heterogeneous simulations w/ Serpent (UM) and OpenMC (MIT).
  - Cataloged sensitivity of trace isotopes on $k_{eff}$
  - Need homogeneous assemblies for TRMM finite core simulations to minimize phase space
- Initial results for minimum critical core (9x9 TR Matrix, 13.5 x 13.5 assemblies, vacuum boundary) look reasonable
Greatest Challenge with Deterministic Modeling – The Void Space

Significant ongoing effort and methods development to update codes to handle this problem
Steady-State Benchmark

MCM

M8CAL
Preliminary Benchmark Report Needs

Section 1

- **Experiment Description**
  - Add additional content
  - Create “TREAT Template” for all TREAT benchmark evaluations
  - Create Experiment Specific Sections

Section 2

- **Uncertainty Evaluation**
  - Provide additional description and explanation

Section 3

- **Provide the benchmark model**
  - Evaluate simplification biases
Bias Evaluation for Benchmark

- Detailed Model
- Remove “Room Return” $\Delta k$
- Remove Impurities $\Delta k$
- Simplify Geometry $\Delta k$
- Adjusted $k_{\text{eff}}$

$1\sigma$ Uncertainty

$\sim k_{\text{exp}}$
Path Forward – IRPhEP Review Process

- **Initial Start-Up Physics Testing Benchmark Report**
  - MCM, MCM+
  - Criticality, Temperature Coefficient, Flux Distributions
  - Available for others to evaluate additional original start-up measurements

- **M8CAL Benchmark Report**
  - Criticality, Rod Worths
  - Later add natural and shaped transient benchmark analysis
  - Available for others to evaluate additional M8CAL series data
  - Jump-start benchmark activities for TREAT restart!!!
## Path Forward – Transient Benchmarks

<table>
<thead>
<tr>
<th>1.2</th>
<th>Transient (TR)</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2.1</td>
<td>Survey available TREAT TR data for benchmark problem</td>
<td>T. Downar, UM</td>
</tr>
<tr>
<td>1.2.2</td>
<td>Preliminary TR modeling of candidate problems</td>
<td>T. Downar, UM</td>
</tr>
<tr>
<td>1.2.3</td>
<td>Down-select to two problems for benchmark evaluation</td>
<td>T. Downar, UM</td>
</tr>
<tr>
<td>1.2.4</td>
<td>Perform TR modeling with deterministic U.S. NRC codes PARCS/AGREE</td>
<td>T. Downar, UM</td>
</tr>
<tr>
<td>1.2.5</td>
<td>Perform TR modeling with deterministic NEAMS code PROTEUS</td>
<td>C. Lee, ANL</td>
</tr>
<tr>
<td>1.2.6</td>
<td><strong>Perform TR modeling with Monte Carlo code OPENMC</strong></td>
<td>W. Martin, UM</td>
</tr>
<tr>
<td>1.2.7</td>
<td>Benchmark level evaluation of selected problems</td>
<td>T. Downar, UM</td>
</tr>
<tr>
<td>1.2.8</td>
<td>Evaluation of uncertainties in selected problems</td>
<td>T. Downar, UM</td>
</tr>
<tr>
<td>1.2.9</td>
<td>Preparation of IRPhE Documentation</td>
<td>T. Downar, UM</td>
</tr>
<tr>
<td>1.2.9</td>
<td>Submission of TR benchmark for peer review</td>
<td>T. Downar, UM</td>
</tr>
</tbody>
</table>
Questions?

That concludes my two-hour presentation. Any questions?

Did you intend the presentation to be incomprehensible, or do you have some sort of rare "PowerPoint" disability?

Are there any questions about the content?

There was content?
Extra Slides
INTERNATIONAL BENCHMARK PROGRAMS

Benchmark Evaluation Process

- Identify
- Verify
- Evaluate
- Compile
- Calculate
- Document

Peer Review (National and International Experts)

Comprehensive Source of Externally Peer Reviewed Integral Benchmark Data

Future Use

- Advanced Modeling and Simulation
- Analytical Methods Development, Validation, and Verification
- Reactor Design and Licensing
- Training
- Criticality and Reactor Safety Analysis
- Fuel Cycle and Related Activities
- Range of Applicability and Experiment Design
- Nuclear Data Refinement

External Data

- Externally Available Technical Journals & Reports
- Internal Reports Letters & Memos
- Logbooks
- Drawings
- Experimenter's Annotated Copy of Published Reports
- Experimenter's (Retired or Working on Other Projects)
- Facilities Awaiting D&D
International Handbook of Evaluated Reactor Physics Benchmark Experiments

March 2015 Edition

- 20 Contributing Countries
- Data from 143 Experimental Series
  - 139 Approved Benchmarks
  - 4 DRAFT Benchmarks

http://irphep.inl.gov/
http://www.oecd-nea.org/science/wprs/irphe/