Criticality benchmark of the Molten Salt Reactor Experiment

Massimiliano Fratoni | University of California, Berkeley

Molten Salt Reactor Workshop 2017 | Key Technology and Safety Issues for MSRs

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A peer-reviewed reactor physics benchmark for molten salt technologies is under development

- DOE NE awarded an NEUP to UC Berkeley, in collaboration with ORNL and the Grenoble Institute of Technology (France), to create an MSRE benchmark (October 2016)

- The target is to create a benchmark for the International Reactor Physics Benchmark Experiment Evaluation Project (IRPhEP) handbook
  - peer-reviewed set of reactor physics-related integral data
  - used by reactor designers to validate analytical tools for advanced reactors
  - used by safety analysts to establish the safety basis for operation of advanced reactors
The benchmark is based on a series of start-up zero-power experiments (June 1965)

- An initial criticality experiment measured the minimum amount of $^{235}$U needed to reach criticality.
- Measurements of the differential worth of one control rod as a function of position with stationary and circulating salt.
- Measurements of the integral worth of various control rod configurations.
- Criticality configurations obtained changing $^{235}$U concentration and control rod positions.
- Measurements with stationary and circulating salt conditions.
- Measurement of the whole core isothermal temperature reactivity coefficient.
- Measurement of the pressure reactivity coefficient.
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Creating a benchmark consists of two main tasks

- Create benchmark specifications
  - Retrieve data and related uncertainty
  - Make assumptions as needed

- Test the benchmark
  - Create and run one or more computational models
  - Assess uncertainties
Fuel geometry

FIG. 5.6.
TYPICAL GRAPHITE STRINGER ARRANGEMENT
Top components
Control rods and sample baskets
Outer core components
Core model

Horizontal cross section of the MSRE model

- Reactor vessel shell
- Cooling annulus Width = 2.54 cm
- Core can
- Control rod thimble location
- Vertical graphite stringer Side length = 5.08 cm
- Sample basket
Dowel section of graphite lattice

Horizontal cross section of the dowel section of the graphite lattice
Taper region

Horizontal cross section of the taper region
Control rods and sample baskets

Horizontal cross section of the control rods and sample baskets
Sample baskets
Control rods
Overall model
The benchmark model was tested on the first MSRE criticality experiment

- Fuel salt composition 65LiF-29.2BeF₂-5ZrF₄-0.8UF₄ (99.99% for ⁷Li enrichment).
- Fuel salt density 145.3 ± 1.0 lb/ft³ (2.3275 ± 0.0160 g/cm³)
- Mass fraction of ²³⁵U in the salt is 1.408 ± 0.007 wt%
- Core temperature 1,181°F (638°C)
- One rod was inserted at 46.6 in. position, other two rods at their upper limits

<table>
<thead>
<tr>
<th>Case</th>
<th>$k_{\text{eff}}$</th>
<th>$100(C-E)/E$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Benchmark</strong></td>
<td>1.0</td>
<td>-</td>
</tr>
<tr>
<td><strong>Calculated</strong> (SERPENT2, ENDF/B-VII.1 cross sections)</td>
<td>$1.01276 \pm 0.000098$</td>
<td>1.276</td>
</tr>
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</table>
Graphite density is the major source of uncertainties on $k_{\text{eff}}$

| Item                                      | Nominal and bounding values | $|\Delta k| \times 10^5$ |
|-------------------------------------------|-----------------------------|-------------------------|
| Graphite density                          | $(1.87 \pm 0.02)$ g/cm³     | 349                     |
| Fuel salt density                         | $(2.3275 \pm 0.0160)$ g/cm³| 83                      |
| $^{235}$U mass fraction in the salt       | $(1.408 \pm 0.007)$ wt%    | 61                      |
| INOR-8 density                            | $(8.7745 \pm 0.0200)$ g/cm³| 9                       |
| Graphite core height                      | $(166.446 \pm 1)$ cm       | 19                      |
| Graphite core radius                      | $(70.168 \pm 0.2)$ cm      | 13                      |
| Fuel channel width                        | $(1.016 \pm 0.127)$ cm     | 100                     |
| Fuel channel length                       | $(3.048 \pm 0.127)$ cm     | 42                      |
| $^6$Li enrichment                         | $(0.01 \pm 0.001)$ at. %   | 174                     |
| Boron concentration in graphite           | $(0.00008 \pm 0.000008)$ wt. % | 18                     |
| Outlet pipe height                        | $39.687$ cm ($1\sigma = 4$ cm) | 31                     |
| Distributor thickness                     | $0.819$ cm ($1\sigma = 0.08$ cm) | 29                     |
| Sample basket shell dimension             | remove one INOR-8 plate    | 16                      |
| INOR-8 composition                        | $0.06\%$ (C mass fraction), $0.08\%$ | 10                     |
| Total (root mean square)                  |                             | 422                     |
The largest sensitivity coefficients for $k_{\text{eff}}$ from cross section data uncertainties are for C and $^{235}\text{U}$.

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Total</th>
<th>Elastic scattering</th>
<th>Disappearance</th>
<th>Fission</th>
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<tbody>
<tr>
<td>Li-6</td>
<td>-0.0286</td>
<td>0.0000</td>
<td>-0.0286</td>
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<tr>
<td>Li-7</td>
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<tr>
<td>Be-9</td>
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<td>0.0283</td>
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<tr>
<td>Zr-90</td>
<td>0.0014</td>
<td>0.0018</td>
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<tr>
<td>Zr-91</td>
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<td>Zr-92</td>
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<td>0.0001</td>
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<tr>
<td>Zr-96</td>
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<td>U-235</td>
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<td>U-238</td>
<td>-0.0857</td>
<td>0.0056</td>
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<td>0.0006</td>
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</tbody>
</table>
Conclusions

- A set of benchmarks based on the MSRE is under development
- The evaluations will include multiple benchmarks following the zero-power experiments campaign of June 1965
- A draft benchmark of the first criticality obtained varying $^{235}$U concentration with steady salt is under review for inclusion in the Reactor Physics Benchmark Experiment Evaluation Project (IRPhEP) Handbook
- If you are interested in the draft benchmark email us: maxfratoni@berkeley.edu
Acknowledgements

Evaluators

Dan Shen
UC Berkeley

Germina Ilas
ORNL

Jeff Powers
ORNL

Internal reviewer

Adrien Bidaud
Grenoble Institute of Technology, France

External reviewer

Luka Snoj
Jozef Stefan Institute, Slovenia
References


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