Hybrid Technique in SCALE for Fission Source Convergence Applied to Used Nuclear Fuel Analysis

Ahmad M. Ibrahim, Douglas E. Peplow, Kursat B. Bekar, Cihangir Celik, John M. Scaglione, Dan Ilas, John C. Wagner

Presented By
Kaushik Banerjee

Reactor and Nuclear Systems Division, ORNL

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Agenda

• Objective of this work

• Canister-specific criticality safety analyses using UNF-ST&DARDS

• Methodology - SOURCERER

• Application of SOURCERER to canister-specific used nuclear fuel problems

• Conclusion and future work
Objective

• Used nuclear fuel criticality safety analyses
  – Reliability
  – Improved reliability @ lower computational expense

• Reliability can be ensured by the fission source convergence using SOURCERER sequence in SCALE
  – Important for As-loaded Used nuclear fuel criticality safety analyses
  – May not be important for licensing criticality assessment
Significance of Canister-specific (as-loaded) analysis and source convergence

- Dry storage systems are robust in design
- Extended storage time and irradiation of nuclear fuel to high-burnup values (>45 GWd/MTU) introduce increased aging related uncertainties
- Licensing calculations are bounding in nature
- Cask specific analysis using as-loaded fuel may be used to offset extended storage (and subsequent transportation) related uncertainties
- UNF-ST&DARDS - UNF-Storage, Transportation & Disposal Analysis Resource and Data System (under development)
- ~1800 loaded canisters in the US × 20 time steps = 36,000 criticality safety calculations
  - Requires reliable, automated and relatively inexpensive methodology
NAC-UMS-TSC-24 – Problem used for this work

Cut-away view

Assemblies Initial enrichment, burnup, and discharge date

- Difficult to capture most reactive regions
  - Small reactivities differences between outer assemblies
- Assemblies decoupled by flux traps and water
Convergence problems of NAC-UMS-TSC-24

- Difficult to capture most reactive regions
- Decoupling due to water and flux traps

$k_{eff}$ with uniform starting source

$\kappa_{ref} - \kappa_{calc} = 7.7\sigma$

30K neutron/cycle

Unaffordable computer and human resources required to ensure reliability of canister-specific calculations
Best practices$^1$

- To prevent bias in $k_{\text{eff}}$, use sufficient number of neutrons per cycle
- Sufficient initial cycles (skipped cycles) must be discarded prior to beginning the tallies
- Essential to monitor convergence of both source distribution and $k_{\text{eff}}$, not just $k_{\text{eff}}$
- Shannon entropy$^2$ was shown to be effective in characterizing source convergence for $k_{\text{eff}}$
  - Can be used to determine number of skipped cycles

Sourcerer

- User input
- CSAS/KENO input
- detSource block
  - Automatic mapping of KENO geometry on user-defined grid
  - Materials mixing (macromaterials) using a volume weighted average of the materials in the MC model

SCALE Driver

DEVC
(Denovo EigenValue Calculation)

detSource block
- Denovo library
- Denovo mesh
- Denovo parameters

Fission starting source

Fluxes

CSAS/KENO

Ibrahim et. al, "Acceleration of Monte Carlo Criticality Calculations Using Deterministic-Based Starting Sources," PHYSOR 2012
Parameters used

• Deterministic
  • $5 \times 5\times10$ cm$^3$ mesh
  • Tight tolerance
    — $10^{-5}$ in the Krylov iterations
    — $10^{-6}$ in the outer eigenvalue iterations
    — 3.89 hr
  • Loose tolerance
    — $10^{-3}$ for both Krylov and outer iterations
    — 1.1 hr

• Monte Carlo
  • 30,000 particles par cycle
  • Other parameters are studied
  • Reference calculation: 10 independent KENO calculations with 100,000 neutrons per cycle, 500 skipped and 1000 active cycles
Reliability

Frequency of **not** calculating $k_{\text{eff}}$ inside confidence interval

$$k_{\text{ref}} - 3\sigma < k_{\text{calc}} < k_{\text{ref}} + 3\sigma$$

Reliability of uniform source is comparable with the reliability of deterministic source after skipping 350 cycles

30,000 Neutrons per cycle and 500 active cycles

100 independent (different random seed) calculations for each point
Efficiency

Step 1: Determination of number of skipped cycle

Skipped cycles are determined from the number of cycles after which the entropy falls inside a band determined by the average and the population standard deviation of the entropy of 1000 cycles. These 1000 cycles are counted after 750 cycles for uniform and 200 cycles for deterministic source.
Step 2: skipped cycle from step 1 and uncertainty threshold of 0.00025 is used to determine the active cycles.

Speedup = \( \frac{\text{MC Time}}{\text{MC Time} + \text{Deterministic Time}} \)

<table>
<thead>
<tr>
<th>Starting source</th>
<th>( k_{\text{eff}} )</th>
<th>Speedup</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uniform</td>
<td>0.68977 ± 0.00025</td>
<td>1.00</td>
</tr>
<tr>
<td>Loose</td>
<td>0.68944 ± 0.00024</td>
<td>1.71</td>
</tr>
<tr>
<td>Tight</td>
<td>0.68900 ± 0.00024</td>
<td>1.36</td>
</tr>
</tbody>
</table>

- 70% speedup
- Deterministic accuracy not critical
Efficiency

\( k_{\text{eff}} \) with 500 active cycles

![Graph showing \( k_{\text{eff}} \) vs. Number of Skip Cycles for different conditions: Reference, Tight, Loose, Uniform.](image)
Conclusion and Future Work

• The hybrid source convergence methodology using SOURCERER sequence of SCALE is applied to criticality analysis of as-loaded UNF cask

• SOURCERER uses deterministic-based starting sources
  – Easier for users: No need of guessing!
  – Reliability: SOURCERER increases probability of obtaining right answer.
  – Efficiency: Right answer using less computer time

• Future work:
  – Importance of deterministic parameters
  – Implementation in UNF-ST&DARDS