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

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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

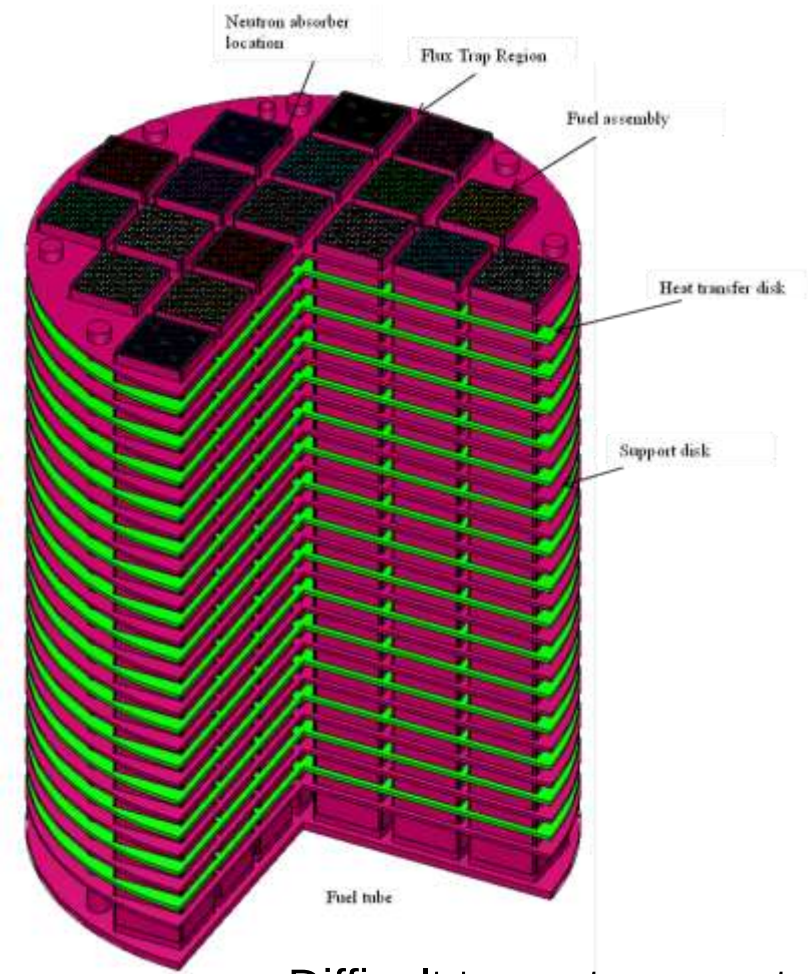
- Used nuclear fuel criticality safety analyses
  - Reliability
  - Improved reliability @ lower computational expense
- Reliability can be ensured by the fission source convergence using SOURCERER sequence in SCALE
  - Important for As-loaded Used nuclear fuel criticality safety analyses
  - May not be important for licensing criticality assessment

Significance of Canister-specific (as-loaded) analysis and source convergence

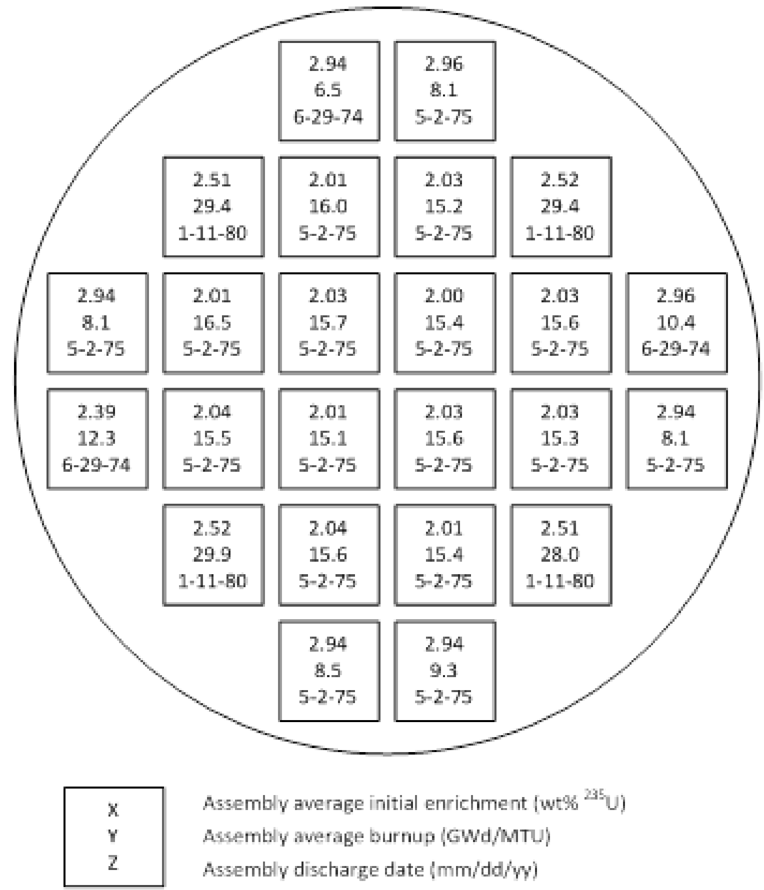
- Dry storage systems are robust in design
- Extended storage time and irradiation of nuclear fuel to high-burnup values (>45 GWd/MTU) introduce increased aging related uncertainties
- Licensing calculations are bounding in nature
- Cask specific analysis using as-loaded fuel may be used to offset extended 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

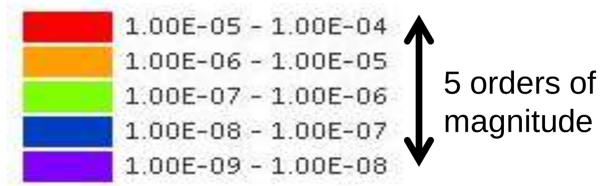


- Difficult to capture most reactive regions
  - Small reactivities differences between outer assemblies
- Assemblies decoupled by flux traps and water

Convergence problems of NAC-UMS-TSC-24

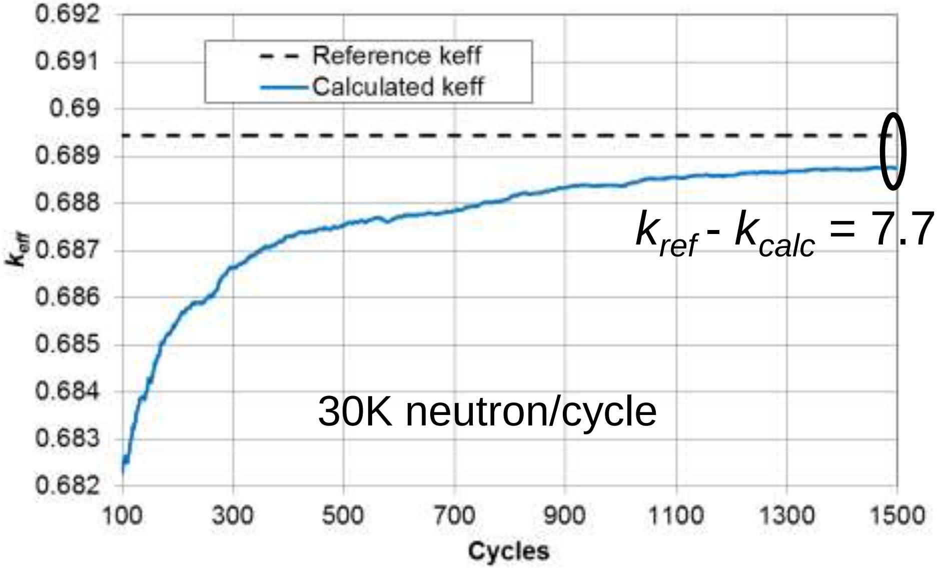
- **Difficult to capture most reactive regions**
- **Decoupling due to water and flux traps**

Reference fission source distribution



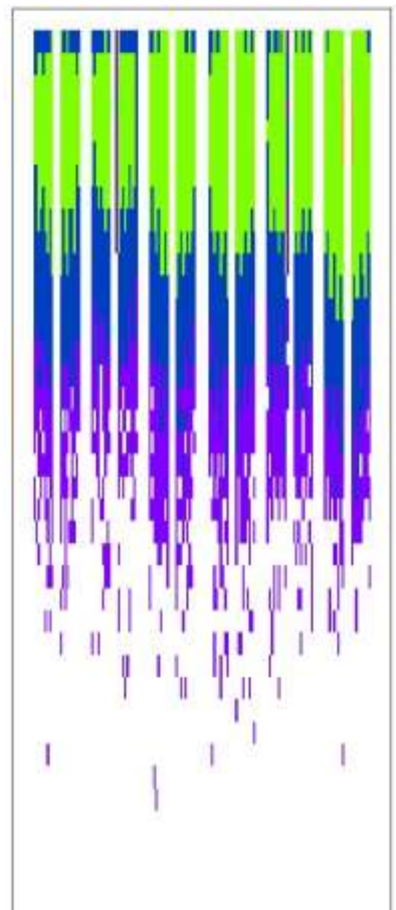
Difficulties in adequately sampling most reactive regions

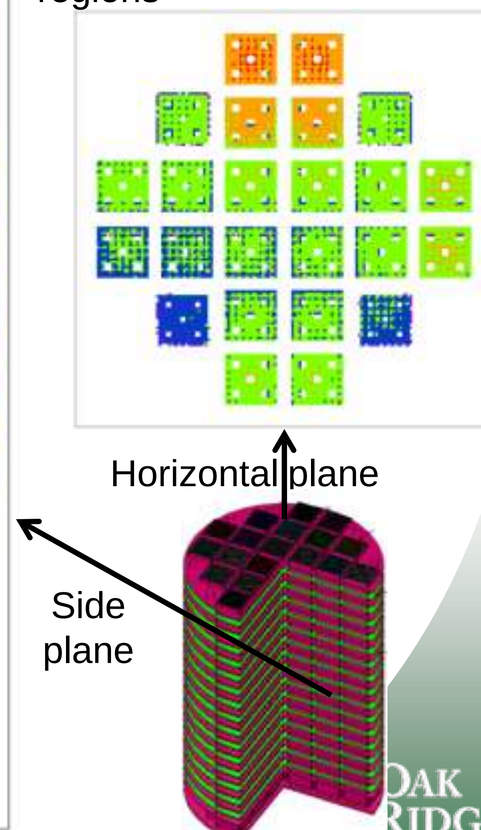
k_{eff} with uniform starting source



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

30K neutron/cycle





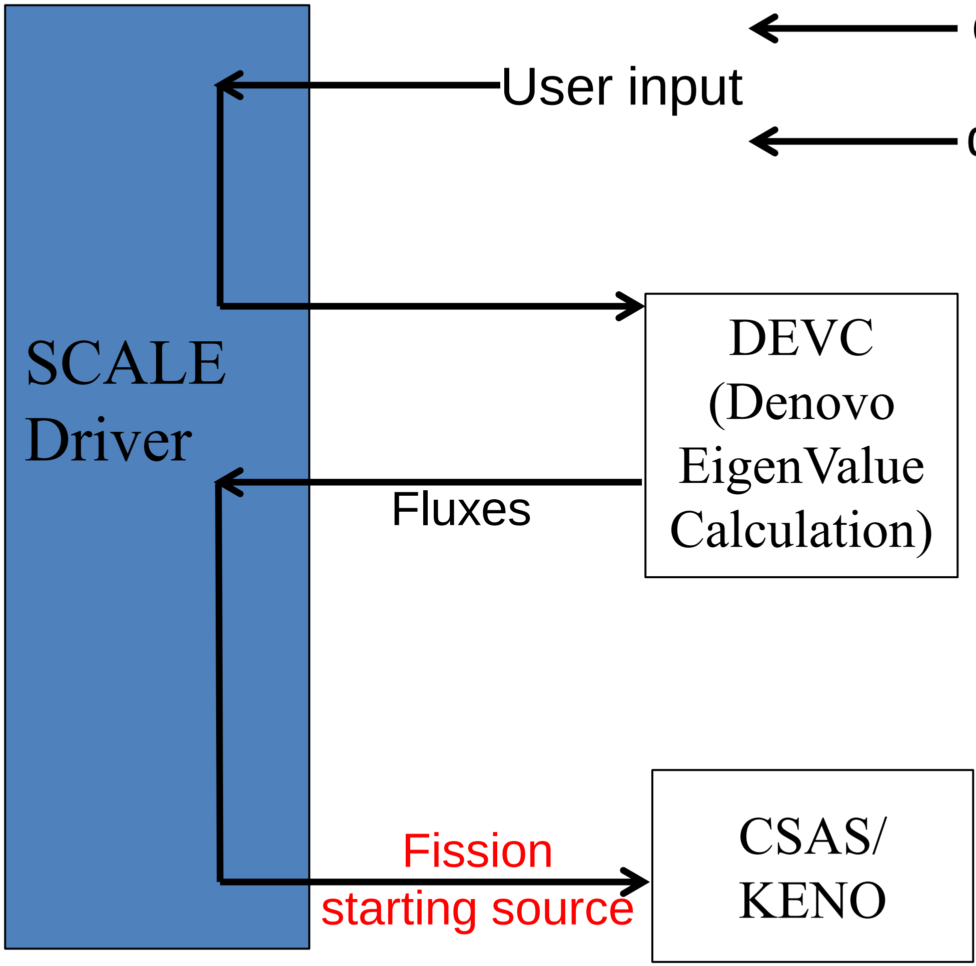
Unaffordable computer and human resources required to ensure reliability of canister-specific calculations

Best practices[1]

- To prevent bias in k_{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_{eff}, not just k_{eff}
- Shannon entropy[2] was shown to be effective in characterizing source convergence for k_{eff}
  - Can be used to determine number of skipped cycles

1. F. Brown, "A Review of Best Practices for Monte Carlo Criticality Calculations," LANL report, LA-UR-09-3136 (2009).
2. Taro Ueki, "Stationary Modeling and Informatics-Based Diagnostics in Monte Carlo Criticality Calculations," *NSE*, **149**, 38(2005).

Sourcerer



<u>detSource block</u>

- Denovo library
- Denovo mesh
- Denovo parameters

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

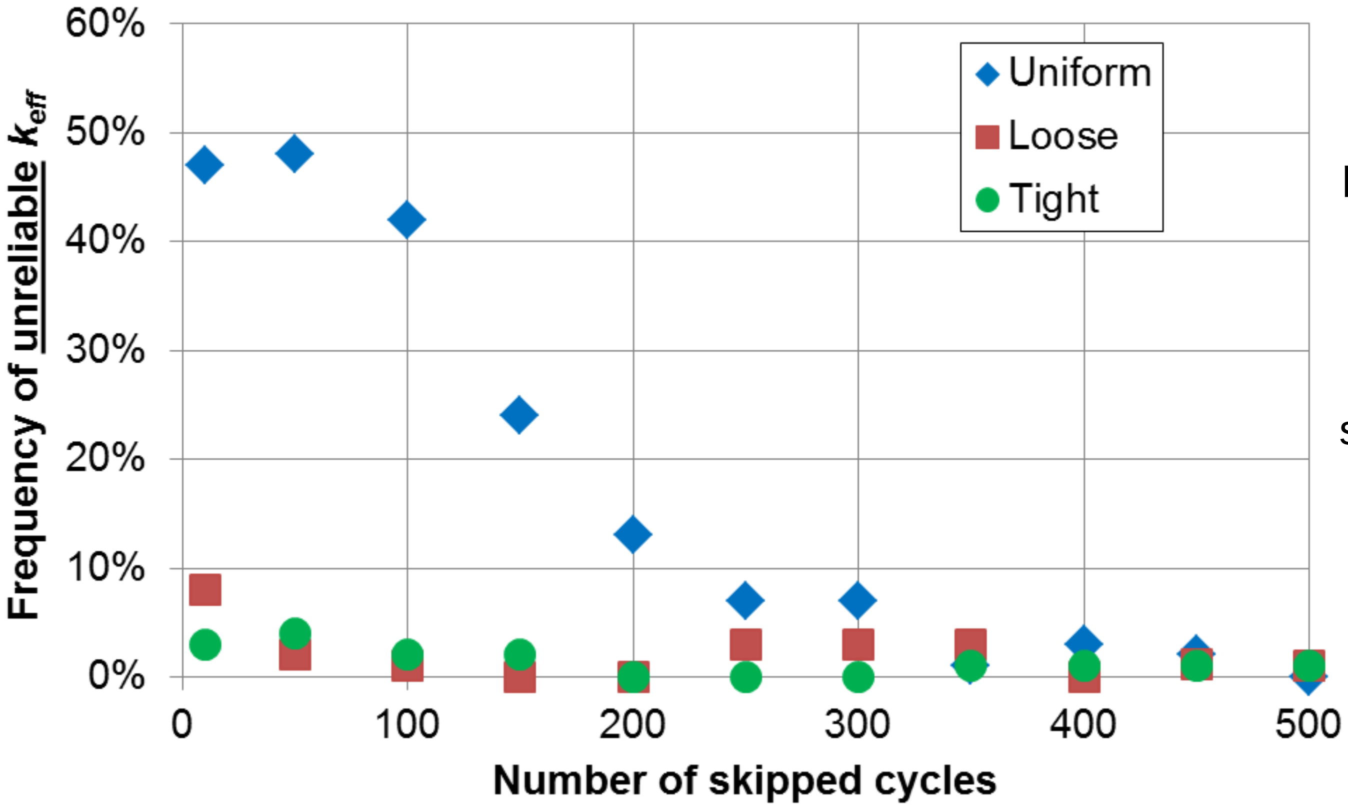
Ibrahim et. al, "Acceleration of Monte Carlo Criticality Calculations Using Deterministic-Based Starting Sources," PHYSOR 2012

Parameters used

- **Deterministic**
  - **5 ×5×10 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_{eff} inside confidence interval
$k_{ref} - 3\sigma < k_{calc} < k_{ref} + 3\sigma$



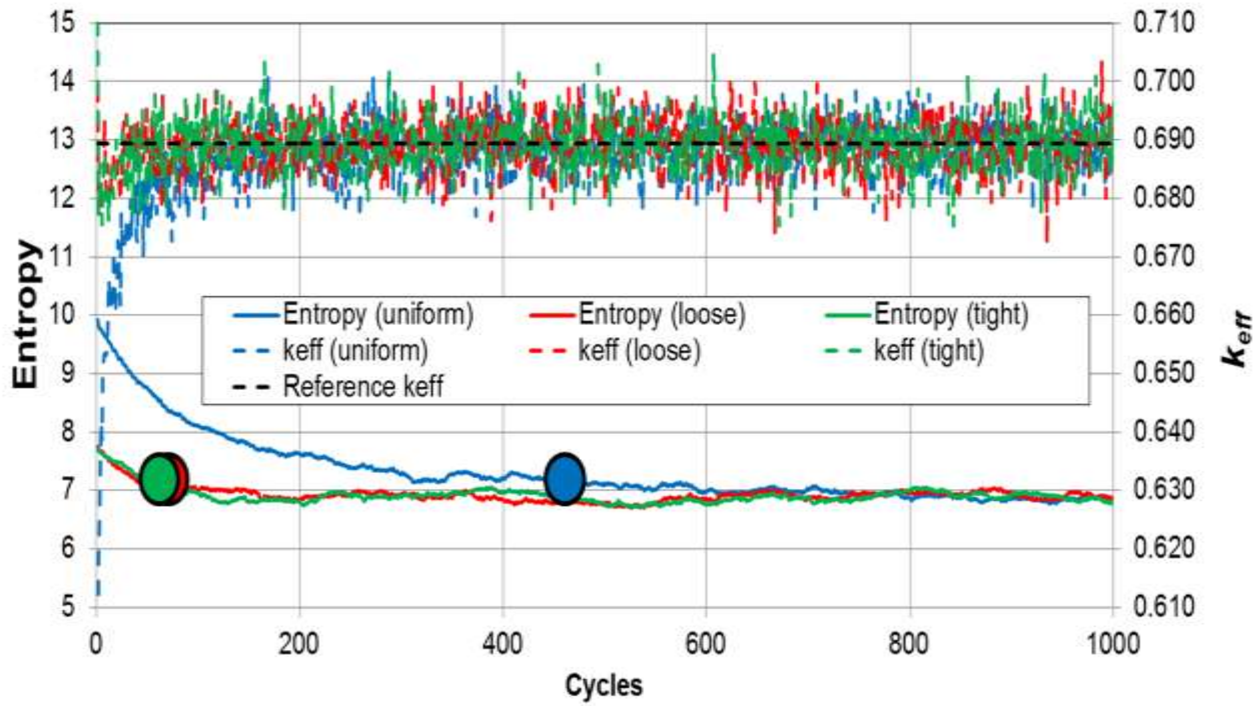
30,000 Neutrons per cycle and 500 active cycles

100 independent (different random seed) calculations for each point

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

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.

Efficiency

Step 2: skipped cycle from step 1 and uncertainty threshold of 0.00025 is used to determine the active cycles.

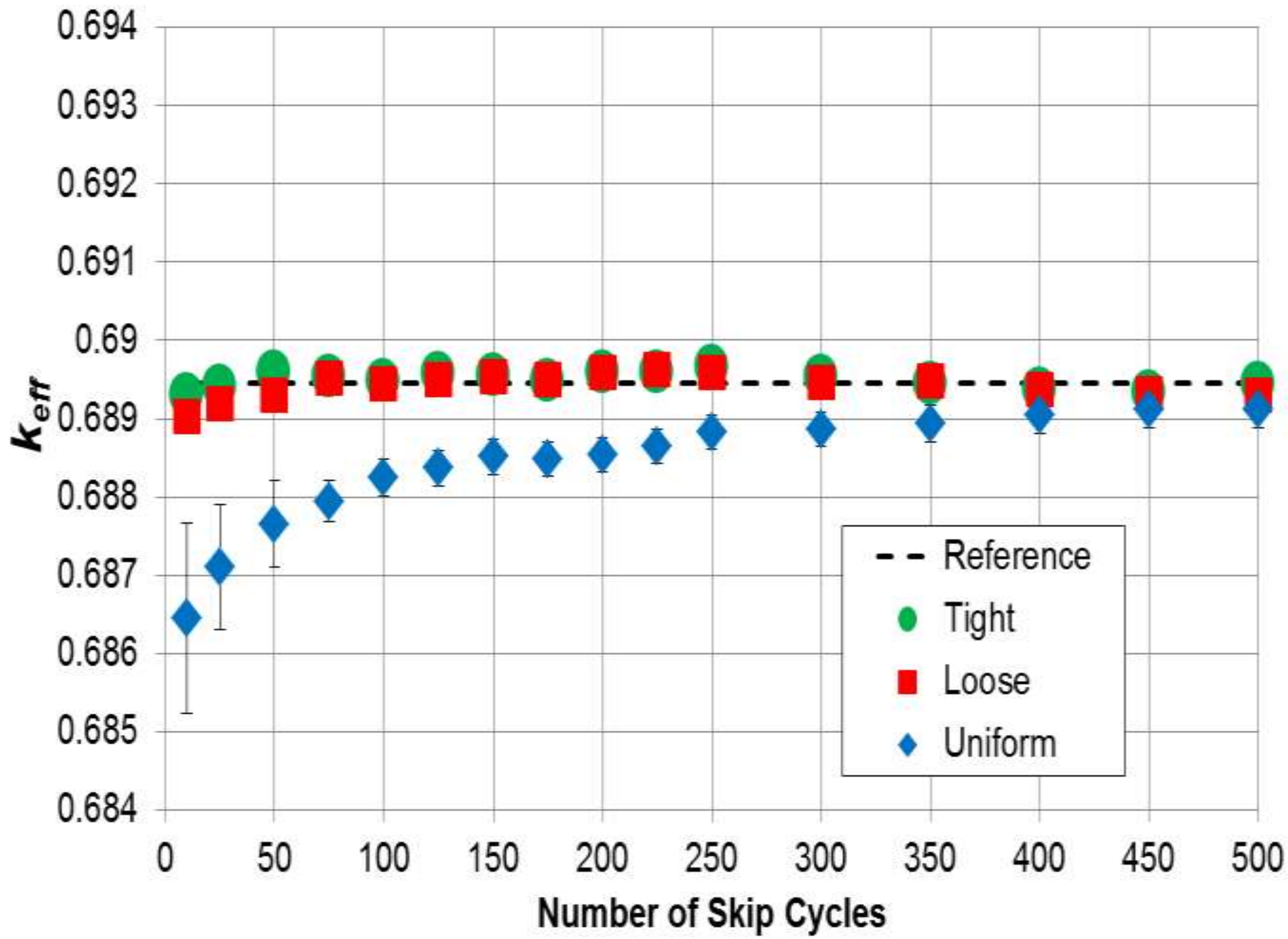
Speedup =(MC Time)/(MC Time + Deterministic Time)

Starting source	k_{eff}	Speedup
Uniform	0.68977 ± 0.00025	1.00
Loose	0.68944 ± 0.00024	**1.71**
Tight	0.68900 ± 0.00024	1.36

- 70% speedup
- Deterministic accuracy not critical

Efficiency

k_{eff} with 500 active cycles



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