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Title: Testing Random Number Strides for Criticality Problems

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Testing Random Number Strides for Criticality Problems

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Introduction

- The random number stride is the number of random numbers allocated for each history. The default stride in MCNP (version >= 4) is 152,917.

- The MCNP6.3 user manual states: "generally, strides of around 4,000 are reasonable for criticality problems, while the default stride or greater may be needed for problems with heavy variance reduction."
  - This statement is not present in previous MCNP manuals.

- This presentation shows the MCNP6.3 results for 31 benchmark problems from the International Criticality Safety Benchmark Evaluation Project (ICSBEP) Handbook, using stride = 152,917 and stride = 3,999.

Random Numbers

- Random numbers are essential for the functioning of the MCNP code.

- Random numbers are typically used:
  - To determine source particle parameters (position, direction, energy, and/or time)
  - To simulate the stochastic processes of particle and material interactions.
  - To sample various probability distributions that describe physical processes, such as, scattering angles, energy loss during interactions, and the distance between collisions.
  - In variance reduction methods.
  - To generate the large number of samples needed to achieve statically significant results.
  - To enable the quantification of uncertainties in the simulations results. For example, running multiple simulations with different random seeds to assesses the variability in the results.

Random Number Information in MCNP Output Files

```
*****************************************************
* Random Number Generator  =                    1 *
* Random Number Seed       =       19073486328125 *
* Random Number Multiplier =       19073486328125 *
* Random Number Adder      =                    0 *
* Random Number Bits Used  =                   48 *
* Random Number Stride     =               152917 *
*****************************************************
```

Random number information is written in an MCNP output file.

- The total number of random numbers generated and the maximum number of random numbers used are recorded in an MCNP output file (in **1problem summary**).

random numbers generated	28577606	
most random numbers used was	562 in history	546912

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Random Number Generators

- The random number generators (RNG) used in the MCNP code were designed and tested to produce high-quality random numbers.
  - Pass statistical tests for randomness and ensure repeatability and reproducibility, essential for verifying and validating simulations results.
  - Produce a long sequence of random numbers but eventually the sequence repeats. Use the stride to skip ahead.

- The RAND card can be used to set the random number generator parameters.
  - **GEN** (Default: GEN=1)
    - 1 for a period of 7E13 numbers, 2 for a period of 9.2E18 numbers, …
  - **SEED (**Default: SEED = 5^{19} = 19073486328125)
  - **STRIDE (**Default: stride=152917)
  - **HIST (**Default: HIST=1**)**

- **GEN=8 is a new feature in MCNP6.3.1. Do not use the stride.**

Notes on RAND Card in MCNP6.3 User Manual

- If the period is exceeded, random numbers will be reused, but the random number sequence used for subsequent histories will differ from the random number sequence used for previous histories. There should be no impact on results.

- Decreasing the stride will reduce the chances of exceeding the period but may cause reuse of random numbers if the stride is exceeded.

- Generally, strides of 4000 or so are reasonable for criticality problems, while the default stride or greater may be needed for problems with heavy variance reduction.

Warning Messages in MCNP Output File

If the period is exceeded, MCNP writes a warning message into an output file.

warning.   random number period exceeded. decrease stride.

If the stride is exceeded, MCNP writes a warning message and the number of histories for which the random number stride is exceeded into an output file.

warning.   random number stride   152917 exceeded   396 times.

- A longer period should be used for a problem with a large number of histories.
  - GEN=1 STRIDE=152917: 7E13/152917 ~ 4.5E8
  - GEN=2 STRIDE=152917: 9.2E18/152917 ~ 6.0E13
  - GEN=2 STRIDE=92000: 9.2E18/92000 = 1E14

Random Number Stride

- The old random number stride was 4,297. The current default stride of 152,917 was adopted in MCNP4. The reason for this change was that the previous stride of 4,297 was too small for some problems (LA-UR-90-1845).
- The the stride is exceeded, the MCNP results can vary: some problems produced statistically valid outcomes, while others yielded incorrect results (LA-UR-90-1845, LA-UR-14-23159).
- **It is crucial for users to verify the reliability of the MCNP results when the stride is exceeded, as the accuracy can depend on the specific problem being analyzed.**

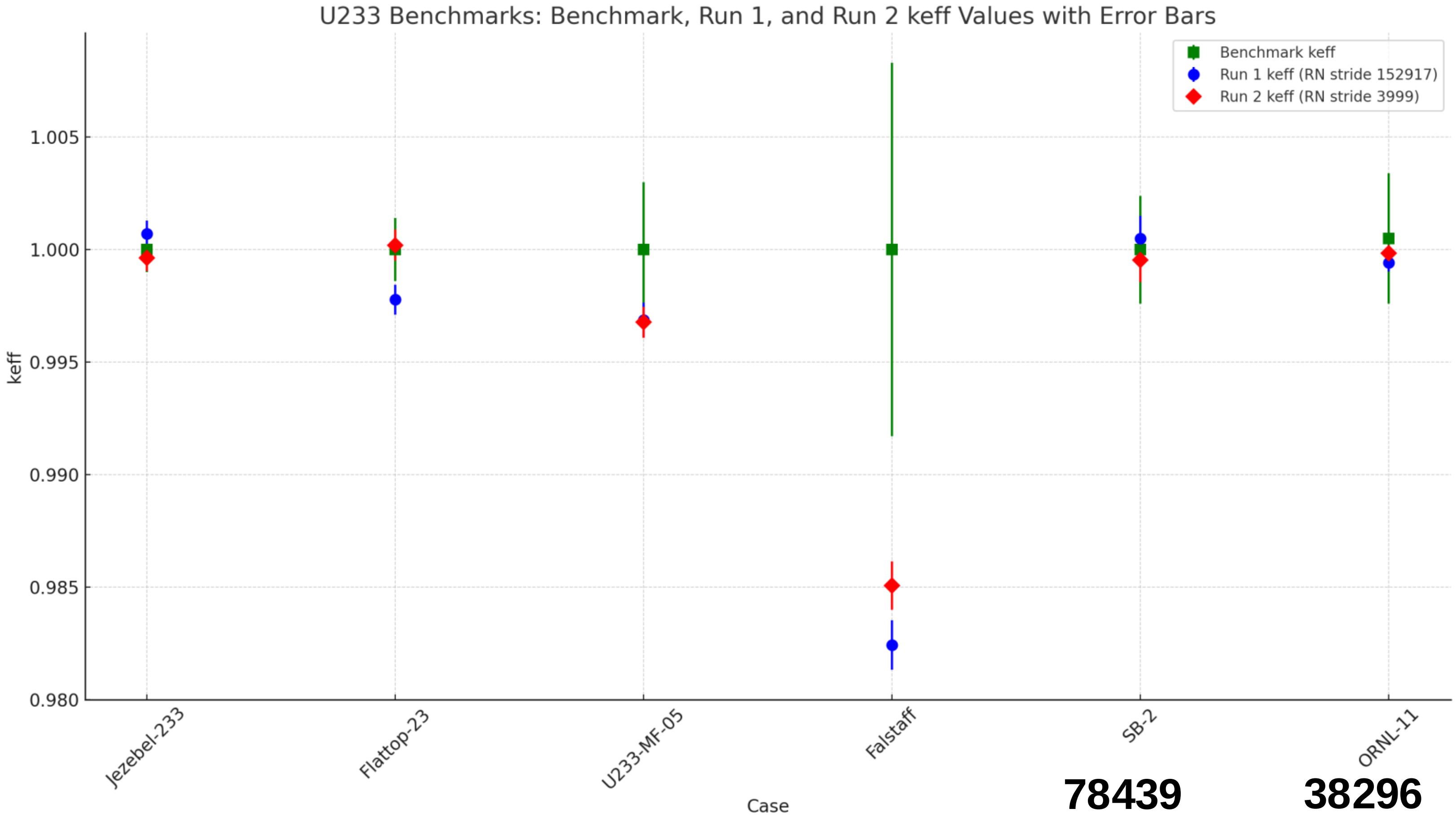
MCNP Calculations

- 31 criticality problems from from the International Criticality Safety Benchmark Evaluation Project (ICSBEP) Handbook.

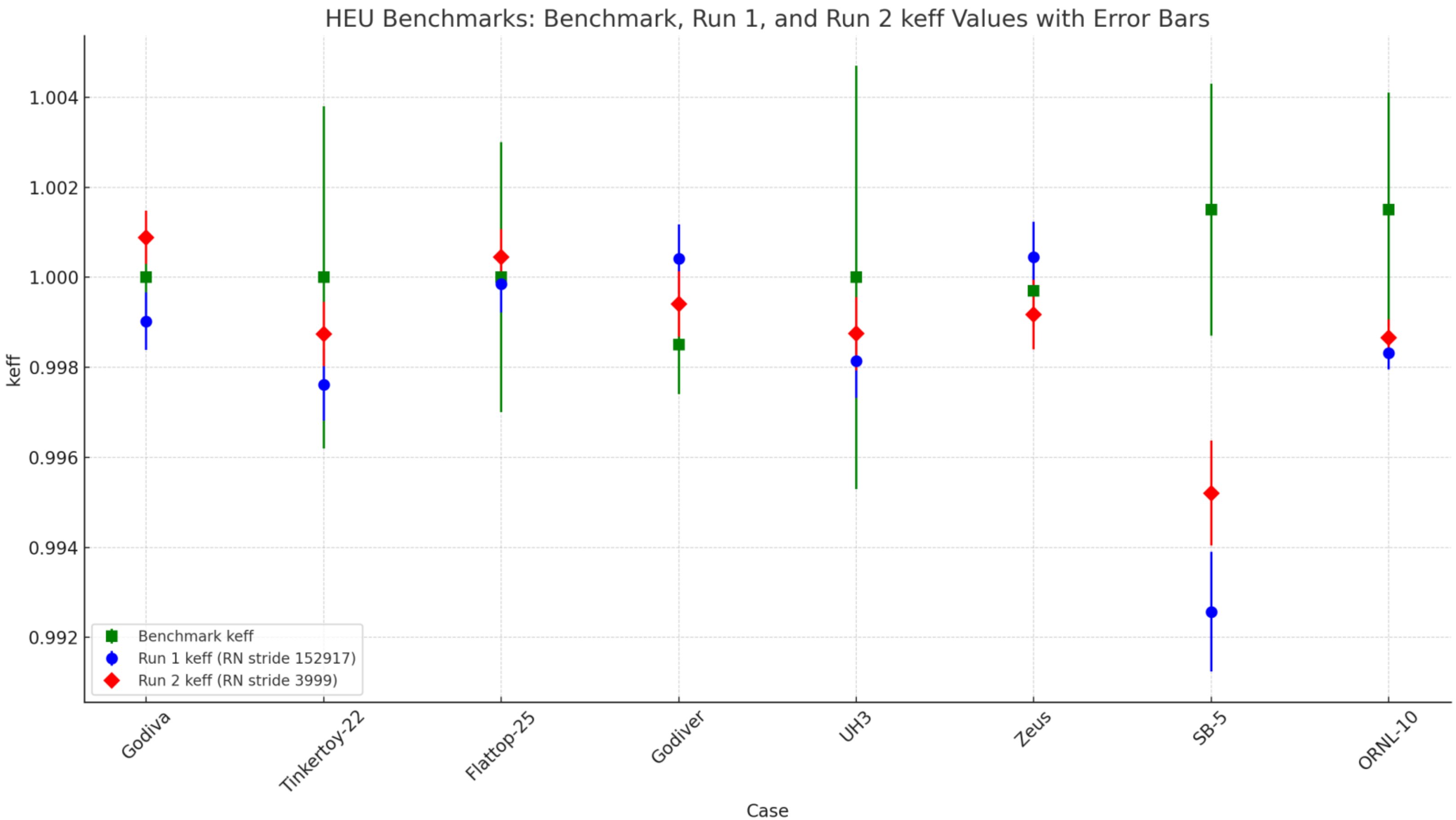
- Two run types:
  - STRIDE = 152917 and STRIDE = 3999
  - Other input parameters are the same.

- Run on LANL’s HPC (rocinante): mixed MPI and OpenMP

- For several test problems, the stride of 3,999 was exceeded, while the stride of 152,917 was not exceeded for any test problems. However, the KEFF values of both test sets were statistically consistent with the benchmark values.

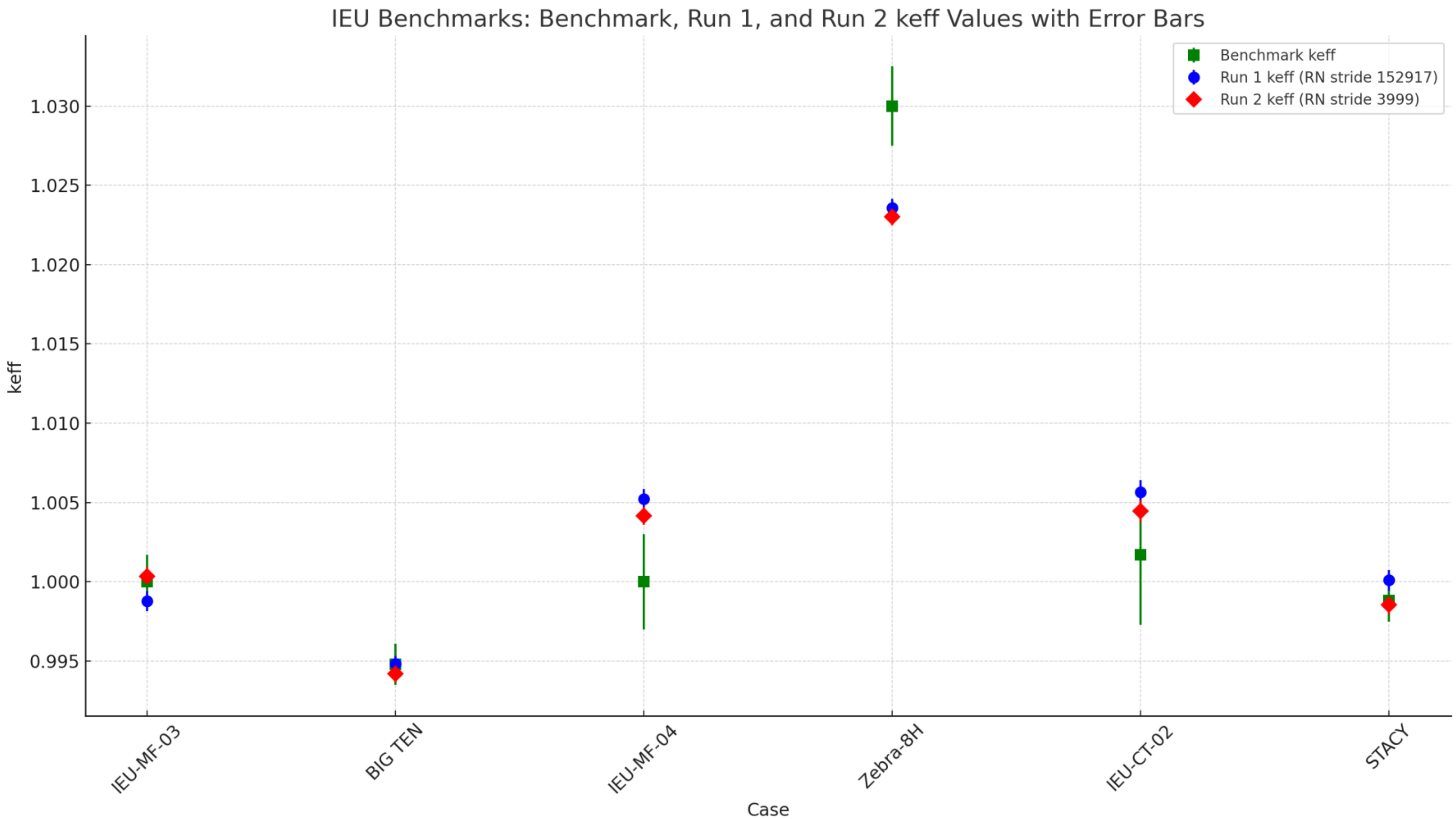


*Case name is from Table 2 in LA-UR-04-6489. The number of histories for which the stride of 3,999 is exceeded is shown in **bold**.*



36532 **84004** **18504** **23246**

Case name is from Table 2 in LA-UR-04-6489. The number of histories for which the stride of 3,999 is exceeded is shown in ***bold****.*



3 **137** **13450** **112**

*Case name is from Table 2 in LA-UR-04-6489. The number of histories for which the stride of 3,999 is exceeded is shown in **bold**.*

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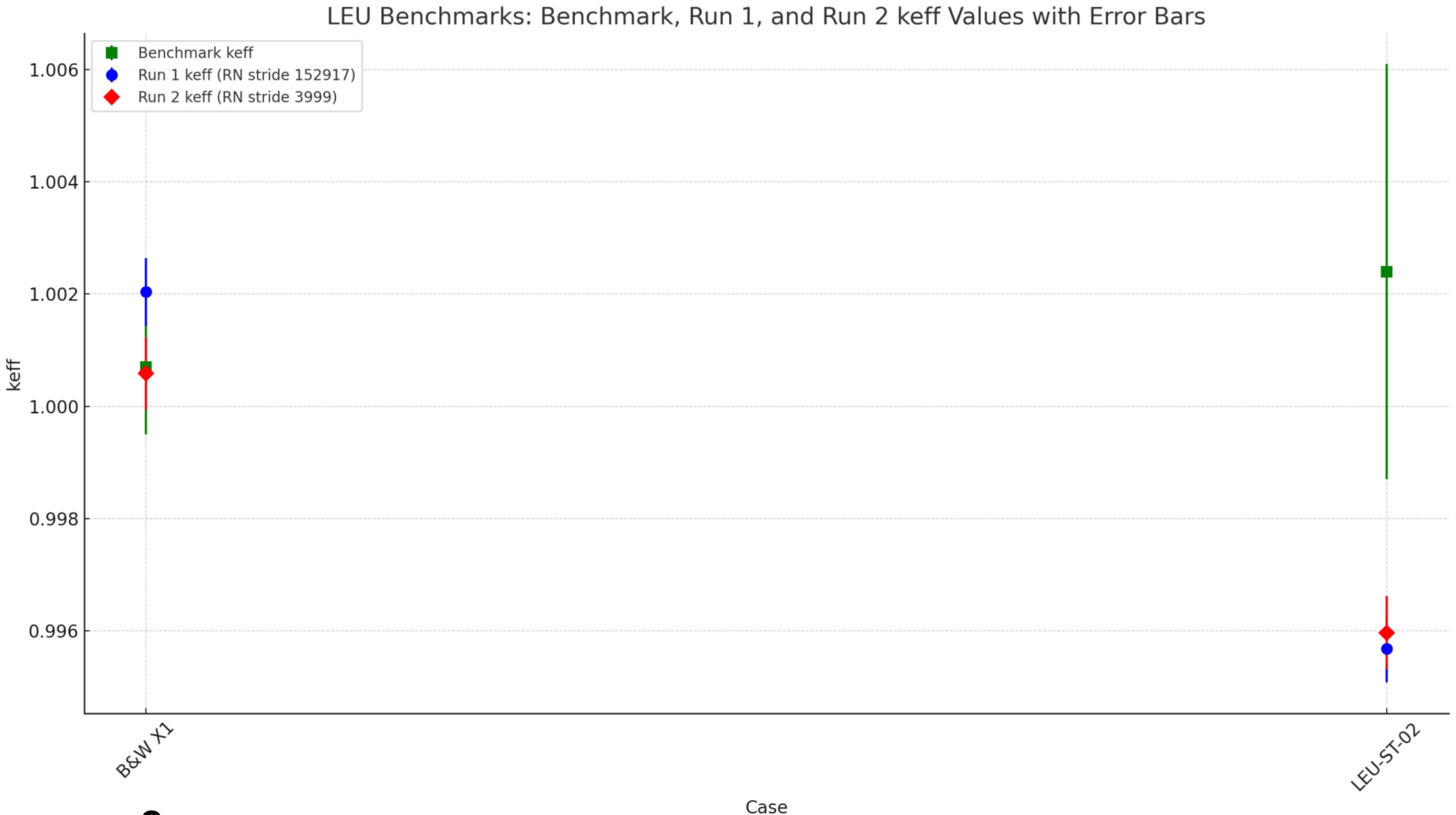
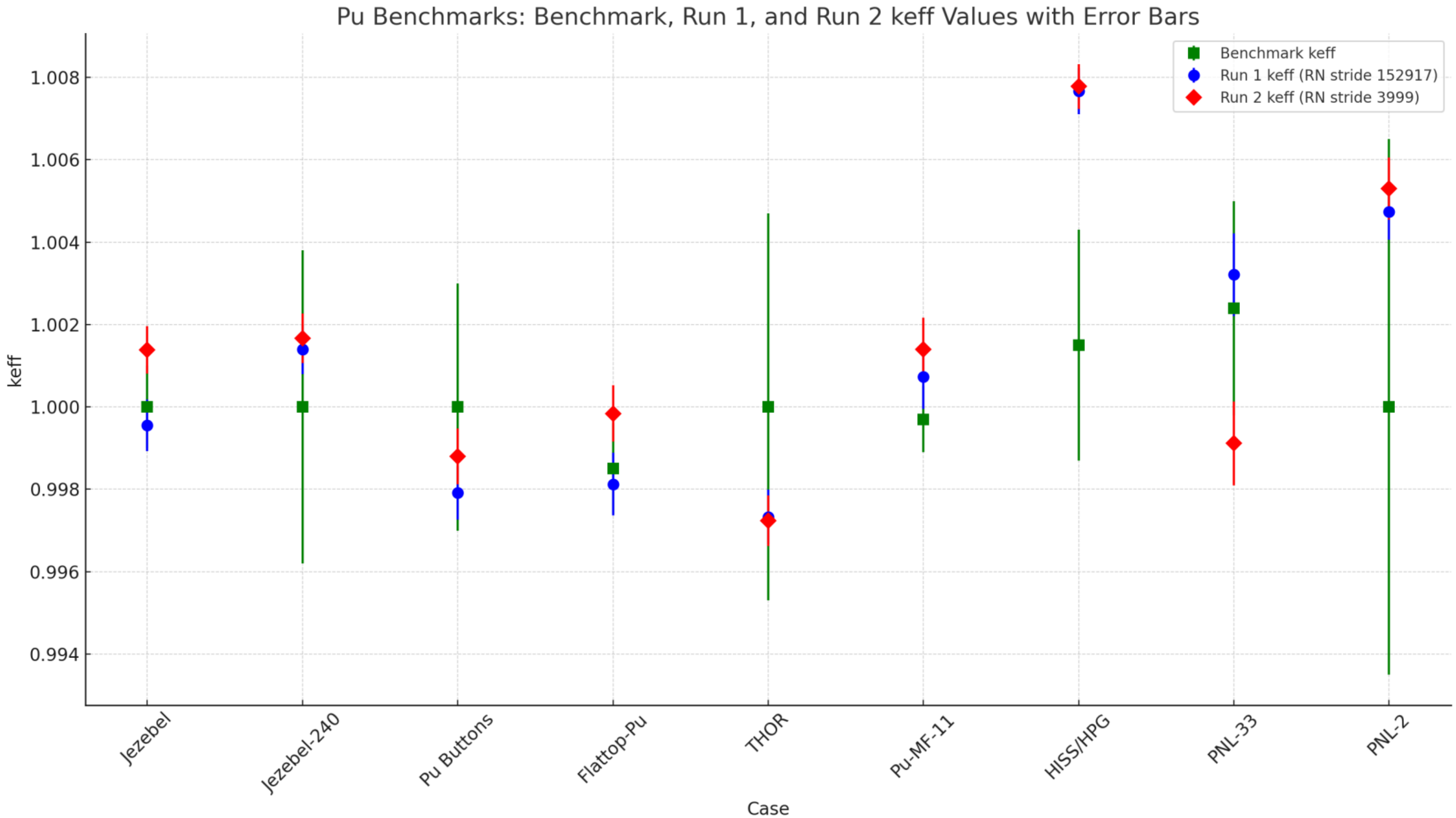


3

2050

Case name is from Table 2 in LA-UR-04-6489. The number of histories for which the stride of 3,999 is exceeded is shown in ***bold****.*



96075

70

Case name is from Table 2 in LA-UR-04-6489. The number of histories for which the stride of 3,999 is exceeded is shown in ***bold****.*

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Conclusions

- Using the stride of 3,999 yields results that are comparable to the default stride of 152,917 across various benchmark categories (U233, HEU, IEU, LEU, Pu).

- It is known that exceeding the stride may affect the reliability and accuracy of MCNP results for some problems.

- It is recommended that users select the stride value based on the complexity of their simulations and carefully monitor the exceeded random stride warning message in the MCNP output file.
  - Monitoring and managing random number strides is essential for setting up reliable MCNP simulations.

- **A new feature in MCNP6.3.1 eliminates the concept of strides and random number reuse (RAND GEN=8).**

References

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Questions?

Additional Slides

U233 Benchmarks

Case	Benchmark keff	Run 1 keff	Run 2 keff	exceed
Jezebel-233	1.0000 ± 0.0010	1.000718 ± 0.000581	0.999634 ± 0.000577	
Flattop-23	1.0000 ± 0.0014	0.997786 ± 0.000666	1.000207 ± 0.000686	
U233-MF-05 (2)	1.0000 ± 0.0030	0.996887 ± 0.000761	0.996777 ± 0.000694	
Falstaff (1)	1.0000 ± 0.0083	0.982427 ± 0.001093	0.985067 ± 0.001079	
SB-$2^1/_2$	1.0000 ± 0.0024	1.000509 ± 0.001007	0.999533 ± 0.000968	78439
ORNL-11	1.0005 ± 0.0029	0.999421 ± 0.000387	0.999850 ± 0.000347	38296

Case name is from Table 2 in LA-UR-04-6489. Run 1: RN stride = 152917; Run 2: RN stride = 3999. The number of particle histories for which stride=3999 is exceeded is shown in the last column.

HEU Benchmarks

Case	Benchmark keff	Run 1 keff	Run 2 keff	exceed
Godiva	1.0000 ± 0.0010	0.999026 ± 0.000641	1.000885 ± 0.000593	
Tinkertoy-22 (11)	1.0000 ± 0.0038	0.997611 ± 0.000795	0.998739 ± 0.000710	36532
Flattop-25	1.0000 ± 0.0030	0.999852 ± 0.000637	1.000452 ± 0.000623	
Godiver	0.9985 ± 0.0011	1.000411 ± 0.000764	0.999404 ± 0.000729	84004
UH_3 (6)	1.0000 ± 0.0047	0.998138 ± 0.000814	0.998748 ± 0.000813	
Zeus (2)	0.9997 ± 0.0008	1.000447 ± 0.000792	0.999172 ± 0.000771	
SB-5	1.0015 ± 0.0028	0.992572 ± 0.001333	0.995207 ± 0.001169	18504
ORNL-10	1.0015 ± 0.0026	0.998318 ± 0.000358	0.998654 ± 0.000409	23246

Case name is from Table 2 in LA-UR-04-6489. Run 1: RN stride = 152917, Run 2: RN stride = 3999. The number of particle histories for which stride=3999 is exceeded is shown in the last column.

IEU Benchmarks

Case	Benchmark keff	Run 1 keff	Run 2 keff	exceed
IEU-MF-03	1.0000 $\pm$ 0.0017	0.998772 $\pm$ 0.000624	1.000328 $\pm$ 0.000616	
BIG TEN	0.9948 $\pm$ 0.0013	0.994839 $\pm$ 0.000475	0.994194 $\pm$ 0.000521	3
IEU-MF-04	1.0000 $\pm$ 0.0030	1.005228 $\pm$ 0.000627	1.004167 $\pm$ 0.000561	
Zebra-8H	1.0300 $\pm$ 0.0025	1.023567 $\pm$ 0.000580	1.023014 $\pm$ 0.000541	137
IEU-CT-02 (3)	1.0017 $\pm$ 0.0044	1.005655 $\pm$ 0.000763	1.004443 $\pm$ 0.000698	13450
STACY (36)	0.9988 $\pm$ 0.0013	1.000098 $\pm$ 0.000658	0.998564 $\pm$ 0.000616	1112

Case name is from Table 2 in LA-UR-04-6489. Run 1: RN stride = 152917, Run 2: RN stride = 3999. The number of particle histories for which stride=3999 is exceeded is shown in the last column.

LEU Benchmarks

Case	Benchmark keff	Run 1 keff	Run 2 keff	exceed
B&W X1 (2)	1.0007 $\pm$ 0.0012	1.002038 $\pm$ 0.000605	1.000585 $\pm$ 0.000644	3
LEU-ST-02 (2)	1.0024 $\pm$ 0.0037	0.995681 $\pm$ 0.000605	0.995967 $\pm$ 0.000651	2050

Case name is from Table 2 in LA-UR-04-6489. Run 1: RN stride = 152917, Run 2: RN stride = 3999.
The number of particle histories for which stride=3999 is exceeded is shown in the last column.

Pu Benchmarks

Case	Benchmark keff	Run 1 keff	Run 2 keff	exceed
Jezebel	1.0000 ± 0.0010	0.999557 ± 0.000626	1.001388 ± 0.000578	
Jezebel-240	1.0000 ± 0.0038	1.001396 ± 0.000595	1.001666 ± 0.000604	
Pu Buttons (103)	1.0000 ± 0.0030	0.997913 ± 0.000648	0.998802 ± 0.000676	
Flattop-Pu	0.9985 ± 0.0011	0.998127 ± 0.000765	0.999842 ± 0.000688	
THOR	1.0000 ± 0.0047	0.997333 ± 0.000663	0.997237 ± 0.000611	
Pu-MF-11	0.9997 ± 0.0008	1.000729 ± 0.000781	1.001393 ± 0.000770	96075
HISS/HPG	1.0015 ± 0.0028	1.007664 ± 0.000560	1.007778 ± 0.000549	
PNL-33	1.0024 ± 0.0026	1.003209 ± 0.001008	0.999113 ± 0.001018	70
PNL-2	1.0000 ± 0.0065	1.004740 ± 0.000681	1.005303 ± 0.000756	

Case name is from Table 2 in LA-UR-04-6489. Run 1: RN stride = 152917, Run 2: RN stride = 3999.

The number of particle histories for which stride=3999 is exceeded is shown in the last column.