

Introduction to the CSAS sequence

SCALE 6.3.2

ORNL is managed by UT-Battelle, LLC for the US Department of Energy

Learning Objectives

- Provide an overview of the CSAS sequence and underlying Monte Carlo theory.
- Demonstrate the capabilities of CSAS parameters and input blocks.
- Describe the various outputs provided by CSAS.

Outline

- Sub module 1: **CSAS sequence description**
- Sub module 2: **Monte Carlo theory**
- Sub module 3: **Parameter and other KENO data**
- Sub module 4: **CSAS definitions and tallies data**
- Sub module 5: **CSAS output**
- Sub module 6: **CSAS5 review**
- Sub module 7: **CSAS6 review**

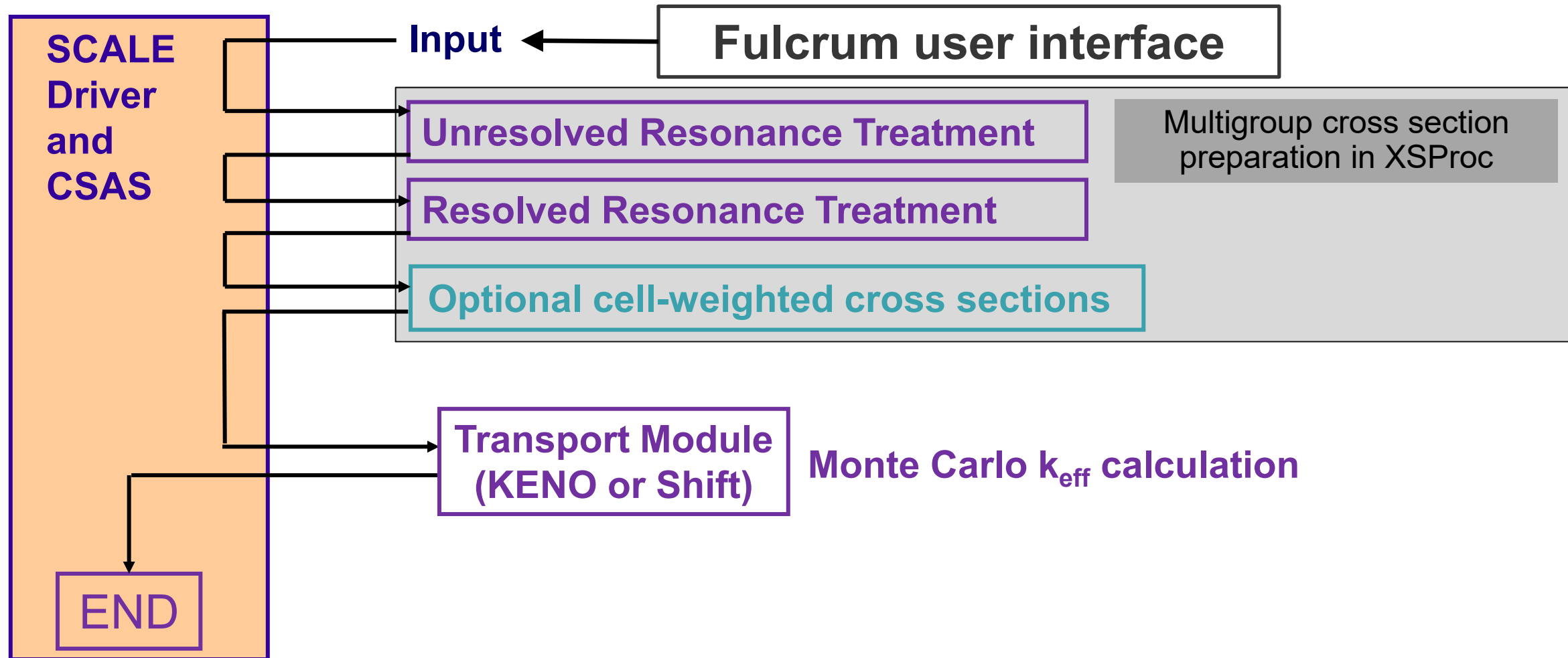
Sub module 1: **CSAS sequence description**



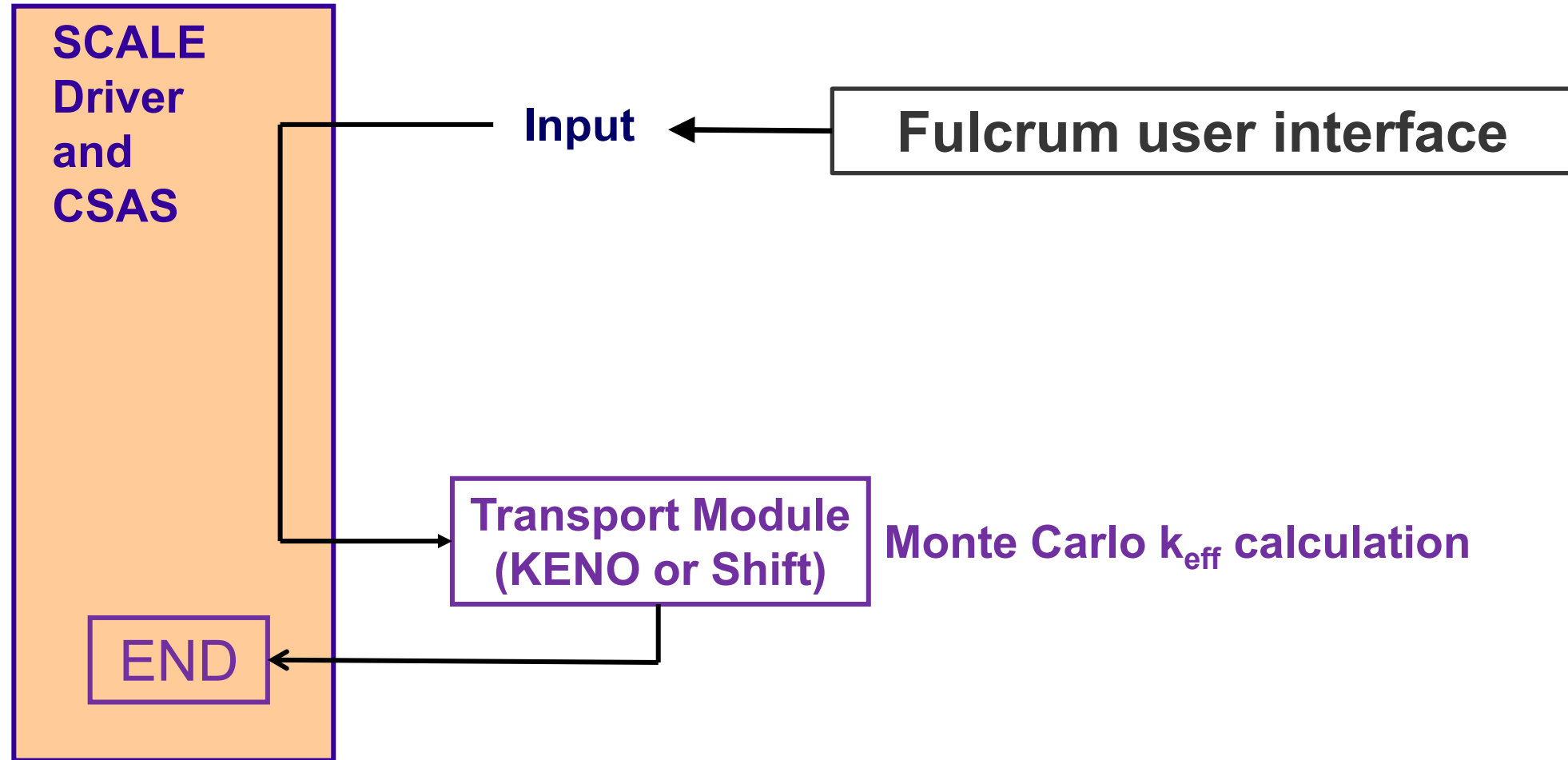
CSAS sequences (control modules)

- Automatically set up the input for each functional module that is called in the sequence
- Automated cross section processing (multigroup only)
 - Simple 1D cell description
- 3D criticality calculation using KENO V.a or KENO-VI Monte Carlo (MC) transport module in multigroup (MG) or continuous energy (CE) mode
- SCALE 6.3 contains Shift as an alternative Monte Carlo transport solver in place of KENO modules
 - Shift is intended to replace KENO in future releases

CSAS criticality safety sequence in MG mode



CSAS criticality safety sequence in CE mode



Available CSAS sequences

- **CSAS5**
 - Transport module: **KENO V.a** (KENO with KENO V.a geometry)
- **CSAS6**
 - Transport module: **KENO-VI** (KENO with KENO-VI geometry)
- **CSAS5-shift**
 - Transport module: **Shift** with KENO V.a geometry
- **CSAS6-shift**
 - Transport module: **Shift** with KENO-VI geometry

KENO V.a, KENO-VI and Shift provides both MG and CE Monte Carlo transport capabilities

- **CSAS-MG: MG cross section processing only**

General information input example

General
Information

=CSAS5 **PARM=CHECK** (OPTIONAL)
Job Title
Cross section library (REQUIRED)

Sequence name is the only
difference

Sequence
input data
blocks

READ COMP
Standard Composition Data (REQUIRED)
END COMP

READ CELLDATA
Unit Cell Data (OPTIONAL)
END CELLDATA

READ DEFINITIONS
*Used to define energy bounds and grid geometries
for the tallies defined in tallies data block (REQUIRED if tallies data block exists)*
END DEFINITIONS

READ TALLIES
Used to define tallies in a more robust way (OPTIONAL)
END TALLIES

Same for all CSAS
sequences

Transport
module's input
data blocks

KENO V.a Transport Data
READ GEOMETRY
Specify the problem geometry (REQUIRED)
END GEOMETRY

Other KENO data blocks (OPTIONAL)

END DATA

Same input blocks valid for
both Shift and KENO

Geometry specific input
blocks show differences

Sequence
termination

END

Same for all CSAS
sequences

Input changes needed to use Shift

- Only input change that should be required is changing **=csas5** or **=csas6** to **=csas5-shift** or **=csas6-shift**

```
1=csas5-shift
2PU-MET-FAST-001-001
3ce_v8.0
4read comp
5pu-239 1 0 3.7047e-2 293.15 end
6pu-240 1 0 1.7512e-3 293.15 end
7pu-241 1 0 1.1674e-4 293.15 end
8ga 1 0 1.3752e-3 293.15 end
9end comp
```

```
1=csas5
2PU-MET-FAST-001-001
3ce_v8.0
4read comp
5pu-239 1 0 3.7047e-2
6pu-240 1 0 1.7512e-3
7pu-241 1 0 1.1674e-4
8ga 1 0 1.3752e-3
9end comp
```

```
1=csas6-shift
2MIX-COMP-THERM-008-001
3ce_v8.0
4read comp
5'MOX fuel with intersti
6u-234 1 0 1.1448e-6 29
7u-235 1 0 1.4987e-4 29
8u-238 1 0 2.0664e-2 29
9pu-239 1 0 3.0307e-4 29
10pu-240 1 0 9.9248e-5 29
11pu-241 1 0 1.6957e-5 29
12pu-242 1 0 2.7874e-6 29
13am-241 1 0 1.6389e-6 29
14o 1 0 4.3090e-2 29
```

```
1=csas6
2MIX-COMP-THERM-008-00
3ce_v8.0
4read comp
5'MOX fuel with inters
6u-234 1 0 1.1448e-6
7u-235 1 0 1.4987e-4
8u-238 1 0 2.0664e-2
9pu-239 1 0 3.0307e-4
10pu-240 1 0 9.9248e-5
11pu-241 1 0 1.6957e-5
12pu-242 1 0 2.7874e-6
13am-241 1 0 1.6389e-6
14o 1 0 4.3090e-2
```

SCALE input types in CSAS

- Single values

- Keyword=number format:

```
gen=10100
```

- Fixed length parameter list

- No end required, but specified number of entries must be present:

```
cuboid 4 1 15 0 7.5 -7.5 17 -3
```

- Array values

- Unknown number of entries, so end is required:

```
xplanes -100 -75 -50 -25 0 25 50 75 100 end
```

SCALE input types in CSAS (cont.)

- Text strings
 - Typically, in com= line, delimited with single repeated character:
`com='fuel rod unit'`, or `com=!fuel rod unit!`, etc.
 - SCALE only uses last comment, but multiple comments can be supplied in a unit
- In text input, comments can be entered with a single apostrophe (') in column 1
 - Entire line is comments; no "in-line" comments
- Fulcrum validation will help sort these out for you

Sub module 2: **Monte Carlo (MC) theory**



Deterministic vs. MC for solving k-eigenvalue equation

k-eigenvalue equation in operator form:

$$[L + T]\Psi = S\Psi + \frac{1}{k_{eff}}F\Psi$$

L = leakage operator

T = collision operator

S = scatter-in operator

F = fission multiplication operator

This equation can be solved iteratively:

$$[L + T - S] \Psi^{(n+1)} = \frac{1}{k_{eff}^{(n)}} F \Psi^{(n)}$$

Deterministic vs. MC for solving k-eigenvalue equation

Deterministic and MC methods are used to solve k-eigenvalue equation by power iteration

Deterministic Methods

- Discretization in space, energy, and angle
- High-order (rapid) convergence
- An exact solution of an approximate (discretized) model

Monte Carlo

- Geometry and nuclear data are accurately represented
- Statistically constrained convergence ($\sim N^{-1/2}$)
- A statistically inexact solution of an exact model

Deterministic vs. MC for solving k-eigenvalue equation

Deterministic Methods

Initial guess: $k_{eff}^{(0)}, \Psi^{(0)}$

Solve $\Psi^{(n+1)}$

Solve linear equations iteratively
 $[L + T - S] \Psi^{(n+1)} = \frac{1}{k_{eff}^{(n)}} F \Psi^{(n)}$

Compute $k_{eff}^{(n+1)}$

$$k_{eff}^{(n+1)} = k_{eff}^{(n)} \frac{1 \cdot F \Psi^{(n+1)}}{1 \cdot F \Psi^{(n)}}$$

Renormalize $\Psi^{(n+1)}$

If converged, stop

k_{eff}, Ψ

Monte Carlo

Initial guess: $k_{eff}^{(0)}, \Psi^{(0)}$

Solve $\Psi^{(n+1)}$

Follow neutron histories to solve
 $[L + T - S] \Psi^{(n+1)} = \frac{1}{k_{eff}^{(n)}} F \Psi^{(n)}$

Bank fission neutrons to use as source in next generation

Compute $k_{eff}^{(n+1)}$

Tally $k_{eff}^{(n+1)}$ during the neutron histories

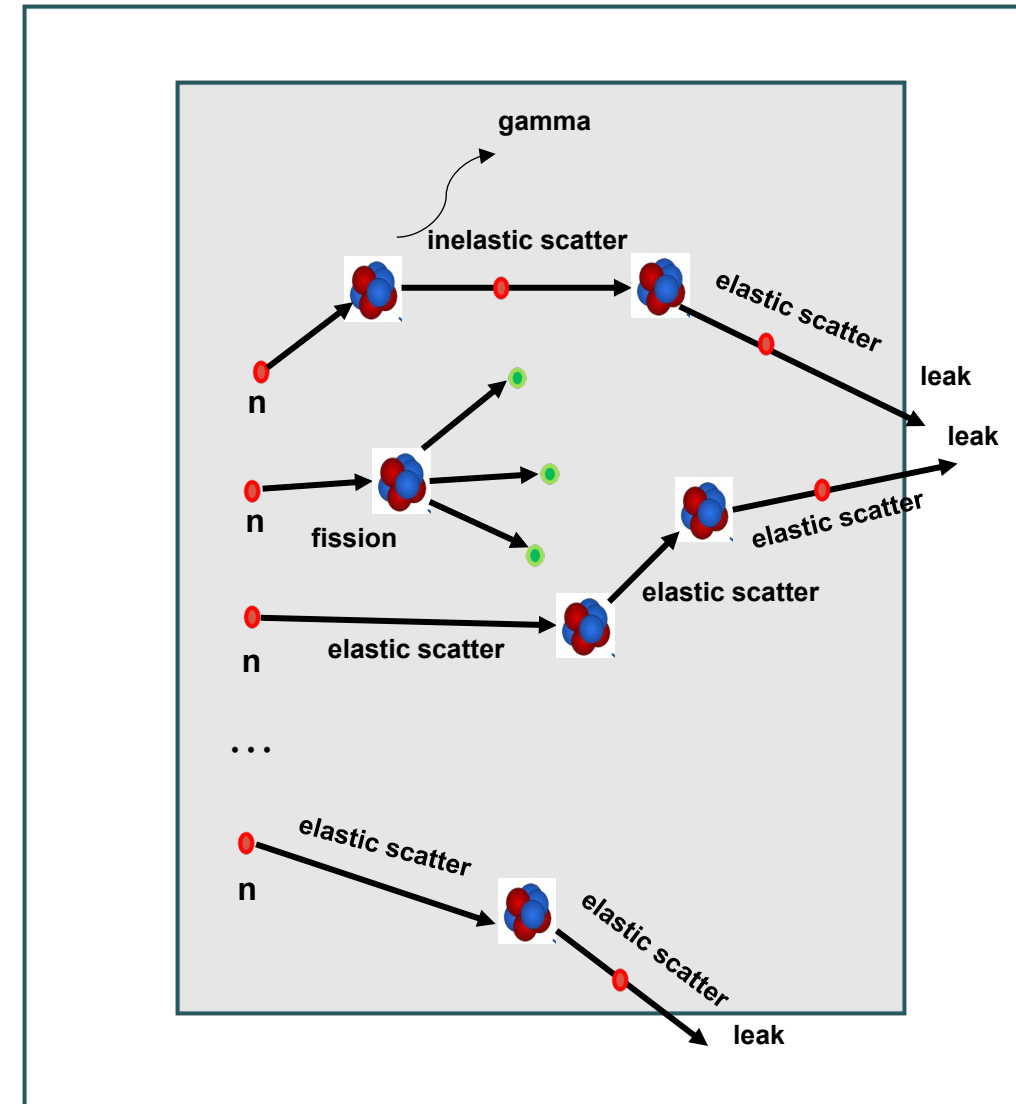
Renormalize $\Psi^{(n+1)}$

If converged, turn on tallies
If statistics small enough, stop

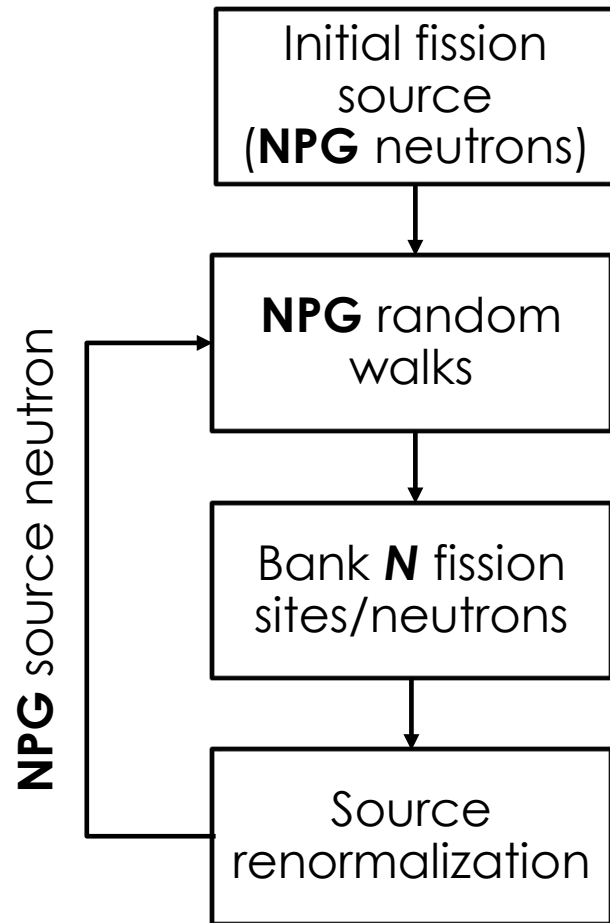
k_{eff}, Ψ

The MC Method

- When a particle traverses any material, it interacts with the nuclei of that material and can be scattered, absorbed, etc.
- These processes are statistical in nature and are described by nuclear cross sections
- Random numbers are used at each collision to randomly sample how the particle will behave at that collision; process continues after either the particle is absorbed or leaks from the system (entire process called the history of a particle)
- Because the life of one particle cannot characterize the behavior of an entire system, a large number of histories must be evaluated to understand the average system behavior



KENO MC algorithms for k_{eff} calculations



- MC criticality calculations for k_{eff} and fission source uses the **power method**
- Several neutron histories are grouped into generations iterated source (k_{eff}) problems
- KENO MC calculation starts with NPG initial neutrons
- Each generation of neutrons creates fissions sites (KENO stores/banks these fission neutrons for the next generation)
- Fission neutrons banked from the previous generation are renormalized to produce a neutron source for the current generation

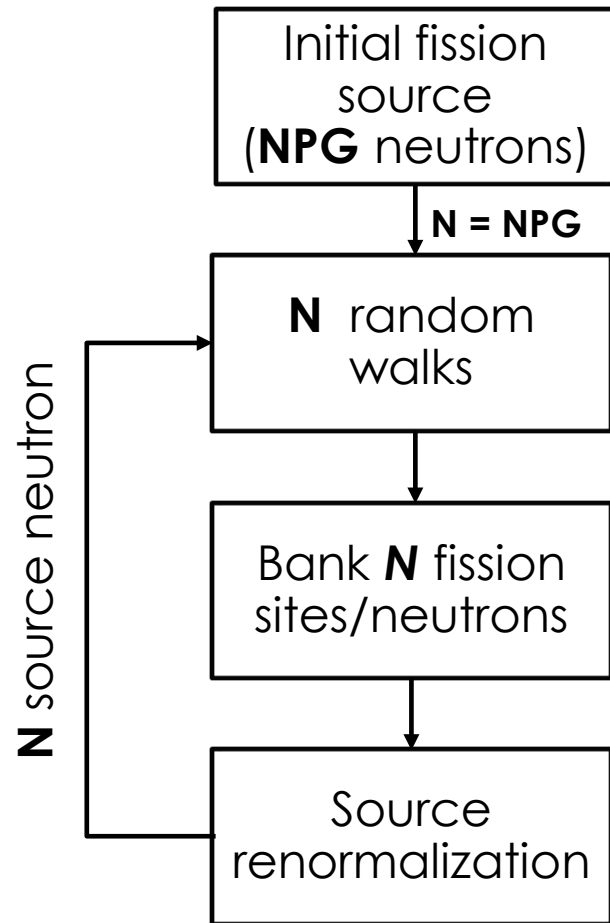
KENO approach: Keep bank size (NPG neutrons) and total neutron weight constant

$N > \text{NPG} \rightarrow$ discard $N - \text{NPG}$ neutrons

$N < \text{NPG} \rightarrow$ complete the bank shortage by adding randomly selected $\text{NPG} - N$ neutrons from N neutrons already banked

- **Source renormalization introduces a bias – and this bias can be mitigated by increasing NPG**
- Calculations are repeated for several generations to obtain results with the desired level of uncertainty

Shift MC algorithms for k_{eff} calculations



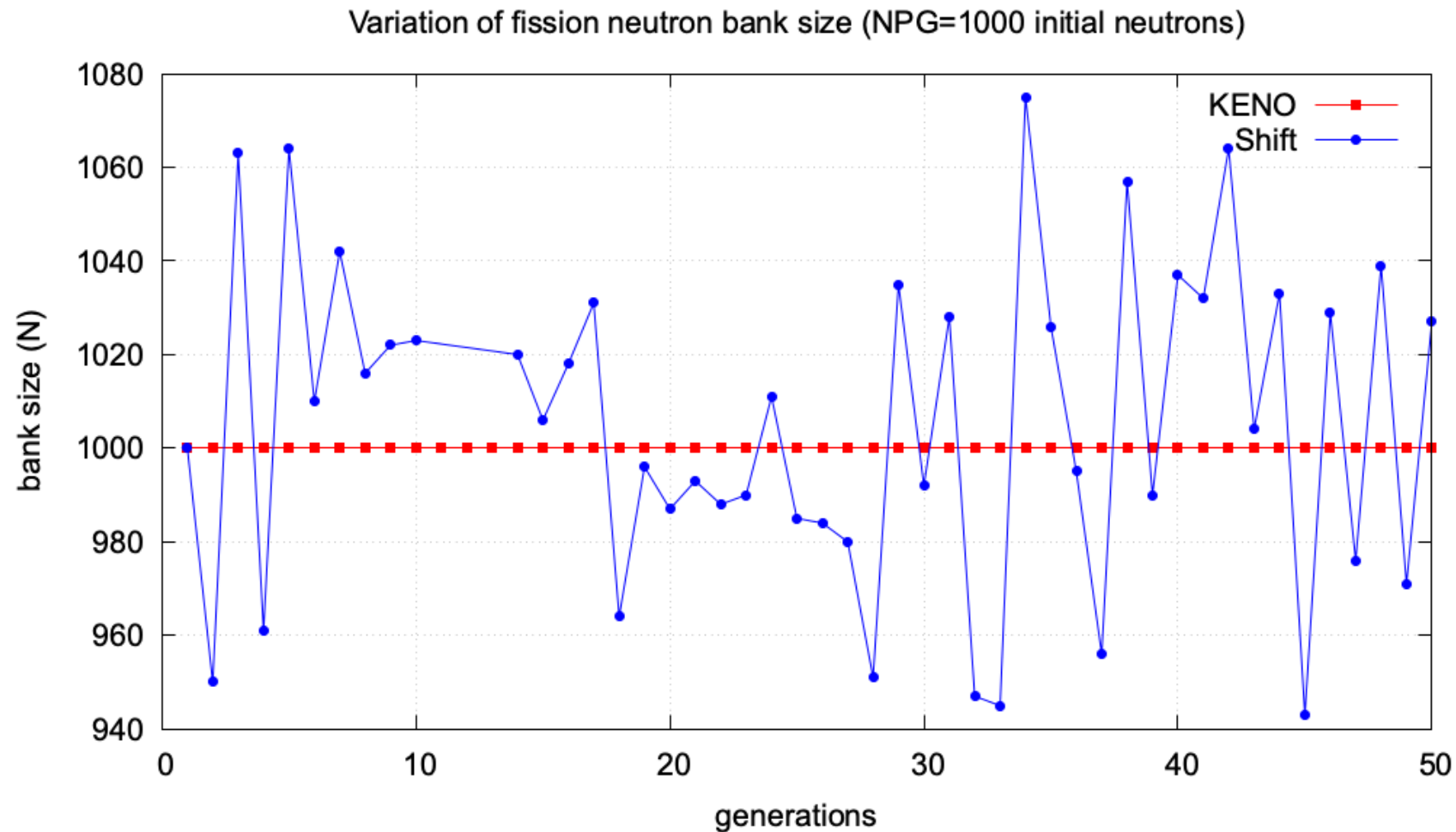
- Shift MC calculation starts with NPG initial neutrons
- Each generation of neutrons creates fissions sites (Shift stores/banks these fission sites for the next generation)
- Fission sites banked from the previous generation are used to sample neutron source for the current generation after their weights are renormalized

Shift approach: Bank size is variable (N neutrons)

Shift keeps the total neutron weight constant

- **Bias introduced source normalization can be mitigated by increasing NPG**
- Calculations are repeated for several generations to obtain results with the desired level of uncertainty

Different fission site treatment in KENO and Shift

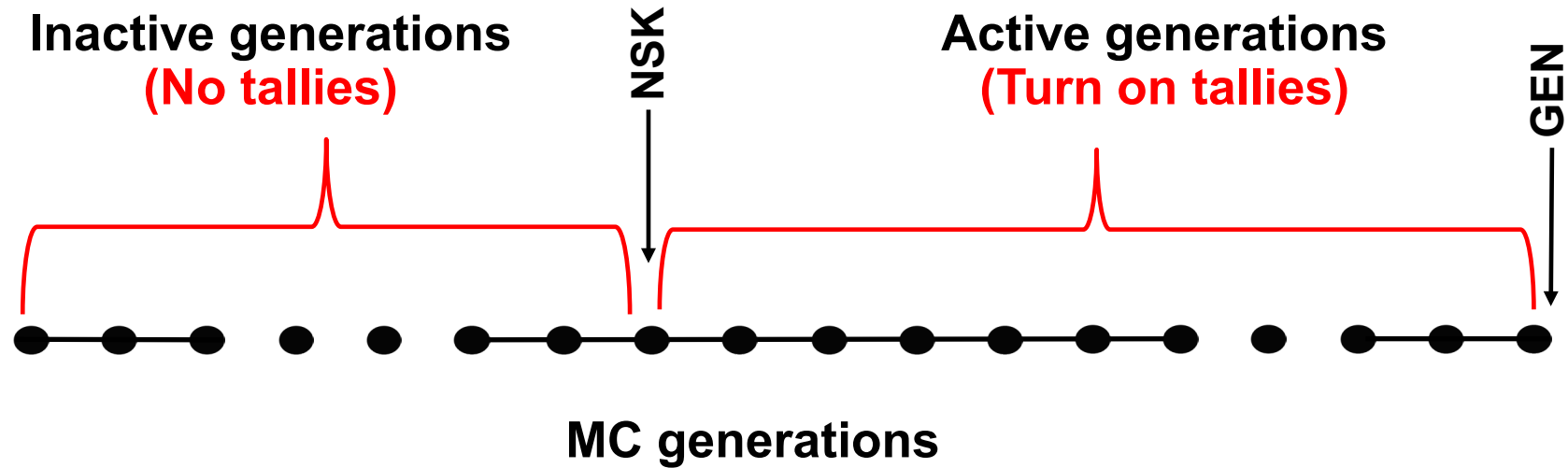


- KENO keeps bank size constant (NPG neutrons)
- Shift has variable bank size
- Both KENO and Shift preserve the total weight (constant)

MC assumptions

- The number of histories simulated is sufficient to characterize the problem and all regions are adequately sampled
- The histories are independent of one another and completely uncorrelated
 - Generations are correlated because source points from the previous generation are used to create neutrons in the next generation
 - The impact is that uncertainty in small region tallies is typically underestimated, and this can increase the uncertainty by a factor of 3–10
- The random numbers sampled are truly random
- The nuclear data are precise

KENO and Shift MC algorithms for k_{eff} calculations



The iterative scheme is executed using the user-defined parameters:

NPG: number of initial neutrons

GEN: number of generations (inactive + active)

NSK: number of generations skipped (inactive)

- several initial generations are run without tallies until k_{eff} and **fission source distribution** have converged (inactive or skipped generations)
- then tallies (k_{eff} , fluxes, and reaction rates) are turned on, and simulation is performed until results are obtained with reasonably small uncertainties

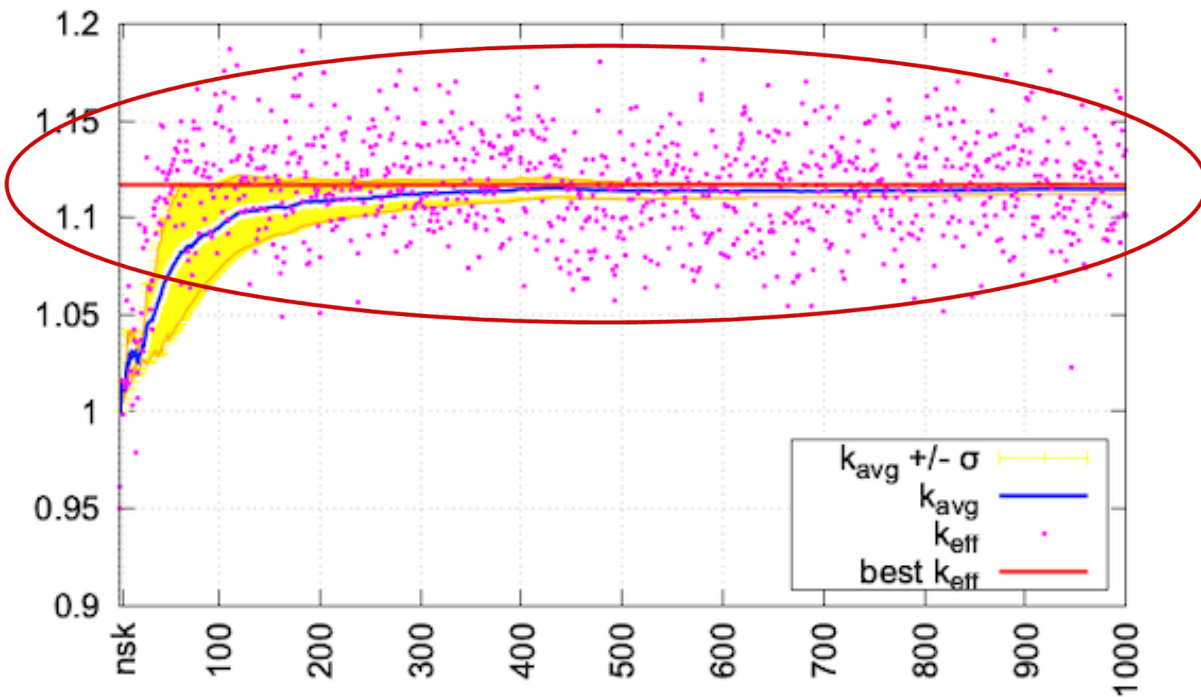
Note that k_{eff} and **fission source distribution** converge differently (when k_{eff} converges, the fission source may not have converged)

MC algorithms for k_{eff} calculations (cont.)

- k_{eff} will statistically fluctuate from generation to generation
- overall estimate of k_{eff} should converge with increasing number of generations

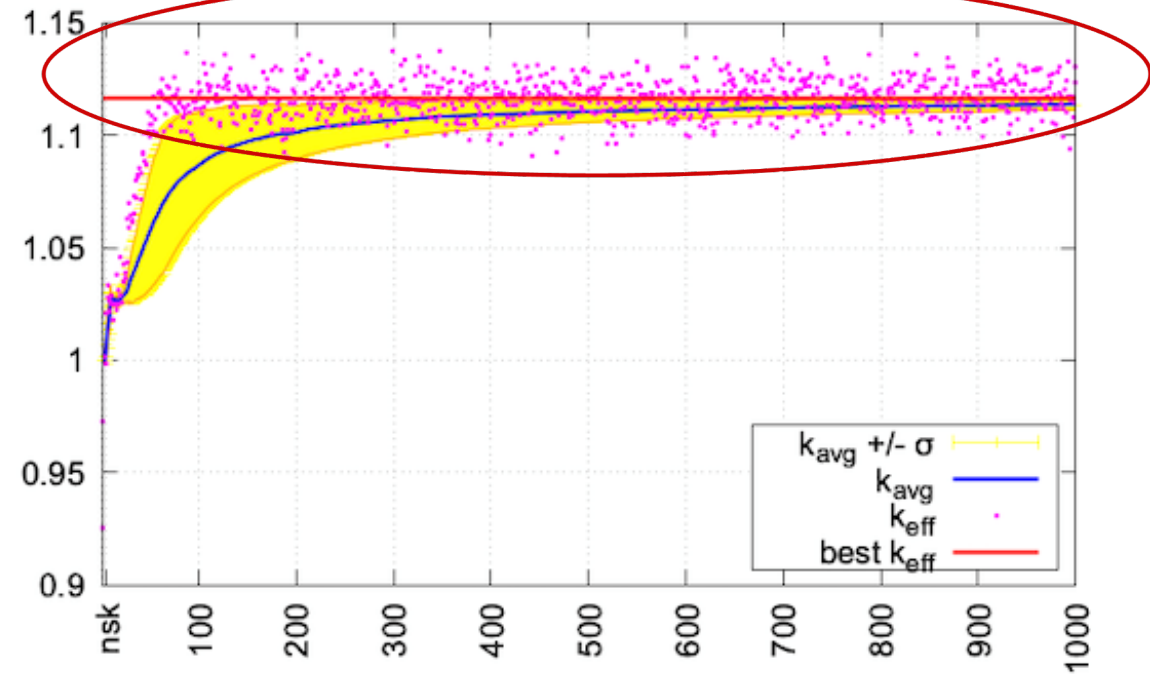
fluctuation in generation k -eff values decreases with NPG

k-eff by generations
(all generations)



NSK=5, GEN= 1000, **NPG=1000**

k-eff by generations
(all generations)

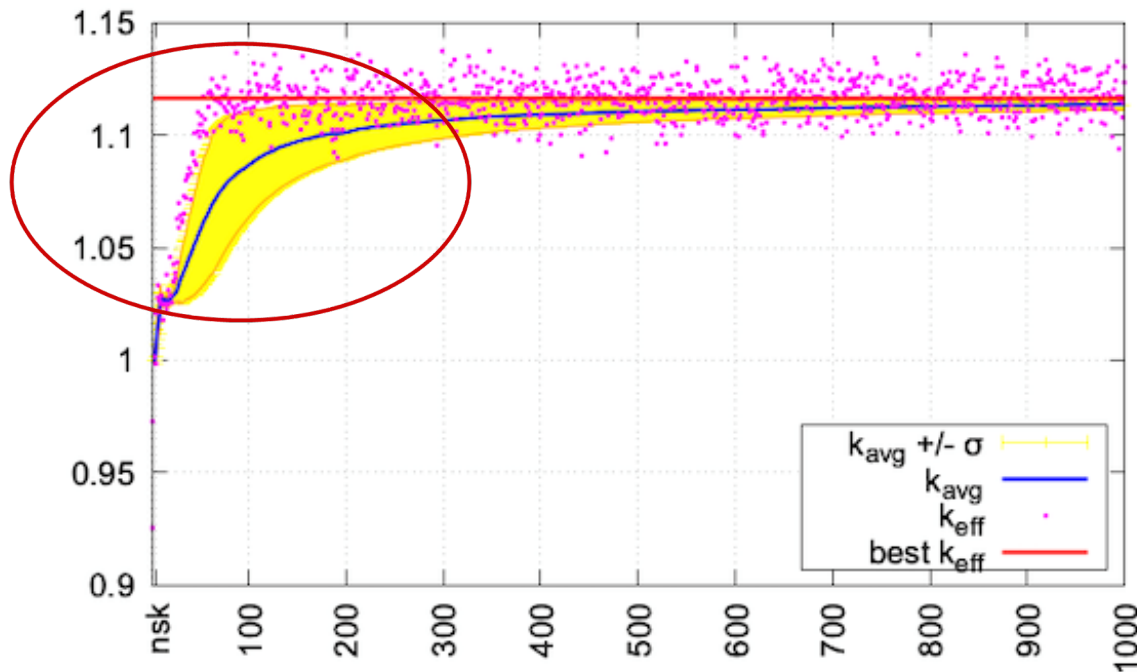


NSK= 5, GEN=1000, **NPG=10000**

MC algorithms for k_{eff} calculations (cont.)

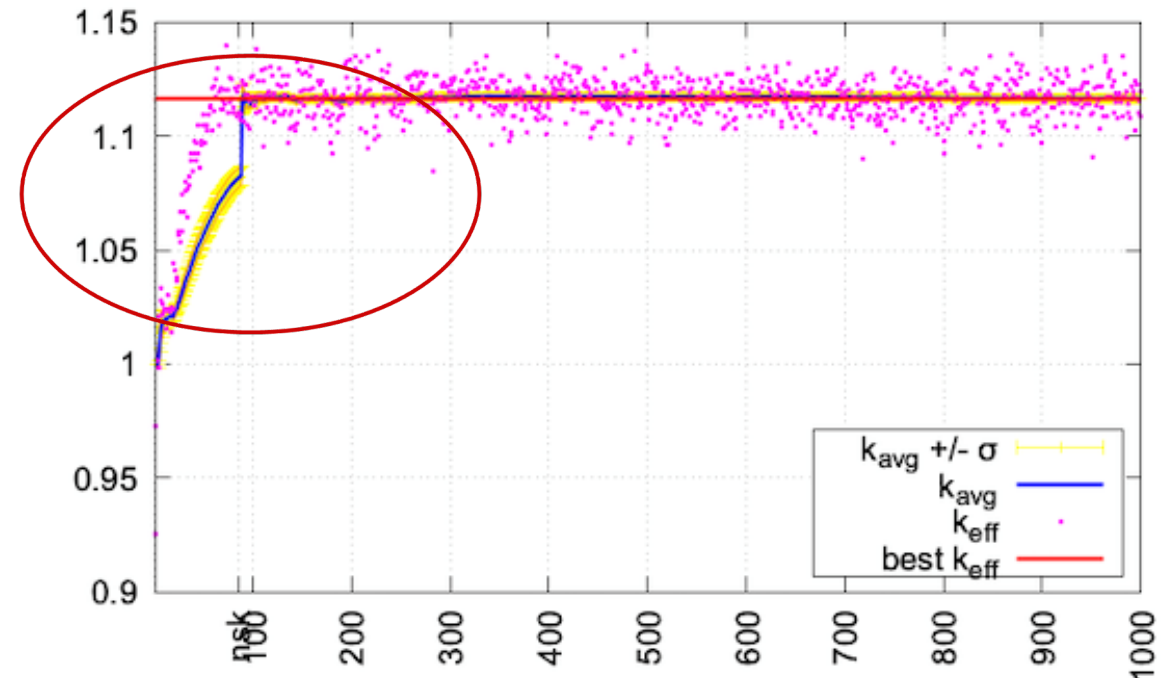
Several initial generations required to obtain tallies with reasonably small uncertainties

k-eff by generations
(all generations)



NSK=5, GEN= 1000, NPG=10000

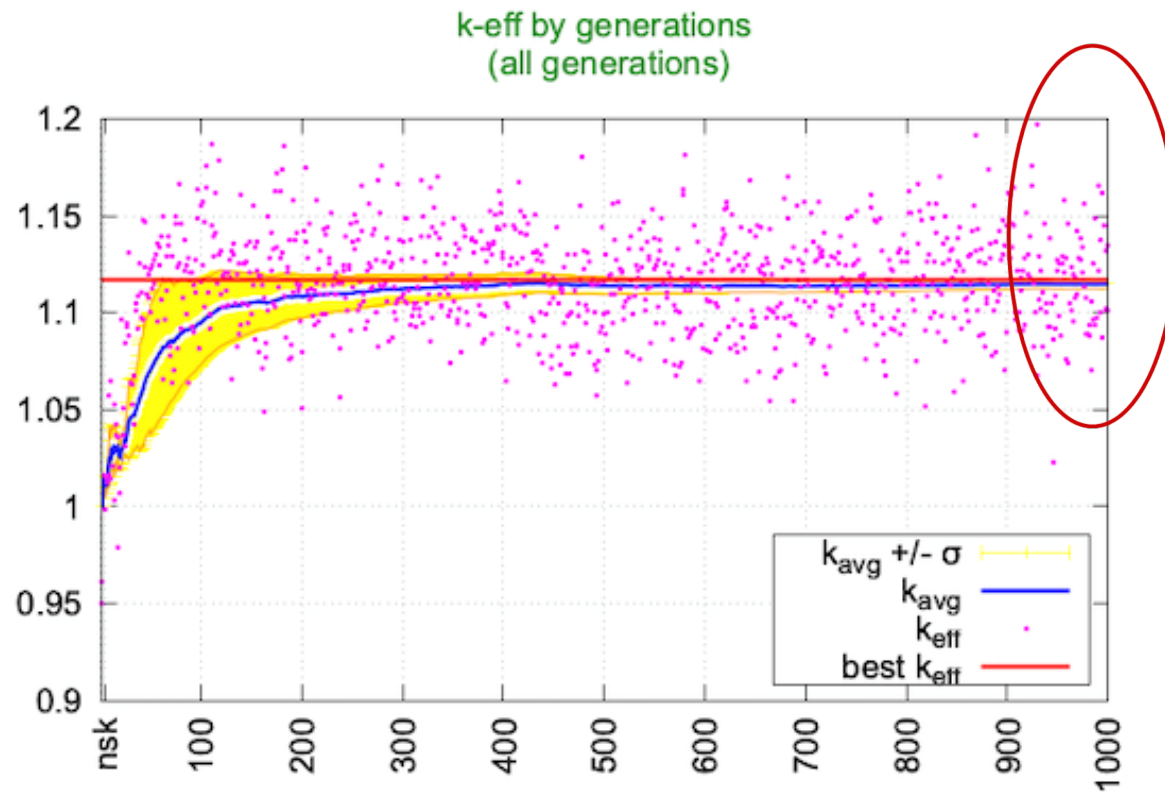
k-eff by generations
(all generations)



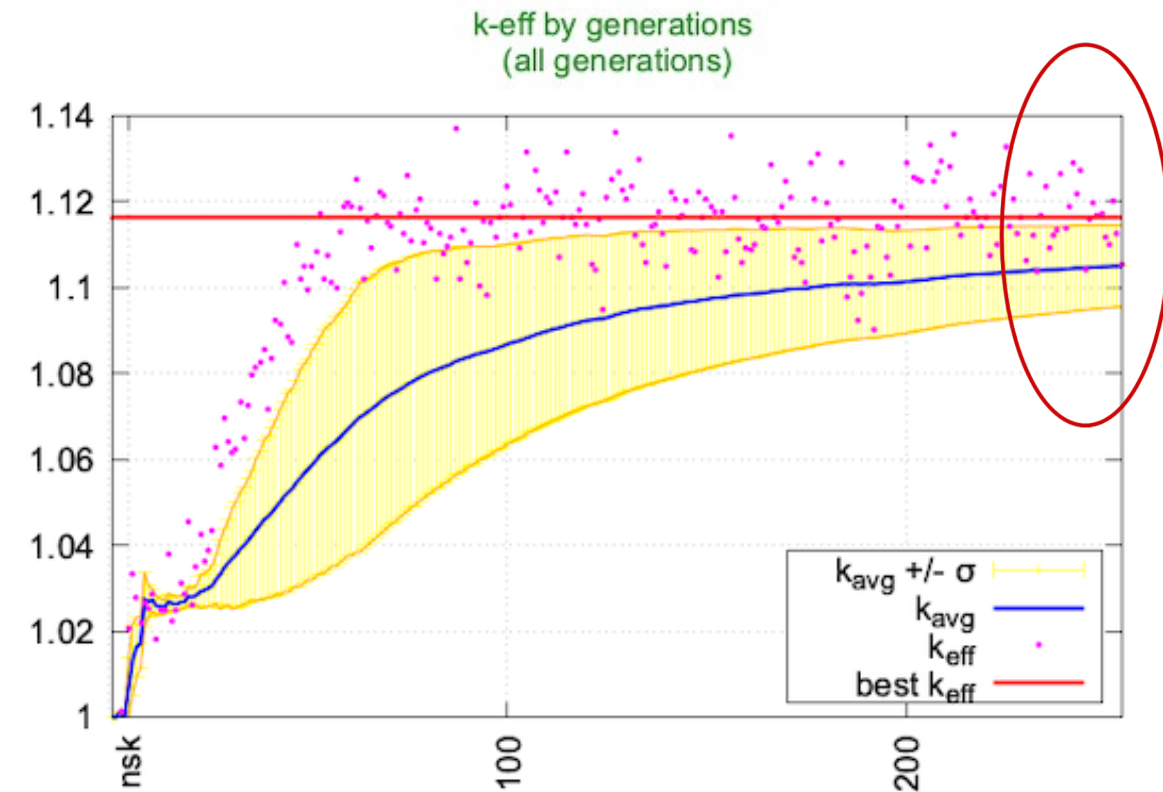
NSK=85, GEN=1000, NPG=10000

MC algorithms for k_{eff} calculations (cont.)

Several active generations required for tally convergence



NSK=5, **GEN= 1000**, NPG=10000



NSK=5, **GEN=250**, NPG=10000

Statistical uncertainty

- MC tallies are each reported with their standard deviation
- The standard deviation for k_{eff} is given by

$$\sigma_{Avg} = \frac{1}{\sqrt{N}} \sigma_{Gen}$$

- Therefore, the standard deviation decreases inversely with respect to the square root of the total sample size
 - To decrease the standard deviation by 50%, one must increase the total number of histories by a factor of 4

Statistical significance

- given $k_1 \pm \sigma_1$ and $k_2 \pm \sigma_2$, the difference is

$$k_1 - k_2 \pm \sqrt{(\sigma_1^2 + \sigma_2^2)}$$

- If $k_1 - k_2 > \sqrt{(\sigma_1^2 + \sigma_2^2)}$, the result is a *statistically significant difference**
- If $k_1 - k_2 < \sqrt{(\sigma_1^2 + \sigma_2^2)}$, the result is a *statistically insignificant difference**
- Small differences can be essentially identical – no conclusion can be drawn for equivalent answers

*Convention or comfort in what constitutes *statistically significant* varies;

$\pm 1\sigma_{12}$ bounds ~68%

$\pm 2\sigma_{12}$ bounds ~95%

$\pm 3\sigma_{12}$ bounds ~99%

k-eff convergence plots

KENO/Shift provides k-eff convergence plots

KENO

- Plot files can be obtained with HTML output option and visualized with Fulcrum
- ASCII char-plots are also available

Shift

- Plot files stored in plots directory can be visualized with Fulcrum
- No ASCII char-plots option

- Average k-eff by generations run

Illustrates details for the k-eff convergence

- Average k-eff by generations skipped

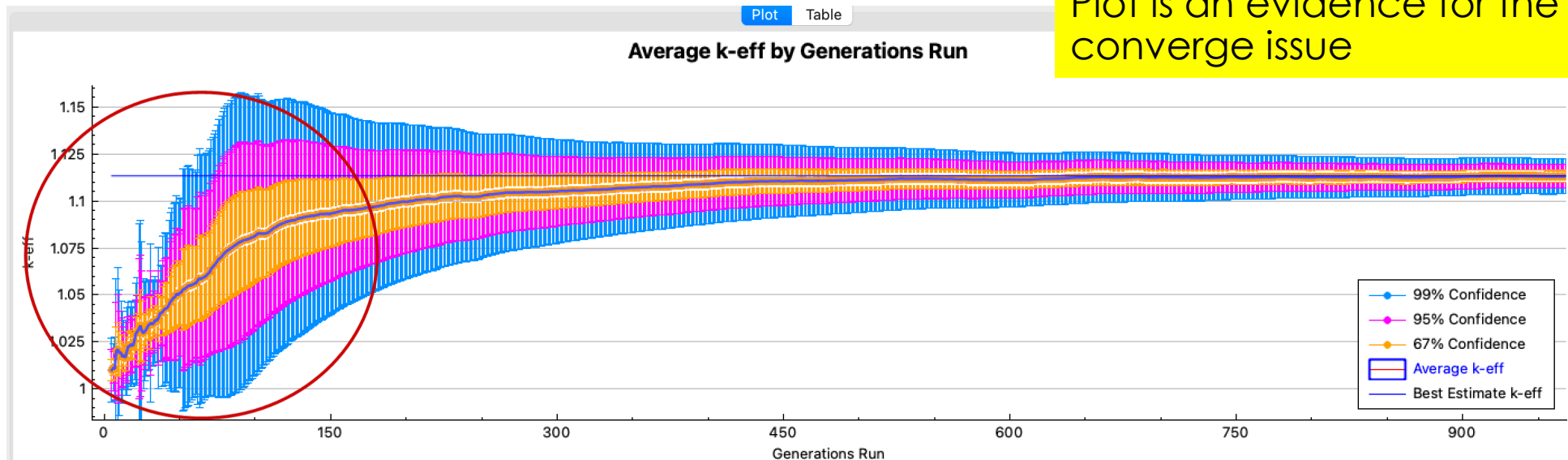
average k-eff and associated uncertainty are calculated by increasing the number of generations skipped by one, starting from NSK



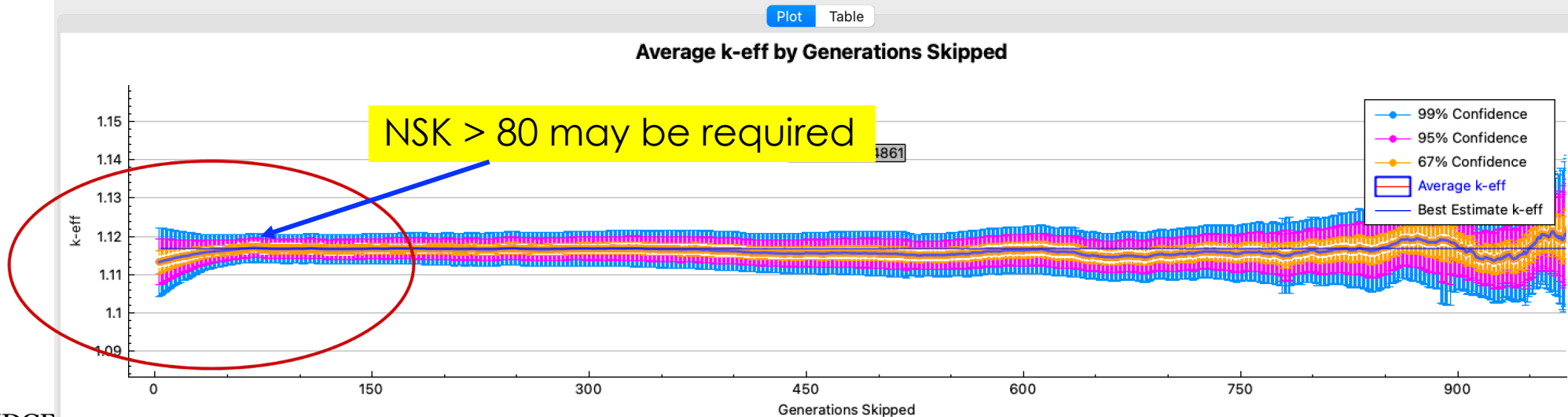
It is useful for determining if source convergence has been achieved.

k_{eff} convergence plots

NSK=5, not sufficient for this case
Plot is an evidence for the source converge issue

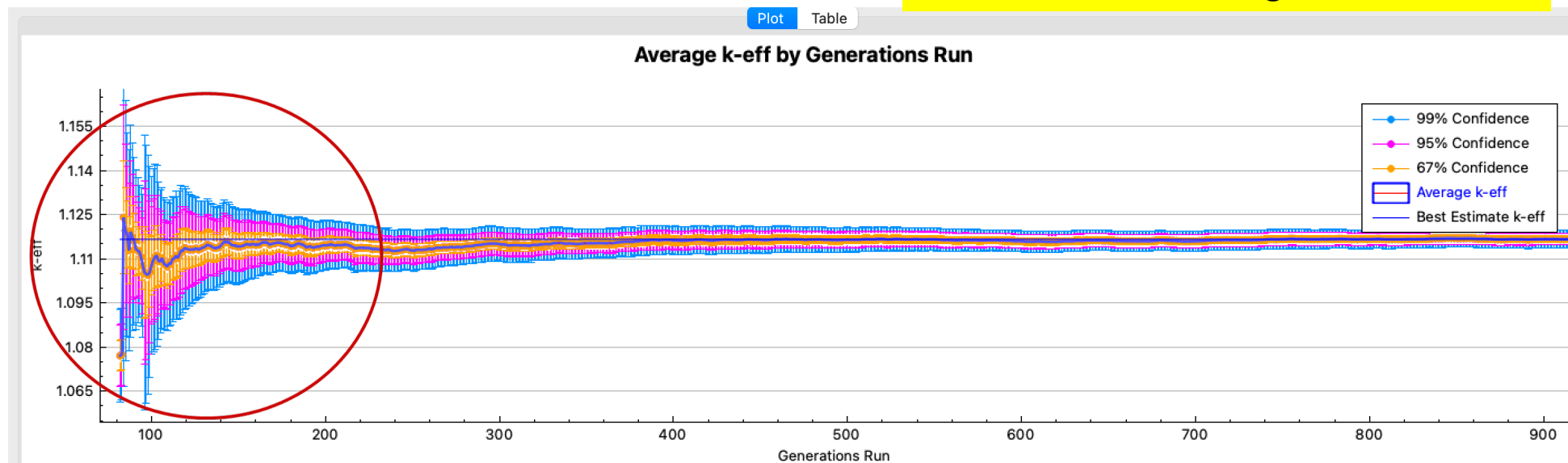


/Users/5kq/Documents/SCALE/Training/Introduction_to_CSAS/supported_analysis/keff_plots/test_b3008/oecd4_gen_1000_nsk_3_npg_1000.plots/oecd4_gen_1000_nsk_3_npg_1000_seq1_csas6_plot_keff_by_generations_skipped.00000.ptp oecd4_gen_1

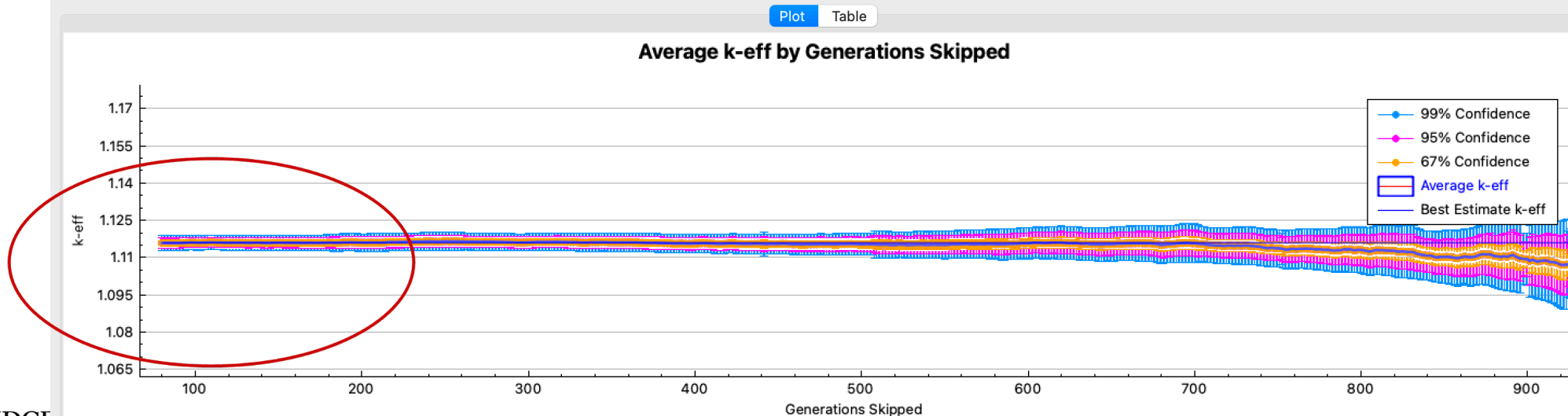


k_{eff} convergence plots

NSK=80 is a better estimate for the source convergence

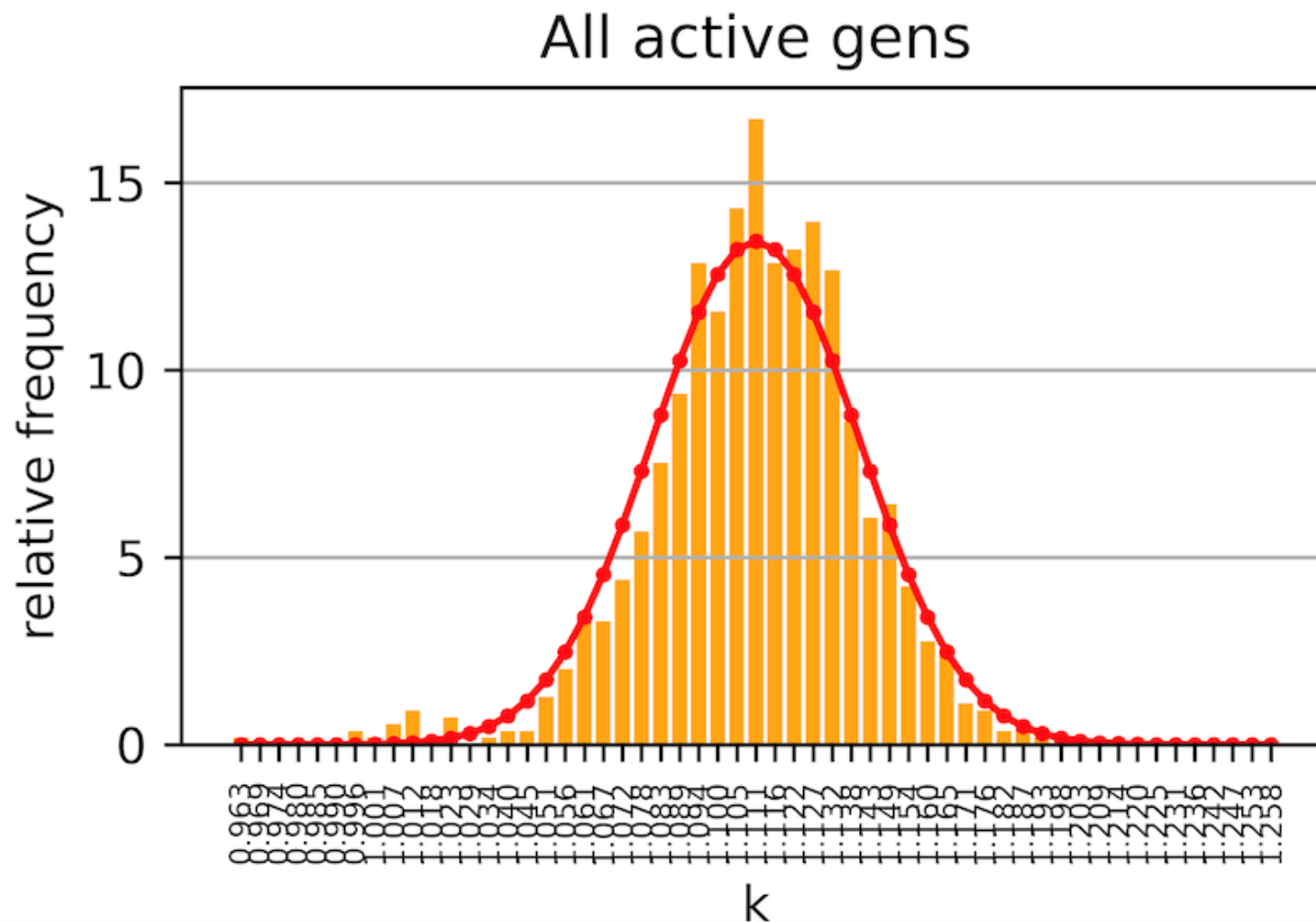


0000.ptp /Users/5kq/Documents/SCALE/Training/Introduction_to_CSAS/supported_analysis/keff_plots/test_b3008/oecd4_gen_1000_nsk_80_npg_1000.plots/oecd4_gen_1000_nsk_80_npg_1000_seq1_csas6_plot_keff_by_generations_skipped.000000.ptp



Distribution of generations

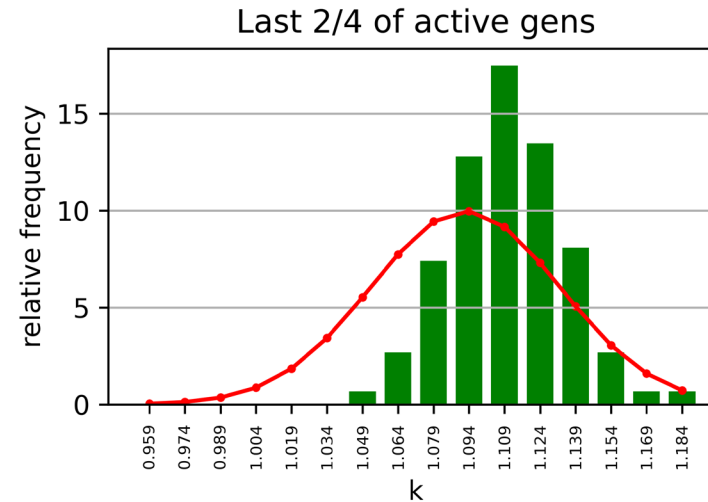
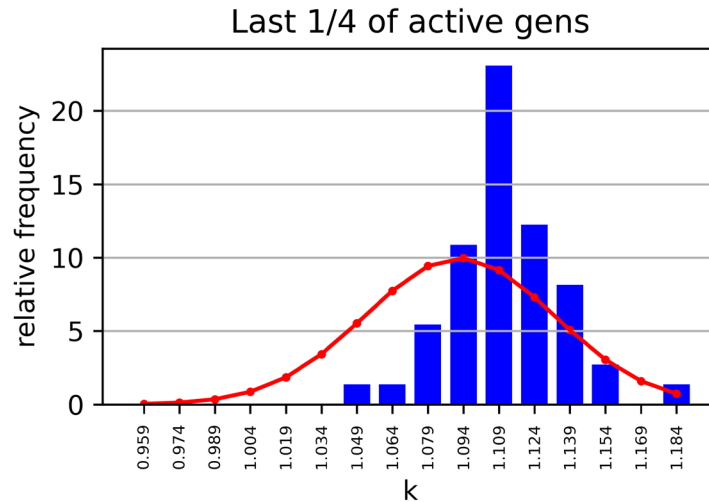
- k_{eff} estimates from the active generations are expected to be normally distributed



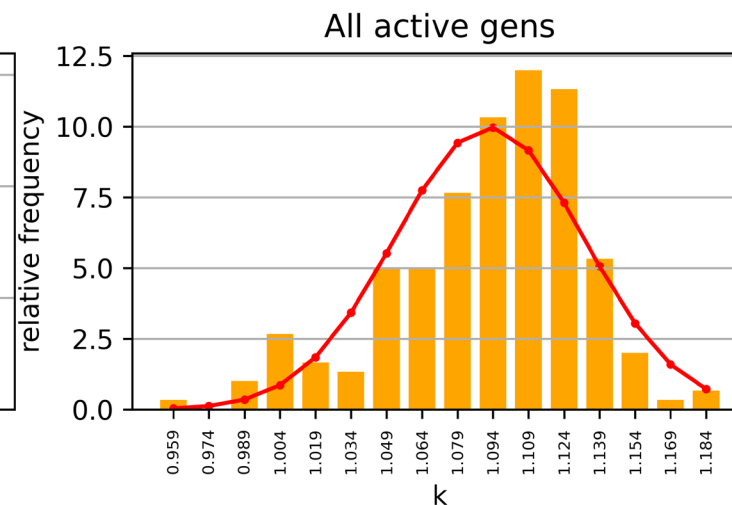
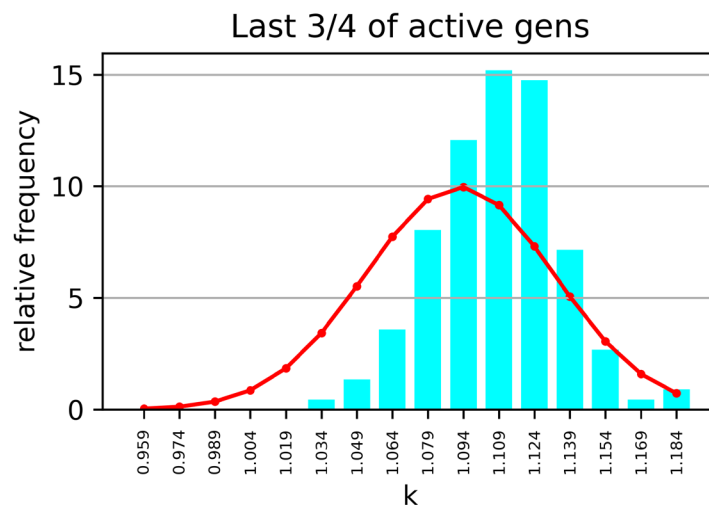
Plot in red color
illustrates the
expected value

Distribution of generations

Departures from normal distributions and radical shifts among them may be indications of source convergence issues in the calculation



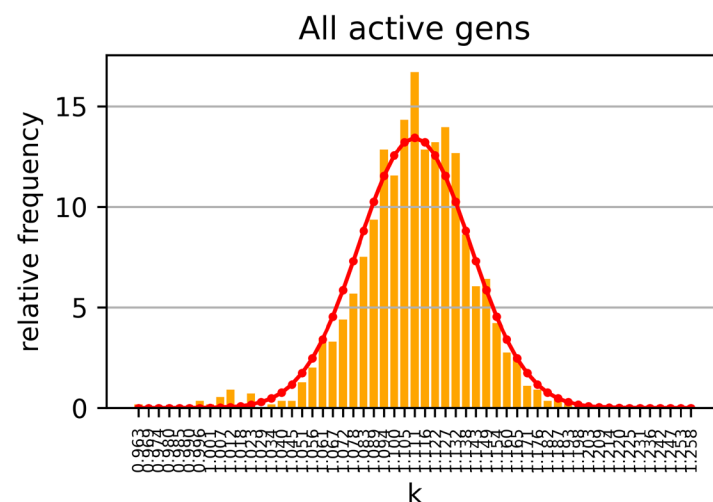
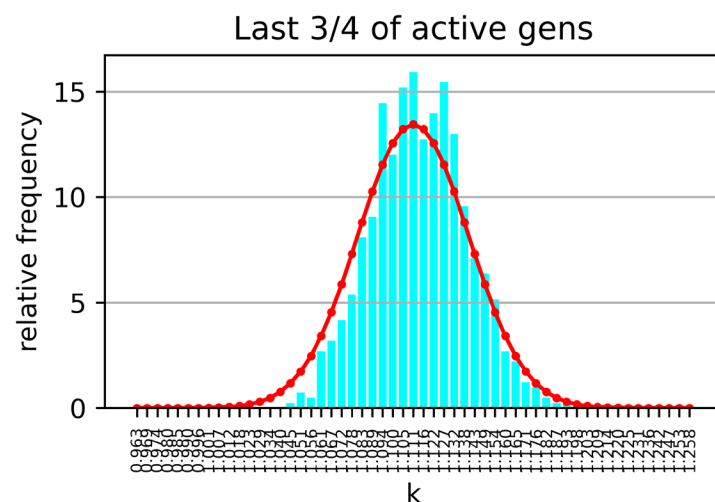
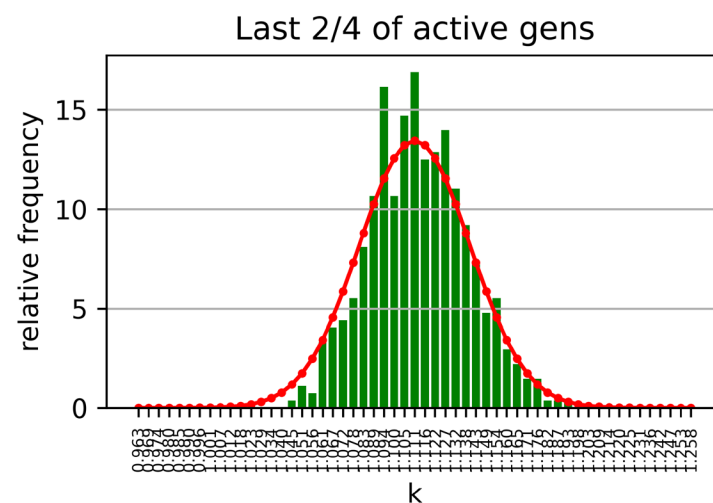
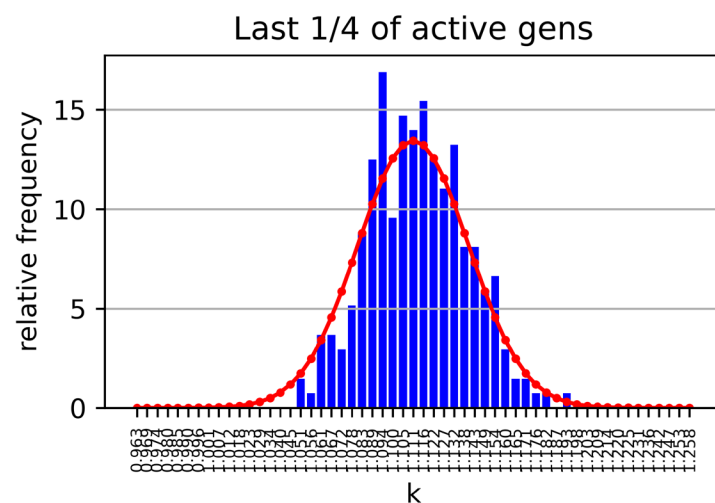
Plot in red color illustrates the expected value



Potential issues in the calculations

Distribution of generations

k_{eff} estimates from the active generations are expected to be normally distributed



Plot in red color illustrates the expected value

Distribution of generations

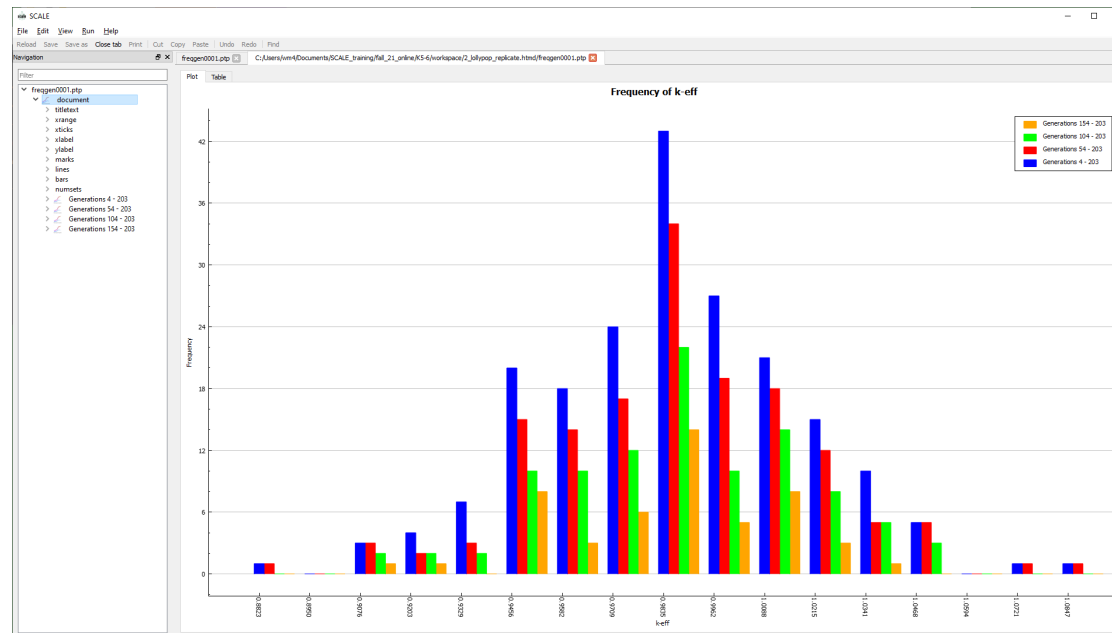
- KENO/Shift performs a χ^2 test and reports result in final results block as one of:
 - Satisfy at 95% level
 - Fail at 95% but pass at 99% level
 - Fail
- Histograms of generations (k-eff frequency plots) in output for all active generations as well as the last 75%, 50%, and 25% of active generations
 - Examine plots for normality and to ensure the distribution doesn't change as problem progresses

k_{eff} frequency plots

Freqgen0001.ptp in
Fulcrum

KENO

The plot file can be obtained with HTML output option and visualized with Fulcrum



Shift
In 6.3.2, this plot is not available

Plot in text output

```
0.9394 to 0.9520
0.9520 to 0.9647
0.9647 to 0.9773
0.9773 to 0.9900
0.9900 to 1.0026
1.0026 to 1.0153
1.0153 to 1.0279
1.0279 to 1.0406
1.0406 to 1.0532
1.0532 to 1.0659
```

```

**
**
*****
*****
*****
*****
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*****
*****
*****
*****
*****
*****

```

ASCII char-plot is available with only KENO transport

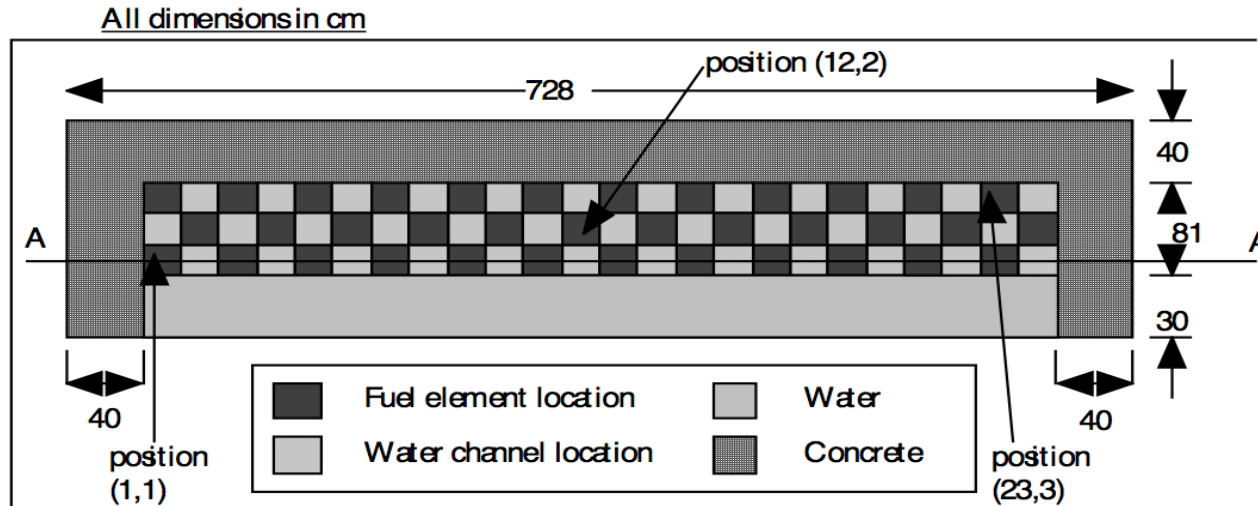
Fission source convergence

- The source must be reasonably converged for the final results to be meaningful
- The source can fluctuate between highly reactive regions or may converge to a region of the problem that is not the most reactive (false convergence)
- Examining the k_{eff} , fluxes, and fission densities can help determine if the entire system is being properly sampled
- Increasing the number generations skipped (NSK) and/or tailoring the initial source distribution can ensure source convergence

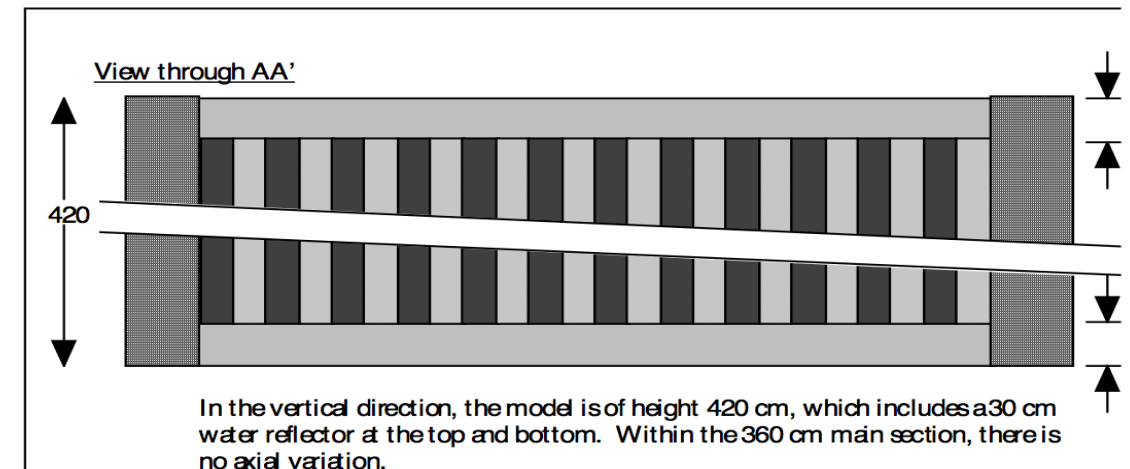
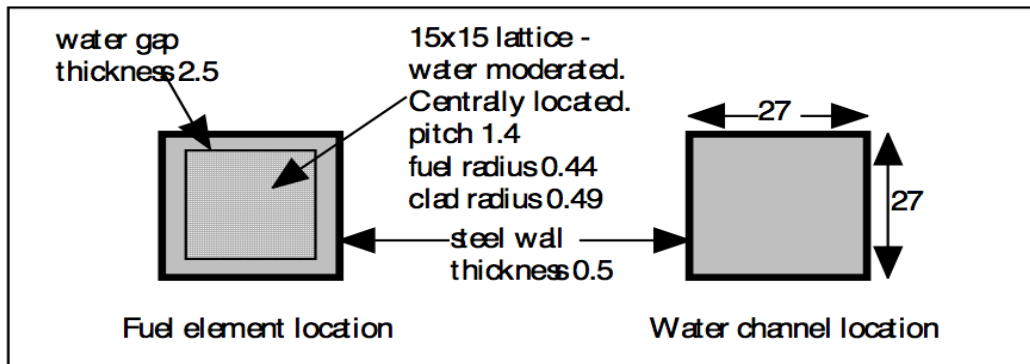
Initial source distribution

- Many skipped generations are usually required for the initial fission source to converge to obtain a stationary fission source distribution
- An initial source guess that closely resembles the converged fission source can reduce the number of generations skipped
- The fission source distribution may not converge without a reasonable initial source guess!!!

OECD/NEA source convergence benchmark 1: Checkerboard storage of assemblies



- 24x3 LWR fuel storage rack with fuel elements stored in alternate locations
- ~5.0 wt% UO_2 , Zr-clad, 15x15 lattice
- water-flooded steel storage racks surrounded by a close-fitting full concrete reflection on three sides
- water on the remaining side and water on the top and bottom



Source convergence in action!

- All source started at position (1,1) in lattice
- The fission source for the Checkerboard OECD/NEA Source Convergence problem was plotted using the Fulcrum mesh overlay capability
- Source convergence is notoriously difficult in this problem with this initial guess
- Unsampld regions are visible in all four cases – not even 1,000 skipped generations can produce a converged fission source for this problem!

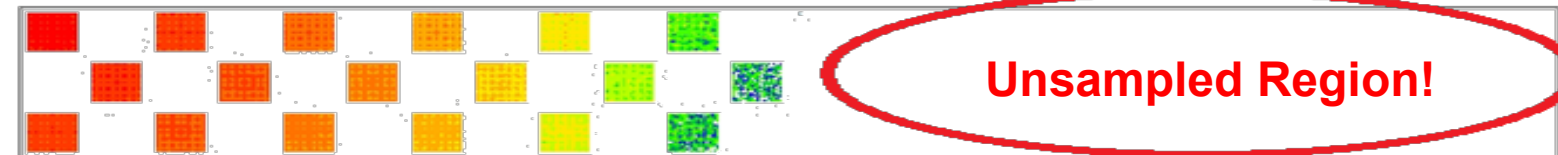
1 Skipped Generation



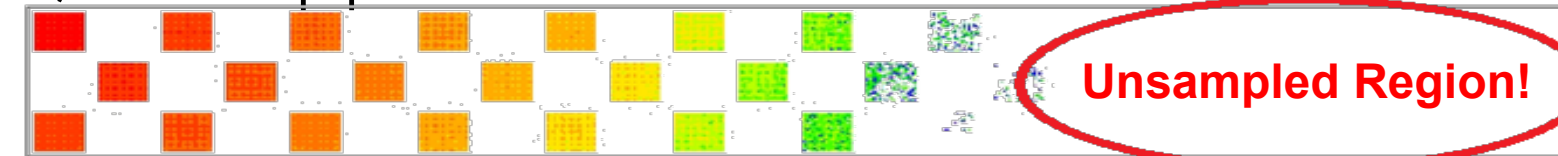
50 Skipped Generations



250 Skipped Generations



1,000 Skipped Generations



Advanced convergence diagnostics

- Shannon entropy is a concept from information theory that measures the amount of information contained in messages in a data stream

$$H = - \sum_n^N p_n \ln(p_n)$$

p_n = Fraction of information in message n

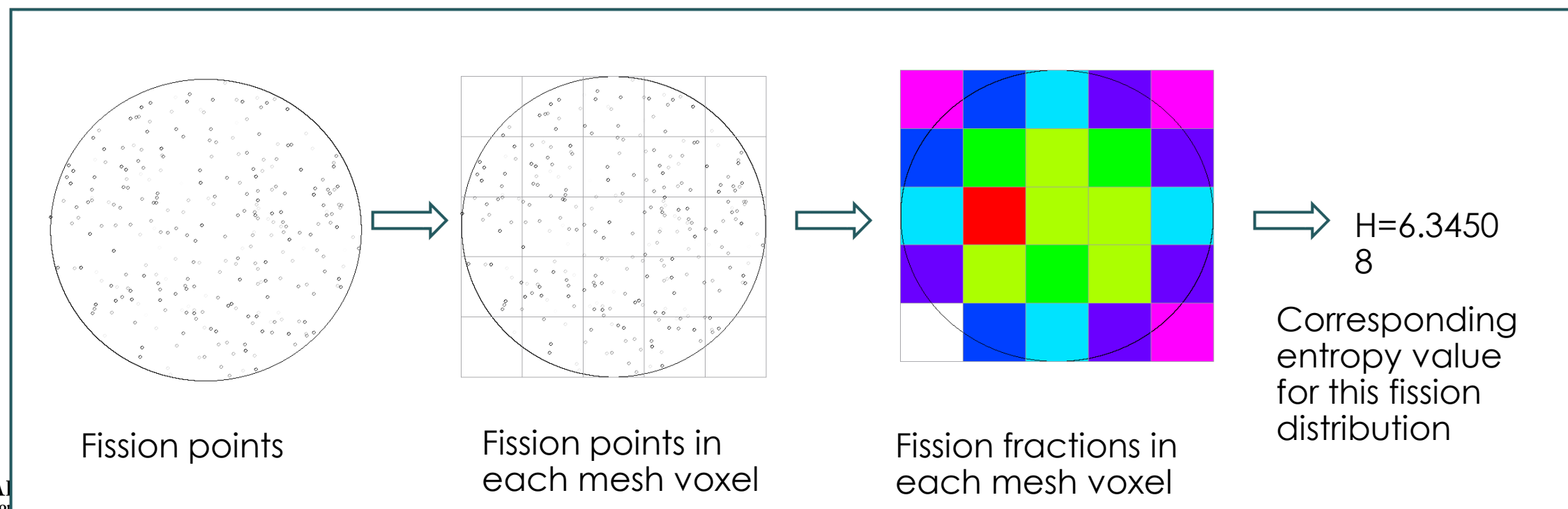
- Brown and Ueki have employed Shannon entropy to diagnose convergence of the fission source in eigenvalue calculations
- The idea is to use Shannon entropy to represent the fission neutron distribution in a generation with a single number

Advanced convergence diagnostics

How to calculate Shannon entropy:

- A mesh is overlayed the entire geometry (5x5x5 by default, covers all fissile regions)
- User can change the default mesh (SCD parameter)
- Fission points are tallied on this mesh, then data in each mesh is normalized with the total fissions
- Mesh-based data (fraction of fission neutrons in each mesh) is used to calculate the entropy

Godiva test case illustrates the entropy calculations in KENO/Shift transport

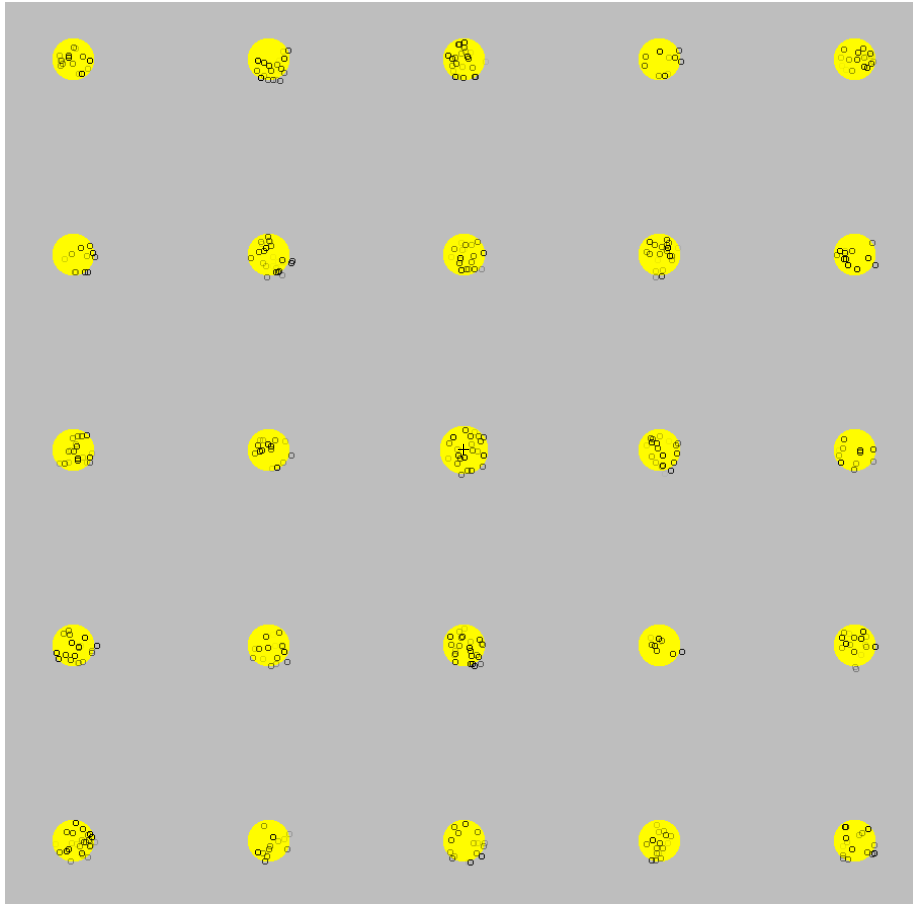


Advanced convergence diagnostics

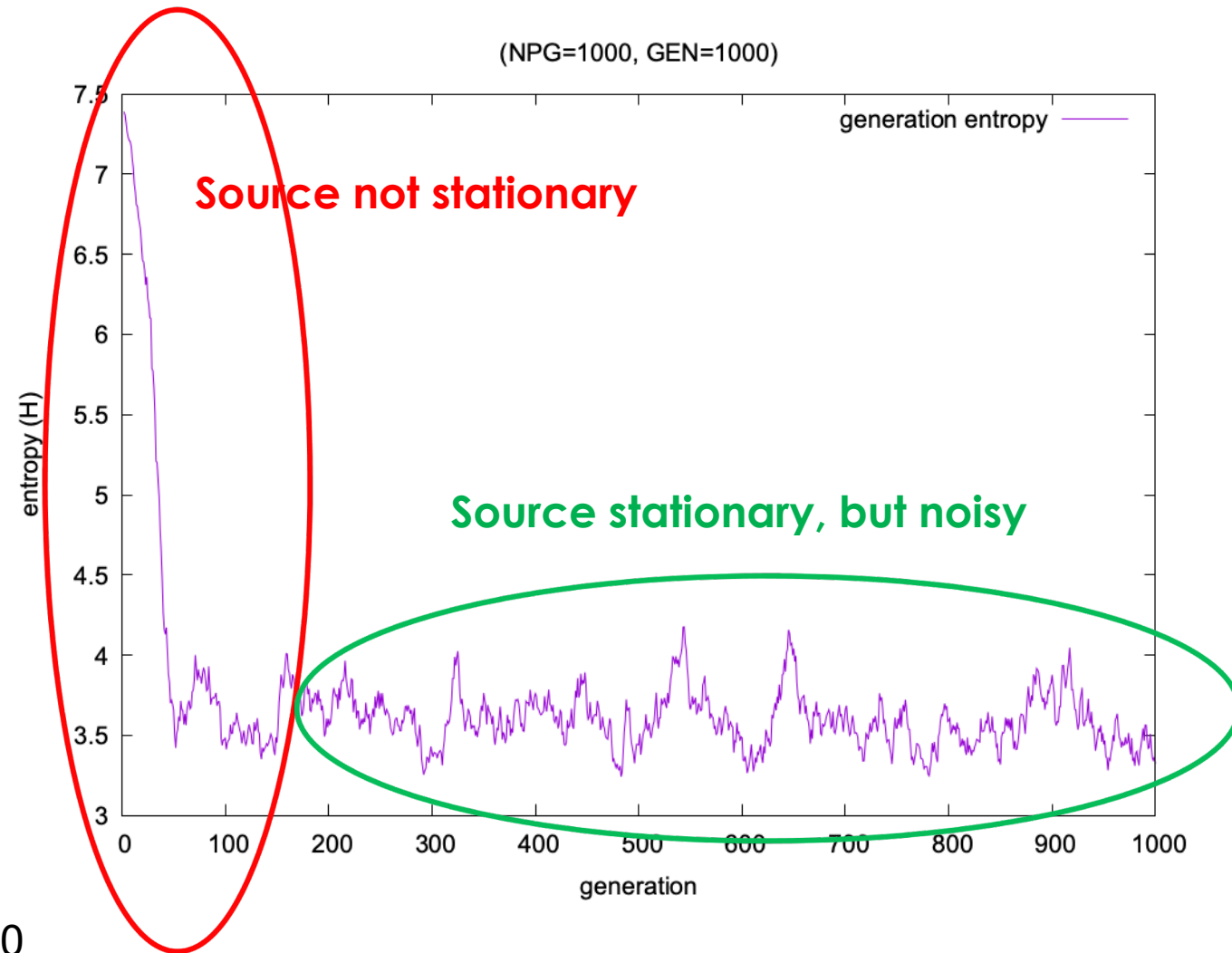
- The fission source may not be converged even if it produces an accurate eigenvalue estimate
 - This can result in inaccurate flux, reaction rate, or sensitivity tallies!
- KENO calculates the Shannon entropy to identify simulations with unconverged fission sources
- In general:
 - High Shannon entropy for uniform fission source
 - Low Shannon entropy for focused fission source

Advanced convergence diagnostics (cont.)

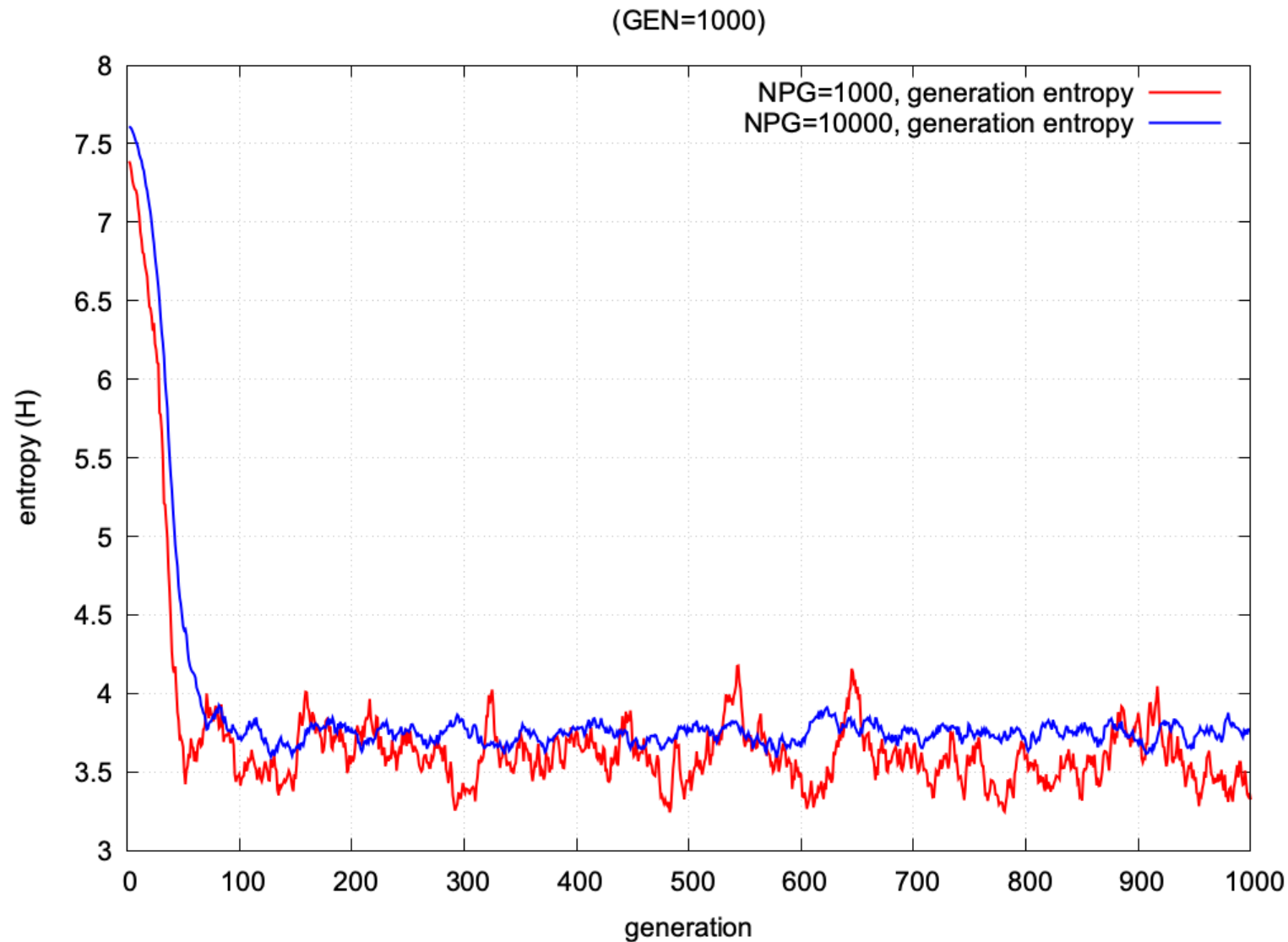
OECD test problem 4: Array of interacting spheres



Initial source distribution, NPG=1000, GEN=1000



Advanced convergence diagnostics (cont.)



Increase in NPG reduce the noise in generation-to-generation entropy values

Entropy convergence tests

KENO contains three statistical tests to check whether the Shannon entropy is converged

- **Test 1:** Is the uncertainty in the entropy larger than the entropy?
- **Test 2:** Does the entropy score from any of the active generations differ significantly from the total average entropy?
 - Note: It is expected that many of the generations will fall more than 1-sigma from the average, so failing this test is not necessarily worrisome
- **Test 3:** Does the entropy from the second half of the active generations differ significantly from the entropy from all generations?

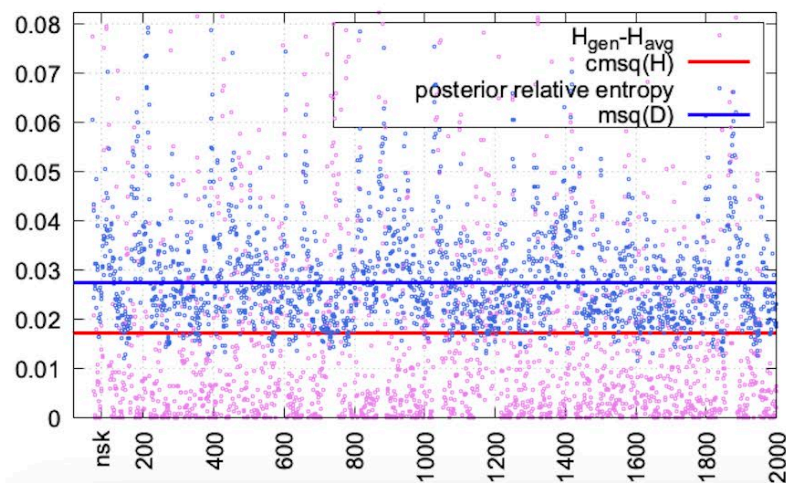
Tests perform better when reducing noise in Shannon entropy calculations (increase in NPG → less noise in the calculations)

These convergence tests are not available with Shift

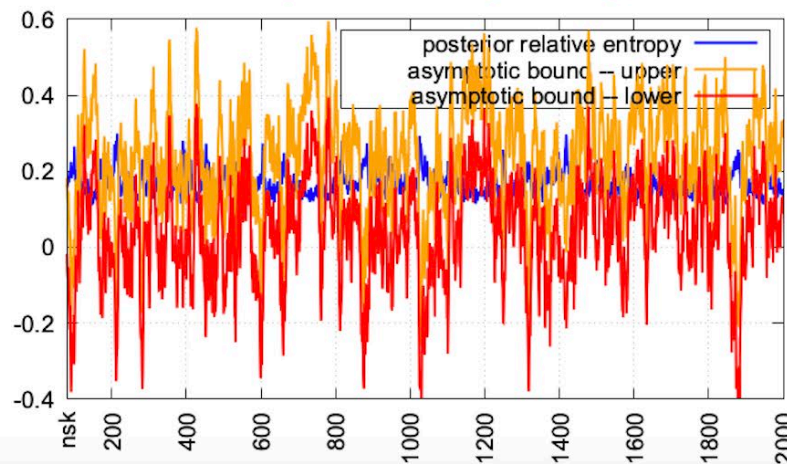
Entropy convergence tests

GEN=2000, NSK=80, NPG=1000

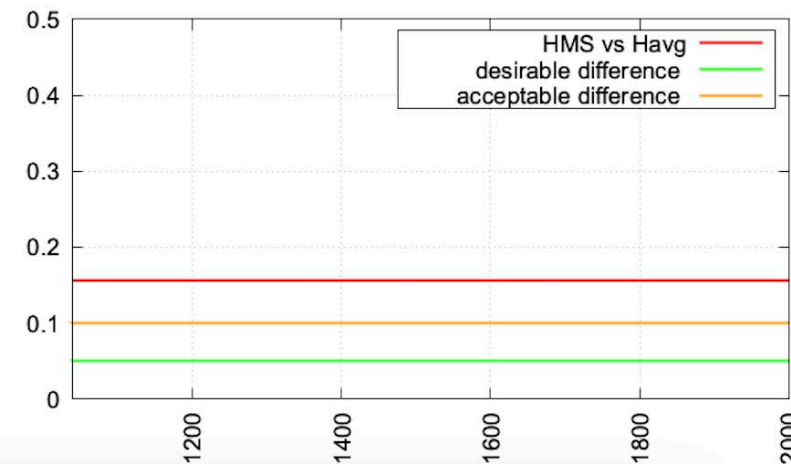
1st test -- Squared entropies
FAILED: $\text{msq}(D)=0.027495 > \text{cmsq}(H)=0.0172143$.



2nd test -- Is posterior relative entropy
within the asymptotic equipartition bounds
FAILED: Only 48.2292% active generations passed.



3rd test -- Does entropy averaged over the 2nd active generations
approach the mean source entropy
FAILED.

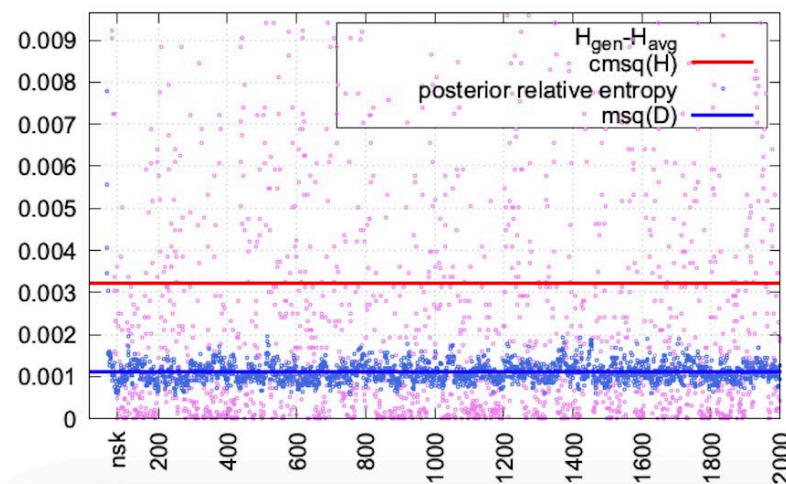


Diagnosics tests are sensitive to the noise in entropy by generations

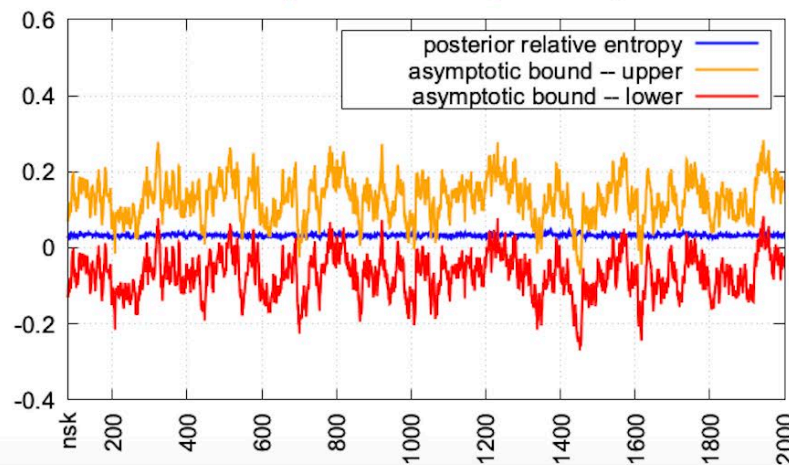
Entropy convergence tests

GEN=2000, NSK=80, NPG=10000

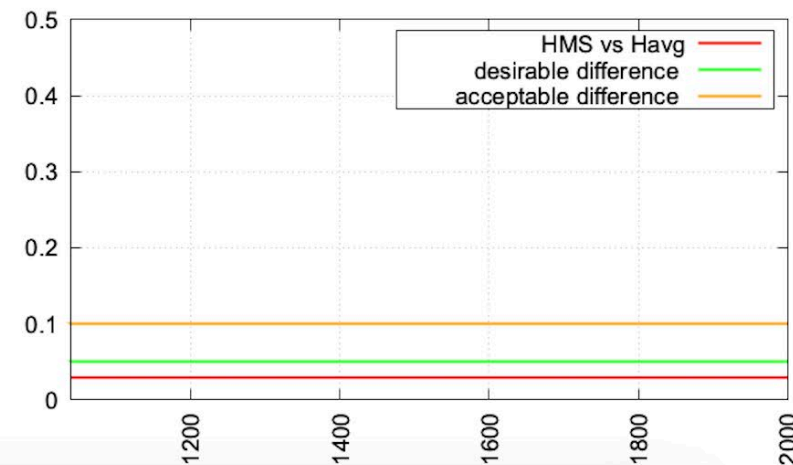
1st test – Squared entropies
PASSED: $\text{msq}(D)=0.00111946 < \text{cmsq}(H)=0.00321995$.



2nd test – Is posterior relative entropy
within the asymptotic equipartition bounds
FAILED: Only 93.5417% active generations passed.



3rd test – Does entropy averaged over the 2nd active generations
approach the mean source entropy
PASSED.

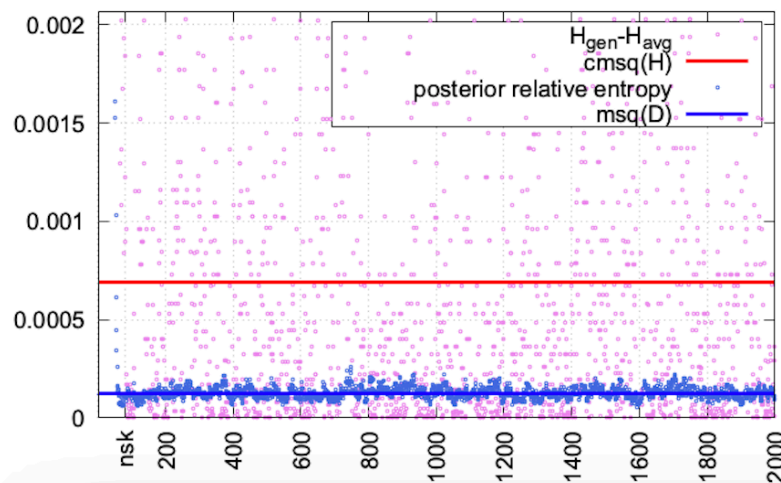


Second test is more sensitive to the noise in entropy by generations

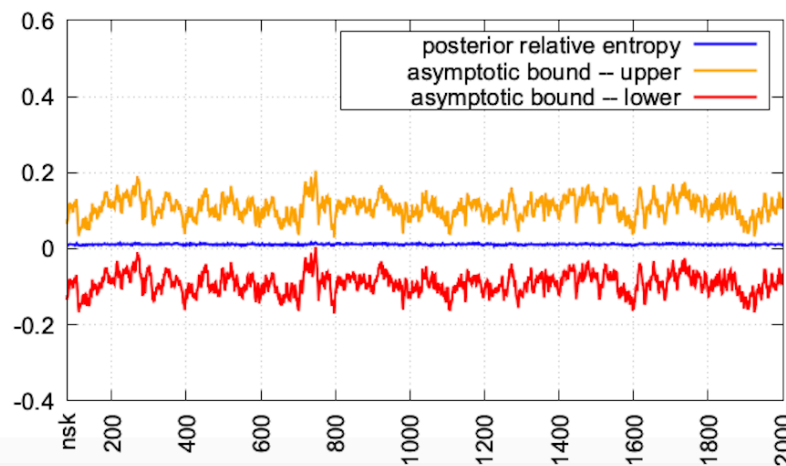
Entropy convergence tests

GEN=2000, NSK=80, NPG=40000

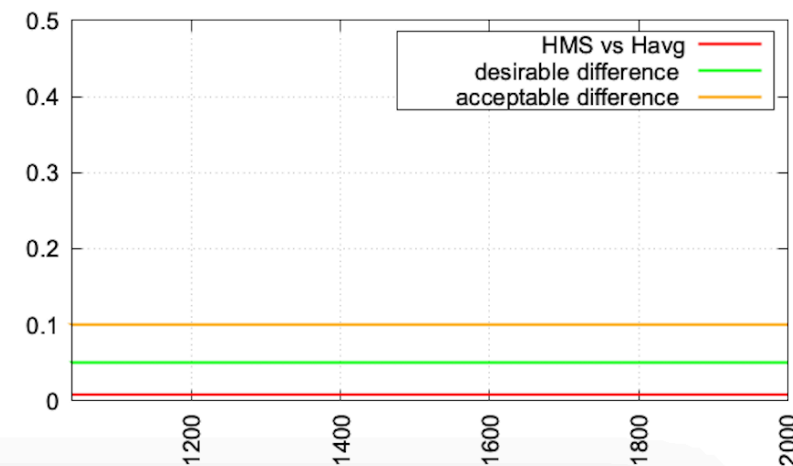
1st test – Squared entropies
PASSED: $\text{msq}(D)=0.000125918 < \text{cmsq}(H)=0.000689928$.



2nd test – Is posterior relative entropy
within the asymptotic equipartition bounds
PASSED.



3rd test – Does entropy averaged over the 2nd active generations
approach the mean source entropy
PASSED.



All tests passed

MC best practices

- Ensure a sufficient number of particles per generation are used
 - $\text{NPG} \geq 100,000$ for reactor physics models
 - $\text{NPG} \geq 10,000$ for crit safety models
- Check convergence plots to ensure NSK is large enough
 - ≥ 200 for reactor physics models; ≥ 25 for simple crit safety models
- Larger numbers of bodies and larger separations lead to larger NPG, NSK, & GEN
 - Set GEN to a large number (10,000+) and use SIG= parameter to reach the desired uncertainty for your results

Conclusions

- MC codes can solve difficult problems with a high degree of accuracy and precision
- All MC results contain uncertainty due to the statistical nature of the method
- A poorly converged fission source distribution can produce incorrect/biased results, and the inaccuracy of these results may not be readily apparent
- A good understanding of the nature of the MC method and the system will help identify incorrect results
- MC codes should never be used as a “black box”

Sub module 3: **Parameter and other KENO data**



CSAS input file layout

=Sequence **PARM=(CHK)**

Title

Cross-section library

Sequence input

**Transport
module input**



END

KENO data blocks

READ PARAM	parameter data	END PARAM (PARM also allowed)
READ GEOM	geometry region data	END GEOM
READ ARRAY	array definition data	END ARRAY
READ BIAS	biasing data	END BIAS
READ BOUNDS	albedo boundary data	END BOUNDS
READ START	initial source distribution	END START
READ PLOT	plot data	END PLOT
READ MIXT	cross-section mixing table	END MIXT
READ X1DS	extra 1-D cross-sections	END X1DS
READ ENERGY	energy group boundaries	END ENERGY
READ VOLUME	data to control volume calcs	END VOLUME
READ GRID	specify grid geometry	END GRID
READ REACTION	specify CE reaction rate data	END REACTION
END DATA		

A note on KENO parameter support in Shift

- The current implementation of Shift does not support all KENO options and parameters
 - And likely never will
- The plan is to add support in future releases of useful capabilities that aren't yet supported
- See Section 2.2 of the manual for more details on CSAS-Shift

KENO Parameter Data

Commonly used parameter data used to control calcs.

<u>Keyword</u>	<u>Default</u>	<u>Type of Data</u>
GEN=	203	Number of generations
NPG=	1000	Number of particles per generation
NSK=	3	Number of skipped generations prior to collecting data
SIG=	0	Run until specified uncertainty is reached
*HTM=	Yes	Generates HTML output
RND=	Given	Random number seed (hexadecimal)
*TME=	0 (unlimited)	Maximum execution time (minutes)
*TBA=	10 min.	Maximum time per generation (Max. starting time)

* Not currently supported in CSAS-Shift

Parameter data for commonly used tallies

<u>Keyword</u>	<u>Default</u>	<u>Type of Data</u>
FLX=	No	Tally fluxes
FDN=	Yes	Tally fission densities
*FAR=	No	Tally fission and absorption by region
*GAS=	FAR	Print FAR by group
CDS=	No	Collect neutron production data on mesh for Monaco or visualization (Yes/No or user-specified mesh #)
FIS=	No	Compute fission rate on mesh (Yes/No or user-specified mesh #)
GFX=	No	Compute fluxes on mesh (Yes/No or user-specified mesh #)
SCD=	Yes	Shannon entropy source mesh (Yes/No or user-specified mesh #)
DBX=	2	Doppler broaden 1D and 2D data (CE mode only)

Fulcrum is used for visualizing mesh tallies (2D and 3D)

* Not currently supported in CSAS-Shift

See Section 8.1.3.3 for additional parameters available

Energy data in parameters block (CE mode only)

<u>Keyword</u>	<u>Default</u>	<u>Type of Data</u>
NGP=	252	Number of groups used to tally data
• Define a global energy grid for all tallies • Will use the energy group structure from the SCALE MG library if the number of groups requested matches the number of groups in SCALE MG library (1457, 302, 252, 56, 44, or 27) • If not, equal lethargy spacing and a bottom group with boundaries of 1E-4 and 1E-5 boundaries • Energy group boundaries entered in READ ENERGY data block overwrites the energy group bounds set via NGP		

Start data (initial neutron distributions)

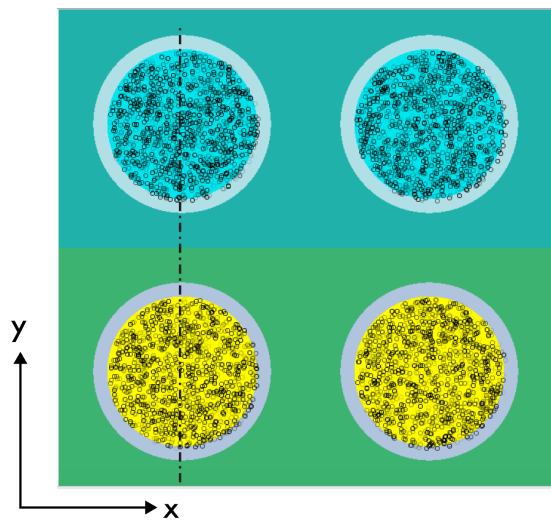
Start data types

<u>Type</u>	<u>Starting Type Description</u>
0	Uniform through fissile material
1	Cosine distribution throughout cuboid volume
2	Fraction at specified location in the Global Array Remainder using cosine distribution
3	At specified location in the unit at the specified position in the global array
4	Randomly distributed at specified location within all units of specified type in the global array

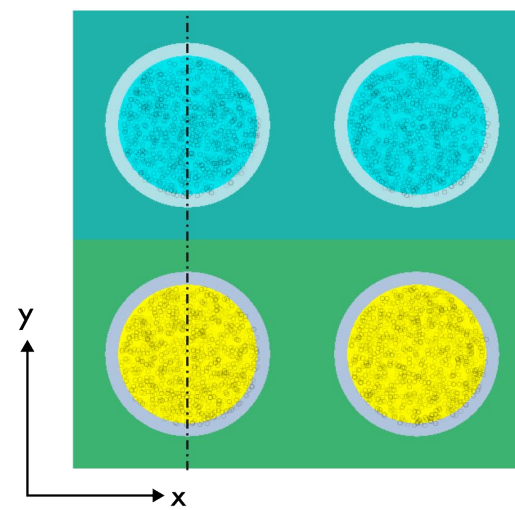
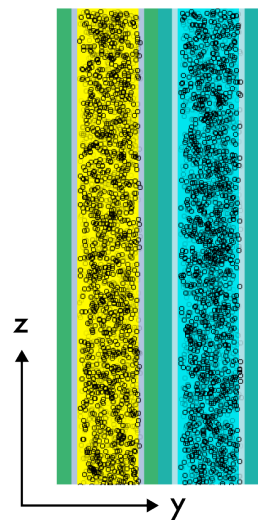
Start data types (cont.)

<u>Type</u>	<u>Starting Type Description</u>
5	Uniformly in fissile material within all units of specified type in the global array
6	Fraction at different specified locations relative to the global unit or in a unit at a specified position in the global array
7	Uniformly in fissile material in X- and Y-, $(1.0 - \cos(z))^2$ in Z-direction, within specified box; intended for high burnup spent fuel applications
8	Uniformly in X- and Y-, segmented in Z direction in specified fractions
9	Read source from file

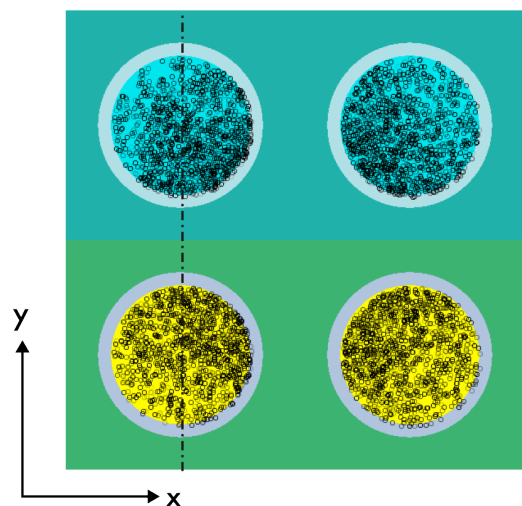
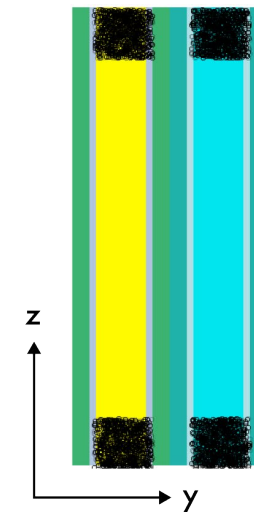
Examples for neutrons' initial distribution obtained with different start types



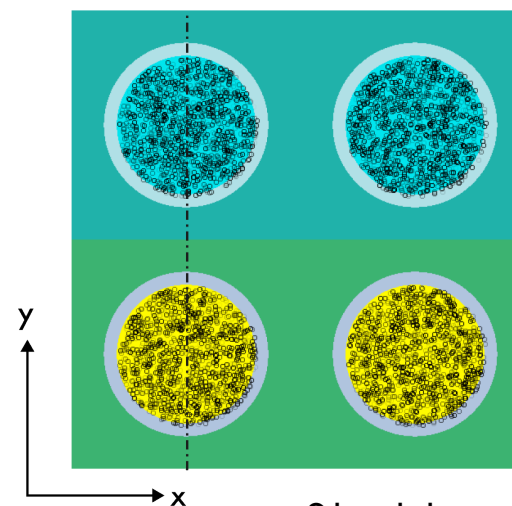
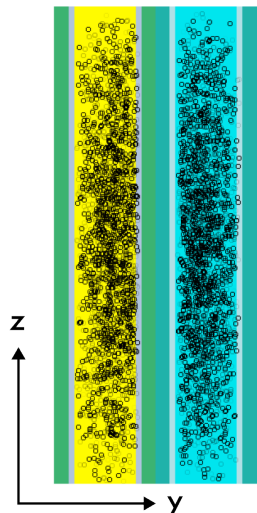
Start type 0



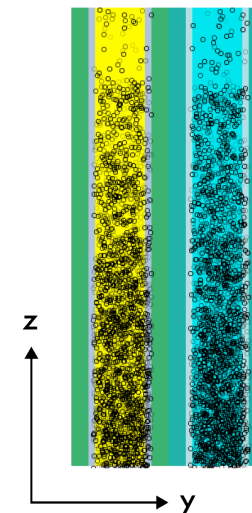
Start type 7



Start type 1



Start type 8



Shift start types

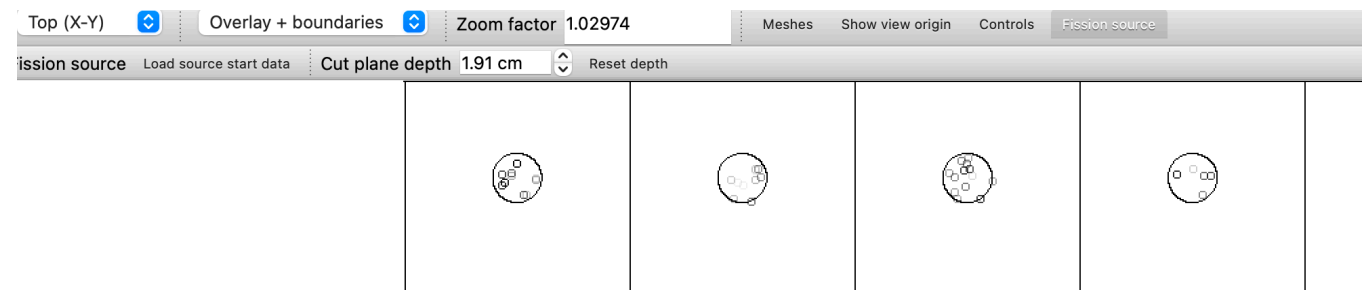
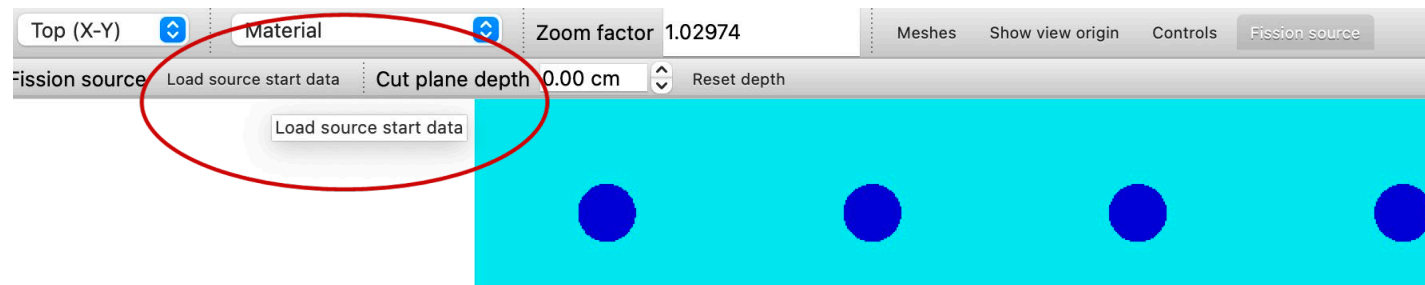
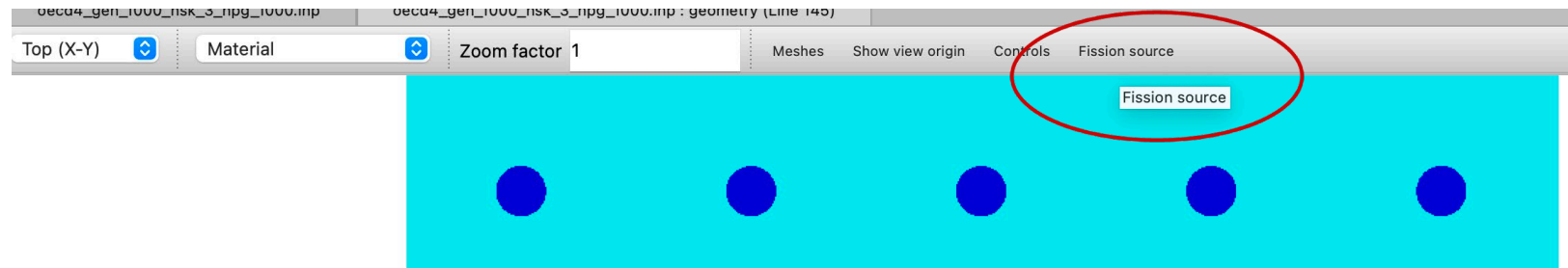
- Shift supports start types 0, 1, 6, 7, and 8
- Shift implementation of types 0, 1, 7, and 8 are essentially identical to those of KENO
- Shift does not require the largest LNU to be NPG
 - Details of treatment are in Section 2.2.4.1.3 of the SCALE 6.3.2 manual

Start data options

- Review options in the manual for selected start type
 - Section 8.1.3.8 and 8.1.4.8 of the KENO manual
- Same start data is used for KENO V.a and KENO-VI
 - KENO-VI does not allow global array for geometry, but it will recognize the global array if needed for start type selected
- Generally, not as important as it used to be because computers are faster and skipped generations are cheap

Fission Point Visualization via Fulcrum

- Initial and final fission points are stored if WS6 entered within start data block
- Start data can be loaded and then visualized by clicking the Fission Source button in geometry view mode



Global unit boundary data

Boundary data

- Used to define boundary conditions for the problem
 - Boundary conditions can reduce model size and setup time
 - Use “standard” BCs: reflective, periodic, vacuum, white
 - Material-based albedo BCs are **NOT** recommended
 - Here “albedo” specifically refers to materials like water, heavy water, concrete, carbon, poly, or paraffin
 - Can result in incorrect calculated k_{eff} values
 - Materials-based albedo data have not been regenerated recently
 - Only available in MG calculations
- Information specified in *BOUNDS* block
- Section 8.1.3.6 (Albedo data) of the KENO manual

KENO V.a style boundary data

READ BOUNDS

Face code=boundary condition

END BOUNDS

- Vacuum (void) is default
- Other BCs can be applied to CUBOIDAL outer boundaries with face codes listed in Table 8.1.21
 - Examples: ALL, SURFACE(k), XFC, XYF, +ZB, +XZ, ...

cuboidal face codes

- ❖ Face codes, which are specific to the cuboidal boundary shape, cannot be used with non-cuboidal boundary shapes
- ❖ **SURFACE(..)** face code **cannot be used** together with any cuboidal face codes listed in Table 8.1.21 if the outermost geometry is cube or cuboid
- ❖ The **ALL** face code refers to all faces of the global boundaries

KENO V.a style boundary data

READ BOUNDS

Face code=boundary condition

END BOUNDS

- Boundary condition (albedo) names listed in Table 8.1.24
 - Recommended: vacuum, mirror, periodic, white
Periodic and white **not** currently supported in Shift
 - Not recommended: material-specific albedos
- Terse input accepted (mir for mirror, etc.)

KENO-VI boundary data: Single geometry record

READ BOUNDS

[BODY=n] *Face code=boundary condition*

END BOUNDS

BODY is an optional keyword
for single geometry record

- Vacuum (void) is default
- Other BCs can be applied to CUBOIDAL outer boundaries with face codes listed in Table 8.1.21
 - Examples: ALL, SURFACE(k), XFC, XYF, +ZB, +XZ, ...

cuboidal face codes

- ❖ Face codes, which are specific to the cuboidal boundary shape, cannot be used with non-cuboidal boundary shapes
- ❖ **SURFACE(..)** face code **cannot be used** together with any cuboidal face codes listed in Table 8.1.21 if the outermost geometry is cube or cuboid
- ❖ The **ALL** face code refers to all faces of the global boundaries

KENO-VI boundary data: Multiple geometry records

READ BOUNDS

[BODY=n] Face code=boundary condition

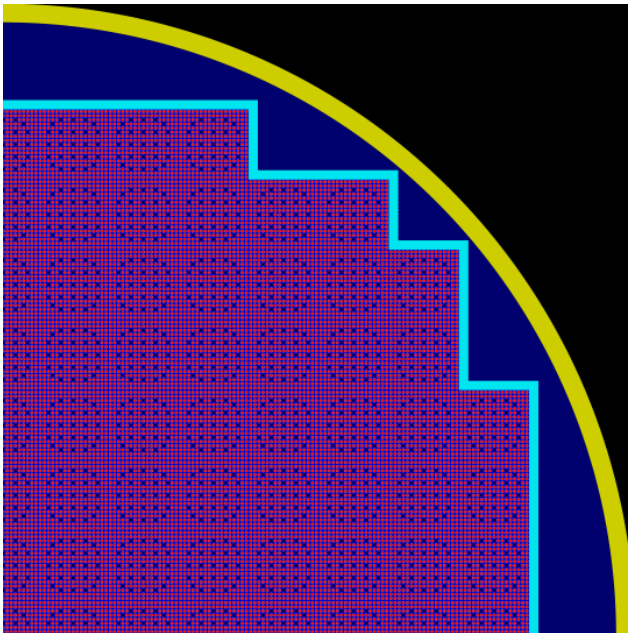
END BOUNDS

- Body is a keyword with n as the integer label (ID) of the geometry record (shape)
- Face codes listed in Table 8.1.21 can be used for boundary condition specification

Chorded surfaces have no numbers and thus cannot be used as non-escape outer boundaries

KENO-VI boundary data: Multiple geometry records)

- Example:



```
global unit 100
cuboid 10 190 0 190 0 395.76 -30
cylinder 20 187.96 395.76 -30
cylinder 30 193.675 395.76 -30
cuboid 40 200 0 200 0 395.76 -30
'
array 41 10 20 place 1 1 1 0 0 0
media 4 1 30 -20
'
boundary 30 40
end geom
'
read bounds
  body=40 surface(2)=refl
  body=40 surface(4)=refl
end bounds
```

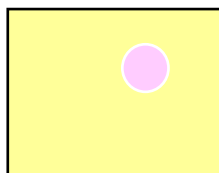
Cuboid 40 is used to cut out quadrant I of a full core model to make a quarter core model. The -X and -Y faces (2 and 4) are set to be reflective.

Periodic versus reflective boundary conditions

- Reflective boundary conditions are simple mirrors
- Periodic boundary conditions apply to the pairs of opposing faces, e.g., the X faces
- Periodic boundary conditions make the outward current on one face the inward current on the opposite face

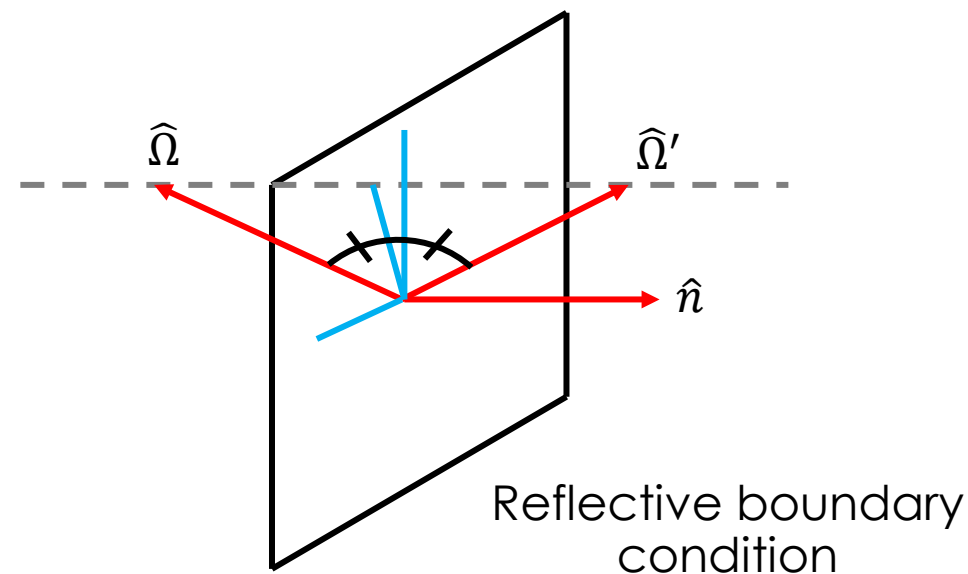
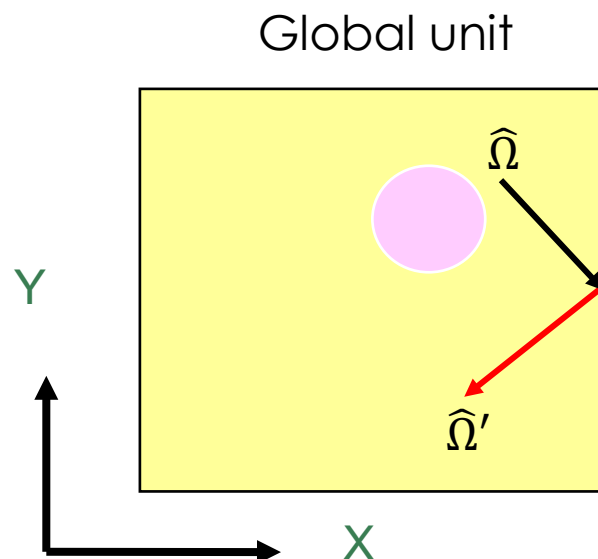
Reflective boundary condition

Given a global unit:



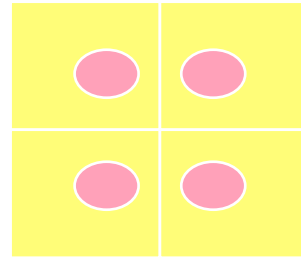
Reflect on opposing faces in X, Y, and Z

Note how the offset positioning translates to the reflected unit

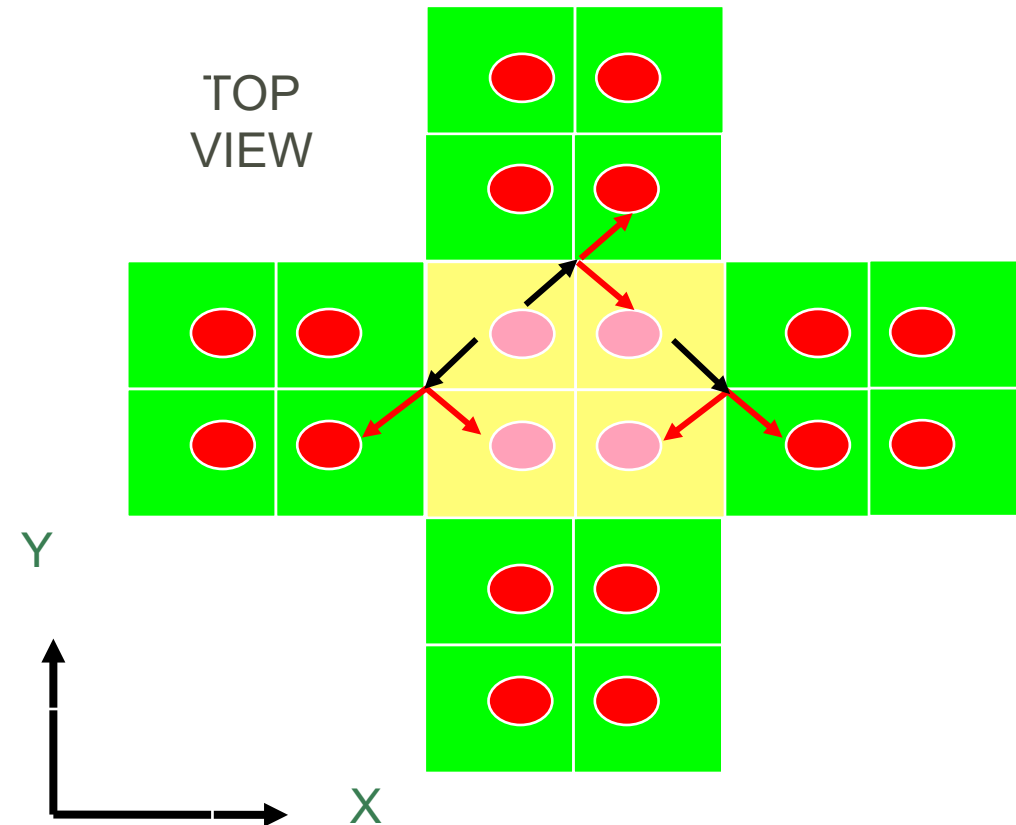


Reflective boundary condition

Given a complex
global unit:

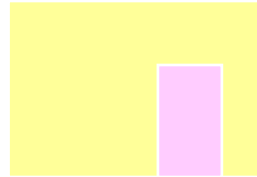


- Note how the offset positioning translates to the reflected array
- Particles re-enter from the same surface with the direction change as if reflected off a mirror
- Not allowed on curvilinear faces on outermost geometry (KENO V.a)

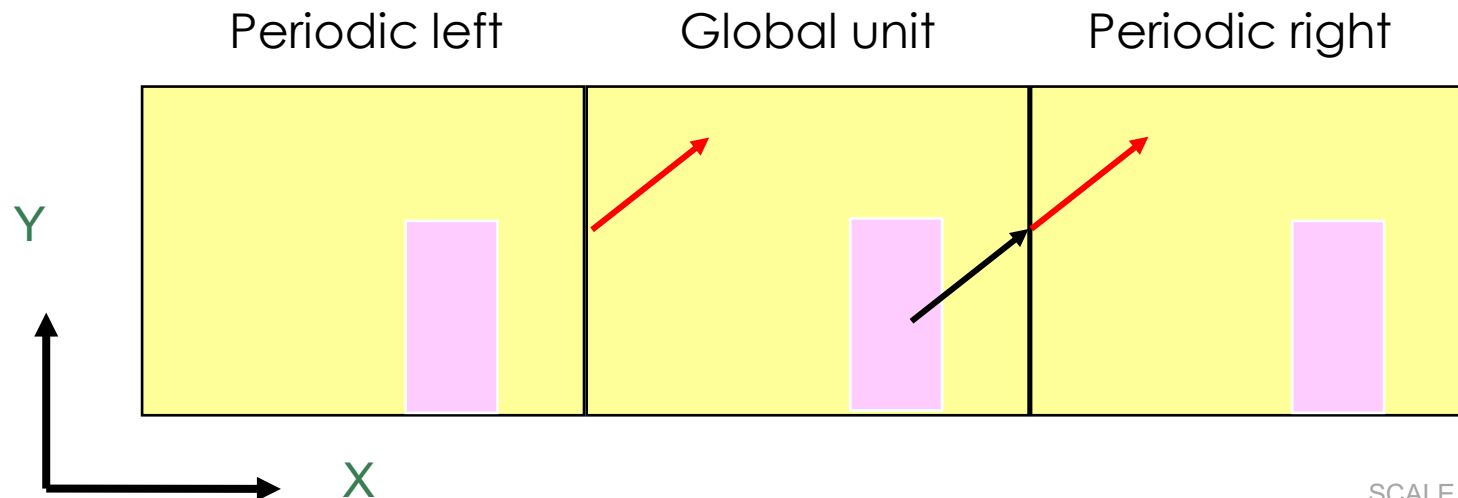


Periodic boundary condition

Given a global unit:



No directional change but re-enters from the opposite boundary surface, as in a periodic lattice structure



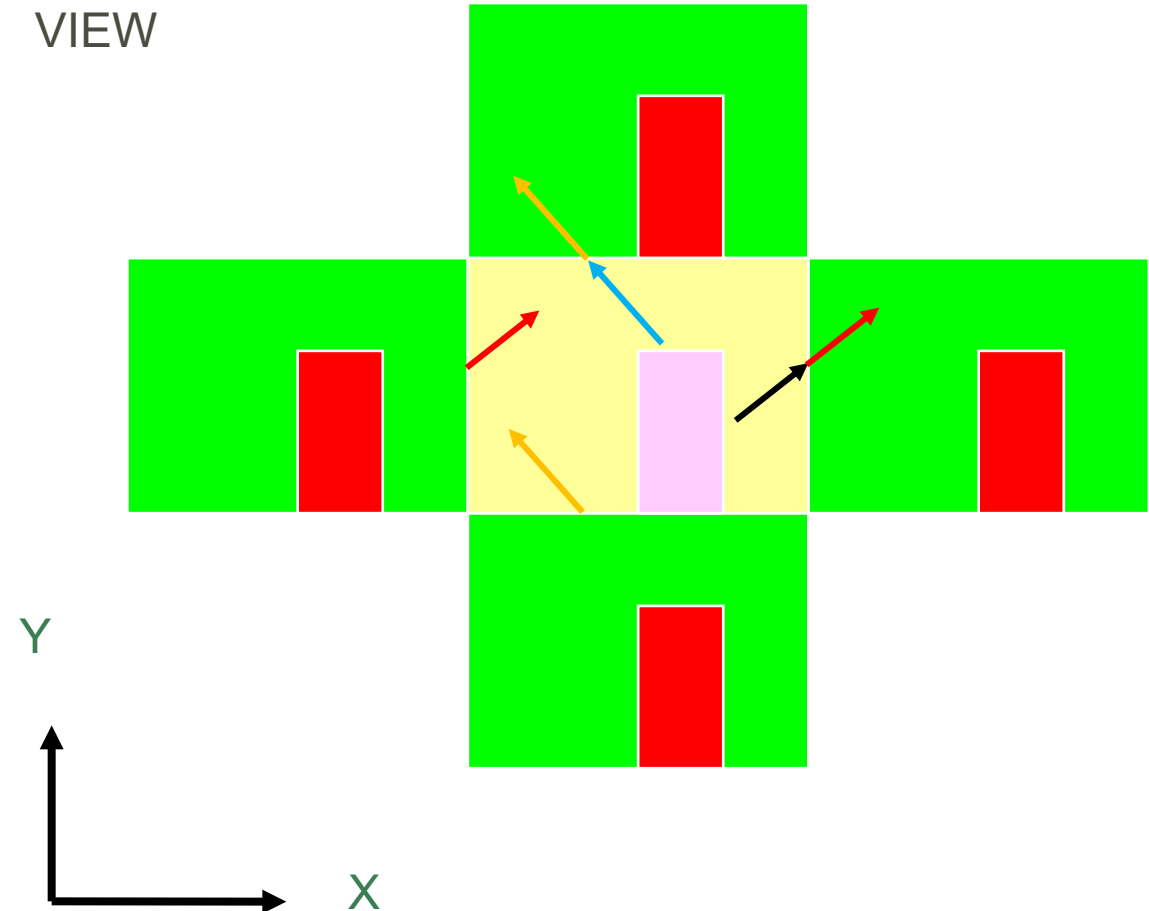
Periodic boundary condition

Given a global unit:



- Reflect on opposing X, Y, and Z faces for a periodic array
- Note how the offset positioning translates to the periodic array
- Particles re-enter from opposing boundary with no direction change
- Note allowed on curvilinear faces on outermost geometry (KENO V.a)

TOP
VIEW



Energy block – CE only

Energy group boundaries – CE only

- Sets arbitrary group boundaries for editing in CE mode
- See *NGP* in parameters block for additional options
- Input format:

READ ENERGY

$EB(1) \ EB(2) \ EB(3) \ \ EB(NGP+1)$

END ENERGY

- $EB(i)$ is upper energy boundary for energy group i in eV for output edits

Energy data example

READ ENERGY

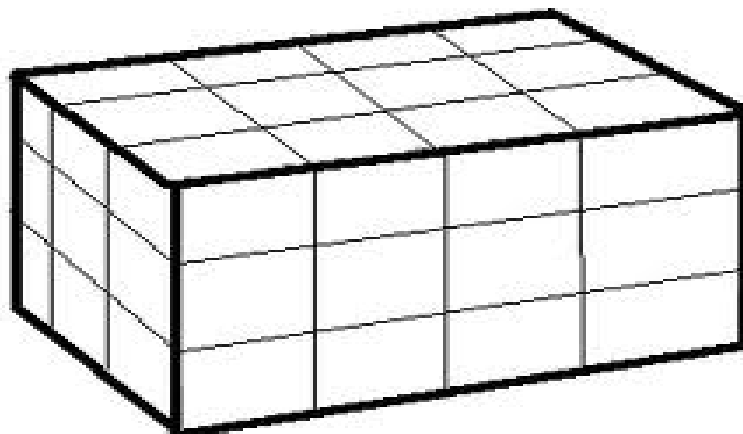
2E7 1E7 1E5 1E3 1 1E-5

END ENERGY

This example sets a 5-group structure for calculated fluxes and reaction rates:

Group 1: from 2E7	to 1E7	(20 MeV – 10 MeV)
Group 2: from 1E7	to 1E5	(10 MeV – 100keV)
Group 3: from 1E5	to 1E3	(100keV – 1 keV)
Group 4: from 1E3	to 1	(1 keV – 1 eV)
Group 5: from 1	to 1E-5	(1 eV – 10^{-5} eV)

Volume block



MC volume calculation

- The volume block is used to control volume calculations in the CSAS6 sequences
- Options described in Section 8.1.3.13 of the KENO manual
- In KENO we have two different volume estimation algorithms; random points and ray-tracing, whereas in Shift only ray-tracing
- Simplest approach:
 - Set type as **random** or **trace**
 - Define a bounding box over volume region to calculate volumes (Optional)
 - (XP, YP, ZP) and (XM, YM, ZM) are corners
 - Set **batches** and **points** for type random, or **nrays** for type trace
 - Volume and uncertainty of each region printed in output

MC volume example

READ VOLUME

```
type=random points=1000000 batches=10000
```

```
xp=60.10 xm=-60.10 yp=60.10 ym=-60.10 zp=115.640 zm=-16.20
```

END VOLUME

READ VOLUME

```
type=trace nrays=1000000
```

```
xp=60.10 xm=-60.10 yp=60.10 ym=-60.10 zp=115.640 zm=-16.20
```

END VOLUME

Extents of the global bounds are used if no bounding box specified

Other volume block options

Other volume input options include:

- Manually inputting vol= on media records
 - Specify **total volume** if unit is used multiple times
 - Take care to account for parts of the volume that are clipped by other regions
- Using Fulcrum to calculate volumes
 - Calculate using ORANGE (new C++ geometry package, the Oak Ridge Adaptable Nested Geometry Engine) ray tracing algorithm
 - Execute using Run → Calculate Volumes
 - User can then specify number of rays to trace in X, Y, and Z dimensions
 - Volumes are then listed by Fulcrum in “Messages”

Reaction block

Reaction rate data

- Three types of reaction rate tallies available
 - Mixture fluxes (**MIXFLUX**) – Tallies fluxes using track length estimate
 - Reaction rate tally (**RRTALLY**) – Tallies reaction rates based on track length estimate fluxes
 - Cross section tally (**XSTALLY**) – Tallies energy collapsed cross sections based on reaction rates and mixture tallies
- Provides a CE equivalent to KMART capability (and more)
- Introduced in in SCALE 6.2
 - Not supported by Shift

Reaction rate data (CE only)

<u>Keyword</u>	<u>Default</u>	<u>Type of Data</u>
MIX=	N/A	Mixture number (* selects all)
MIXLIST=	N/A	List of mixtures
NUC=	N/A	Nuclide Identifier (* selects all)
NUCLIST=	N/A	List of nuclide identifiers
MT=	N/A	Reaction identifiers (* selects all)
MTLIST=	N/A	List of reaction identifiers

Reaction identifiers (MT numbers) are given in Section 10.1.3 of the SCALE manual

Reaction rate examples

RR filter for fission of ^{235}U in mixture 10

READ REACTION

MIX=10 NUC=92235 MT=18

RRTALLY=Yes

END REACTION

RR filter for fission of ^{235}U in mixture 10 with request for cross section tally

READ REACTION

MIX=10 NUC=92235 MT=18

XSTALLY=YES RRTALLY=YES

END REACTION

RR filter for all reactions of ^{235}U in mixture 10

READ REACTION

MIX=10 NUC=92235 MT=*

RRTALLY=yes

END REACTION

Reaction rate examples (cont.)

Defines a complex reaction filter used to tally:

- a) (n, γ) capture reaction (**MT**=102) of U-238 in mixtures 10, 20 and 30 respectively,
- b) Fission reaction (**MT**=18) of Pu-239 in mixture 20,
- c) All reactions of H-1 in mixture 40,
- d) Elastic scattering reaction of O-16 in all mixtures,
- e) Total absorption reaction of all nuclides in all mixtures.

READ REACTION

MIXLIST 10 20 30 **END**

NUC=92238

MT=102

MIX=20 **NUC**=94239 **MT**=18

MIX=40 **NUC**=1001 **MT**=*

MIX=* **NUC**=8016 **MT**=2

MIX=* **NUC**=* **MT**=27

...

END REACTION

Reaction tally results are stored in separate output files

Sub module 4: **CSAS definitions and tallies data**



CSAS input file layout

=Sequence **PARM=(CHK)**

Title

Cross-section library

Sequence input



**Transport
module input**

END

CSAS data blocks

READ COMP

composition data

END COMP

READ CELLDATA

unit cell data for MG

END CELLDATA

READ DEFINITIONS

definitions for tallies

END DEFINITIONS

READ TALLIES

tallies data

END TALLIES

- KENO parameter block can be used to activate tallies (FLX, FDN, GFX, FIS, CDS, SCD, ...)
 - but with some limitations:
 - A global energy group structure for all tallies (NGP parameter or ENERGY DATA block)
 - A tally can only be requested once
- New definitions and tallies data blocks remove these limitations: Flexible tally specification
 - Multiple tally definitions with the same response
 - In SCALE 6.3.2, available for only mesh tallies
 - Mesh tallies are available with FLUX, FISSION_DENSITY and FISSION_SOURCE responses
 - Each tally can use a different energy and spatial grids

Definitions block

Definitions data

- More convenient spatial and energy grid specification for tallies
- Not recommended to be used with NGP, ENERGY BLOCK data and GRIDGEOMETRY DATA
- Available with KENO and Shift

```
READ DEFINITIONS
  read grid 1
    xlinear 30 -10 70
    ylinear 10 -20 60
    zlinear 50 -30 40
  end grid
  'user specified energy grid
  read energyBounds 1
    bounds 2e7 0.625 1e-5 end
  end
  'SCALE 56-group neutron structure with additional energy points'
  energyBounds 10
    56n bounds
    1.1 0.11 0.011 0.0011
  end energyBounds
END DEFINITIONS
```

Section 2.1.4.2.1 provides more details

Tallies block

Tallies data

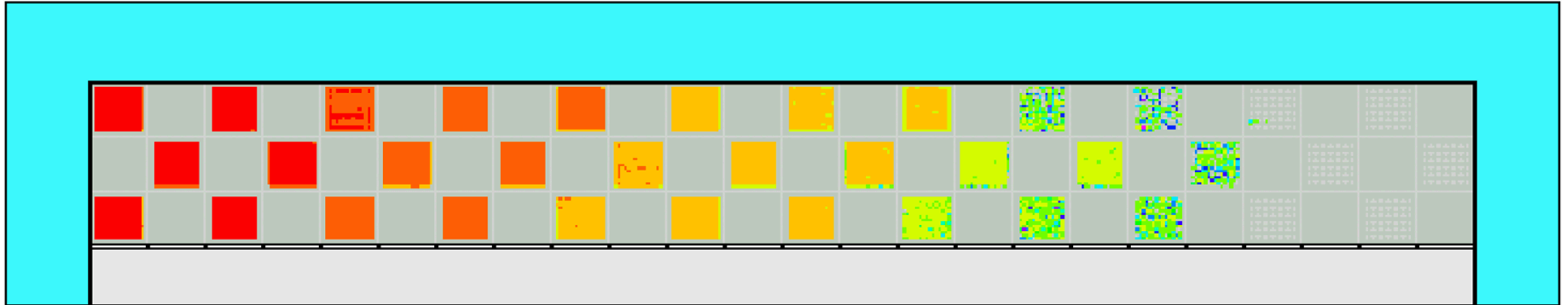
- Currently provides convenient definitions of mesh tallies
- Only with FLUX, FISSION_DENSITY and FISSION_SOURCE responses
- Mesh tallies with same response can be defined multiple times
- Will be extended by adding other tallies in future (region-averaged, mixture-averaged, sensitivity tallies)

```
READ TALLIES  
  read mesh 1  
    response=FLUX  
    grid=1  
    energy= 1  
  end  
  read mesh 1  
    response=FLUX  
    grid=127  
    energy= 18  
  end  
END TALLIES
```

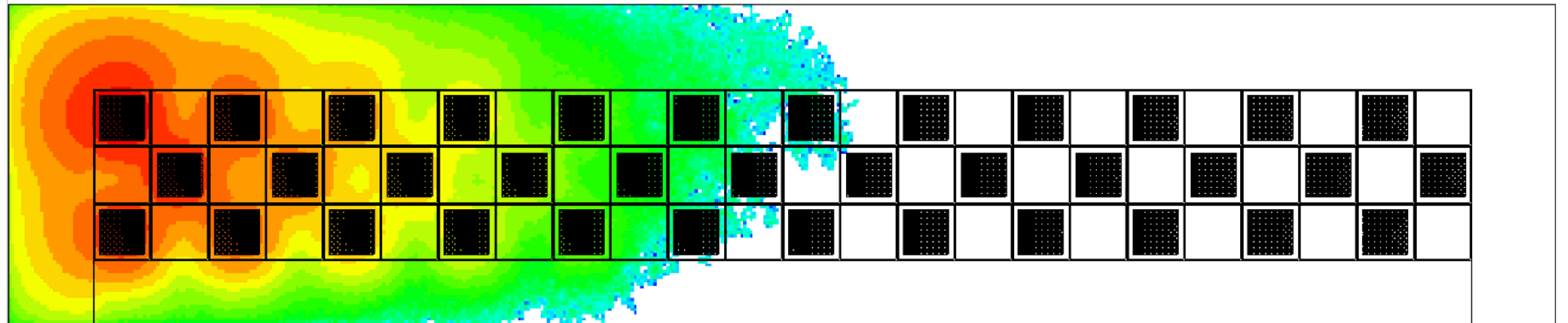
- Mesh tally results stored in 3dmap files can be visualized via Fulcrum

Section 2.1.4.2.2 provides more details

Tallies data



Fission source distribution



Flux distribution

Sub module 5: **CSAS output**



CSAS output

- Lecture provides walkthrough of KENO HTML and text outputs
- Example output is from KENO V.a, but the information from KENO-VI is the same
- Discussion of CSAS-Shift output also included
 - No HTML output support
 - HDF5 file created with additional information, but use is not recommended
 - Format is designed for large data storage, primarily useful for other SCALE sequences
 - Requires specialty software for viewing and interacting
 - Plots directory contains several plots, such as:
 - k_{eff} by generation
 - k_{eff} by skipped generation
 - Shannon entropy

KENO text output

- Lady Godiva output with 203 generations



System information

```
*****
*
*                               SCALE 6.3.2                               *
*                               -----                               *
*                               2024-02                               *
*
*   SCALE:  A Comprehensive Modeling and Simulation Suite             *
*           for Nuclear Safety Analysis and Design                   *
*
*           Reactor and Nuclear Systems Division                   *
*           Oak Ridge National Laboratory                           *
*
*           http://scale.ornl.gov                                    *
*           scalehelp@ornl.gov                                       *
*
*****
*****

Job Information
-----

Job started on mac0136419 on Wed 2025-03-05 03:13:43
Working directory: /private/var/folders/6y/gm6k_jf51nz93gs73fgs8n2hvsyht9/T/scale.6tg.95718
Input file name   : /Users/6tg/Desktop/l_godiva_keno.inp
Output file name  : /Users/6tg/Desktop/l_godiva_keno.out
SCALE executable  : /Applications/SCALE-6.3.2.app/Contents/Resources/bin/scale

*****
```

Input echo

```
module csas5 will be called on Wed Mar 5 15:13:48 2025.
sequence specification record:=csas5 parm=()
Input Data:

    godiva
    ce_v7.1_endf
    read composition
      uranium      1 den=18.742 1 300
                                     92235 93.7112
                                     92238 5.2686
                                     92234 1.0202      end
    end composition
    read geometry
    global unit 1
      sphere 1 1      8.741
    end geometry
    end data
end
```

Mixing table from VULCAN

```
-----  
Mixture table for component comps at line:4, column:1  
-----  
Mixture = 1 with density(g/cc) = 18.7420 and temperature(K) = 300.00  
      Entry      Mixture      Nuclide      Density (atoms/b-cm)      Temperature (K)  
-----  
          1          1      92234          4.919947e-04          300.00  
          2          1      92235          4.499968e-02          300.00  
          3          1      92238          2.498000e-03          300.00  
-----  
      Entry      Mixture      Nuclide      Density (atoms/b-cm)      Temperature (K)  
-----  
End of mixture table for component comps at line:4, column:1  
-----
```

Mixing table from KENO

mixing table

mixture =	1	density(g/cc) =	18.742	temperature(K) =	300.00		
nuclide	atom-dens.	wgt. frac.	za	awt	temp	nuclide	title
92234	4.91995E-04	1.02020E-02	92234	234.0410	300.00	u-234	@ 300K
92235	4.49997E-02	9.37112E-01	92235	235.0439	300.00	u-235	@ 300K
92238	2.49800E-03	5.26860E-02	92238	238.0508	300.00	u-238	@ 300K

Geometry summary

```
***** global *****
----- unit 1 -----

1 sphere          1 1 radius = 8.7410    the center is located at ( 0.0000 , 0.0000 , 0.0000 ).
```

***** warning ***** keno message number k5-316 follows:
No mesh provided for Source Convergence Diagnostics (SCD). Continue with default mesh.

Godiva				
volumes for those units utilized in this problem				
unit	region	geometry region	volume	cumulative volume
1	1	1	2.79751E+03 cm**3	2.79751E+03 cm**3

unit	uses	region	mixture	total volume
1	1	1	1	2.79751E+03 cm**3

total mixture volumes		
mixture	total volume	mass (g)
1	2.79751E+03 cm**3	5.24310E+04

More geometry

problem 2c8 - 2x2x2 array of metal cylinders
volumes for those units utilized in this problem

unit	region	geometry region	volume	cumulative volume
1	1	1	1.11737E+03 cm**3	1.11737E+03 cm**3
	2	2	1.33876E+03 cm**3	2.45613E+03 cm**3



unit	uses	region	mixture	total volume
1	8	1	1	8.93897E+03 cm**3
		2	0	1.07100E+04 cm**3



total mixture volumes		
mixture	total volume	mass (g)
0	1.07100E+04 cm**3	
1	8.93897E+03 cm**3	1.67733E+05

Initial histories

volume fraction of fissile material in the system= 1.00000E+00

start type 0 was used.

the neutrons were started uniformly throughout the entire volume defined by the outermost geometry card.

0.00000 minutes were required for starting. total elapsed time is 0.09667 minutes.
lgodiva

generation	generation k-effective	average k-effective	avg k-eff deviation	generation entropy	matrix k-effective	matrix k-eff deviation
1	9.26888E-01	1.00000E+00	0.00000E+00	6.38854E+00	0.00000E+00	0.00000E+00
2	9.70361E-01	1.00000E+00	0.00000E+00	6.25103E+00	0.00000E+00	0.00000E+00
3	9.78194E-01	9.78194E-01	0.00000E+00	6.18852E+00	0.00000E+00	0.00000E+00
4	9.71353E-01	9.74773E-01	3.42050E-03	6.11712E+00	0.00000E+00	0.00000E+00
5	9.95984E-01	9.81843E-01	7.34078E-03	6.04635E+00	0.00000E+00	0.00000E+00
6	1.02103E+00	9.91640E-01	1.10866E-02	6.05841E+00	0.00000E+00	0.00000E+00
7	9.87496E-01	9.93965E-01	1.46607E-02	6.05613E+00	0.00000E+00	0.00000E+00
8	9.79474E-01	9.91067E-01	1.10213E-02	6.10372E+00	0.00000E+00	0.00000E+00
9	1.01318E+00	9.94753E-01	9.65703E-03	6.16797E+00	0.00000E+00	0.00000E+00
10	9.76500E-01	9.92145E-01	8.46705E-03	6.12891E+00	0.00000E+00	0.00000E+00

Final histories and initial job summary

200	9.71181E-01	1.00209E+00	1.73048E-03	6.16733E+00	0.00000E+00	0.00000E+00
201	9.47351E-01	1.00182E+00	1.74396E-03	6.13259E+00	0.00000E+00	0.00000E+00
202	1.02604E+00	1.00194E+00	1.73944E-03	6.02412E+00	0.00000E+00	0.00000E+00
203	1.05433E+00	1.00220E+00	1.75058E-03	6.05919E+00	0.00000E+00	0.00000E+00

keno message number k5-123
1

execution terminated due to completion of the specified number of generations.
godiva

lifetime = 6.25898E-09 + or - 1.59876E-11 generation time = 5.70544E-09 + or - 1.92314E-11
nu bar = 2.59831E+00 + or - 4.28588E-04 average fission group = 2.59437E+01 + or - 2.76388E-02
energy(ev) of the average lethargy causing fission = 8.21707E+05 + or - 2.24749E+03
system mean free path (cm) = 2.56084E+00 + or - 1.07315E-03

no. of initial generations skipped	average k-effective	deviation	67 per cent confidence interval	95 per cent confidence interval	99 per cent confidence interval	number of histories	deviation of variance (per cent)
3	1.00220	+ or - 0.00175	1.00045 to 1.00395	0.99870 to 1.00570	0.99695 to 1.00745	200000	10.8000
4	1.00236	+ or - 0.00175	1.00060 to 1.00411	0.99885 to 1.00586	0.99710 to 1.00761	199000	10.8509
5	1.00239	+ or - 0.00176	1.00063 to 1.00415	0.99887 to 1.00591	0.99711 to 1.00767	198000	10.8380

Entropy tests

-----|-----

Test 1: Is the final fission source converged? | Test 1: failed

-----|-----

Test 1 details:

Is the mean square posterior relative entropy < the center mean square Shannon entropy?

(msq(D) < cmsq(H(S)))

generations	skipped	msq	cmsq
	3	1.00939E-02	1.56362E-03
	13	1.00469E-02	1.54749E-03
	23	1.00804E-02	1.56412E-03
	33	1.00179E-02	1.56527E-03
	43	1.01442E-02	1.63947E-03
	53	1.01857E-02	1.59460E-03
	63	1.00784E-02	1.59247E-03
	73	1.00973E-02	1.44774E-03
	83	1.00684E-02	1.33165E-03
	93	1.00834E-02	1.37228E-03
	103	9.89006E-03	1.30156E-03
	113	9.92880E-03	1.26039E-03
	123	1.00131E-02	1.37221E-03
	133	9.91569E-03	1.39461E-03
	143	9.56307E-03	1.26725E-03
	153	9.02795E-03	1.16550E-03
	163	8.21383E-03	8.50892E-04
	173	7.59013E-03	6.87027E-04
	183	6.88406E-03	4.85875E-04
	193	5.50991E-03	6.48632E-04

Entropy tests

-----|-----
Test 2: Are all the active generations within epsilon of the average?
-----|-----

Test 2: failed

Test 2 details:

Does the Shannon entropy of each active generation vary from the average Shannon entropy of the system?

$(|D(S||T) - [H(T-H(S))] | < 0.1)$

2 active generations failed the test.

The maximum value for the test is 1.13935E-01 which occurred for active generation 1.

-----|-----
Test 3: Are there adequate active generations after the source is converged?
-----|-----

Test 3: failed

Test 3 details:

Does the Shannon entropy for the last half of the active generations vary from the Shannon entropy of all active generations?

$(|H(T) - H_b| < 0.1)$

$|H(T) - H_b| = 1.02064E-01$

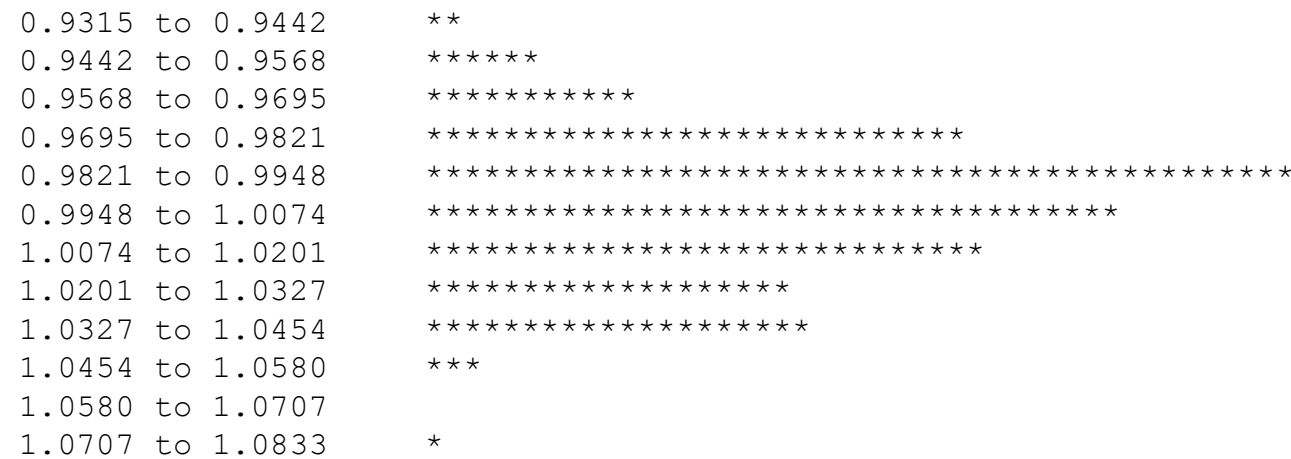
Plot of generation entropy values

plot of Shannon Entropy by generation

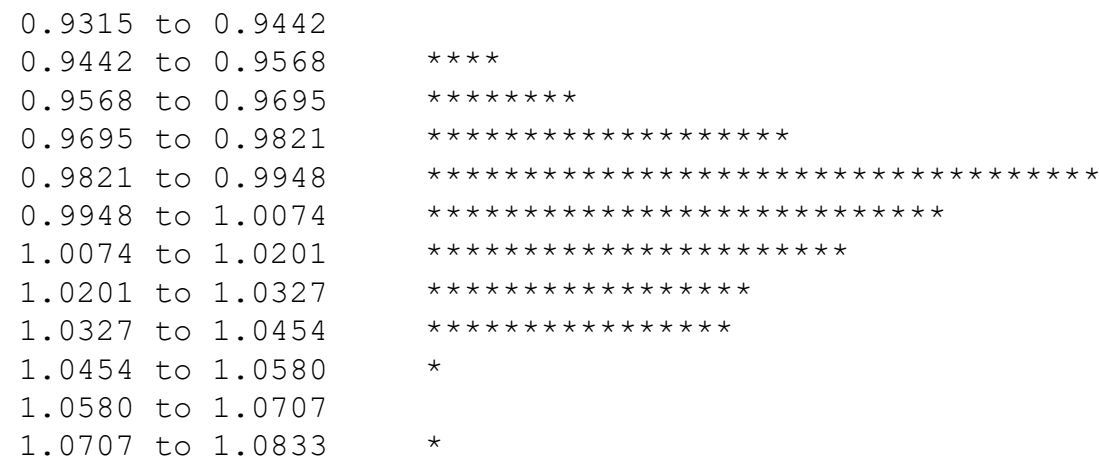


KENO ASCII histograms

frequency for generations 4 to 203 each asterisk represents 1.0000 generations



generations frequency for generations 54 to 203 each asterisk represents 1.0000



KENO only makes *.ptp files for use in Fulcrum with HTM=yes, but always includes ASCII art histograms in the text output.

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SCALE 6.3.2| Last Updated: March 2025

Shift text output

- Lady Godiva output with 203 generations



System information

```
*****
*
*                               SCALE 6.3.2                               *
*                               -----                               *
*                               2024-02                               *
*
*   SCALE:  A Comprehensive Modeling and Simulation Suite               *
*            for Nuclear Safety Analysis and Design                     *
*
*            Reactor and Nuclear Systems Division                       *
*            Oak Ridge National Laboratory                             *
*
*            http://scale.ornl.gov                                       *
*            scalehelp@ornl.gov                                         *
*
*****
*****

Job Information
-----

Job started on mac0136419 on Wed 2025-03-05 03:29:07
Working directory: /private/var/folders/6y/gm6k_jf51nz93gs73fgs8n2hvsyht9/T/scale.6tg.96344
Input file name   : /Users/6tg/Desktop/1_godiva_shift.inp
Output file name  : /Users/6tg/Desktop/1_godiva_shift.inp
SCALE executable  : /Applications/SCALE-6.3.2.app/Contents/Resources/bin/scale

*****
```

Input echo

```
module csas5-shift will be called on Wed Mar 5 15:29:08 2025.
sequence specification record:=csas5-shift parm=()
Input Data:

godiva
ce_v7.1_endf
read composition
  uranium      1 den=18.742 1 300
                                     92235 93.7112
                                     92238 5.2686
                                     92234 1.0202      end
end composition
read geometry
global unit 1
  sphere 1 1      8.741
end geometry
end data

end
```

Mixing table from VULCAN

Mixture table for component comps at line:4, column:1				

Mixture = 1 with density(g/cc) = 18.7420 and temperature(K) = 300.00				
Entry	Mixture	Nuclide	Density (atoms/b-cm)	Temperature (K)

1	1	92234	4.919947e-04	300.00
2	1	92235	4.499968e-02	300.00
3	1	92238	2.498000e-03	300.00

Entry	Mixture	Nuclide	Density (atoms/b-cm)	Temperature (K)

End of mixture table for component comps at line:4, column:1				

Mixing table from Shift

=====

Mixing Table

=====

mixture =	1	density(g/cc) = 1.87420e+01				temperature(K) =		300.00
nuclide	nucmix	atom-dens.	wgt. frac.	za	awt	temp	nuclide title	
92234	1	4.91995e-04	1.02020e-02	92234	234.0410	300.00	u-234 @ 300.00K	
92235	1	4.49997e-02	9.37112e-01	92235	235.0439	300.00	u-235 @ 300.00K	
92238	1	2.49800e-03	5.26860e-02	92238	238.0508	300.00	u-238 @ 300.00K	

Geometry summary

=====

Geometry Essentials

=====

"unit 1" (<inp>:11)

:Type: masked unit

:# Cells: 2 (offset = 0)

:# Surfaces: 1 (offset = 0)

:Bounding box: ``{-8.741 -8.741 -8.741 to 8.741 8.741 8.741}``

Cell	Z	Name	Surface logic
0	B	bnds	0 (from ``<inp>:12``)
1	M	1.1	0 ~ (from ``<inp>:12``)

Surface	Name	Description
0	reg@12.s	Sphere: r=8.741 (from ``<inp>:12``)

Cell	Fill
bnds	---
1.1	Material 0

More geometry

Volumes for those units utilized in this problem

unit	region	geometry region	volume	cumulative volume
1	1	1	2.79751e+03 cm**3	2.79751e+03 cm**3

unit	uses	region	mixture	total volume
1	1	1	1	2.79751e+03 cm**3

total mixture volumes		
mixture	total volume	mass (g)
1	2.79751e+03 cm**3	5.24310e+04

More geometry

Volumes for those units utilized in this problem

unit	region	geometry region	volume	cumulative volume
1	1	1	1.11737e+03 cm**3	1.11737e+03 cm**3
	2	2	1.33876e+03 cm**3	2.45613e+03 cm**3

unit	uses	region	mixture	total volume
1	8	1	1	8.93897e+03 cm**3
		2	0	1.07100e+04 cm**3

total mixture volumes		
mixture	total volume	mass (g)
0	1.07100e+04 cm**3	
1	8.93897e+03 cm**3	1.67731e+05

Initial histories

=====

k-effectives by Generation

=====

generation	generation k-effective	average k-effective	avg k-eff deviation	generation entropy
1	9.05099e-01	1.00000e+00	0.00000e+00	6.11784e+00
2	9.53453e-01	1.00000e+00	0.00000e+00	5.98769e+00
3	9.59652e-01	9.39401e-01	0.00000e+00	5.86742e+00
4	9.74478e-01	9.74478e-01	9.74478e-01	5.93846e+00
5	9.83748e-01	9.79113e-01	4.63529e-03	5.88455e+00
6	9.82719e-01	9.80315e-01	2.93366e-03	5.86241e+00
7	1.01610e+00	9.89262e-01	9.18425e-03	5.81024e+00
8	1.02951e+00	9.97311e-01	1.94577e-02	5.84836e+00
9	1.00640e+00	9.98825e-01	1.59869e-02	5.78629e+00
10	1.03956e+00	1.00464e+00	2.08032e-02	5.75077e+00

Final histories

200	9.96142e-01	9.99683e-01	1.80256e-03	5.86793e+00
201	9.63137e-01	9.99499e-01	1.80845e-03	5.89179e+00
202	9.83848e-01	9.99420e-01	1.81007e-03	5.88711e+00
203	9.84767e-01	9.99347e-01	1.81333e-03	5.88174e+00

*** Execution terminated due to completion of the specified number of generations.

=====

Final k-eff Edits

=====

no. of initial generations skipped	average k-effective	deviation	67 percent confidence interval	95 percent confidence interval	99 percent confidence interval	number of histories	deviation of variance (per cent)
3	0.99935 + or - 0.00181		0.99753 to 1.00116	0.99572 to 1.00297	0.99391 to 1.00479	200000	5.8812
4	0.99947 + or - 0.00181		0.99767 to 1.00128	0.99586 to 1.00308	0.99405 to 1.00489	199000	5.9663

Shift k_{eff} plots

```
=====
Plot of average k-effective by generations run
=====
```

```
Plot file, 1_godiva_shift_keff_by_generations00000.ptp, copied to 1_godiva_shift.plots directory.
```

```
=====
Plot of average k-effective by generations skipped
=====
```

```
Plot file, 1_godiva_shift_keff_by_generations_skipped00000.ptp, copied to 1_godiva_shift.plots directory.
```

```
***** k-effective satisfies the chi**2 test for normality at the 95 % level
```

Shift always makes *.ptp files for use in Fulcrum, but never makes ASCII art histograms in the text output

Shift Shannon entropy tests

```
=====
Shannon Entropy Diagnostics
=====
```

```
Inactive cycles 5.99099 +- 0.0723084
Active cycles 5.84307 +- 0.00300115
First half of active cycles 5.83862 +- 0.00413161
Last half of active cycles 5.84752 +- 0.00432894
```

The difference between the first and second half of the active cycles ($\text{delta} / \text{sigma} = 1.48668$) is inside the 95% confidence interval

The first cycle to cross over one sigma of the final entropy was cycle 6, which was after the first active cycle 3.

```
=====
Plot of Shannon Entropy by generation
=====
```

Plot file, 1_godiva_shift_shannon_entropy00000.ptp, copied to 1_godiva_shift.plots directory.

KENO HTML output

Deprecated output option in SCALE 6.3



Click the logo to go to the SCALE web page.

SCALE OUTPUT
1_godiva_keno

Select an Output Below

godiva
1. KENO-V.a

Comments, Suggestions, User Assistance:

[Contact SCALE Help](#)
scalehelp@ornl.gov
or visit the SCALE website
<http://scale.ornl.gov/>

Click the module name for output you'd like to see. Note that this is by module and not be sequence. Some modules called in the sequence produce no HTML output, and other sequences call a module twice and get HTML output both times.

KENO-V.a

file:///C:/Users/wm4/Documents/SCALE_training/fall_23/k5-6/HTML/1_godiva_keno.htm/KENO-V.a.0001.html

General Information

Messages

Input Data

Derived Data

Results

scale

KENO-V.a - Program Verification Information

godiva

scale

Program Verification Information

code system	SCALE
version	6.3.1
program	kenova
creation date	10_feb_2023
library	/scale/release/6.3.1/serial/bin
prod	kenova
version	6.3.1
jobname	wm4
machine name	node39
date of execution	19_sep_2023
time of execution	20:38:21.82

Comments, Suggestions, User Assistance:

Contact SCALE Help

scalehelp@ornl.gov

or visit the SCALE website

http://scale.ornl.gov

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SCALE 6.3.2| Last Updated: March 2025

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KENO-V.a

file:///C:/Users/wm4/Documents/SCALE_training/fall_23/k5-6/HTML/1_godiva_keno.htm/KENO-V.a.0001.html

General Information

Messages

- Warning Messages

Input Data

Derived Data

Results

scale

KENO-V.a - Warning Messages

godiva

scale

***** warning ***** keno message number k5-374 follows: no energy boundaries specified. DEFAULT energy group boundaries used for tallying will be obtained from 252-group SCALE multi group library.

***** warning ***** keno message number k5-410 follows: energy boundaries marked as DEFAULT will be used in all tally calculations if otherwise not requested.

***** warning ***** keno message number k5-316 follows: No mesh provided for Source Convergence Diagnostics (SCD). Continue with default mesh.

keno message number k5-123 execution terminated due to completion of the specified number of generations.

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SCALE 6.3.2| Last Updated: March 2025

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General Information

Messages

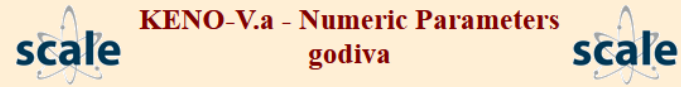
- Warning Messages

Input Data

- Numeric Parameters
- Logical Parameters
- Additional Information
- Mixing Table
- Geometry
- Biasing Information
- Starting Information

Derived Data

Results



Parameter	Description	Value
tme	maximum problem time (min)	0.00
tba	time per generation (min)	10.00
gen	number of generations	203
npg	number per generation	1000
nsk	number of generations to be skipped	3
beg	beginning generation number	1
res	generations between checkpoints	0
x1d	number of extra 1-d cross sections	1
nbk	neutron bank size	1025
xnb	extra positions in neutron bank	0
nfb	fission bank size	1000
xfb	extra positions in fission bank	0
sig	cut off standard deviation	0.0000
wta	default value of weight average	0.5000
wth	weight high for splitting	3.0000
wtl	weight low for russian roulette	0.3333
rnd	starting random number	000015714D98EE96
nb8	number of d.a. blocks on unit 8	1000
nl8	length of d.a. blocks on unit 8	512
nqd	quadrature order for angular fluxes	0
pnm	highest order of flux moments	0
msh	mesh size for mesh flux tally	0.0000
adj	mode of calculation	forward
tps	sampling sites per track length	5

KENO-V.a

file:///C:/Users/wm4/Documents/SCALE_training/fall_23/k5-6/HTML/1_godiva_keno.htm/KENO-V.a.0001.html

General Information

Messages

Input Data

Derived Data

Results

Warning Messages

Numeric Parameters

Logical Parameters

Additional Information

Mixing Table

Geometry

Biasing Information

Starting Information

scale

KENO-V.a - Mixing Table

godiva

scale

Mixture 1

Density: 18.742 g/cm³ , Temperature: 300.00 K

Nuclide ID	Nuclide	Atom Density	Weight Fraction	ZA	Atomic Weight	Temperature	Nuclide Title
92234	²³⁴ U	4.91995E-04	1.02020E-02	92234	234.0410	300.00	u-234 @ 300K
92235	²³⁵ U	4.49997E-02	9.37112E-01	92235	235.0439	300.00	u-235 @ 300K
92238	²³⁸ U	2.49800E-03	5.26860E-02	92238	238.0508	300.00	u-238 @ 300K

Mixture

Mixture 1

OAK RIDGE

National Laboratory

SCALE 6.3.2| Last Updated: March 2025

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KENO-V.a

file:///C:/Users/wm4/Documents/SCALE_training/fall_23/k5-6/HTML/1_godiva_keno.htm/KENO-V.a.0001.html

General Information

Messages

Input Data

Derived Data

Results

Warning Messages

Numeric Parameters

Logical Parameters

Additional Information

Mixing Table

Geometry

Biasing Information

Starting Information

Global

Unit 1

1 sphere 1 1 radius = 8.7410 the center is located at 0.0000 , 0.0000 , 0.0000

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KENO-V.a

file:///C:/Users/wm4/Documents/SCALE_training/fall_23/k5-6/HTML/1_godiva_keno.htm/KENO-V.a.0001.html

General Information

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Logical Parameters

Additional Information

Mixing Table

Geometry

Biasing Information

Starting Information

Volumes

scale

KENO-V.a - Volumes

godiva

scale

Volumes for those Units Utilized in this Problem

Unit	Region	Geometry Region	Volume	Cumulative Volume	Array Boundary
1	1	1	2.79751E+03 cm ³	2.79751E+03 cm ³	

Total Volumes for those Units Utilized in this Problem

Unit	Uses	Region	Mixture	Total Volume
1	1	1	1	2.79751E+03 cm ³

Total Mixture Volumes

Mixture	Total Volume	Mass (g)
1	2.79751E+03 cm ³	5.24310E+04

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General Information

Messages

- Warning Messages

Input Data

- Numeric Parameters
- Logical Parameters
- Additional Information
- Mixing Table
- Geometry
- Biasing Information
- Starting Information

Derived Data

- Volumes

Results

- Final Results
- Problem Characterization
- k_{eff} Results
- Source Convergence
 - Shannon Entropy by Generation
 - Source Convergence Tests
- Fissions and Absorptions



KENO-V.a - Source Convergence Tests



Test 1	Is the final fission source converged?	Test 1: failed
Test 2	Are all the active generations within epsilon of the average?	Test 2: failed
Test 3	Are there adequate active generations after the source is converged?	Test 3: failed

Test 1 details:

Is the mean square posterior relative entropy < the center mean square Shannon entropy?

(msq(D) < cmsq(H(S)))

generations skipped	msq	cmsq
3	1.06547E-02	1.42582E-03
13	1.07271E-02	1.40075E-03
23	1.07716E-02	1.44471E-03
33	1.07358E-02	1.40890E-03
43	1.08077E-02	1.43301E-03
53	1.05509E-02	1.48888E-03
63	1.05574E-02	1.44907E-03
73	1.06946E-02	1.46222E-03
83	1.07104E-02	1.39602E-03
93	1.08112E-02	1.48464E-03
103	1.06914E-02	1.57672E-03
113	1.06766E-02	1.50364E-03
123	1.06412E-02	1.65916E-03
133	1.04230E-02	1.80644E-03
143	9.88165E-03	1.34241E-03
153	9.73066E-03	1.49264E-03
163	1.01635E-02	1.76241E-03
173	9.04228E-03	2.17912E-03
183	8.33378E-03	2.10914E-03
193	6.38150E-03	3.60216E-03

Test 2 details:

Does the Shannon entropy of each active generation vary from the average Shannon entropy of the system?

(|D(S)||T|-H(T-H(S))| < 0.1)

2 active generations failed the test

KENO-V.a

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General Information

Messages

• Warning Messages

Input Data

• Numeric Parameters

• Logical Parameters

• Additional Information

• Mixing Table

• Geometry

• Biasing Information

• Starting Information

Derived Data

• Volumes

Results

• Final Results

• Problem Characterization

• k_{eff} Results

• Source Convergence

◦ Shannon Entropy by Generation

◦ Source Convergence Tests

• Fissions and Absorptions

scale

KENO-V.a - Final Results

godiva

scale

Best Estimate System k_{eff}	1.0022 ± 0.0017
Energy of Average Lethargy of Fission (eV)	8.21707E+005 ± 2.24749E+003
System $\bar{v}$	2.59831E+000 ± 4.28588E-004
System Mean Free Path (cm)	2.56084E+000 ± 1.07315E-003
Number of Warning Messages	4
Number of Error Messages	0
k_{eff} satisfies the χ^2 for normality at the 95 % level	
Source convergence tests failed (125 source bins/mesh)	

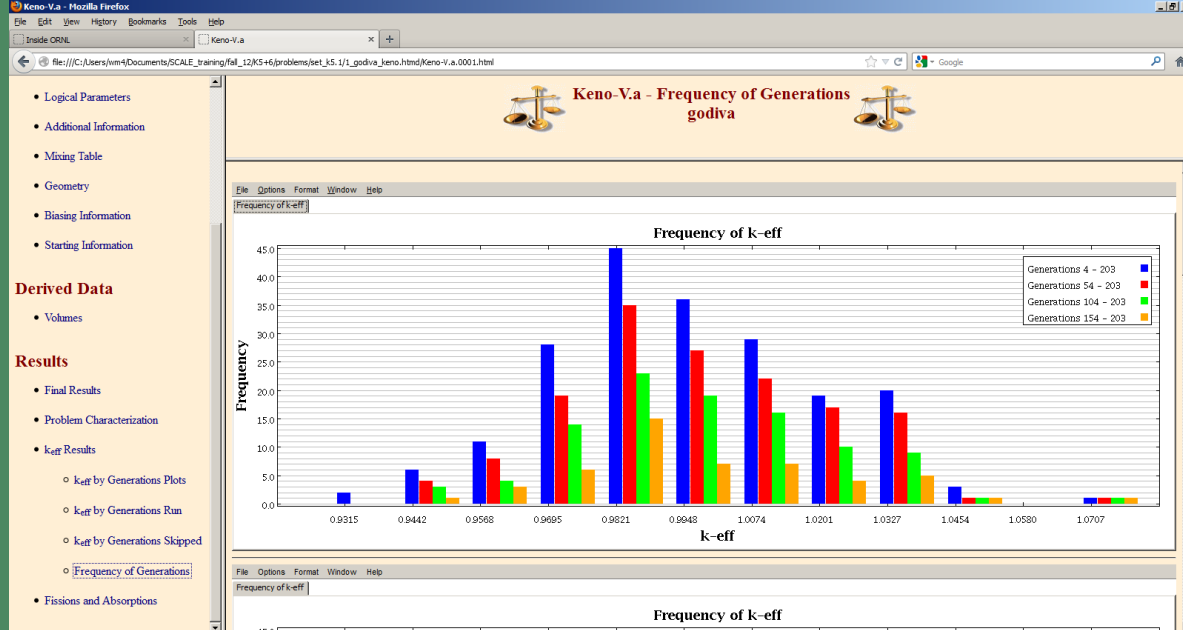
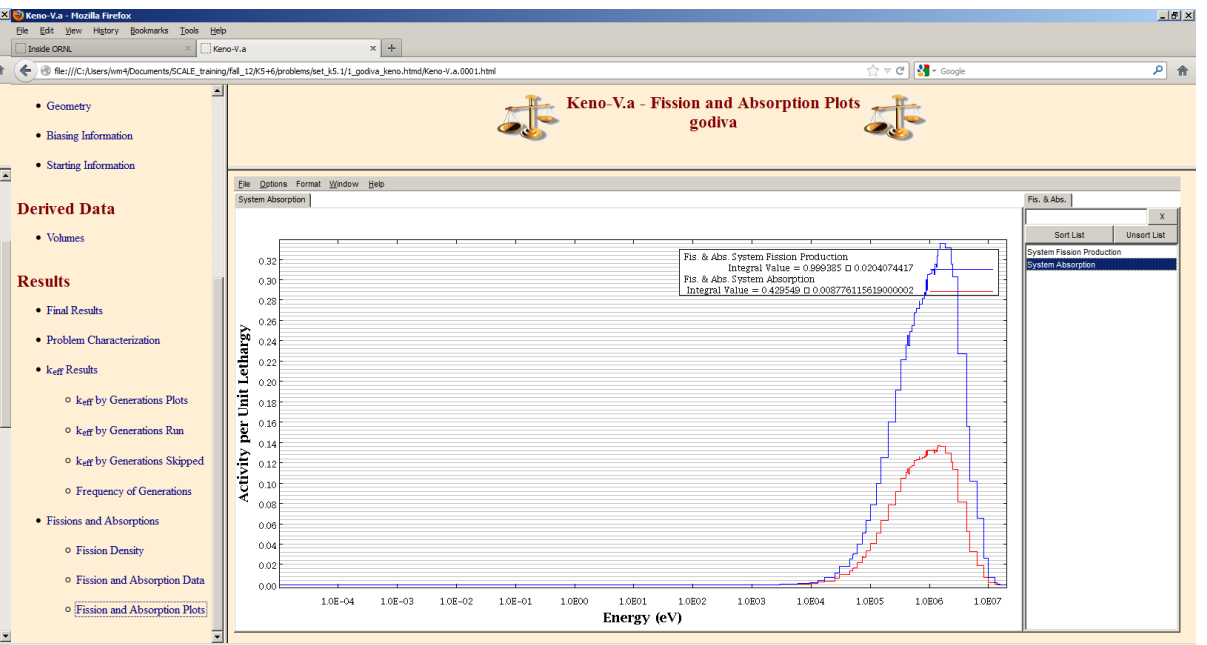
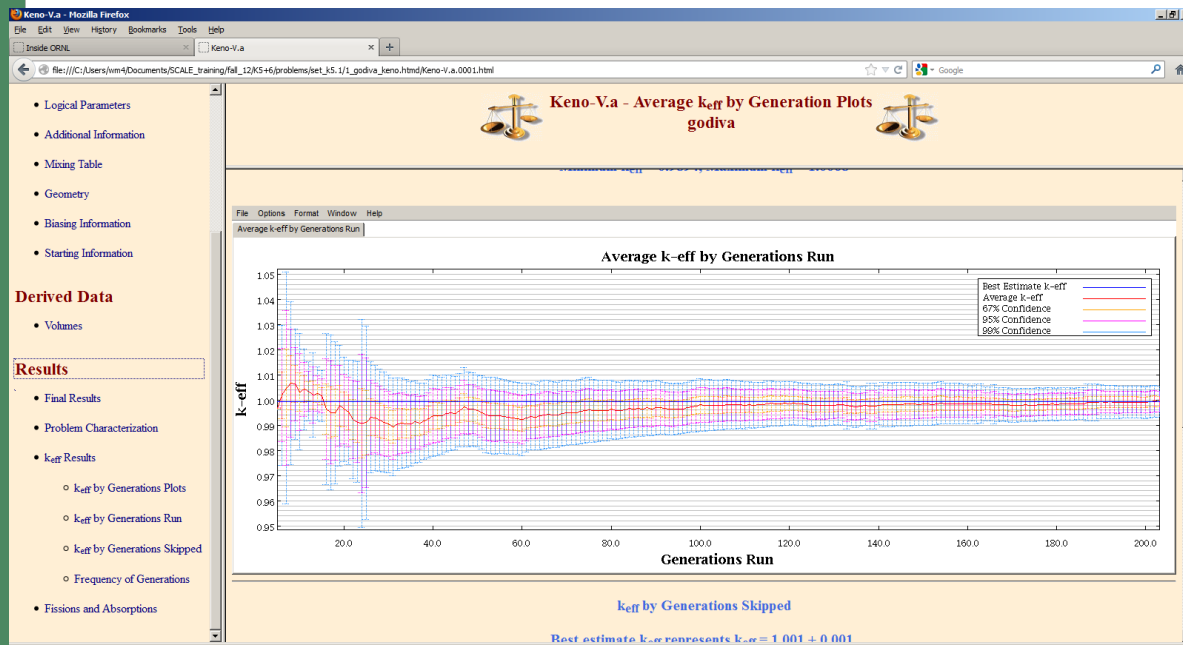
Congratulations! You have successfully traversed the perilous path through KENO-V.a in 0.26700 minutes

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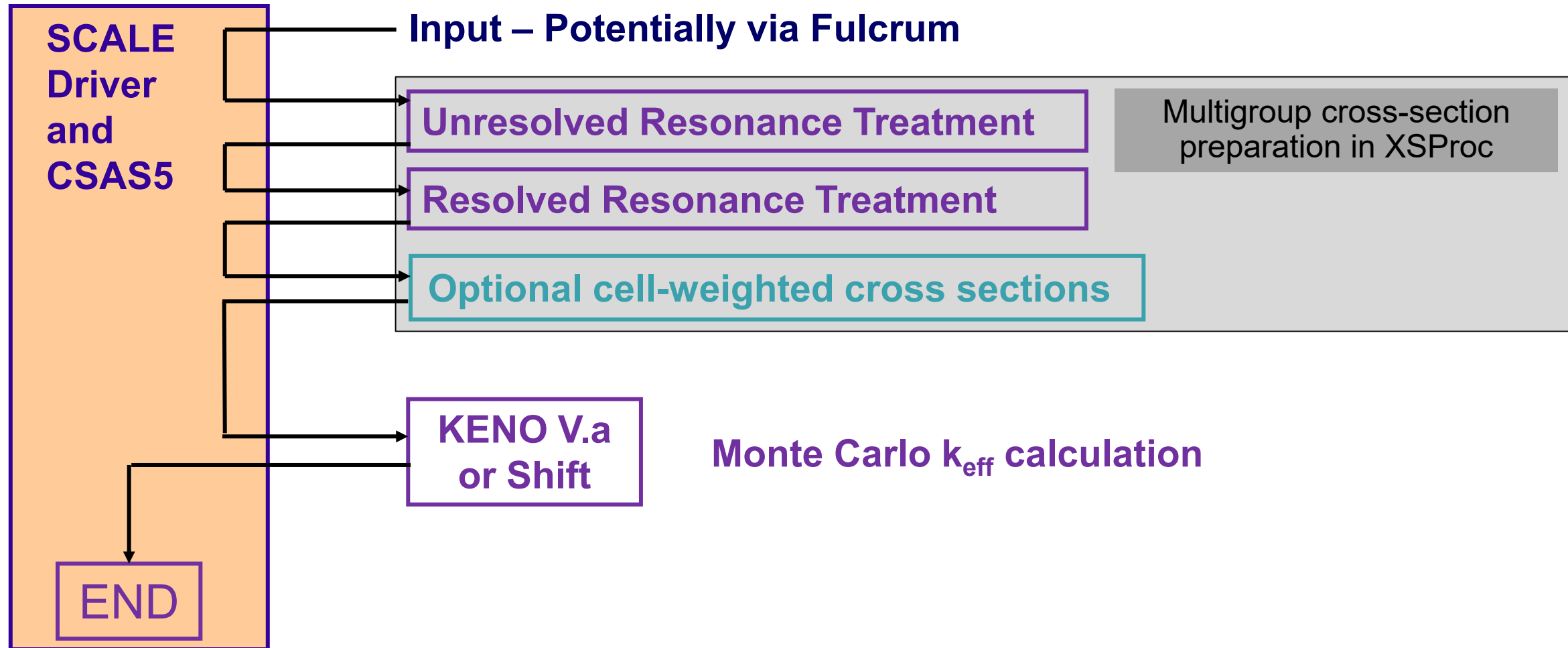
The embedded javapeno applet doesn't work anymore because of Java changes. Instead, you can open the *.ptp files directly in Fulcrum. The *.ptp files are located in the BASENAME.html directory.

They are not generated if HTML output is disabled (*htm=no*).

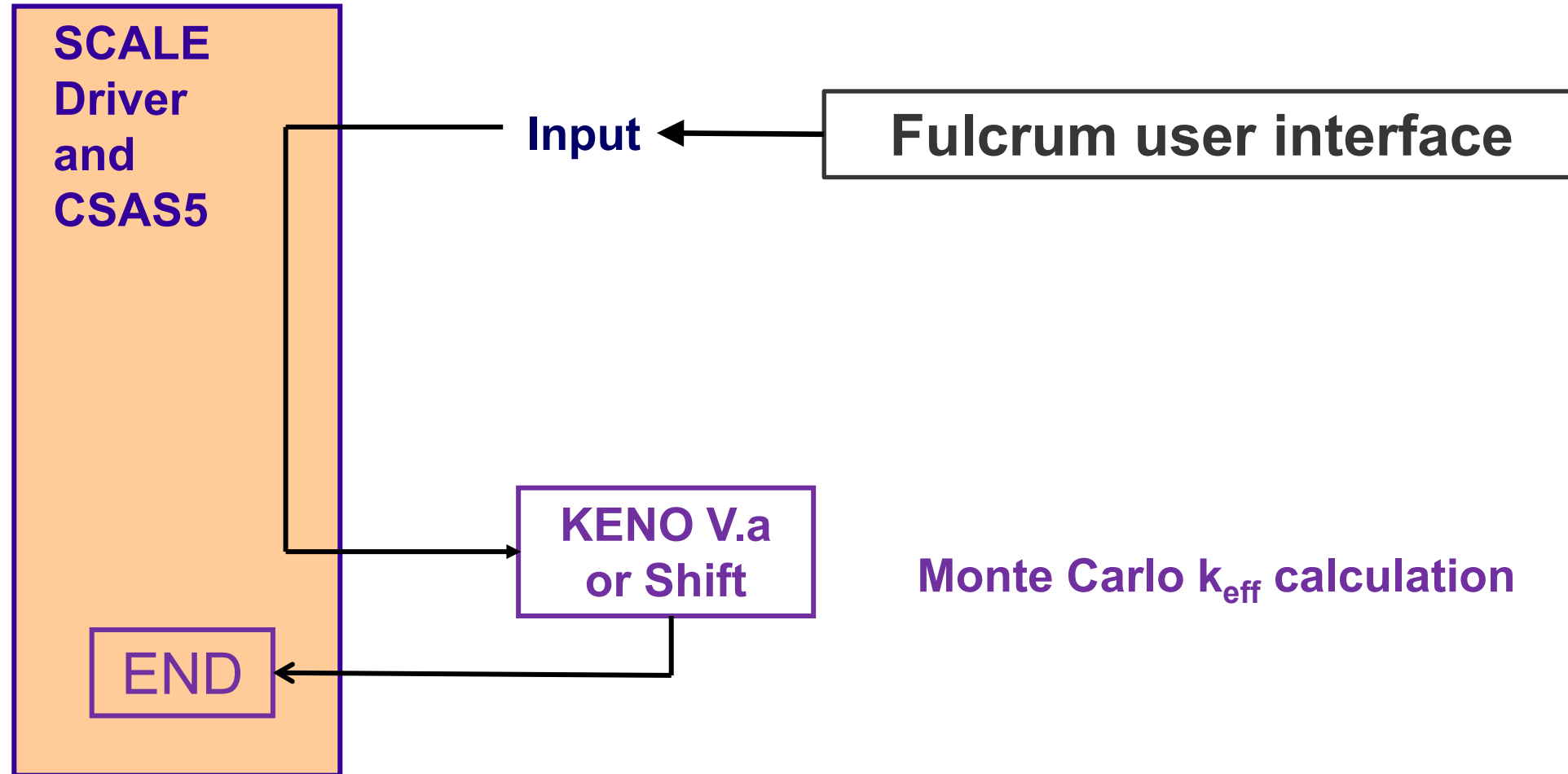
Sub module 6: **CSAS5 review**



CSAS5 criticality safety sequence in MG mode



CSAS5 criticality safety sequence in CE mode



MC calculations

- Neutron histories are grouped into generations in eigenvalue (k_{eff}) problems
- Multiple generations are needed along with a sufficient number of histories to characterize the problem and ensure that all regions are adequately sampled
- A poorly converged fission source can produce incorrect/biased results, and the inaccuracy of these results may not be readily apparent
- The uncertainty or error in the estimate of k_{eff} decreases inversely with respect to the square root of the total sample size (number of generations times number of particles)

Statistical uncertainty

- MC tallies are each reported with their standard deviation
- The standard deviation for k_{eff} is given by

$$\sigma_{Avg} = \frac{1}{\sqrt{N}} \sigma_{Gen}$$

- Therefore, the standard deviation decreases inversely with respect to the square root of the total sample size
 - To decrease the standard deviation by 50%, one must increase the total number of histories by a factor of 4

Statistical significance

- given $k_1 \pm \sigma_1$ and $k_2 \pm \sigma_2$, the difference is

$$k_1 - k_2 \pm \sqrt{\sigma_1^2 + \sigma_2^2}$$

- If $k_1 - k_2 > \sqrt{\sigma_1^2 + \sigma_2^2}$, the result is a *statistically significant difference**
- If $k_1 - k_2 < \sqrt{\sigma_1^2 + \sigma_2^2}$, the result is a *statistically insignificant difference**
- Small differences can be essentially identical – no conclusion can be drawn for equivalent answers

*Convention or comfort in what constitutes *statistically significant* varies;

$\pm 1\sigma_{12}$ bounds ~68%

$\pm 2\sigma_{12}$ bounds ~95%

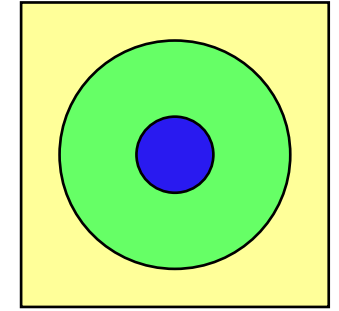
$\pm 3\sigma_{12}$ bounds ~99%

KENO V.a data blocks

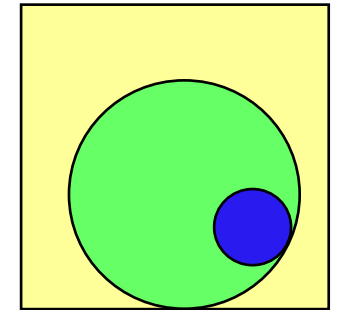
READ PARM	parameter data	END PARM
READ GEOM	geometry region data	END GEOM
READ ARRAY	array definition data	END ARRAY
READ BIAS	biasing data	END BIAS
READ BOUNDS	albedo boundary data	END BOUNDS
READ START	initial source distribution	END START
READ PLOT	plot data	END PLOT
READ MIXT	cross-section mixing table	END MIXT
READ X1DS	extra 1-D cross-sections	END X1DS
READ ENERGY	energy group boundaries	END ENERGY
READ VOLUME	perform volume calculation	END VOLUME
READ GRID	specify Cartesian meshes	END GRID
READ REACTION	generate reaction rate tallies	END REACTION
END DATA		

KENO V.a geometry rules

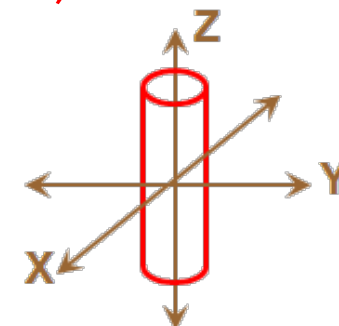
1. *Volumes are built in sections called UNITS.* Each UNIT is independent of all other units and has its own coordinate system.
2. *Units are built from the inside out using REGIONS.* Regions are made using the KENO V.a geometry shapes. Each region must fully enclose all previously defined regions in the unit.
3. *Regions may share boundaries but may not intersect.*
4. *All regions are oriented along a major axis (X, Y, or Z). Regions may not be rotated.*



Regions in a unit



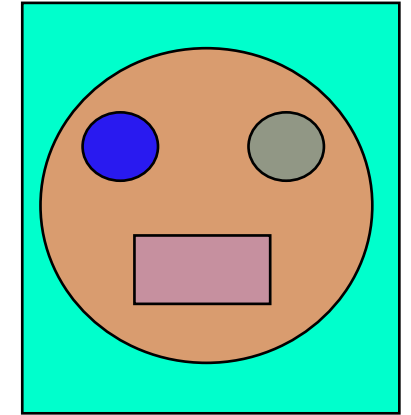
Shared boundaries



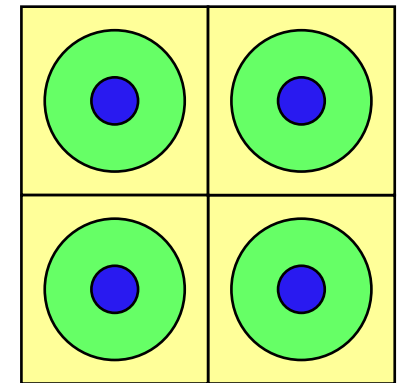
Cylinder oriented on Z axis

KENO V.a rules (cont.)

5. *A HOLE is used to place a unit within a region in a different unit.* The HOLE must be completely contained within the region. As many HOLES as required may be placed in a unit as long as they do not intersect other HOLES or regions.
6. *An ARRAY is an ordered stack of units.* The touching faces of adjacent units in an array must be rectangular and must be the same size. Only one array may be placed directly in a unit. Additional arrays may be placed in units using HOLES.
7. *A GLOBAL unit or array, which defines the outermost boundary of the problem, must be specified for each problem.*

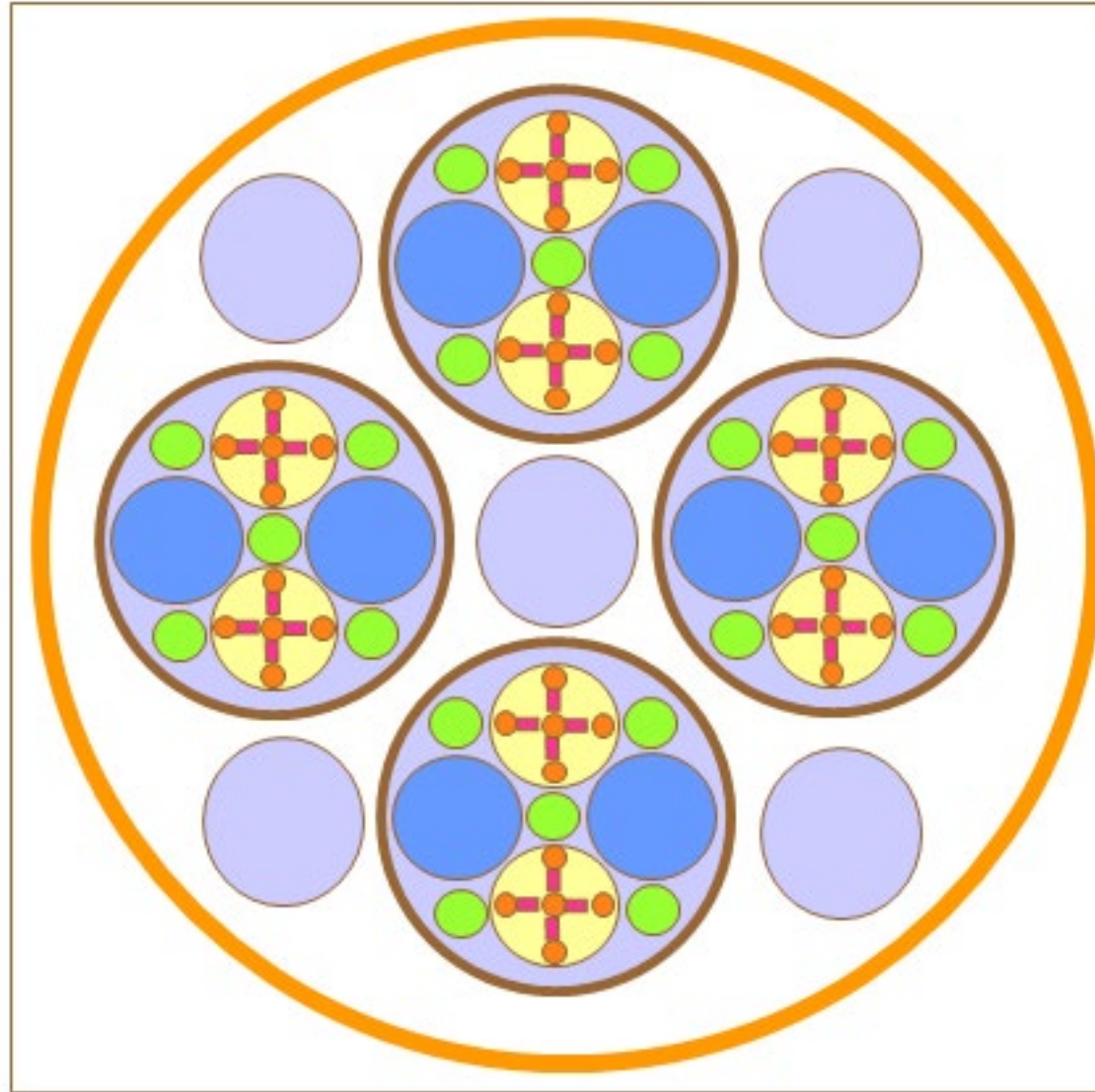


Unit Containing HOLES



Array of units

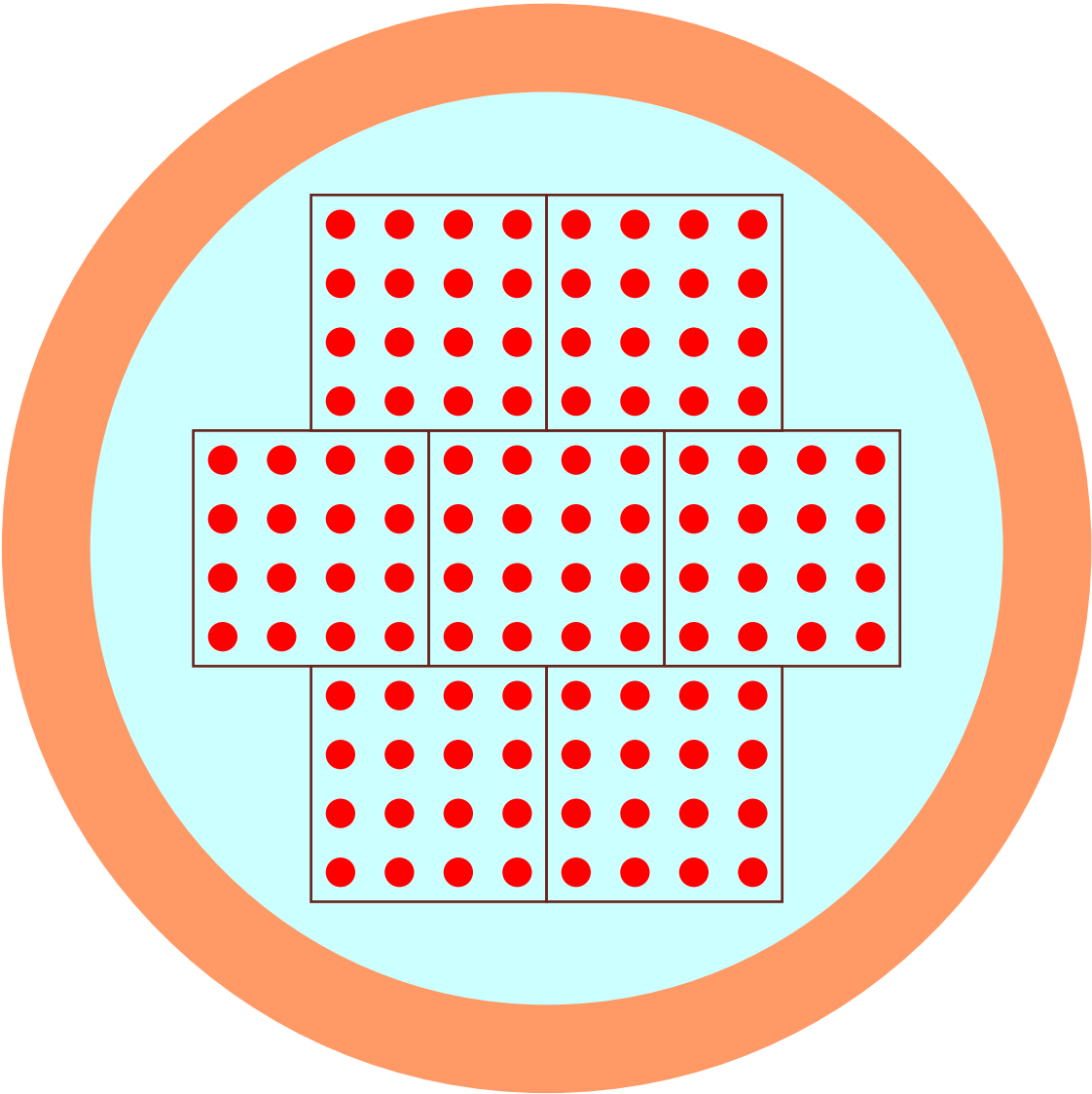
HOLE data



HOLES

- Holes combine multiple units in a problem by inserting one complete unit into another
 - One step process, *not* creating a hole and putting another unit in it
- HOLES may not intersect
- A HOLE may be inserted inside another UNIT subsequently used as a HOLE (i.e., nested)
- As many HOLES as are needed may be placed in a region
- HOLE must be entered directly after the region into which it is being inserted

Array data

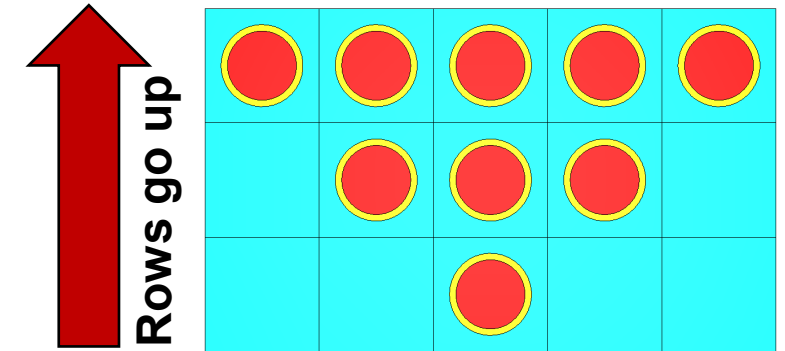
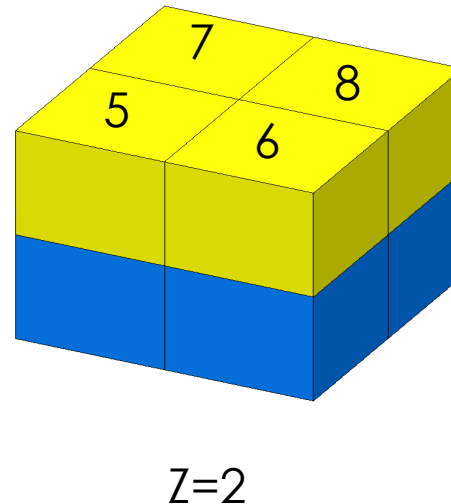
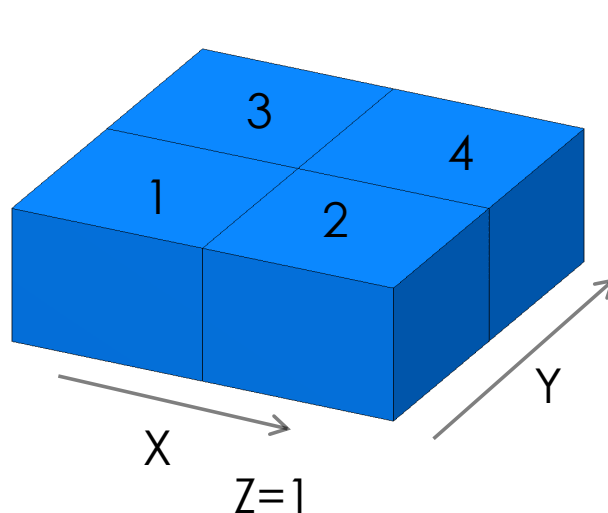


Array placement

- An array is an ordered set of rectangular units
- Arrays are defined in the array block
 - n_{ux} , n_{uy} , n_{uz} and unit numbers to fill array
- Faces that *touch* in array must have the **same dimensions**
- Arrays are then placed in a unit in the geometry block
- Array is positioned within the unit by defining the (x,y,z) position of the left, front, bottom corner of the array
 - In other words – the most negative point in the array

Filling arrays

- Array block used for array definitions
- Dimensions ($nux \times nuy \times nuz$), type, and fill

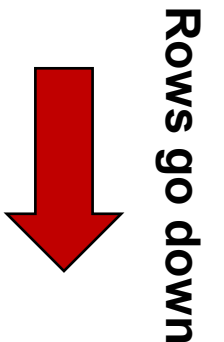


read array
ara=1 nux=5 nuy=3

fill

2 2 1 2 2
2 1 1 1 2
1 1 1 1 1

end fill
end array



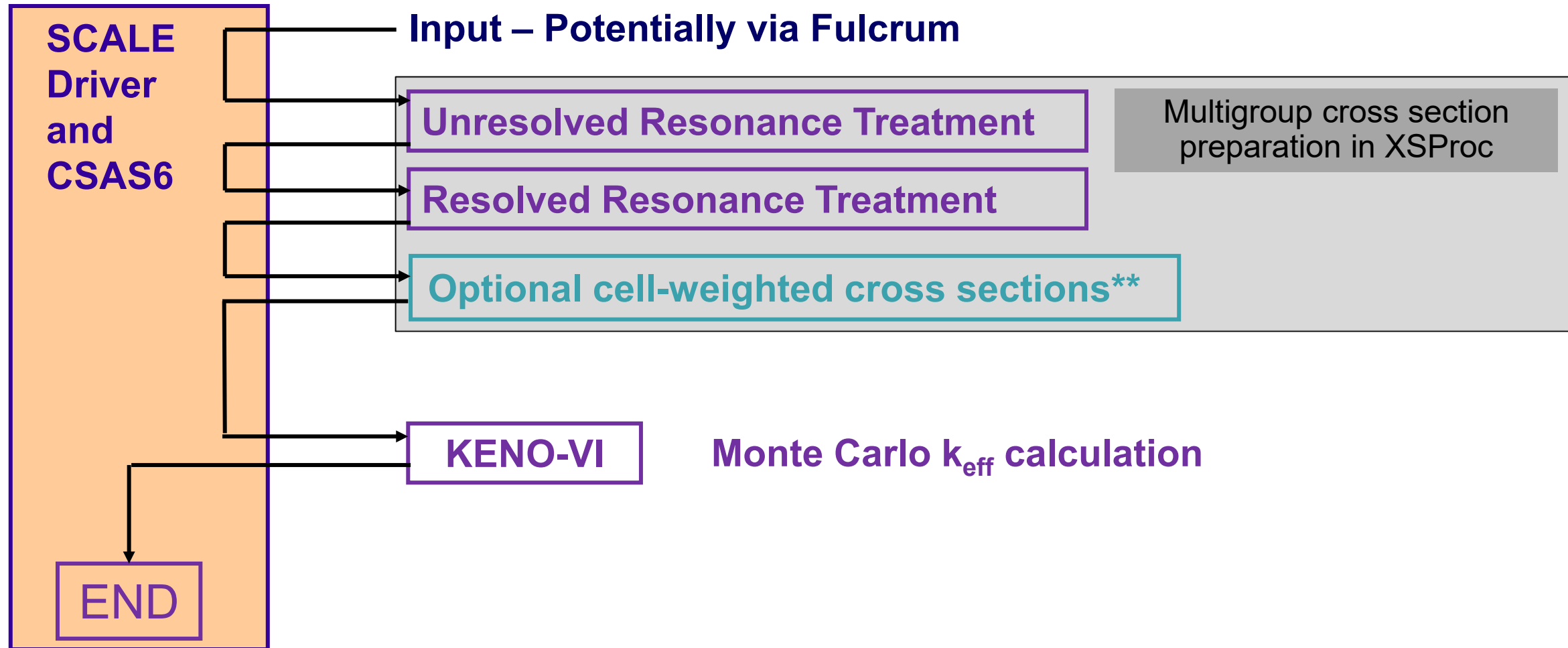
Boundary conditions

- Vacuum is the default boundary condition
- Non-vacuum boundary conditions can only be applied to cuboids
- Face codes are listed in Table 8.1.20
- Allowed BC names are listed in Table 8.1.23

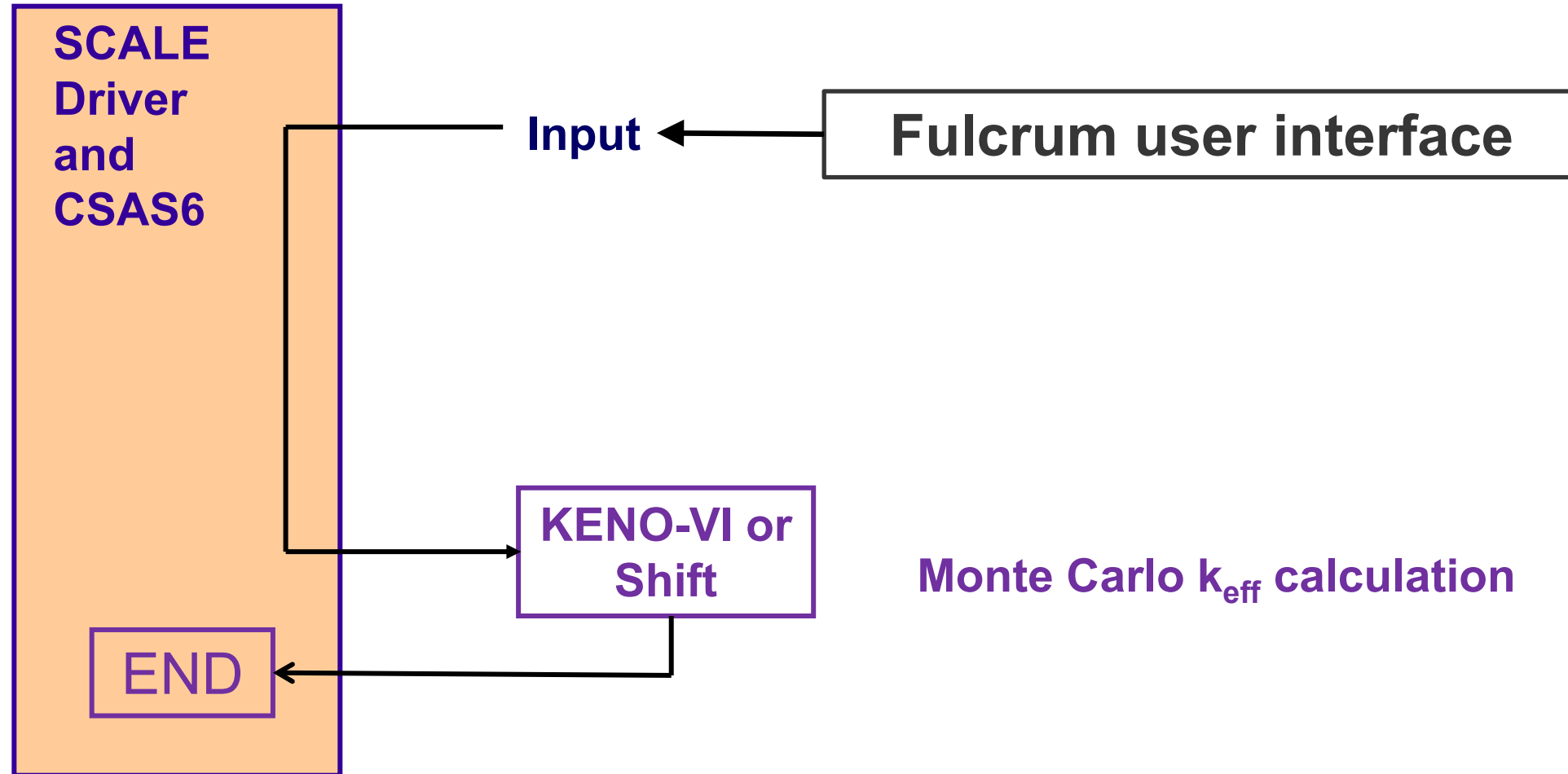
Sub module 7: **CSAS6 review**



CSAS6 criticality safety sequence in MG mode

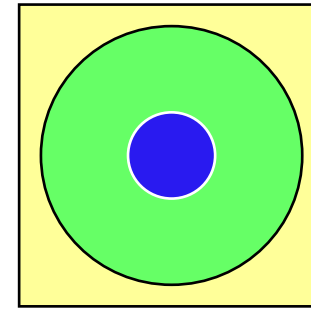


CSAS6 criticality safety sequence in CE mode

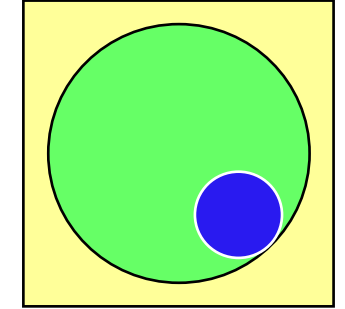


KENO-VI basics

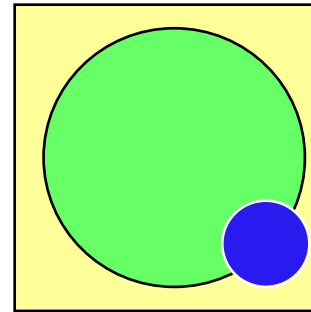
1. *Volumes are built in sections called **UNITS**.* Each UNIT is independent of all other units and has its own coordinate system.
2. *Units are built using **REGIONS**.* Regions are made using the KENO-VI geometry shapes. The unit boundary must fully enclose all defined regions in the unit.
3. *Regions may share boundaries and may intersect.* (Not allowed in KENO V.a)
4. *Regions may be rotated.* (Not allowed in KENO V.a)



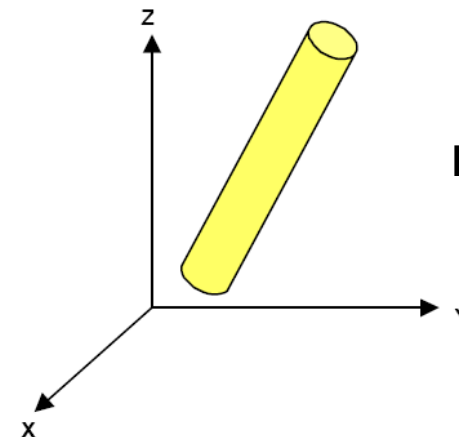
Regions in a unit



Shared boundaries



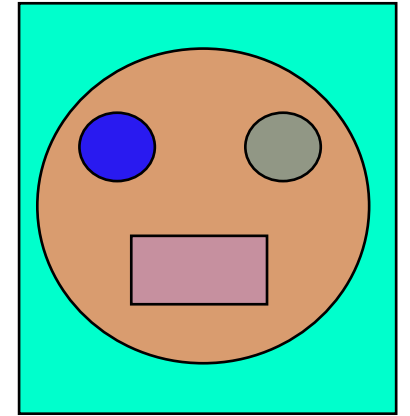
Intersecting regions



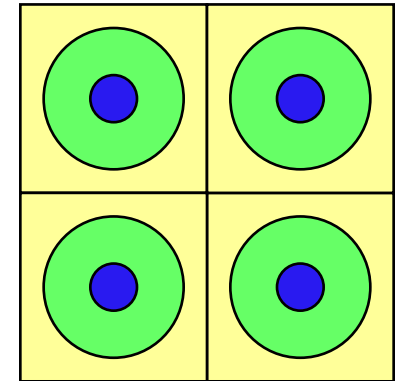
Rotated cylinder

KENO-VI basics (cont.)

5. *A HOLE is used to place a unit within a region of a different unit.* The HOLE must be completely contained within the region and may not intersect other holes or nested arrays. As many HOLES as required may be placed in a unit.
6. *An ARRAY is an ordered stack of units.* The touching faces of adjacent units in an array must be the same size. Multiple arrays may be placed directly in a UNIT by placing them in separate regions. Arrays can also be placed within a unit using HOLES.
7. *A GLOBAL UNIT that encloses the entire system must be specified.* All geometry data used in a problem are correlated by the global unit coordinate system.



**Unit Containing
HOLES**



Array of units

KENO-VI input records

- Three types of records are used to define the volume, position, and material contents of the regions in a unit
 - Geometry record
 - Contents record
 - Boundary record
- Each unit may have as many *Geometry* and *Contents* records as needed but must have one and only one *Boundary* record

Geometry record

- Specifies the volumes that make up the unit
- Consists of the following components
 - Geometry keyword
 - Geometry record label
 - Geometry boundary definitions
 - Geometry modification data

Contents records

- Specifies the contents of a volume defined relative to the Geometry records in that unit
- Consists of the following components
 - Contents Keyword (**Array**, **Hole**, **Media**)
 - ID Number (**Array #**, **Unit #**, **Mixture #**)
 - Bias ID Number (**Media only**)
 - Region Definition Vector (**Array**, **Media**)

Contents records (cont.)

Keyword

Contents Record Input

MEDIA

Mixture Number,
Bias ID Number,
Region Definition Vector

ARRAY

Array Number,
Region Definition Vector,
Keyword PLACE followed by the I, J, K element and the X, Y, Z position of the origin of the unit found in that element

HOLE

Unit number,
Keywords ORIGIN and ROTATE, if desired

MEDIA contents records

- Used to place a mixture into a region defined in the current unit
- Consists of the following components
 - Keyword (Media)
 - Mixture ID number
 - Bias ID number
 - Region Definition Vector

Geometry modification data

- These options modify the previous geometric volume and are always performed in the order listed below:
 1. Chord: Truncates the volume with a plane perpendicular to a major axis
 2. Rotate: Rotates the volume
 3. Origin: Translates the volume origin

Geometry modification keywords

Keyword

Input Values

CHORD

+X=, -X=, +Y=, -Y=, +Z=, -Z=

ROTATE

A1=, A2=, A3=

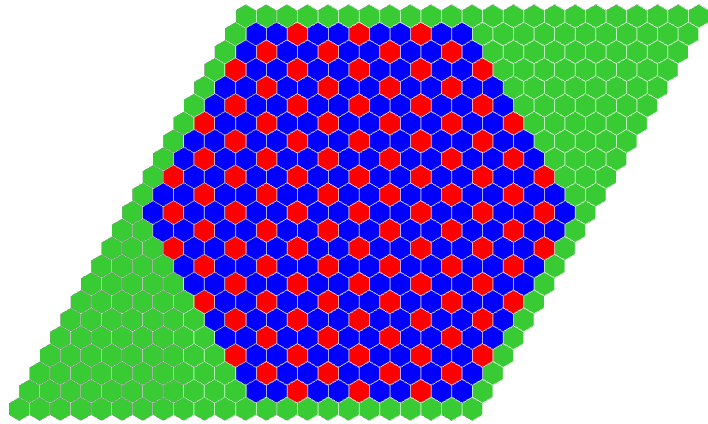
ORIGIN

X=, Y=, Z=

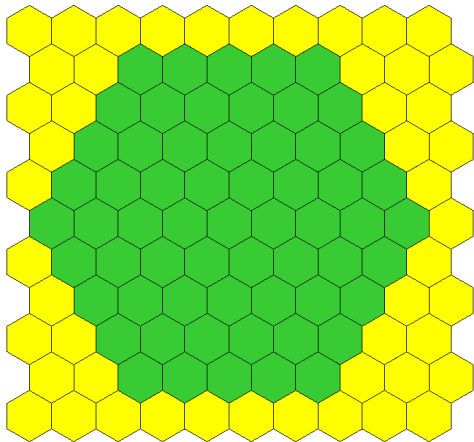
HOLE contents record

- Used to place a unit into a region defined in a different unit
- Consists of the following components
 - Keyword (HOLE)
 - Unit ID number to be placed as Hole
 - Modification data (Origin, Rotate) used to place the origin of the unit being inserted to the desired position and orientation

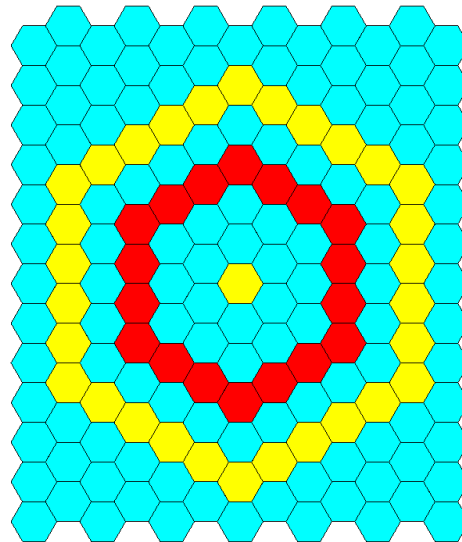
KENO-VI array types



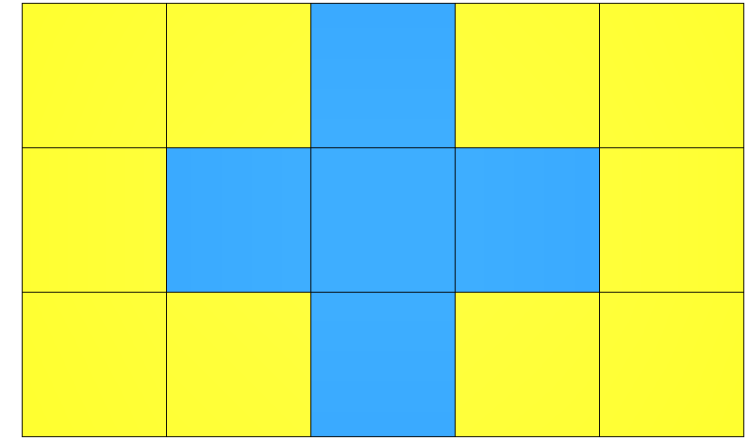
Hexagonal (or Triangular)



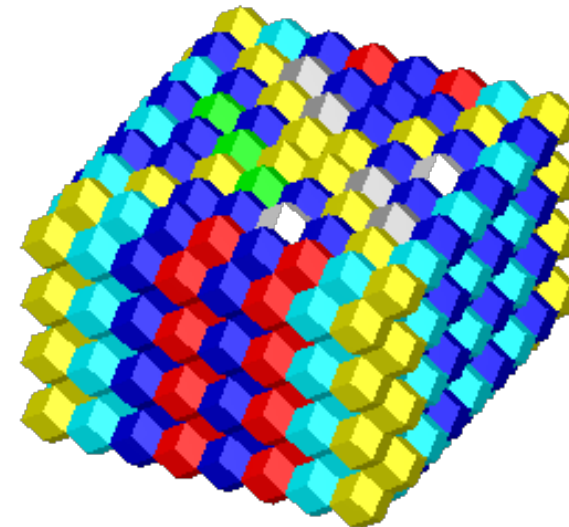
Standard hex



Rotated hex



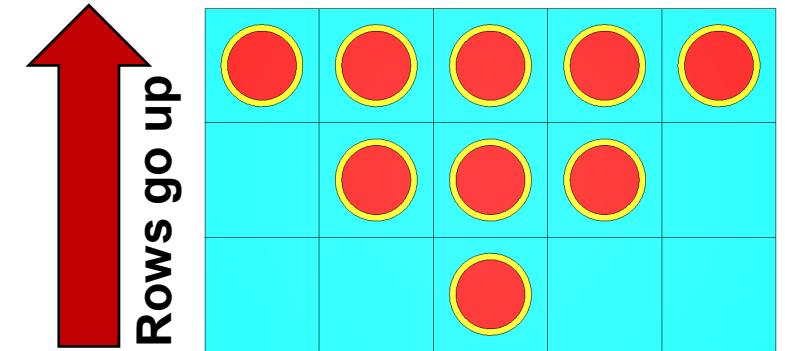
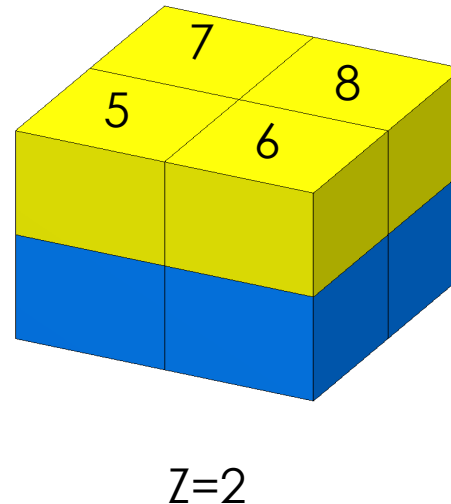
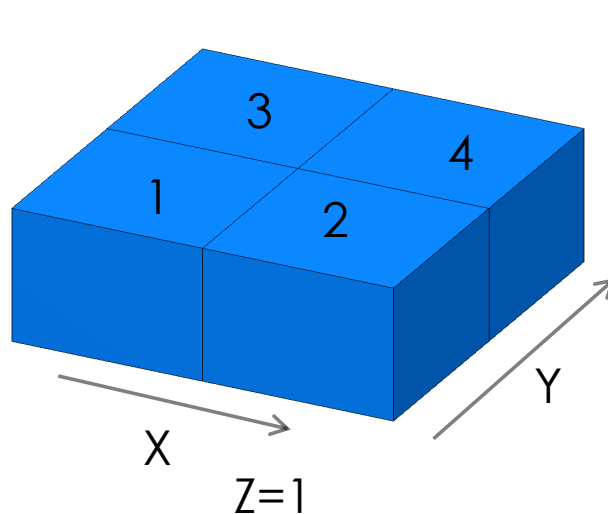
Rectangular



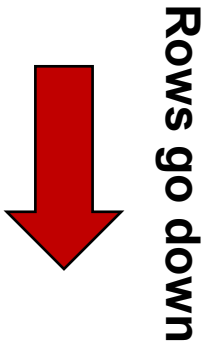
Dodecahedral

Defining arrays

- Array block used for array definitions
- Dimensions ($nux \times nuy \times nuz$), type, and fill



```
read array  
ara=1 nux=5 nuy=3  
typ=square  
fill  
  2 2 1 2 2  
  2 1 1 1 2  
  1 1 1 1 1  
end fill  
end array
```



ARRAY contents records

- Used to place an array into a region defined in the current unit
- Composed of the following components
 - Keyword (ARRAY)
 - Array ID Number
 - Region Definition Vector
 - Keyword PLACE followed by data to position the array in the region

Array PLACE data

- Data following the keyword PLACE used to position the array in a region consists of:
 - Element i, j, k in the array used to establish the location of the array
 - the X, Y, Z coordinates of the origin of that array element, in the coordinate system of the unit into which the array is being placed

In other words:

PLACE the origin of the unit that is the ijk^{th} element in the array at position (X, Y, Z) in the current unit coordinate system

Boundary record

- Specifies the overall volume of a unit
 - One and only one boundary record is required for each unit
 - Only the volume defined in the region definition vector of the unit's boundary record is contained within the unit
 - Other specified volumes, outside the boundary record's region definition vector, are not included in the unit
- Composed of a region definition vector

Boundary conditions

- Any shape can be used as an outer boundary in KENO-VI
- Boundary conditions can be applied with traditional facecodes for cuboid boundaries
- KENO-VI also allows *BODY* and *SURFACE(i)* keywords
- *BODY* uses a geometry label in the global unit
- *SURFACE(i)* uses surface numbers as listed in Table 8.1.22 of the SCALE Manual

Boundary conditions (cont.)

- Use caution in applying anything other than MIRROR or VACUUM
- Consider whether the specified boundary condition is actually possible
- Select appropriate boundary conditions for the model based on situation being modeled
- Chorded surfaces do not get surface numbers and thus can only have vacuum boundary conditions

MC calculations

- Neutron histories are grouped into generations in eigenvalue (k_{eff}) problems
- Multiple generations are needed along with a sufficient number of histories to characterize the problem and that all regions are adequately sampled
- A poorly converged fission source can produce incorrect/biased results, and the inaccuracy of these results may not be readily apparent
- The uncertainty or error in the estimate of k_{eff} decreases inversely with respect to the square root of the total sample size (number of generations times number of particles)

Statistical uncertainty

- MC tallies are each reported with their standard deviation
- The standard deviation for k_{eff} is given by

$$\sigma_{Avg} = \frac{1}{\sqrt{N}} \sigma_{Gen}$$

- Therefore, the standard deviation decreases inversely with respect to the square root of the total sample size
 - To decrease the standard deviation by 50%, one must increase the total number of histories by a factor of 4

Statistical significance

- given $k_1 \pm \sigma_1$ and $k_2 \pm \sigma_2$, the difference is

$$k_1 - k_2 \pm \sqrt{\sigma_1^2 + \sigma_2^2}$$

- If $k_1 - k_2 > \sqrt{\sigma_1^2 + \sigma_2^2}$, the result is a *statistically significant difference**
- If $k_1 - k_2 < \sqrt{\sigma_1^2 + \sigma_2^2}$, the result is a *statistically insignificant difference**
- Small differences can be essentially identical – no conclusion can be drawn for equivalent answers

*Convention or comfort in what constitutes *statistically significant* varies;

$\pm 1\sigma_{12}$ bounds ~68%

$\pm 2\sigma_{12}$ bounds ~95%

$\pm 3\sigma_{12}$ bounds ~99%