Criticality Convergence Confusion

DALE LANCASTER
NUCLEARCONSULTANTS.COM

CHARLES ROMBOUGH
CTR TECHNICAL SERVICES, INC.

Background

- In recent years, the NRC has given license applicants a number of questions on convergence.
- SCALE 6.2 has added convergence tests to the output.
- How should these be used?
- This presentation is limited to PWR or BWR fuel.

How Converged Do We Need to Be?

- From the criticality benchmarks, there is a base uncertainty of about 0.005 in k.
- We statistically combine uncertainties.
- A 0.001 uncertainty in convergence would have at most a $(0.005^2+0.001^2)^{0.5} - 0.005 = 0.0001$ effect on the final answer.
- Typical margin in the analysis is **<u>0.01</u>** in k and only report to 0.0001.
- Typical SCALE Monte Carlo uncertainty is about 0.0001 (8000 generations, 8000 neuts/generation). (Other analyst use less neuts but generally the current uncertainty is 0.0002 or less)
- We do not care about convergence issues that are less than 10 times uncertainty.

What is the problem to be solved?

- We want to know the highest k.
- We do not care about the flux distribution.
- We sometime only care that k is less than some other case. (For example, we may be interested in the k at an interface being less than the k in the main section of the pool.)

Parameters We Control

- We can set the initial source location. (default is uniform over fuel)
- We can change the number of neutrons per generation.
- We can change the number of generations.
- We can change the number of generations skipped in the calculation of k.

When are we converged?

- chi**2 test for normality at the 95 % level?
  - Repeatedly we fail this test. One engineer noted that if we run less neuts we pass this test more often. We have often rerun to pass this test but have never seen a significant change.
  - The chi**2 test is for normality of the generation k's. With higher number of generations this test is harder to pass.
  - Often the source is still slowly moving to the more reactive condition. However, the movement in the source is not significant to k for commercial fuel when the number of generations and neuts per generation are multiple thousands.
- Conclusion: Ignore this edit for our normal runs.

When are we converged?

- For Millstone 3 Dominion:

  "K-eff convergence of KENO cases is verified by comparing the k-eff at the midpoint of retained generations (3500 retained generations) to the final k-eff (7000 retained generations) with the difference in k-eff expressed as the number of final sigma."

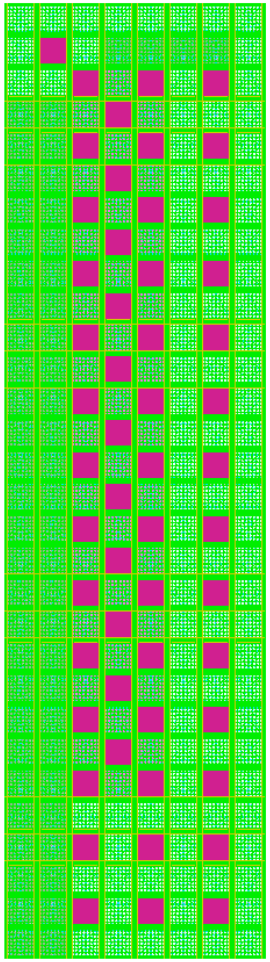
- Some cases were rerun with added neuts but no significant change.
- Conclusion: This effort was not needed and not recommended for future efforts.

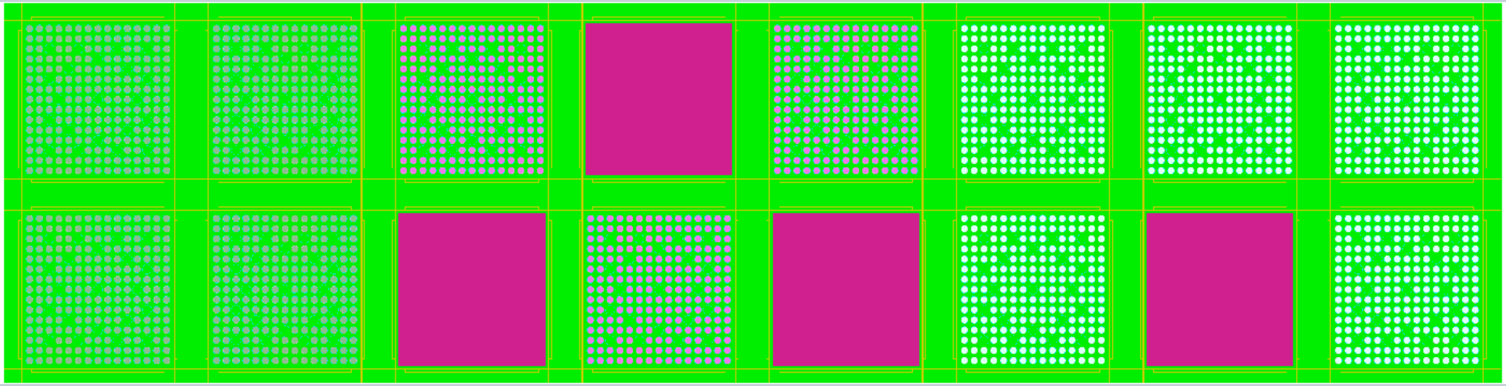
When are we converged?

- We always fail one or more Shannon Entropy tests.
- The reasons are not clear to us.
- All the EPRI benchmark cases fail the first Shannon Entropy test and pass the other two.
  - These cases are 2D single assembly cases with very little source peaking in any area.
  - The Shannon entropy does not change much from generation to generation.

Shannon Entropy Experience

A case with spatial effects was selected as a test. This case is a flux trap (Boraflex gone) using leakage and empty cells for reactivity control. Fresh fuel of 3 enrichments and IFBA rods. (full pool modeled on right, blowup below)





Results of test case

Gens	NPG	Skip	k	sigma	Shn 1	Shn 2**	Shn 3**
200	400	6	0.980	.002	failed	2.1	0.71
2000	4000	12	0.97984	.00026	failed	3.1	0.24
2000	4000	22	0.97952	.00028	failed	1.6	0.26
2000	4000	1000	0.97983	.00039	failed	0.6	0.21
4000	8000	1000	0.97956	.00016	failed	0.52	0.18
8000	20000	4000	0.97982	.000087	passed	0.52	0.07*
16000	40000	8000	0.97975	.000044	passed	0.32	0.05*

*Passed
** Passing for these tests is less than 0.1

Chi squared passed for all cases except when rerun with SCALE 6.2.3

Comments on Test Results

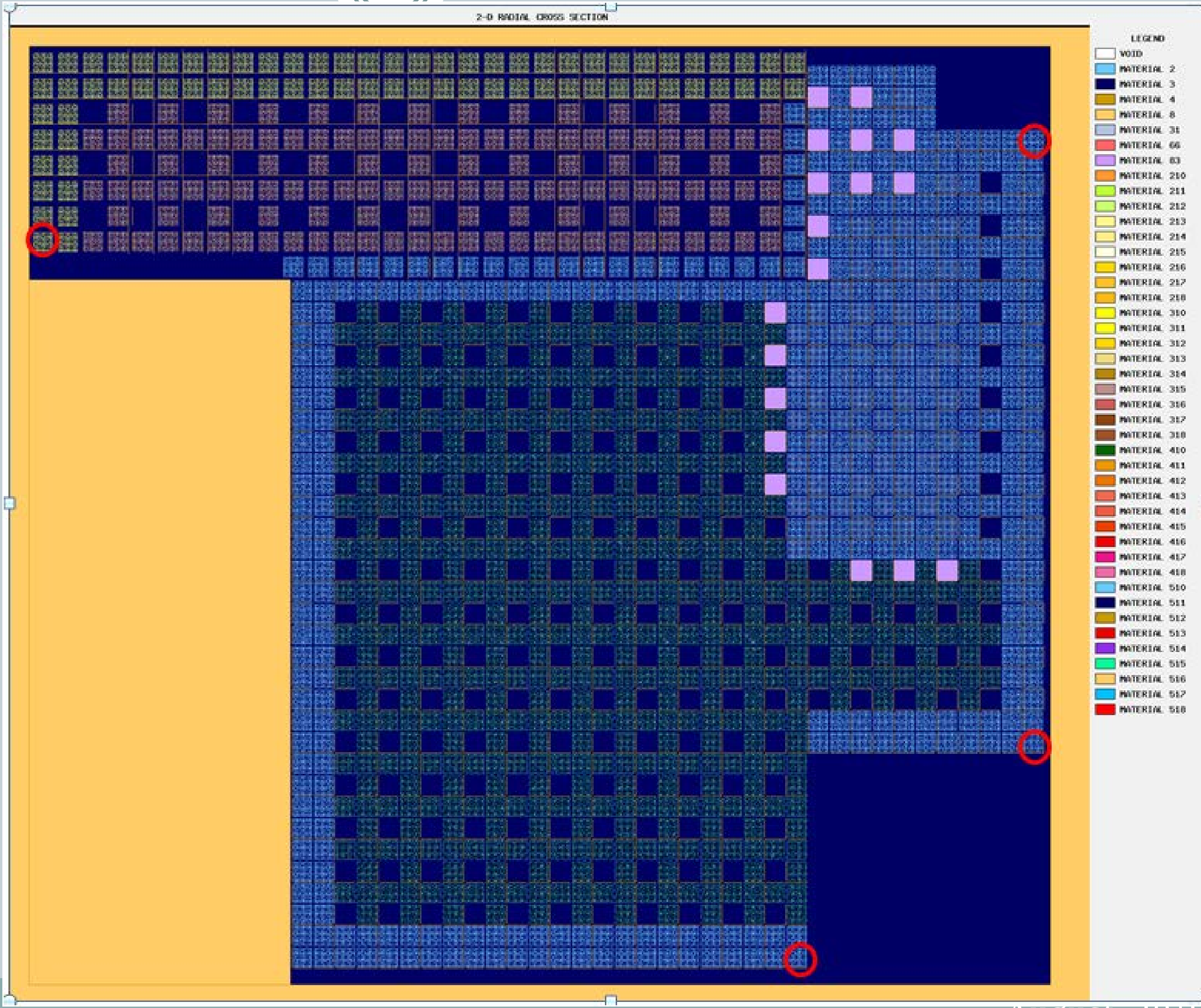
- All cases including the very low neut case were within the final k and 2 sigma.
- Even with the 16000 generations and 40000 neuts per generation the output says the source convergence is not met.
- Trying to pass all the Shannon Entropy tests does not seem worthy.
- Will ignore the Shannon Entropy tests.
- The next slides discuss what we think is important.

Practical Convergence

- Know your problem. If there is an isolated feature that can raise k place your start source at that feature.
- Use significant number of generations and neuts per generation. (at least 4000 and 4000)
- Use the KENO generated number of skipped generations. Will skip a large number if a feature was missed.

How A Large Number of Neuts and Viable Skips Can Save You

- Problem:



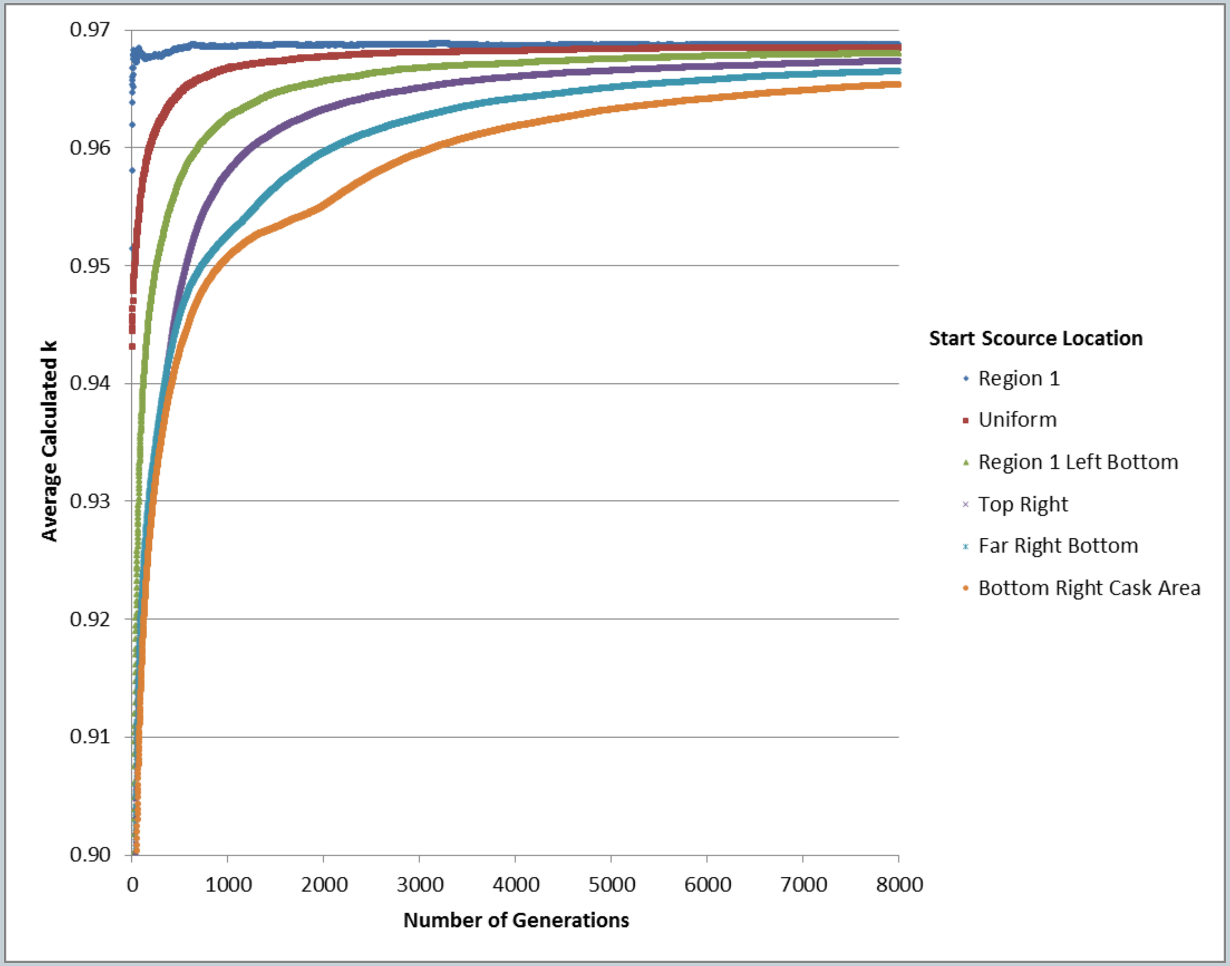
How A Large Number of Neuts and Viable Skips Can Save You

Problem used 8000 Generations and 16000 neuts per generation.

Source Location	Calculated k	Reported Sigma	Generations Skipped
Region 1 only	0.968708	0.000067	662
Uniform for Problem (Region 1 and 2)	0.968724	0.000066	372
Region 1 Bottom Left	0.968704	0.000066	445
Top Right	0.968663	0.000066	525
Bottom Right to Cask Area	0.968809	0.000075	2066
Bottom Far Right Above Cask Area	0.968682	0.000068	1282

Note that all cases are within 2 sigma of each other.

Average k as a function of generation



Average Calculated k still includes the skipped generations

Sometime Convergence is Not Needed

- If you want to know if a feature, such as an interface, increases k then place the start neutrons at that feature.
- If it does not increase k the average k will slowly increase as the neuts travel to the reactive area.
- Assuming you have a calculation without the feature, if the k is less than the reference case then you have your answer without worrying about convergence.

Conclusions

- Convergence is not a problem worthy of additional work assuming you are using enough neuts to create a sigma of 0.0002 or less.
- Chi square and Shannon Entropy tests can be ignored as long as you let KENO determine the number of generations to skip.
- Pay attention to features that can increase k and use the start source option to start neutrons at these features.

Discussion

- Looking forward to learning from other points of view.