Symmetry in Monte Carlo

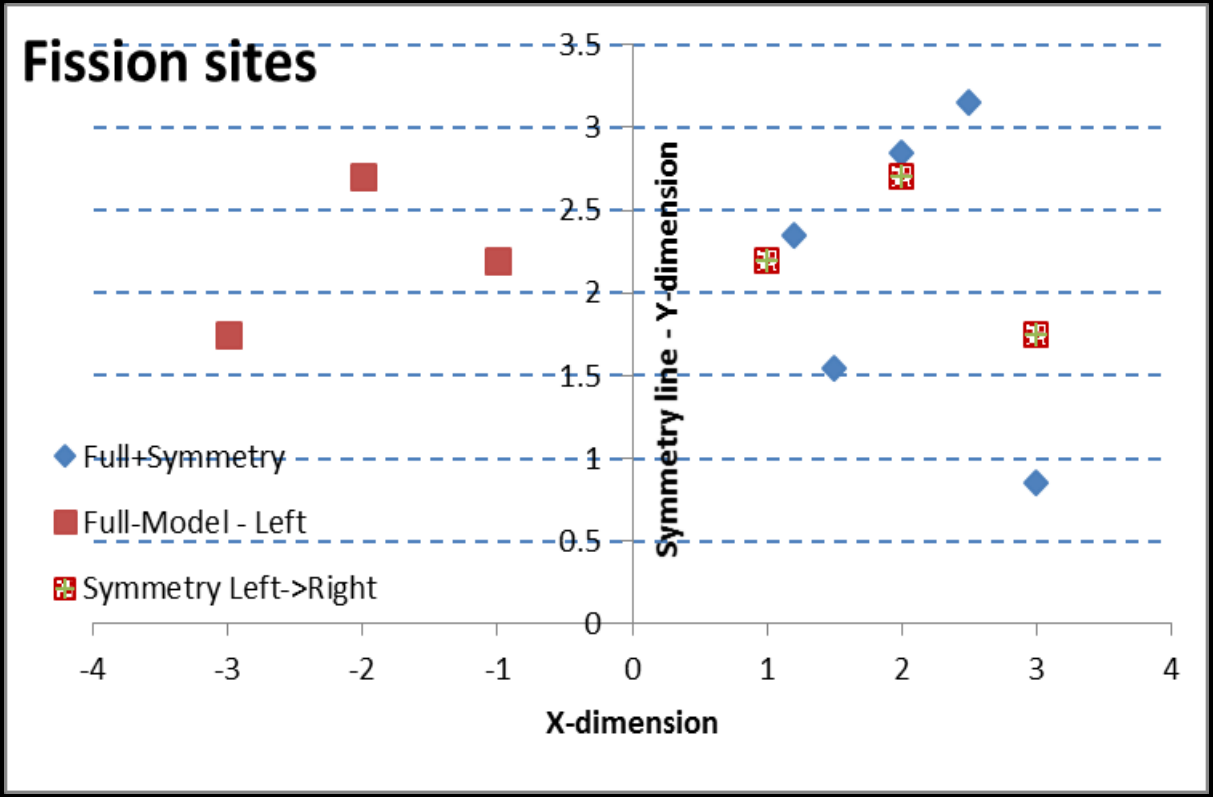
Dennis Mennerdahl

OECD/NEA/NSC/WPNCS/AMCT EG, Paris, 18 September 2014

OVERVIEW

- Identical events - Full model results contain everything ”and more”
- Symmetry to improve convergence? MC developers & mathematicians
- Dominance ratio (DR) – ”Read the bible”
- DR for short and long infinite cylinders with mirror axial reflection
- Check your methods with known facts and observations

FULL MODEL - EVERYTHING "AND MORE



Infinite slab – Symmetry around midplane
Eight fission sites in symmetric and full model calculations

Symmetry in Monte Carlo – MCNP forum I

17 October 2012. MCNP-source 1

"Representing symmetry … eliminates the possible existence of some higher eigenmodes and will always improve the convergence rate for a problem (i.e. fewer inactive cycles will be required to converge the fission source distributions".

18 October 2012. MCNP-source 1

"Most often we agree. However, in the present case, I very much disagree with you. Nearly all of your assertions and explanations are incorrect. I'd highly recommend that you … look at some of the references on the MCNP website … with over 50 references"

21 November 2012. MCNP-source 4

"There IS more information available about the RATE at which a physical system will reach the dominate mode if you model the full system. Putting in a reflecting surface changes the system. The eventual eigenmode is preserved by this change, but certainly the rate at which the calculation system reaches the eigenmode is faster with the reflecting system."

Dominance Ratio (DR) – MCNP forum II

"Dominance ratio calculations with MCNP", PHYSOR 2008:

"The dominance ratio is a fundamental property of a physical system"

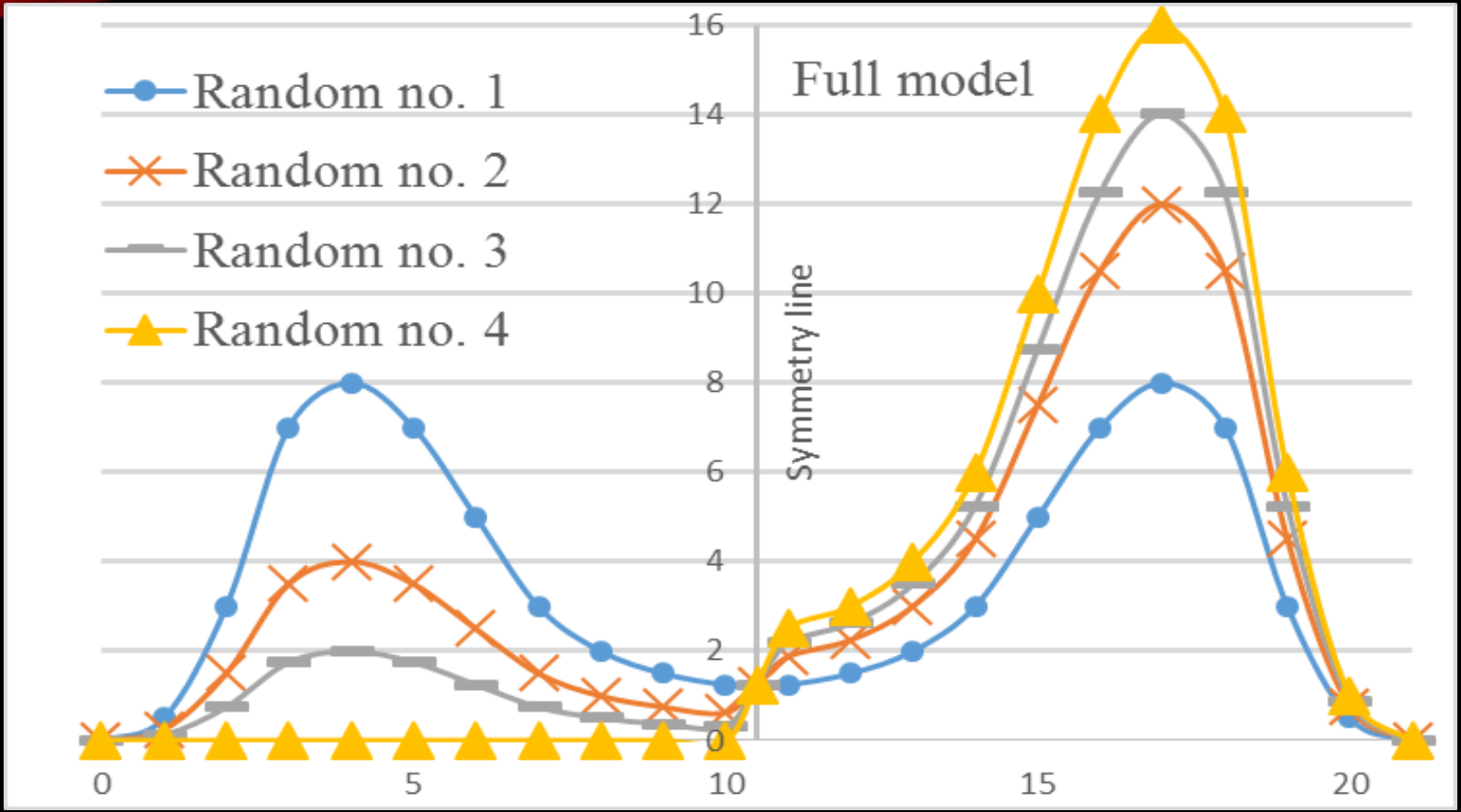
21 November 2012, D. Mennerdahl to MCNP-sources 1 and 4

"The fission distribution and other tallies are results of the sampling. They are not needed, to determine k-eff, only the integral is needed. They can be used to draw conclusions about the convergence and even more important, the realism in the obtained k-eff. I get more information from a full model than from a symmetry model. The convergences are identical"

"If I wanted to determine DRs … I would look for a code that did that for me. The symmetry test will tell me if the code is accurate"

"I see it as a criticality safety issue where leading MCNP developers mislead the users. It is also another reminder to criticality safety people that human error needs consideration in all its forms"

FLUX DISTRIBUTION –RANDOM NUMBER SEEDS



- Four calculations with different random number seeds.
- All results have identical reactions with blue curve in agreement with average

REPEATING UNDERSAMPLED SOLUTION

- It is suggested in the Phase I exersize to repeat a MC calculation 25 times, using different random number seeds to get the ”true uncertainty”
- How can the seed influence stationary solution (no initial traces) for identical systems?
- In EG UACSA Phase II, the random number seeds changed the system. Repetition with different seeds is necessary for such simulation.
- In the figure, the observed variation in the flux results is very large.
- Reason: Contamination with transient phase (seed effects) and possibly incorrect input. Only full model reveals the problem
- Symmetric model result would not indicate non-convergence

DR ESTIMATION FOR CYLINDER

- $\mathrm{DR} = \frac{k_1}{k_0} = \frac{\sum_a + D(\pi/L)^2}{\sum_a + D(2\pi/L)^2}$ L=Extrapolated length
- The French paper referring to this equation uses infinite cylinder as example
- Recent MCNP workshops provide similar DR results
- The paper describes that DR is defined such that symmetry gives the same DR as a truncated system (half for finite cylinder axial symmetry)
- Different infinite cylinder lengths between 10 cm and 500 cm give different DRs. Convergence is claimed to be better with a shorter infinite cylinder.
- "This kind of formula may be extended to a 3-D cylindrical geometry that could represent a power reactor such as a PWR core."

AXIAL AND AZIMUTHAL UNIFORMITY

- An infinitely long cylinder with axial and azimuthal uniformity only has a variation in the radial dimension.
- It is a 1-dimensional problem.
- Particle collision variation in the axial and azimuthal directions are irrelevant for convergence but provide insight on physics and data quality.
- Only radial variation should be tested for convergence.
- The extrapolated length is where the flxu goes to zero.
- An short infinite cylinder has the same extrapolated length as a long one
- The French paper expressly ignores the extrapolation (L is infinite)

EXAMPLE DR CALCULATIONS

- ” this formula remains valid for an infinite geometry modeled with a finite length *L* and using reflection boundary conditions”.
- Example for typical infinite PWR fuel rod. L is not extrapolated.
- *L* = 500 cm -> DR = 0.997
- *L* = 10 cm -> DR = 0.327
- “the fuel pin was subdivided into 40 z sections characterized by a thickness of *L*/40 for each section” erroneously too small.”

- ” In the case where *L* = 500 cm, the plotted fluxes were also integrated over 200 and 800 cycles. One sees that they not only have lost their flat shape but also are not consistent anymore as their discrepancies are much larger than the computed standard deviation, which is erroneously too small”.
- ” a long-range oscillation of the flux can be observed even if the initial source distribution is flat. It most probably results from a cycle-to-cycle amplification of the statistical errors exciting the first-order harmonic of the flux.
- ” Figures 4 and 6 show that in the high dominance ratio case, where L = 500 cm, the source convergence is not reached. The cycle-to-cycle correlation appearing in Fig. 6 is induced by the high dominance ratio.”

"ASSESSING THE DOMINANCE RATIO"

- "Section II shows that the closer to one the dominance ratio was, the stronger the flux errors were.
  Consequently, it is legitimate to assume that the flux errors observed previously are primarily driven by the dominance ratio."
- "Consequently, for high dominance ratio problems, these results allow one to justify the following assumption:
  The dominance ratio depends on the length *L* of the model …, whatever the boundary condition considered."

CONCLUSION

- Use full model whenever computer storage allows it.
- If symmetrical, take advantage of the information
- Solution should be adequately symmetrical
- For tallies, integrate symmetrical positions or volumes
- Check you method with known states of the solution