OAK RIDGE National Laboratory

Sensitivity Calculations for Systems with Fissionable Reflector Materials Using TSUNAMI

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Outline

- TSUNAMI family tree
- Bad sensitivity results identified (and fixed) during validation of SCALE 6.2.2
- Relevant CLUTCH theory
- Case study from Lady Godiva to Flattop
- Conclusions

TSUNAMI Family tree

- SCALE contains 5 different methods for calculating k_{eff} sensitivity data:

Sequence	Transport Code	Energy Treatment
TSUNAMI-1D	XSDRNPM	Multigroup
TSUNAMI-2D	NEWT	Multigroup
TSUNAMI-3D	KENO	Multigroup
	KENO (CLUTCH)	Continuous energy
	KENO (IFP)	Continuous energy

- In examining spherical systems, I'll use all of them but T2D

Suboptimal sensitivity results generated

- All cases TSUNAMI-3D models in VALID were rerun in SCALE 6.2.2 as part of the validation effort
- CLUTCH was initially used for FAST systems
  - Introduces CE TSUNAMI into VALID
  - Prior work indicates that FoM is higher for CE than MG TSUNAMI for fast spectrum systems
- Problems noted for sensitivity results for reflector region for a few systems
  - Comparisons with MG SDFs from SCALE 6.1
  - Confirmed with direct perturbation calculations

Problem systems

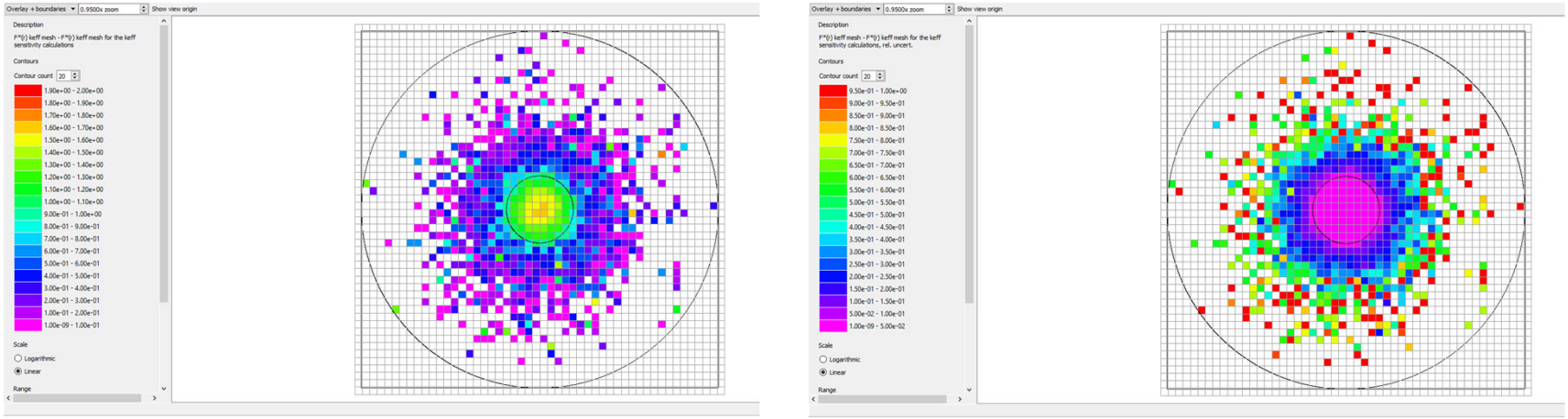
- HMF-030, HMF-038, HMF-052, HMF-094, IMF-002, IMF-007, PMF-006, PMF-008, and PMF-010
- What do these systems have in common?
- Fissionable material reflectors
  - Most are natural or depleted uranium reflected
  - Two (PMF-006 and -008) are thorium reflected
- To understand and explain the problem, we have to take a quick foray into the theory behind CLUTCH

CLUTCH Theory

- CLUTCH is a CE TSUNAMI method, and uses a single forward calculation to determine sensitivities
- An F*(r) function provides the importance of each voxel in a mesh over all regions where fission can occur
- The F*(r) function is calculated using the IFP method during the otherwise discarded generations
- A sufficient number of fissions must be simulated in each voxel in which fission is possible to generate an accurate estimate of the importance of a fission in that voxel
  - Sets requirement for number of "skipped" generations given number of particles per generation

So what's the problem?

- Very few fissions occur in the fissionable reflectors
- This leads to poor estimates of the importance of fissions that happen in the reflector
- For example, 200 "skipped" generations of 10,000 particles



PMF-006 F*(r) values and relative uncertainties

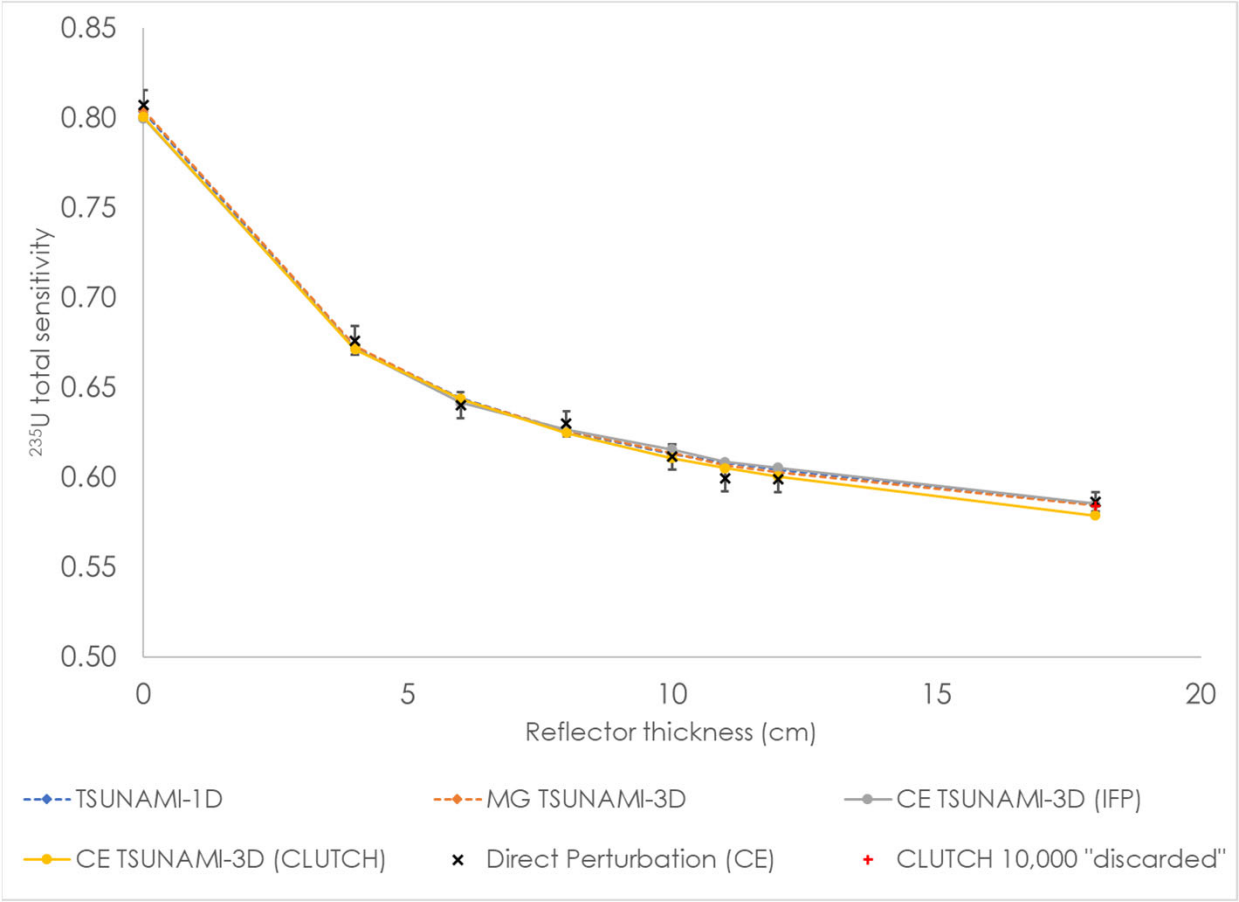
Resolution

- Run more skipped generations
  - Ultimately works but increases run-time
- Use a different method
- I did both and examined the effect using a set of hypothetical systems spanning from Lady Godiva (bare sphere) to Flattop (thick natural U reflector)
  - How thick a reflector is necessary to cause difficulty?
  - How many skipped generations are needed to resolve the problem?

Case study: Lady Godiva to Flattop

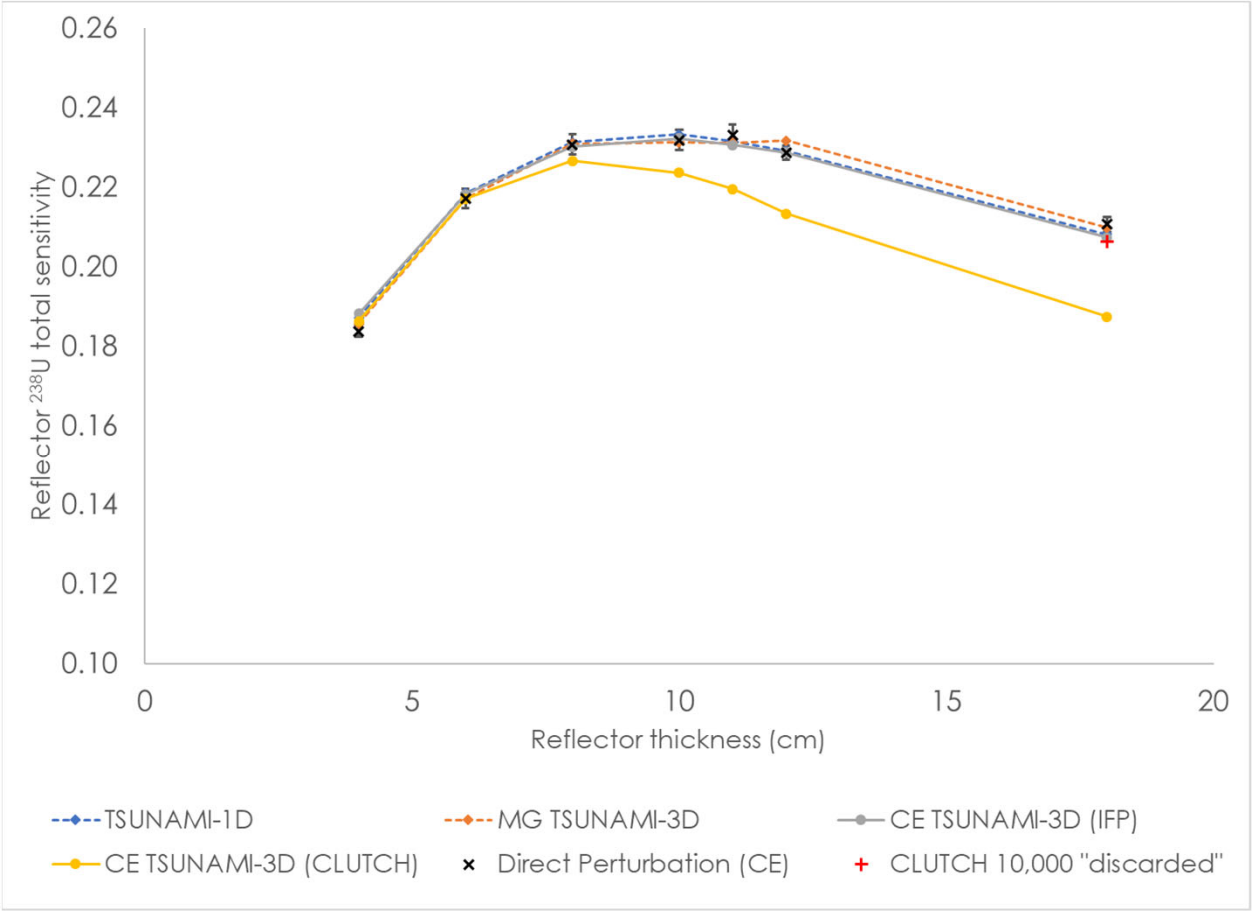
- Created models with natural uranium reflector with thicknesses of 4, 6, 8, 10, 11, and 12 cm
  - Material specification taken from Flattop evaluation (HMF-028)
- Models adjusted to critical by adjusting radius of HEU inner sphere
  - CE KENO calculations aiming for k_{eff} of 1.0: calculated values in paper
- Arbitrary selection of reflector thicknesses to map out variation in sensitivities
  - Examined sensitivity of both ^{235}U in HEU sphere and ^{238}U in reflector
- Used TSUNAMI-1D, MG TSUNAMI-3D, and both CE TSUNAMI-3D methods

Results: ^{235}U in HEU sphere



- All methods work well
- CLUTCH may be drifting low as reflector thickness increases, but still within ~1 sigma
  - Probably better with 10,000 "skipped" generations

Results: ^{238}U in reflector



- Clear problems with CLUTCH with thicknesses of about 10 cm or above
- It is possible to get the right answer by investing enough computing time
  - NSK=1000 took 4851s
  - NSK=10,000 took 18,979s
  - Similar parallel efficiencies (16 cores)

Conclusion

- Beware of CLUTCH calculations involving fissionable material reflectors
  - It is possible to generate correct sensitivities with the investment of additional calculation time
- Other TSUNAMI methods generate reliable estimates of the sensitivity of fissionable nuclides in the reflector
- Confirm results of sensitivity calculations