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 $k_{\text{eff}}$ sensitivity data:

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Transport Code</th>
<th>Energy Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSUNAMI-1D</td>
<td>XSDRNPM</td>
<td>Multigroup</td>
</tr>
<tr>
<td>TSUNAMI-2D</td>
<td>NEWT</td>
<td>Multigroup</td>
</tr>
<tr>
<td>TSUNAMI-3D</td>
<td>KENO</td>
<td>Multigroup</td>
</tr>
<tr>
<td></td>
<td>KENO (CLUTCH)</td>
<td>Continuous energy</td>
</tr>
<tr>
<td></td>
<td>KENO (IFP)</td>
<td>Continuous energy</td>
</tr>
</tbody>
</table>

- 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 $k_{\text{eff}}$ of 1.0: calculated values in paper
- Arbitrary selection of reflector thicknesses to map out variation in sensitivities
  - Examined sensitivity of both $^{235}\text{U}$ in HEU sphere and $^{238}\text{U}$ 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