Calculating the Effective Delayed Neutron Fraction (β_{eff}) with the SCALE Prompt Fission Neutron Spectrum.

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Delayed Neutrons

- Certain fraction of neutrons resulting from fission are from decay of fission products
- Typically, 6 groups in time and energy to describe the most relevant emitters
- β_{eff} is a condensed fraction resulting from all groups (effective delayed neutron fraction)
- Time delay from decay allows for safe operation of reactor- reactivity often referred to as fractions(¢) or multiples($) of β_{eff}
- No impact on steady state calculations and included as supplementary fissions

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Prompt Fission Neutron Spectrum (PFNS)

- Delayed neutrons are more thermal than prompt neutrons
- Different fissionable materials result in specific fission products and therefore in different effective delayed neutron fraction
- Without delayed neutrons, the PFNS is harder with a lower neutron yield
- PFNS capability first introduced in SCALE 6.2

5 Steps to Calculating β_{eff} in KENO

1. Calculate k_{eff} with full spectrum KENO model => k
   – E.g., KENO.inp
2. Create a copy of the KENO model
   – E.g., KENO_prompt.inp
3. Add "pnu=yes" to parameters
4. Calculate k_{eff} with *prompt* spectrum KENO model => k_p
5. $\beta_{eff} = 1 - \frac{k_p}{k}$

```
read parameters
      sig=0.00002 gen=60300 npg=65000 nsk=300

end parameters
```

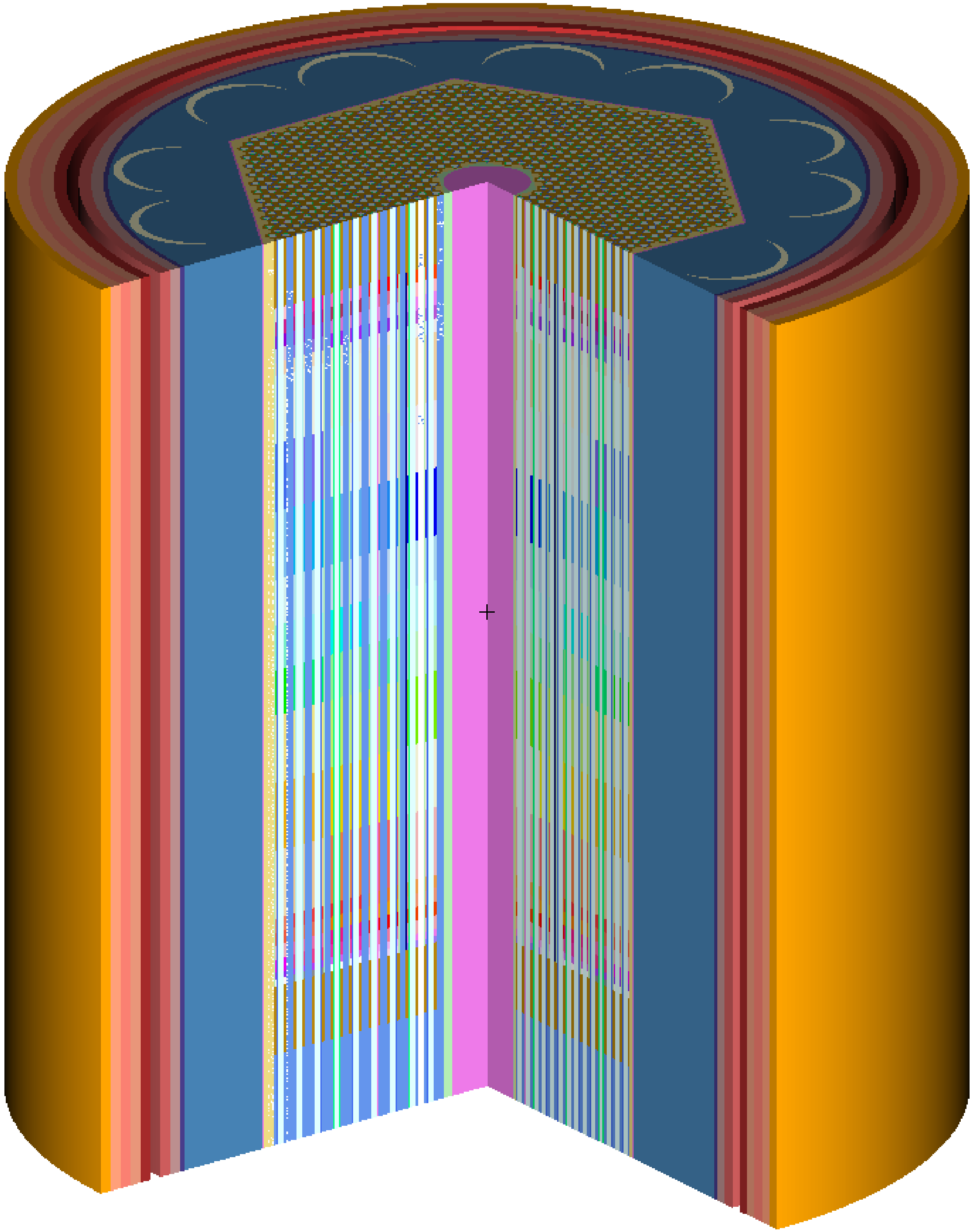
```
read parameters
      sig=0.00002 gen=60300 npg=65000 nsk=300 pnu=yes

end parameters
```

Example with the INL Heat Pipe

- INL Report[1] β_{eff} calculation with MCNP 6.1 and ENDF/B-VII.0:
  - β_{eff}=0.007 (700 pcm)

- β_{eff} calculation[2] with SCALE 6.3 b15 and ENDF/B-VII.1:
  - k=1.03144 ± 9E-5
  - k_p=1.02395 ± 9E-5
  - $\beta_{\text{eff}} = 1 - \frac{k_p}{k}$ = 726 ± 13 pcm



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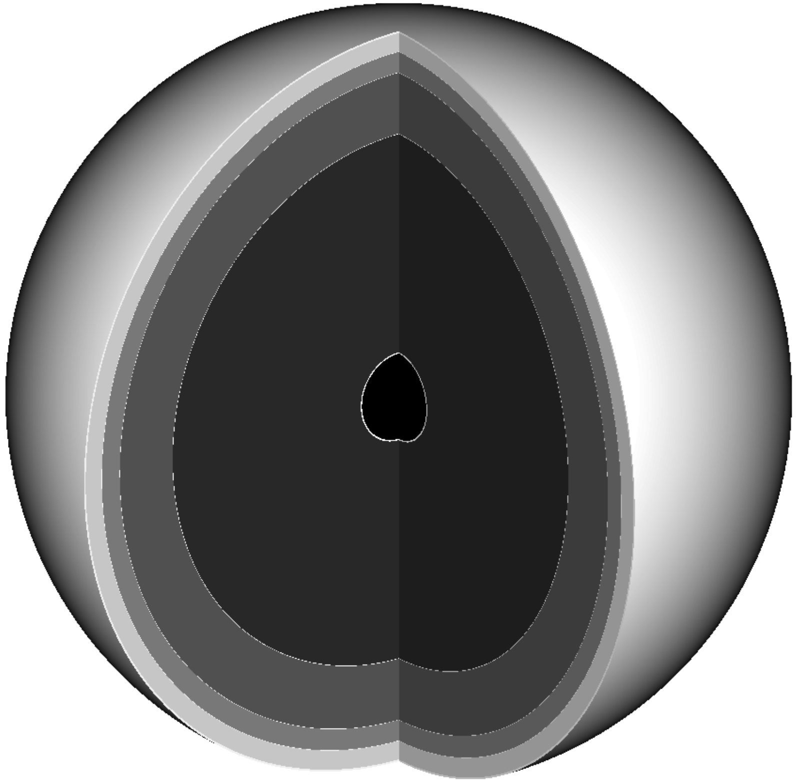
Benchmark Validation

- Several ICSBEP benchmarks include delayed neutron measurements
- Shell Model input of Godiva (HEU-MET-FAST-001) included in VALID (SCALE 6.3 b15, ENDF/B-VII.1)
- Concentric spheres of HEU metal



Model	Reference β_{eff} [3]	k_{eff} (± 2 pcm)[4]	Calculated β_{eff} [4]
Shell Godiva	659 ± 28	0.999961	653 ± 3
		0.993427	

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Areas of Expansion

- β_{eff} to be included in KENO validation reports
- So far, β_{eff} validation limited to fast HEU systems
  - Extend to thermal, intermediate spectrums
  - Extend to other fissionable materials
- Uncertainty Quantification with SAMPLER
- SHIFT implementation

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References

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3. G. R. Keepin, “Physics of Nuclear Kinetics,” Addison-Wesley, Reading, Massachusetts (1965)
4. A. M. Shaw and W. J. Marshall, “Validation of KENO Delayed Neutron Fraction Capabilities,” Manuscript submitted for publication.

Discussion