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Title: MCNP6 Nuclear Data Sensitivity Capability: Current Status and Future Prospects

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MCNP6 Nuclear Data Sensitivity Capability: Current Status and Future Prospects

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Abstract

MCNP6 has the capability to compute k-eigenvalue sensitivity coefficients using continuous-energy physics. Sensitivity profiles are generated for Jezebel and Copper-Reflected Zeus. The new MCNP uncertainty quantification project at LANL is discussed along with other future plans.

Introduction

- Sensitivity Method
- Sensitivity Results
- Uncertainty Quantification & the Future

Motivation

- Applications of sensitivity analysis allow...
    1. Assessment data performance for predicting criticality.
    2. Quantification uncertainties in calculations arising from nuclear data.
    3. Designing integral (critical) experiments to improve data.

Perturbation Theory in Neutronics

- Perturbation theory gives the following result:

$$\frac{dk}{k} = -\frac{\left\langle \psi^{\dagger}, (d\Sigma_t - d\mathcal{S} - k^{-1} d\mathcal{F})\psi \right\rangle}{\langle \psi^{\dagger}, k^{-1}\mathcal{F}\psi \rangle}.$$

- k = multiplication factor.
- ψ = neutron (angular) flux.
- $\psi^{\dagger}$ = adjoint function.
- Σ_t = total interaction cross section.
- $\mathcal{S}$ = scattering source.
- $\mathcal{F}$ = fission source.

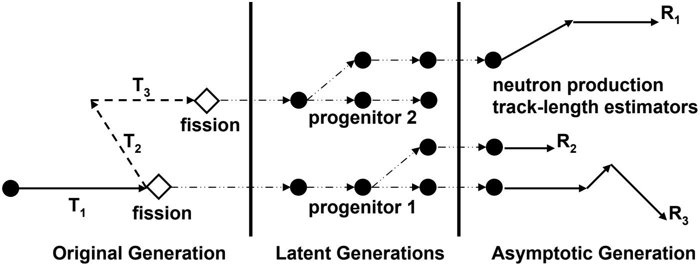
Solution Technique

$$S_{k,x} = -\frac{\langle \psi^\dagger, (\Sigma_x - \mathcal{S}_x - k^{-1}\mathcal{F}_x)\psi \rangle}{\langle \psi^\dagger, k^{-1}\mathcal{F}\psi \rangle}.$$

- Accurate solutions to this equation for can readily be obtained by continuous-energy Monte Carlo – no energy discretization.
- Can get energy-resolved sensitivity profiles for cross sections, fission ν, fission χ, and scattering distributions.
- **New capability in MCNP6!**
- Verfication by direct perturbations and comparisons to other codes (e.g., TSUNAMI) shows generally good agreement.
- See upcoming journal paper in Nuclear Science and Engineering (LA-UR-12-22089).

Iterated Fission Probability Method

- Divide active cycles of eigenvalue calculation into "blocks" of some size (default 10).
- First cycle: accumulate scores and tag neutrons.
- Follow neutrons through generations, preserving tags.
- Last cycle: multiply scores by neutron production of corresponding progeny.



Constraining Sensitivities

- Fission χ and scattering laws are normalized in outgoing energies E and angles μ.
- An increase somewhere must result in decrease(s) elsewhere to preserve normalization.
- Common technique is to increase the distribution in some energy interval and renormalize.
- The sensitivity is constrained by the following relation:

$$\hat{S}_{k,x}(E,\mu|E_i) = S_{k,x}(E,\mu|E_i) - x(E,\mu|E_i)S_{k.x}(E_i).$$

- Note: Because of normalization, the sensitivity integrated over all outgoing energies and angles is zero.

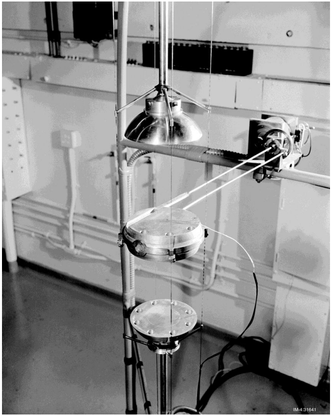
Results

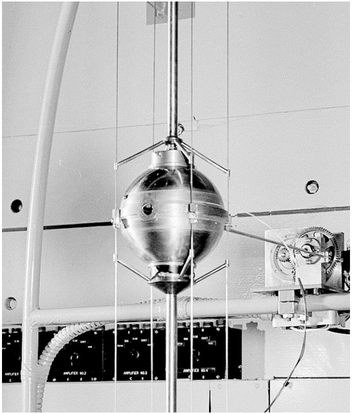
- Two fast-critical experiments were analyzed:
  1. Jezebel
  2. Copper-Reflected Zeus

- Profiles obtained for total, capture [(n,γ), (n,p), ...], elastic, inelastic (40 discrete levels and continuum), fission, fission ν, fission χ, scattering distributions.
- 100 uniform lethargy bins per decade used.

Jezebel

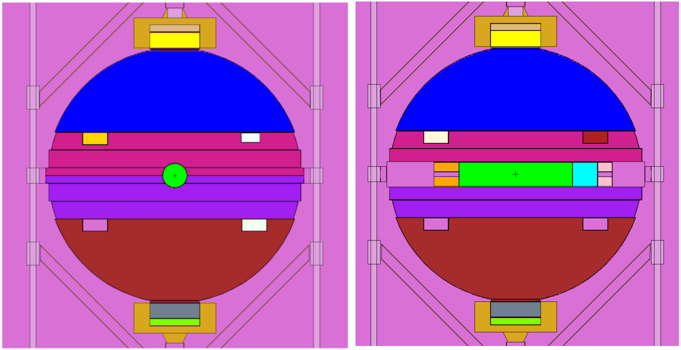
- Plutonium critical experiment at LASL in 1950's:





Jezebel

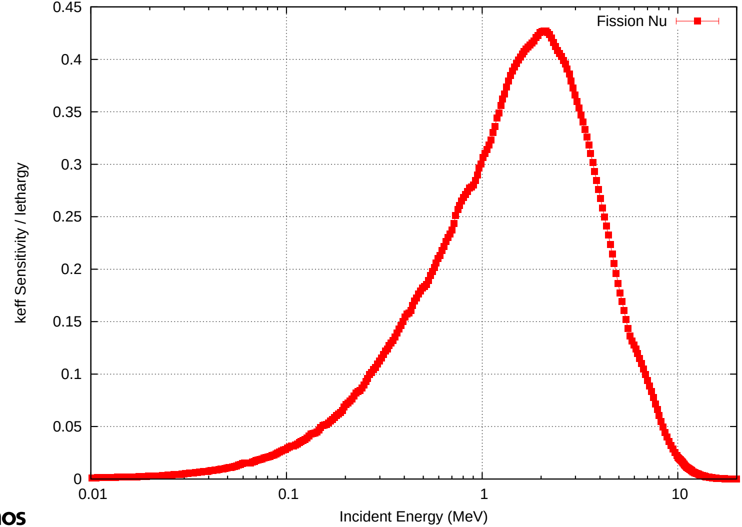
- Detailed MCNP model by R. Brewer and J. Favorite:



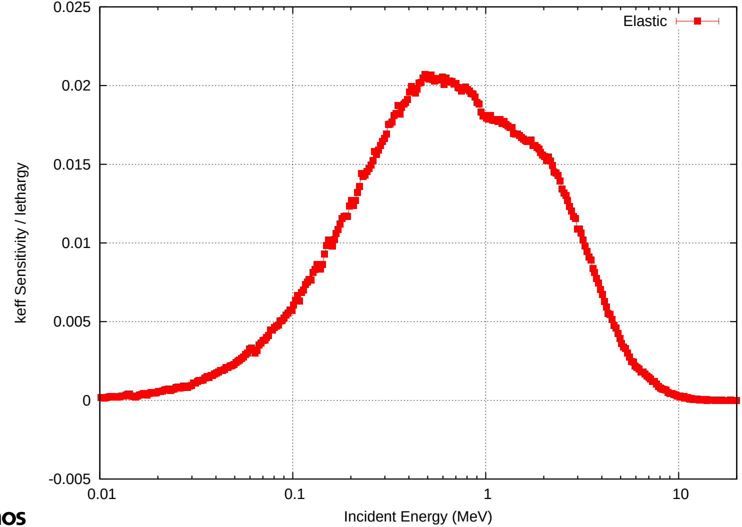
Jezebel: Top Sensitivities

Isotope	Data	$S_{k,x}$
Pu-239	ν	$+9.662$E-01 $\pm$ 0.00%
Pu-239	Fission	$+7.274$E-01 $\pm$ 0.02%
Pu-239	Elastic	$+6.200$E-02 $\pm$ 0.20%
Pu-240	Fission	$+2.291$E-02 $\pm$ 0.03%
Pu-239	n,n' Continuum	$+1.008$E-02 $\pm$ 0.34%
Pu-239	n,n' Level 2	$+9.487$E-03 $\pm$ 0.31%
Pu-239	n,n' Level 1	$+8.906$E-03 $\pm$ 0.32%
Pu-239	n,γ	-7.673E-03 $\pm$ 0.08%
Pu-240	Elastic	$+3.268$E-03 $\pm$ 0.55%
Pu-241	ν	$+2.905$E-03 $\pm$ 0.02%
Ni-58	Elastic	$+2.435$E-03 $\pm$ 0.48%
Pu-241	Fission	$+2.185$E-03 $\pm$ 0.03%
Pu-239	n,n' Level 3	$+1.829$E-03 $\pm$ 0.54%

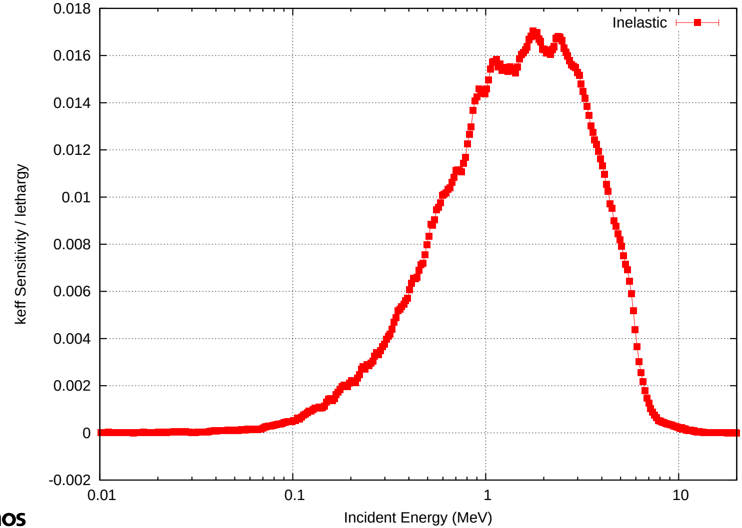
Jezebel: Pu-239 Fission-ν Sensitivity



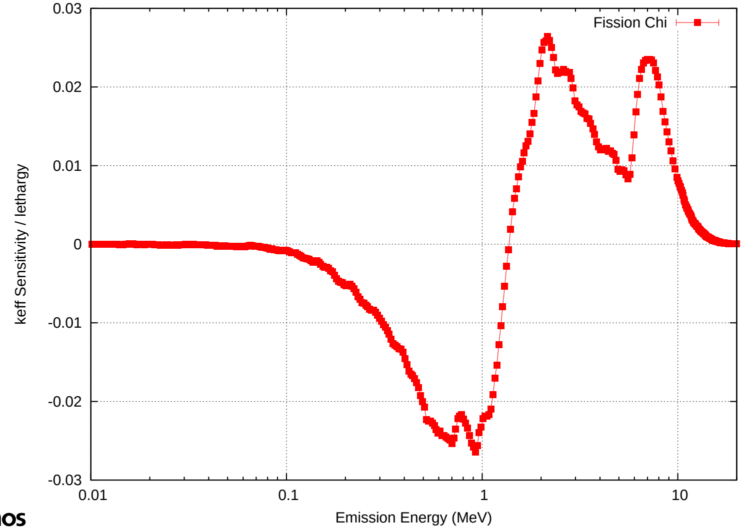
Jezebel: Pu-239 Elastic Cross-Section Sensitivity



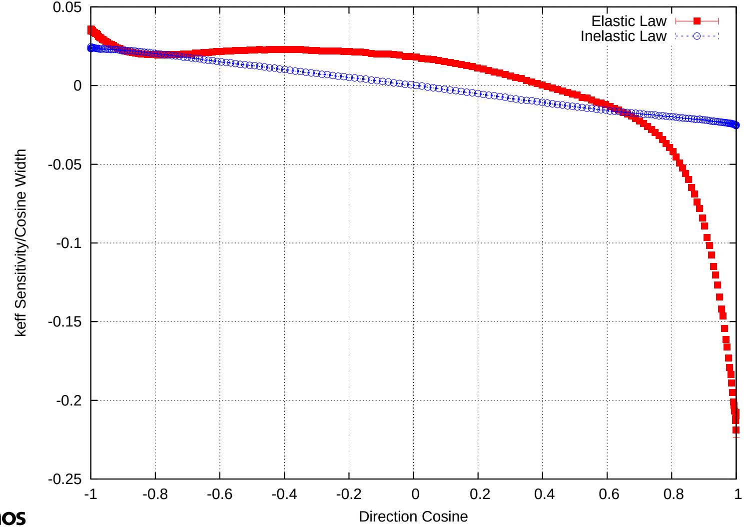
Jezebel: Pu-239 Inelastic Cross-Section Sensitivity



Jezebel: Pu-239 Fission-χ Sensitivity



Jezebel: Pu-239 Scattering Law Sensitivity



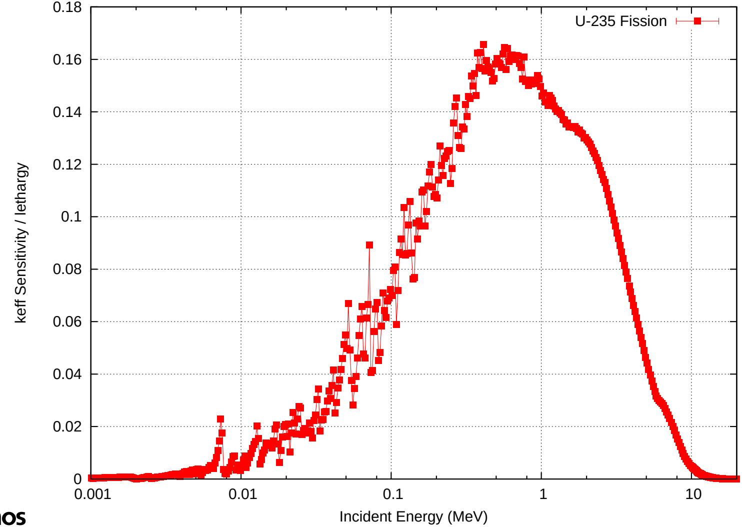
Copper-Reflected Zeus

- HEU plates surrounded by a copper reflector:

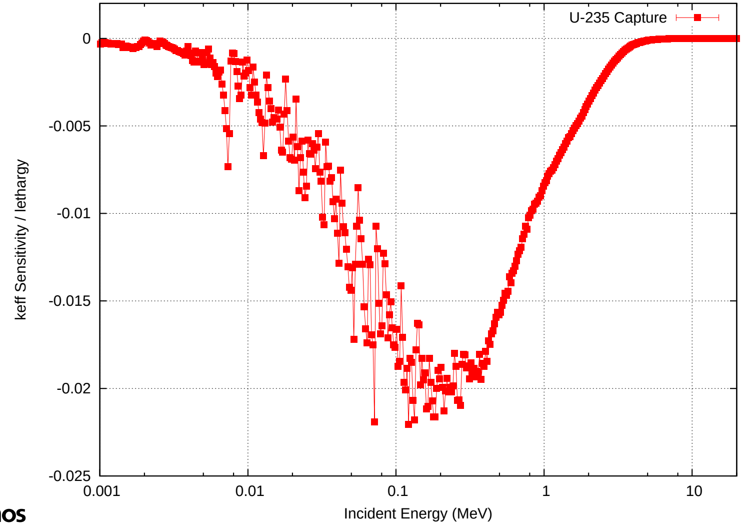
Copper-Reflected Zeus: Top Sensitivities

Isotope	Data	$S_{k,x}$
U-235	ν	$+9.874$E-01 $\pm$ 0.00%
U-235	Fission	$+5.771$E-01 $\pm$ 0.03%
Cu-63	Elastic	$+1.937$E-01 $\pm$ 0.22%
Cu-65	Elastic	$+9.576$E-02 $\pm$ 0.28%
U-235	n,γ	-6.734E-02 $\pm$ 0.05%
Cu-63	n,γ	-3.555E-02 $\pm$ 0.07%
Cu-63	n,n' Level 2	$+1.012$E-02 $\pm$ 0.32%
Cu-65	n,γ	$+9.767$E-03 $\pm$ 0.08%
Al-27	Elastic	$+8.951$E-03 $\pm$ 0.43%
Cu-63	n,n' Level 1	$+8.021$E-03 $\pm$ 0.36%
U-235	n,n' Continuum	$+6.713$E-03 $\pm$ 0.57%
Cu-63	n,n' Continuum	$+6.221$E-03 $\pm$ 0.31%
U-234	ν	$+6.044$E-03 $\pm$ 0.04%

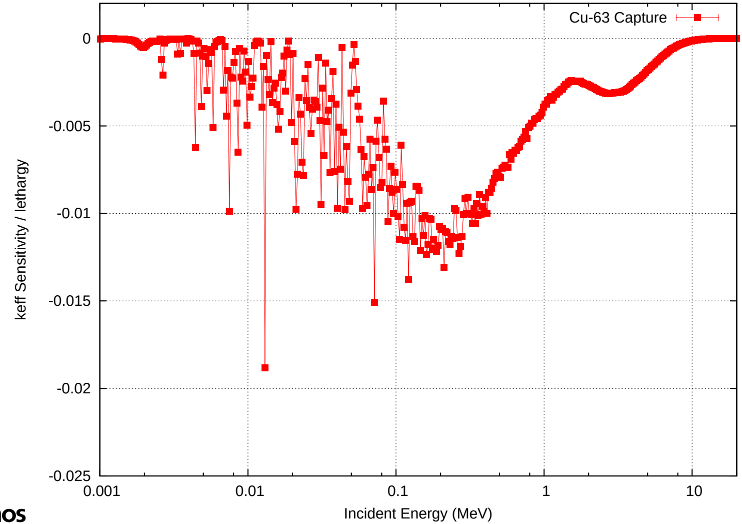
Zeus: U-235 Fission Cross-Section Sensitivity



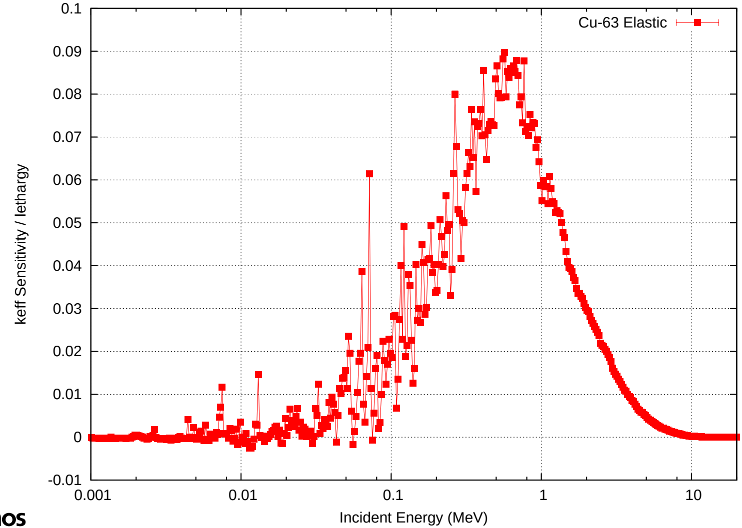
Zeus: U-235 Capture Cross-Section Sensitivity



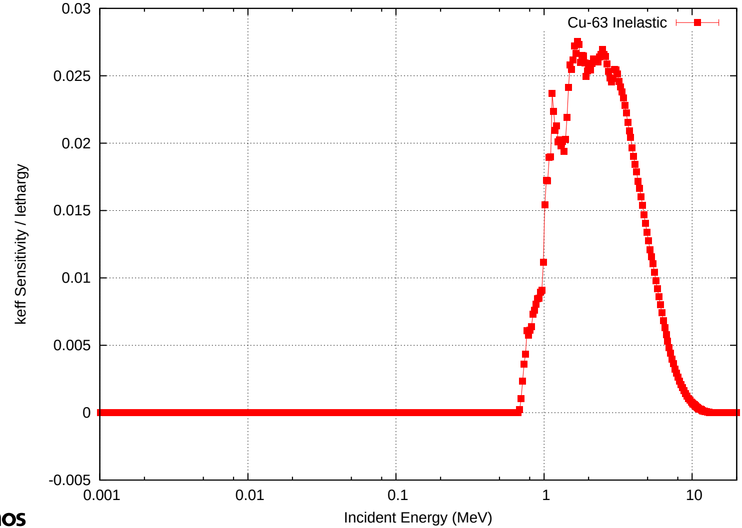
Zeus: Cu-63 Capture Cross-Section Sensitivity



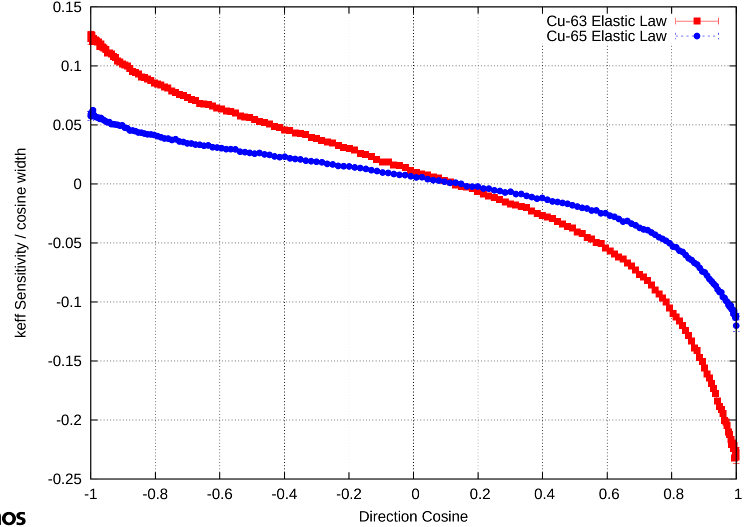
Zeus: Cu-63 Elastic Cross-Section Sensitivity



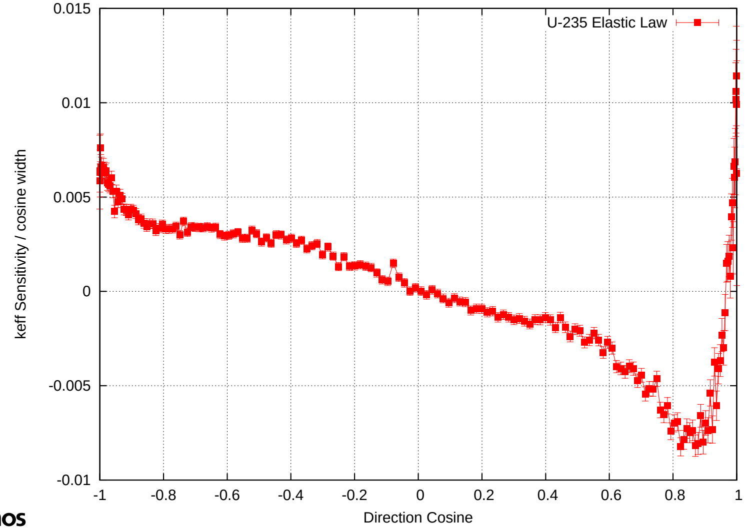
Zeus: Cu-63 Inelastic Cross-Section Sensitivity



Zeus: Cu Elastic Scattering Law Sensitivity



Zeus: U-235 Elastic Scattering Law Sensitivity



Connection to Uncertainty Quantification

- The uncertainty in k because of uncertain parameters x_i is estimated by:

$$\left(\frac{\Delta k}{k}\right)^2 = \sum_{i=1}^{N} \left(\frac{\Delta x}{x}\right)^2 S_{k,x}^2$$

- Covariance data is available for some isotopes, reactions, and energy ranges in ENDF.
- New project starting to look at defining ACE format for MCNP.

MCNP Uncertainty Quantification Project

1. Develop a compact format for ACE data files that can be utilized by MCNP.
2. Modify NJOY to produce ACE covariance files.
3. MCNP can compute or read a provided sensitivity data file and compute an estimate of the uncertainty in k from nuclear data.

Improved MCNP Criticality Validation

- Identify nuclear data coverage of the 119 problem MCNP Criticality Validation Suite.
- Identify trends in biases in k (e.g., tungsten in fast benchmarks leads to overprediction of k).
- Expand Suite based on identified gaps and anomolies.

MCNP Sensitivity Improvements & Enhancements

- File format interoperability with SCALE and other tools.
- Increased development on scattering distribution sensitivities (automated incident energy grid).
- Improve efficiency via the development of special variance reduction techniques.
- Extend to other responses: foil activation, leakage, reactor period, etc.

Acknowledgments

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Questions?